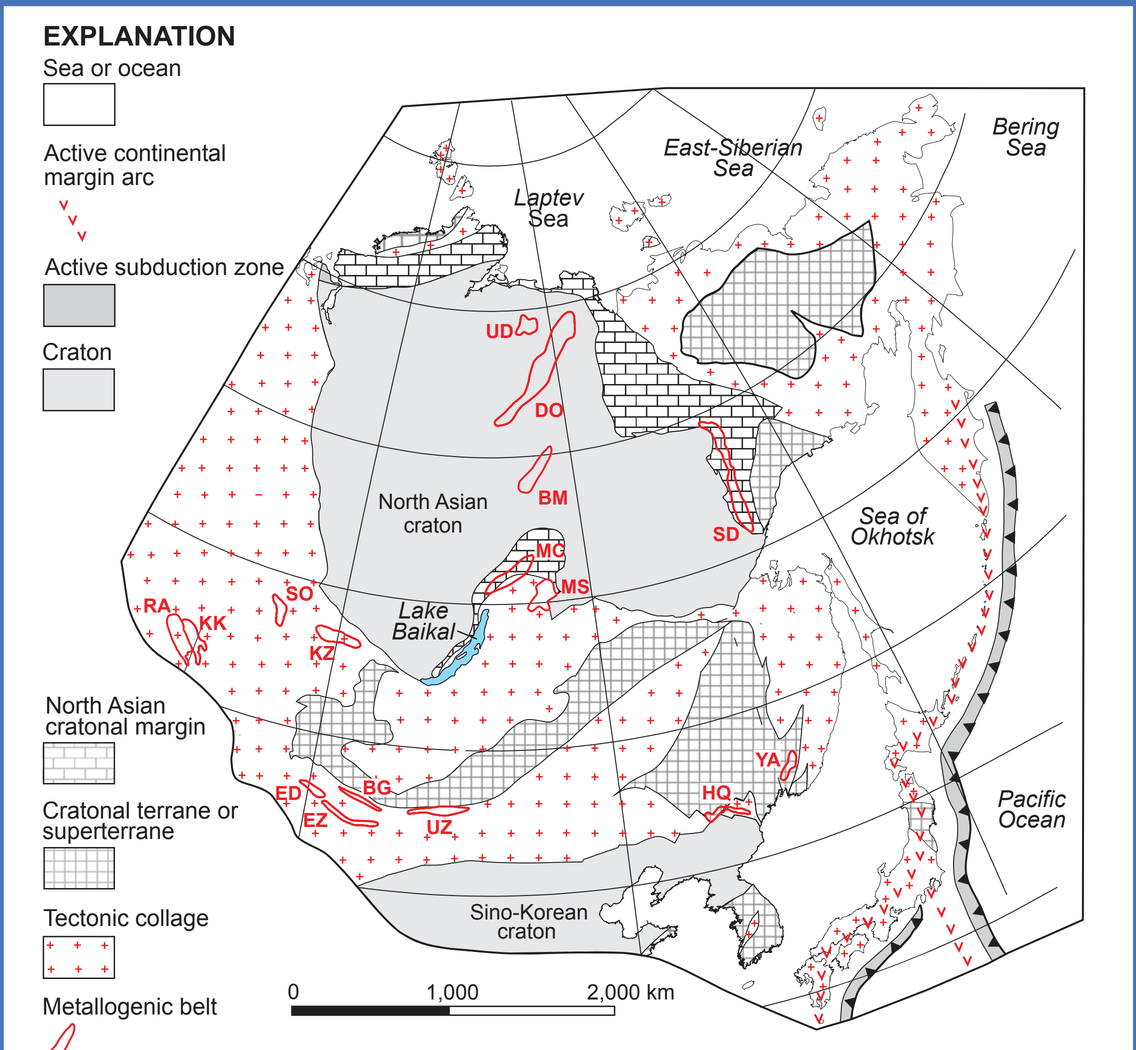
Prepared in collaboration with the Russian Academy of Sciences, Mongolian Academy of Sciences, Korean Institute of Geosciences and Mineral Resources, Geological Survey of Japan/AIST, and Jilin University

Metallogenesis and Tectonics of Northeast Asia



MAJOR TECTONIC ELEMENTS AND DEVONIAN AND EARLY CARBONIFEROUS METALLOGENIC BELTS FOR NORTHEAST ASIA

Professional Paper 1765

U.S. Department of the Interior
U.S. Geological Survey

COVER:

Major present-day tectonic elements and Devonian and Early Carboniferous metallogenic belts for Northeast Asia. The major tectonic elements are (1) the North Asian and Sino-Korean cratons; (2) cratonal margin units overlapping the cratons; (3) a suite of cratonal terranes or superterranes derived from the North Asian and Sino-Korean cratons or from other cratons; (4) a tectonic collage of accreted cratonal, craton margin, island arc, and subduction zone terranes; (5) the active Izu-Bonin, Japan, and Kuril-Kamchatka continental margin volcanic arcs; and (6) two major and active subduction zones that occur outboard of the arcs and into which the Pacific Ocean plate is being thrust under the continental margin. The major metallogenic belts for the Devonian and Early Carboniferous formed in a variety of tectonic environments, including island arc volcanism, transpressive continental-margin arc volcanism, terrane accretion, transpressional faulting, rifting, and kimberlite pipe intrusion. Refer to chapter 6 for detailed information on Devonian and Early Carboniferous regional geology, metallogenic belts, and tectonics.

Metallogenesis and Tectonics of Northeast Asia

Edited by Warren J. Nokleberg

Professional Paper 1765

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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Contents

Chapter 1

Introduction

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Executive Summary

The major purpose of this volume is to provide a comprehensive synthesis of the regional geology, tectonics, and metallogenesis of Northeast Asia for readers who are unfamiliar with the region and for researchers who desire detailed information on the region. The major parts of the volume are (1) an introductory chapter; (2) a chapter on methodology of regional metallogenic and tectonic analysis; (3) a chapter on mineral deposit models for the region; (4) five chapters that describe the regional metallogenesis and tectonics of the region from the Archean through the Present for successive time stages; (5) a chapter on a metallogenic and tectonic model for the region; and (6) three appendixes, including on a description of the project and products, a description of map units for the Northeast Asia geodynamics map, and a summary table of metallogenic belts for the region.

An important goal of the volume is to demonstrate how a high-quality metallogenic and tectonic analysis, including construction of an associated metallogenic-tectonic model, greatly benefits other mineral resource studies by (1) synthesizing of mineral-deposit models, (2) improving prediction of undiscovered mineral deposits as part of quantitative mineral-resource-assessment studies, (3) assisting land-use and mineral-exploration planning, (4) improving knowledge of regional geology; (5) improving interpretations of the origins of host rocks, mineral deposits, and metallogenic belts, and (6) suggesting new research.

Research on the metallogenesis and tectonics of such major regions as Northeast Asia requires a complex methodology including (1) definitions of key terms, (2) compilation of a regional geologic base map that can be interpreted according to modern tectonic concepts and definitions, (3) compilation of a mineral-deposit database that enables a determination of mineral-deposit models and clarification of the relations of deposits to host rocks and tectonic origins, (4) synthesis of a series of mineral-deposit models that characterize the known mineral deposits and inferred undiscovered deposits in the region, (5) compilation of a series of metallogenic-belt belts constructed on the regional geologic base map, and (6) construction of a unified metallogenic and tectonic model.

The Northeast Asia study area consists of eastern Russia (most of eastern Siberia and the Russian Far East), Mongolia, northern China, South Korea, Japan, and adjacent offshore areas. Major cooperative agencies are the Russian Academy of Sciences; the Academy of Sciences of the Sakha Republic (Yakutia); VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation; the Mongolian Academy of Sciences; the Mongolian University of Science and Technology; the Mongolian National University; Jilin University, Changchun, People's Republic of China; the China Geological Survey; the Korea Institute of Geosciences and Mineral Resources; the Geological Survey of Japan/AIST; the University of Texas, Arlington; and the U.S. Geological Survey (USGS).

This study builds on and extends the data and interpretations from a previous project on the *Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera* conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of

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Geological and Geophysical Surveys, and the Geological Survey of Canada. The major products of the Northeast Asia project are described in appendix A.

Definitions, Geologic Time Scale, and Tectonic Environments

To illustrate the regional geology and tectonics of Northeast Asia, figure 2 applies the concept of a tectonic collage, herein defined as a series of linear island or continental-margin-arcs and tectonically linked (companion) subduction zone and (or) forearc and backarc basins that formed in a major tectonic event during a relatively brief geologic timespan. A few these tectonic collages consist of fragments of cratonal and cratonal margin terranes that were amalgamated before accretion to a continent. This definition enables (1) a readily understood conceptual framework for understanding the regional geology and tectonics Northeast Asia, (2) depiction at small scales of major geologic units and structures that formed in a single tectonic

Figure 1. Regional summary regional geographic map of Northeast Asia, showing locations of major regions, countries, and capitals. International boundaries of onshore areas are approximate and do not imply endorsement by participating countries.

event, and (3) depiction of the major metallogenic belts related to tectonic collages. Definitions of other key terms for metallogenic and tectonic analysis, adapted from Jones and others (1983), Howell and others (1985), Nokleberg and others (2000, 2004, 2005) are listed in table 1; geologic time terms are from the International Union of Geological Sciences Global Stratigraphic Chart (Remane, 1998). For this study, in the descriptions of some Proterozoic geologic units in Russia, the term Riphean is used for Mesoproterozoic through middle Neoproterozoic (1,600 to 650 Ma), and Vendian is used for Neoproterozoic III (650 to 540 Ma)

For a modern metallogenic and tectonic analysis, an interpretation of tectonic environments is essential for determining the origins of major geologic units and contained mineral deposits and metallogenic belts. Such an interpretation permits linking the geologic origins for these sometimes-disparate datasets. As described below, interpretation of the tectonic environments for mineral deposits is also important for constructing mineral-deposit models. For the tectonic analyses of Northeast Asia and the Circum-North Pacific (Nokleberg and others, 1997b,c, 2000, 2004, 2005; Scotese and others, 2001; Obolenskiy and others, 2003 and this volume, chap. 3; Parfenov and others, 2003, 2004a,b), we interpreted the major geologic units (terranes, overlap assemblages, plates), mineral deposits, mineral-deposit types, and metallogenic belts according to the following tectonic environments (table 1) (1) cratonal and cratonal margin, (2) passive-continental-margin, (3) low-grade metamorphosed continental margin, (4) continental-margin-arc and backarc, (5) island arc and backarc, (6) oceanic crust, seamount, or ophiolite related to rifting and sea-floor spreading, (7) subduction zone, (8) turbidite basin, (9) collisional, (10) transform continental-margin faulting and associated bimodal volcanic-plutonic belt, (11) plume, and (12) metamorphic. For terranes with complex geologic histories, the chosen tectonic environment is the one most prevalent during the history of the terrane.

Regional Geologic Map–A Basis for Metallogenesis

To compile a metallogenic-belt map for metallogenic analysis, a regional geologic base map must be constructed that permits the display of metallogenic belts as a function of host rock-geology or structures (Nokleberg and others, 1997b,c; Parfenov and others, 2003, 2004a,b). To facilitate analysis of the crustal origin and evolution of mineralizing systems, the regional geologic base map must be constructed at a scale that reveals the major geologic data that are important for a valid synthesis. Such a synthesis should be able to reveal the tectonic origins of host-rock geologic units and structures that controlled the formation of groups of mineral deposits in metallogenic belts.

For the synthesis and interpretation of the metallogenesis and tectonics of Northeast Asia (fig. 1), a regional-geodynamics map was compiled at a scale of 1:5,000,000 to display major features the host rock geology and structures (Nokleberg and others, 1997b,c; Parfenov and others, 2003, 2004a,b) and major belts of mineral and fuel resources. To illustrate these major features on a page-size illustration (fig. 2), a summary regional-geodynamics map was synthesized display (1) the surface extent of major geologic units (cratons, cratonal margins, tectonic collages of island-arc, continental-margin-arc, subduction-zone, and passive-continental-margin terranes, and volcanic and plutonic igneous arcs), (2) major fault and rift systems, and (3) active subduction zones. A list of the major host-rock geologic units is provided in the explanation to figure 2, and the major geologic units are described in an appendix B. The regional geologic map also provides descriptive data on the tectonic origins of major host-rock geologic units needed to establish geologic controls on the formation of metallogenic belts.

Methodology of Regional Geologic and Tectonic Analysis

The methodology used to construct figure 2 consists of the following three steps (1) correlation of major geologic units, (2) tectonic linking (pairing) of major geologic units, and (3) alignment of coeval arc and tectonically linked subduction zones into curvilinear complexes. This methodology, which was originally established for the tectonic synthesis of the Circum-North Pacific by Nokleberg and others (2000) and modified for Northeast Asia by Parfenov and others (1998), is explained in detail by Nokleberg and others (this volume, chapter 2).

In step 1, correlations are attempted for major geologic units that are interpreted as originally contiguous but subsequently tectonically displaced during rifting or major thrusting, or displaced along strike-slip faults and for all tectonic units (cratons, cratonal margins, terranes, and overlap assemblages) that are interpreted to have the same origin, (*that is*, as parts of a single elongate passive-continental-margin, continental-margin-arc, island arc, or subduction zone) contemporaneously and originally on strike with each other. This correlation of major geologic units also illustrates the original continuity of lithologic units, provides important constraints on past regional tectonics, and provides a series of interpretations to be further evaluated by additional stratigraphic, geochemical, isotopic, paleomagnetic, and geophysical studies.

In step 2, tectonic links (pairings) are accomplished (1) between subduction-related igneous arcs, now preserved as various igneous-arc terranes or overlap assemblages, and former subduction zones, now preserved as subduction-zone terranes, (2) between belts of anatectically-related igneous rocks and major faults (sutures) that bound the collisional margins of terranes, between terranes and cratonal margin, and (3) between belts of igneous rocks that are coeval with, and occur along, major transpressional fault zones. These tectonic links are based on an examination of the detailed geology and

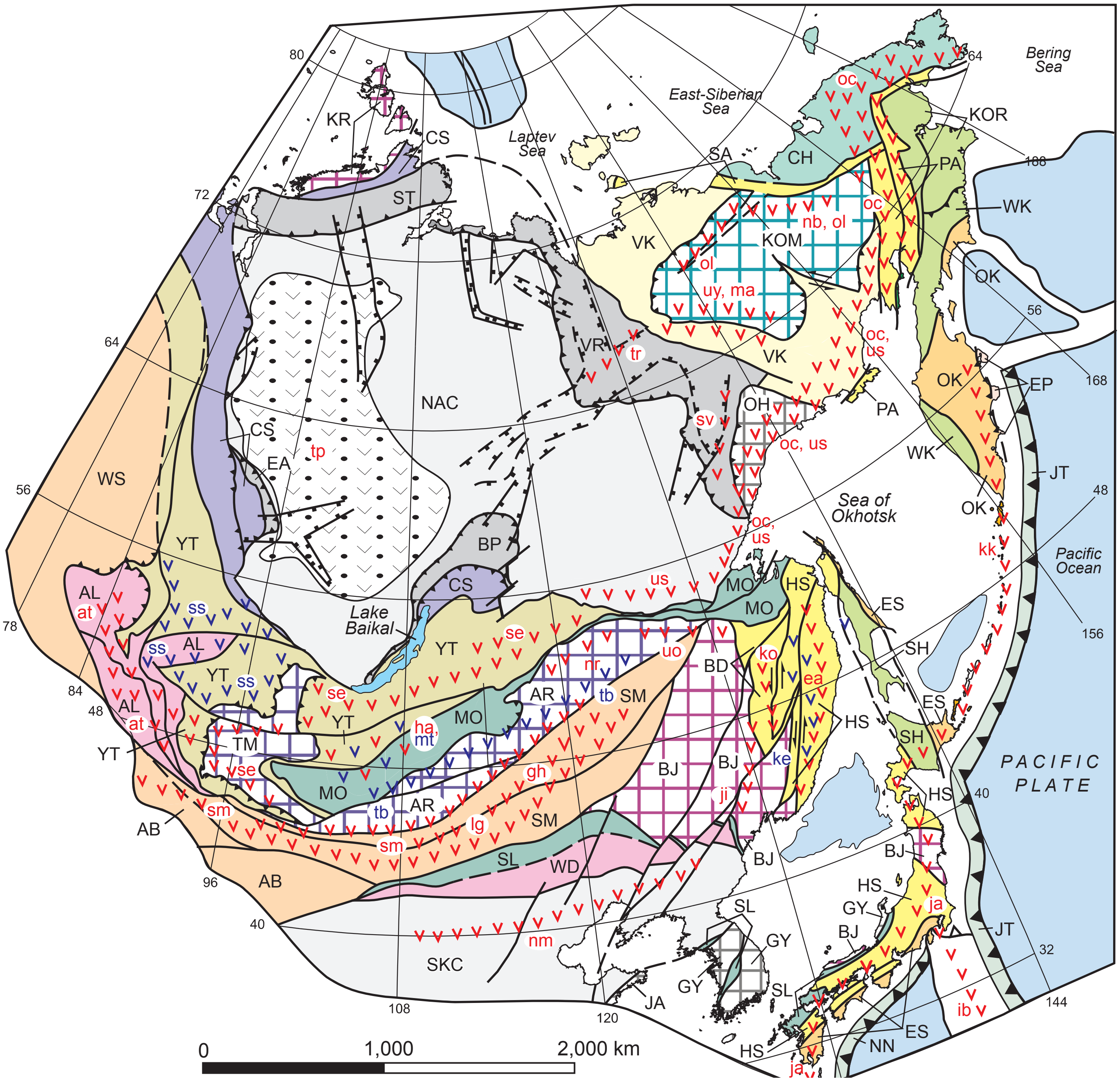

Figure 2. Northeast Asia summary geodynamics map (scale, approx 1:34,000,000) showing locations major geologic and tectonic units including cratons, cratonal margins; cratonal terranes and superterranes; tectonic collages; overlap and transform continental-margin-arcs; island arcs, and sea and ocean units. From (1) a generalized geodynamics map of Northeast Asia (scale, 1:10,000,000) by Parfenov and others (2004), (2) a more detailed geodynamics map Northeast Asia (scale 1:5,000,000 and (3) tectono-stratigraphic terrane maps of the western part of a Circum-North Pacific (scale, 1: 10,000,000) by Nokleberg and others (1997). Tectonic interpretations are based on the major interpretative reports of collaborative international studies of Northeast Asia (Nokleberg and others, 2004) and the Circum-North Pacific (Nokleberg and others, 2000, 2004), with descriptions of geologic units adapted from reports by Nokleberg and others (2000, 2004) and Parfenov and others (2004). See appendix B for descriptions of map units.

EXPLANATION

Cratons and Cratonal Margins

Cratons: NAC - North Asian (Archean and Proterozoic); SKC - Sino-Korean (Archean and Proterozoic)

Cratonal Margin: BP - Baikal-Patom (Riphean through Cambrian and older basement; EA - East Angara (Riphean and older basement; ST - South Taimyr (Ordovician through Jurassic); VR - Verkhoyansk (Devonian through Jurassic).

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

AL - Altay (Vendian to Ordovician)
WD - Wundurmiao (Riphean through Ordovician)

AB - Atasbogd (Ordovician through Permian); SM - South Mongolia-Khingan (Ordovician through Carboniferous); WS - West Siberian (Ordovician through Carboniferous)

MO - Mongol-Okhotsk (Devonian through Late Jurassic); SL - Solon (Carboniferous and Permian)

Tectonic Collages Along the Northern and Eastern Margins of North Asian and Sino-Korean Cratons

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

BD - Badzhal (Triassic through Early Cretaceous); PA - Penzhina-Anadyr (Late Jurassic and Cretaceous); HS - Honshu-Sikhote-Alin (Jurassic and Early Cretaceous); SA - South Anyui (Permian through Jurassic);

KOR - Koryak (Late Jurassic through Paleocene; SH - Sakhalin-Hokkaido (Cretaceous); WK - West Kamchatka (Mid-Cretaceous through Early Tertiary)

ES - East Sakhalin (Late Cretaceous and Early Tertiary); OK - Olyutorka-Kamchatka (Late Cretaceous to Paleocene)

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

JT- Japan Trench (including Kuril-Kamchatka trench) (Miocene through Holocene;
NN - Nankai (Miocene through Holocene)

Cratonal Terranes and Superterranes

Cratonal terranes (Archean and Proterozoic): GY - Gyeonggi-Yeongnam; JA - Jiaonan; OH - Okhotsk

Late Proterozoic and Cambrian superterranes: AR - Argun-Idermeg; TM - Tuva-Mongolia

Archean through Permian superterranes: BJ - Bureya-Jiamusi; KR - Kara

Jurassic Superterrane:
KOM - Kolyma-Omolon (Archean through Jurassic)

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

at - Altay arc (Devonian and early Carboniferous, 381 to 290 Ma)
ea - East Sikhote-Alin arc (Late Cretaceous through early Tertiary, 96-65 Ma)
gh - Gobi-Khankaisk-Daxing'anling arc (Permian, 295 to 250 Ma)
ha - Hangay arc (Late Carboniferous and Early Permian, 320 to 272 Ma)
ji - Jihei arc (Permian, 295 to 250 Ma)
ko - Khingan arc (Early and mid-Cretaceous)
lg - Lugyngol arc (Permian and Triassic, 295 to 250 Ma)
ma Main granite belt (Late Jurassic, 144 to 134 Ma)
nb - Northern granite belt (Early Cretaceous, 138 to 120 Ma)
nm - North Margin (Late Carboniferous and Permian, 320 to 272 Ma)
nr - Norovlin arc (Devonian and Early Carboniferous, 410 to 255 Ma)
oc - Okhotsk-Chukotka arc (Late Cretaceous and early Tertiary, 96 to 53 Ma)
ol - Oloy arc (Late Jurassic, 154 to135 Ma)
se - Selenga arc (Permian through Jurassic, 295 to135 Ma)
sm - South Mongolian arc (Carboniferous through Triassic, 320 to 203 Ma
ss - South Siberian arc (Devonian)
sv - South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157 to 93 Ma)
tr - Transverse granite belt (Early Cretaceous, 134 to 124 Ma)
uo - Umlekan-Ogodzhin arc (Cretaceous, 135 to 65 Ma)
us - Uda-Murgal and Stanovoy arc (Jurassic and Early Cretaceous, 203 to 96 Ma)
uy - Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154 to 120 Ma)

Plume-Related Igneous Province

tp - Tungus Plateau igneous province - (Late Permian and Early Triassic, 245 Ma)

Active Arcs

ib - Izu-Bonin (late Cenozoic, 20 to 0 Ma)
ja - Japan (late Cenozoic, 23 to 0 Ma)
kk - Kuril-Kamchatka (late Cenozoic, 11 to 0 Ma)

Transpressional Arcs

ke - Kema (Mid-Cretaceous)
mt - Mongol-Transbaikal (Late Triassic through Early Cretaceous, 230 to 96 Ma)
ss - South Siberian (Early Devonian, 415 to 400 Ma)
tb - Transbaikalian-Daxinganling (Middle Jurassic through Early Cretaceous,175 to 96 Ma)

Symbols, Faults, and Contacts

Overlap-continental-margin arc
Transform-continental-margin arc
Active subduction zone
Thrust
Strike-slip fault
Fault
Contact
Riphean aulacogen
Devonian aulacogen
Modern rift system (Gakkel Ridge)
os Metallogenic belt

Figure 2.—Continued.

Table 1. Definitions of key terms for analysis of regional geology and metallogenesis.

[Adapted from Jones and others (1983), Howell and others (1985), Nokleberg and others (2000, 2004, 2005)]

Term	Definition
Accretion	Tectonic juxtaposition of terranes to a cratonal or continental margin. Accretion of terranes to one another or to a craton margin also defines a major change in the tectonic evolution of terranes and craton margins.
Amalgamation	Tectonic juxtaposition of two or more terranes before accretion to a cratonal or continental margin.
Continent	A large section of continental crust surrounded by oceans on all sides that consists, in its core, of one or more cratons framed by younger tectonic collages (accretionary and collisional orogenic belts).
Continental-margin arc terrane	Fragment of an igneous belt of coeval plutonic and (or) volcanic rocks and associated sedimentary rocks that formed above a subduction zone dipping beneath a continent. May possess a sialic basement.
Craton	Chiefly regionally metamorphosed and deformed shield assemblages of Archean, Paleoproterozoic, and (or) Mesoproterozoic sedimentary, volcanic, and plutonic rocks and overlying platform successions of Paleoproterozoic, Paleozoic, and, locally Mesozoic and Cenozoic sedimentary and lesser volcanic rocks.
Cratonal margin	Chiefly Neoproterozoic through Jurassic sedimentary rocks deposited on a continental shelf or slope. Consists mainly of platform successions. Locally has or may have had an Archean and Paleoproterozoic, and (or) Mesoproterozoic cratonal basement.
Cratonal terrane	Fragment of a craton.
Island-arc system	An island arc and tectonically linked subduction zone terranes.
Island-arc terrane	Fragment of an igneous belt of plutonic and (or) coeval volcanic rocks and associated sedimentary rocks that formed above an oceanic subduction zone. May possess a simatic basement.
Metallogenic belt	A geologic unit (area) that either contains or is favorable for the occurrence of a group of coeval and genetically related, significant lode and (or) placer deposits. Has the following characteristics: (1) is favorable for the occurrence of known or inferred mineral deposits of specific types; (2) may be irregular in shape and vary in size; (3) need not contain known deposits; and (4) is based on geologic mapping as the primary source of information for the delineation of areas that are favorable for the occurrence of specific deposit types.
Metamorphic terrane	Fragment of a highly metamorphosed or deformed assemblage of sedimentary, volcanic, or plutonic rocks that cannot be assigned to a single tectonic environment because the original stratigraphy and structure are obscured. May include structural melange that contains fragments of two or more terranes.
Mine	A site where valuable minerals or rocks have been extracted.
Mineral deposit	A site with concentrations of potentially valuable minerals for which grade and tonnage estimates have been made. In this study, also used as a general term for any mineral occurrence or prospect.
Mineral occurrence	A site of potentially valuable minerals on which no visible exploration has occurred or for which no grade and tonnage estimates are available. Synonymous with prospect.
Oceanic crust, seamount, and ophiolite terrane	Fragment of part or all of a suite of deep-marine sedimentary rocks, pillow basalt, gabbro, and ultramafic rocks (former eugeoclinal suite) that are interpreted as oceanic sedimentary and volcanic rocks and upper mantle. Includes both inferred offshore oceanic and marginal ocean-basin rocks, minor arc-derived volcaniclastic rocks, and major marine volcanic accumulations formed at a hotspot, in a fracture zone, or along a spreading axis.
Overlap assemblage	A postaccretionary unit of sedimentary or igneous rocks deposited on or intruding two or more adjacent terranes.
Passive-continental-margin terrane	Fragment of a cratonal (continental) margin.

Table 1. Definitions of key terms for analysis of regional geology and metallogenesis. —Continued

[Adapted from Jones and others (1983), Howell and others (1985), Nokleberg and others (2000, 2004, 2005)]

Term	Definition
Subduction zone terrane	Fragment of a mildly to intensely deformed accretionary complex consisting of varying amounts of turbidite deposits, continental-margin rocks, oceanic crust and overlying units, and oceanic mantle. Units are interpreted to have formed during tectonic juxtaposition in a zone of major thrusting of one lithosphere plate beneath another, generally in zones of thrusting along the margin of a continent or an island arc. May include large fault-bounded fragments with a coherent stratigraphy. Many subduction-zone terranes contain fragments of oceanic crust and associated rocks that exhibit a complex structural history, occur in a major thrust zone, and possess blueschist-facies metamorphism. Synonymous with accretionary wedge terrane.
Superterrane	An aggregate of terranes that is interpreted to share either a similar stratigraphic affinity or a common geologic history after accretion. Approximately synomous with *Composite terrane*.
Tectonic collage	A series of linear island arcs or continental margin arcs and tectonically linked (companion) subduction zones and (or) forearc and backarc basins that formed during a major tectonic event within a relatively narrow geologic timespan. May consist of fragments of cratonal and cratonal-margin terranes that were amalgamated before accretion to a continent.
Tectonic linkage	A genetic relation of a continental margin or island arc to a companion accretionary wedge that formed in a subduction zone which was adjacent to and underthrusting the arc.
Tectonostratigraphic terrane (terrane)	A fault-bounded geologic unit or fragment characterized by a distinctive geologic history which differs markedly from that of adjacent terranes. (Jones and others, 1983; Howell and others, 1985).
Turbidite-basin terrane	Fragment of a basin filled with deep-marine clastic deposits in either an orogenic forearc or backarc setting. May include continental-slope and continental-rise turbidite deposits, submarine-fan turbidite deposits, and minor epiclastic and volcaniclastic deposits deposited on oceanic crust.

ages (fossil and geochronologic) of lithologic units, and the interpretation of an originally adjacent loci.

The first type of tectonic link is based on (1) interpreting an original physical proximity between an arc and a subduction zone, (2) determining the similarity in age of formation of an igneous-arc and subduction-zone terrane, (3) determining a subduction polarity from tectonic-transport direction in a melange for subduction-zone terranes, where not disrupted by later deformation, and (4) recognizing the occurrence of disrupted layers of arc-derived volcanic or volcaniclastic rocks from a specific igneous arc in the melange of the linked subduction-zone terrane. The second type of tectonic link is based on the spatial and temporal (age) association of collisional (S-type) granitic plutons and associated volcanic rocks (1) with major fault zones (sutures) between terranes or between a terrane and a cratonal margin, and (or) (2) with belts of highly deformed, regional-grade metamorphic rocks that occur along fault zones. Collision-related igneous belts are interpreted as having formed either during accretion of one terrane to another or during accretion of one or more terranes to a craton or cratonal margin. The third type of tectonic link is based on the spatial and temporal (age) association of mainly intermediate-composition and silicic igneous belts that are coeval with, and intrude along major transpressional fault zones.

In step 3, terranes and overlap assemblages are grouped into larger entities that probably were once continuous and coeval igneous arcs and companion subduction zones, on the basis, to varying degrees, of (1) similar stratigraphy, fauna, lithologic-unit age, and structure, (2) paleomagnetic data, and (3) assumed simplicity rather than complexity. As a result of these groupings, coeval igneous-arc overlap assemblages and igneous-arc terranes and tectonically linked (companion) subduction-zone terranes are aligned with coeval, curvilinear arc-subduction-zone complexes herein termed *tectonic collages*. Thus, this grouping represents an interpretation of single rather than multiple continental-margin or island/arc-subduction-zone complexes.

Summary of Regional Geology and Tectonics

The major geologic and tectonic units of Northeast Asia (fig. 1) are cratons and cratonal margins; cratonal terranes and superterranes, tectonic collages, overlap and transform continental-margin-arcs, island arcs, and pelagic and oceanic rocks (fig. 2). Detailed descriptions of geologic units were provided by Nokleberg and others (2000, 2004) and Parfenov and others (2004b). The abbreviations in parentheses in the following list are the same as those used on the summary geodynamics map (fig. 2); more detailed descriptions of map units are provided in appendix B. Two geologic ages are stated for each collage; one for the time of formation of the contained units and another for the time of accretion (formation) of the tectonic collage to another terrane, superterrane, or continent.

Major Cratons and Cratonal Margins

The backstop or core tectonic units for Northeast Asia (fig. 1) are six Archean and Proterozoic cratons and their cratonal margins:

The North Asian craton (NAC), which consists of Archean and Proterozoic metamorphic basement and non-deformed, flat-laying platform cover consisting of late Precambrian, Paleozoic, and Mesozoic sedimentary and volcanic rocks.

The Sino-Korean craton (SKC), which consists of several major Archean and Proterozoic metamorphic-basement terranes and later Paleozoic through Cenozoic overlap units.

The Baikal-Patom cratonal margin. (BP), which consists of a fault-bounded basin containing Riphean carbonates and terrigenous sedimentary rocks, and later Vendian and Cambrian sedimentary rocks that discordantly overlie a fragment of pre-Riphean basement of the North Asian craton.

The East Angara cratonal margin (EA), which consists of late Riphean terrigenous carbonate sedimentary rocks (sandstone, siltstone, and mudstone with interlayered dolomite and limestone) that overlie a fragment of the North Asia craton.

The South Taimyr cratonal margin (ST), which consists chiefly of a thick wedge of Ordovician through Jurassic cratonal margin and deep basin deposits.

The Verkhoyansk (North Asian) cratonal margin (VR), which consists chiefly of a thick wedge of Devonian through Jurassic miogeoclinal deposits.

Cratonal Terranes and Superterranes

Three cratonal terranes that occur along the margins of the North Asian and Sino-Korean cratons and are interpreted as rifted and reaccreted fragments of these cratons:

The Okhotsk terrane (OH) consists of Archean and Proterozoic gneiss and schist and early and middle Paleozoic miogeoclinal sedimentary rock. The terrane is interpreted as a fragment of the North Asian craton and cratonal margin that was rifted in the Late Devonian or Early Carboniferous.

The Gyenggi-Yeongnam terrane (GY) consists of two major Archean and Proterozoic basement rock terranes. The terrane is interpreted as a displaced fragment of the Sino-Korean craton, or possibly a fragment of the South China (Yangzi) craton.

The Jiaonan cratonal terrane (JA) consists of a Paleoproterozoic major high pressure terrane that is interpreted as a displaced fragment of the Sino-Korean craton.

Along the margins of the North Asian and Sino-Korean cratons are several superterranes, which are interpreted as rifted and reaccreted fragments of these cratons and others interpreted as having originally formed elsewhere:

The Proterozoic through Cambrian Argun-Idermeg superterrane (AR), which consists of the Paleoproterozoic through late Paleozoic Argunsky, and Idermeg, passive continental-margin terranes. This superterrane may be either exotic with respect to the North Asian craton or a rifted fragment of that craton.

The late Riphean and older Tuva-Mongolia superterrane (TM), which consists of a series of Archean and Paleoproterozoic cratonal terranes (Gargan and Baydrag), the Sangilen passive continental-margin terrane, and the Muya metamorphic terrane. All of these terranes are interpreted as having been accreted together to form the backarc of the Baikal-Myra island arc described below.

The Proterozoic through Permian Bureya-Jiamusi superterrane (BJ), which consists of a tectonic collage of early Paleozoic metamorphic, continental-margin-arc, subduction zone, passive continental-margin and island-arc terranes. This superterrane is interpreted as a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

The Proterozoic through Ordovician Kara superterrane (KR), which consists of the late Neoproterozoic through Ordovician Kara continental-margin turbidite terrane. This superterrane is interpreted as a rift fragment of the North Asian craton that was reaccreted in the Jurassic.

The Archean to Jurassic Kolyma-Omolon superterrane (KOM), which consists of a tectonic collage of cratonal, passive-continental-margin, island-arc, and ophiolite terranes. The cratonal and passive-continental core of this superterrane was rifted from the North Asian craton and cratonal margin in the Late Devonian or Early Carboniferous, and after subsequent building of overlying island arcs, reaccreted to the North Asian cratonal margin in the Late Jurassic with the formation of collisional granites of the Main and Northern granite belts.

Tectonic Collages Between the North Asian and Sino-Korean Cratons

Between the North Asian and Sino-Korean cratons are a series of accreted tectonic collages composed primarily of Paleozoic island arcs and tectonically linked subduction zones. Most of these tectonic collages, which were successively accreted southward during closures of the Paleo-Asian and Solon Oceans, collages contain one ore more island arcs and tectonically linked subduction zones. Because of these successive accretions, the collages generally young southward; however, this pattern is locally disrupted because some tectonic collages or parts them were interspersed by subsequent strike-slip faulting.

The Circum-Siberia tectonic collage (CS; Paleoproterozoic and Mesoproterozoic, accreted in the Neoproterozoic), which consists of the Baikal-Muya island arc, the Near Yenisey Ridge island arc, and the Zavhan continental-margin-arc, all of Neoproterozoic age, as well as small fragments of cratonal and metamorphic terranes of Archean and Proterozoic age. These three separate Neoproterozoic island-arc systems formed south (present-day coordinates) of the North Asian craton and cratonal margin.

The Yenisey-Transbaikal tectonic collage (YT; Vendian through Devonian, accreted in the Vendian through Early Ordovician), which consists of the Vendian through Middle Cambrian Kuznetsk-Tannuola and the Dzhida-Lake island-arc terranes, tectonically linked backarc basins, and now tectonically eroded subduction-zone terranes. This tectonic collage is interpreted as a linear array of island-arc systems that formed south (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. The eastern part of the tectonic collage includes the West Stanovoy metamorphosed terrane, which may be a displaced fragment of the North Asian craton or of another craton.

The Altay tectonic collage (AL; Vendian through Ordovician, accreted in the Late Silurian), which consists of the Vendian through Early Ordovician Salair island-arc terrane and various fragments of arc-related turbidite terranes, subduction-zone terranes, metamorphic terranes derived from arc-related rocks, thick Cambrian and Ordovician overlap turbidites that formed on a continental slope and rise, and fragments of originally adjacent oceanic terranes. This tectonic collage is interpreted as an island-arc system that was active near the southwestern margin (present-day coordinates) of the North Asian craton and previously accreted terranes.

The Wundurmiao tectonic collage (WD; Mesoproterozoic through Silurian, accreted in the Late Silurian), which consists of the Late Ordovician and Silurian Laoling island-arc terrane, the Mesoproterozoic through Middle Ordovician Wundurmiao subduction-zone terrane, and the Neoproterozoic Seluohe subduction-zone terrane. The collage is interpreted as the Laoling island-arc system that formed near Sino-Korean craton. Both the island-arc system and craton were widely separated from the North Asian craton in the early Paleozoic.

The Atasbogd tectonic collage (AB; Ordovician through Permian, accreted in the Late Carboniferous or Early Permian), which consists of: the Ordovician through Permian Waizunger-Baaran terrane, the Devonian and Carboniferous Beitianshan-Atasbogd terrane, and (3) the Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin-arc terrane. This tectonic collage is interpreted as a southwestard continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. This tectonic collage was initially separated from the North Asian craton by a large backarc basin.

The South Mongolia-Khingan tectonic collage (SM; Ordovician through Carboniferous, accreted in the Late Carboniferous or Early Permian), which consists of the South Mongolia-Khingan island-arc and tectonically linked subduction-zone terranes. This tectonic collage is interpreted as a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. This tectonic collage was initially separated from the North Asian craton by a large backarc basin.

The West Siberian tectonic collage (WS; Ordovician through Carboniferous, accreted in the Late Carboniferous or Early Permian), which consists of the Late Silurian through Early Carboniferous Rudny Altai island arc and the tectonically linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. This tectonic collage is interpreted as a northwest continuation (present-day coordinates) of the South Mongolia-Khingan tectonic collage.

The Mongol-Okhotsk tectonic collage (MO; Devonian through Late Jurassic, accreted in the late Paleozoic through early Mesozoic), which consists mainly of the Permian through Jurassic Selenga, the Late Carboniferous and Early Permian Hangay, and the Uda-Murgal and Stanovoy continental-margin-arcs. These arcs are composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically linked, outboard subduction-zone terranes and overlap the southern margin of the North Asian craton and cratonal margin, and previously accreted terranes. This tectonic collage is interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean with oblique subduction of terranes beneath the southern margin of the North Asian craton and previously accreted terranes.

The Solon tectonic collage (SL; Carboniferous to Permian, accreted in the late Paleozoic through early Mesozoic), which consists of the Carboniferous and Early Permian North Margin, the Late Carboniferous to Permian Solon, the Devonian Imjingang, the Paleozoic Ogcheon, and the Silurian through Permian Sangun-Hidagaien-Kurosegawa subduction-zone terranes. Parts of this tectonic collage are interpreted as fragments of the Solon Ocean plate that were subducted to form the South Mongolian, Lugyngol, Gobi-Khankaisk-Daxing'anling, and Jihei continental-margin-arcs, and other parts are interpreted as fragments of the Solon Ocean plate that were subducted to form the North Margin continental-margin-arc on the Sino-Korean craton.

Tectonic Collages East of the North Asian and Sino-Korean Cratons

East of the North Asian and Sino-Korean cratons are a series of tectonic collages that were successively accreted from eastward during closures of parts of the ancestral and modern Pacific and older oceans in the region (fig. 1). Thus, these tectonic collages generally young eastward; however, this pattern is locally disrupted because some of them were interspersed by subsequent strike-slip faulting. Except for the first two collages (Verkhoyansk-Kolyma and Chukotka) the others contain one or more island arcs or continental-margin-arcs and tectonically linked subduction-zone terranes.

The Verkhoyansk-Kolyma tectonic collage (VK, late Paleozoic through Early Jurassic age, accreted in the Late Jurassic and Early Cretaceous), which consists of a deformed passive-continental-margin, accreted ophiolites, and subduction zone and is interpreted as having formed during accretion of the outboard Kolyma-Omolon superterrane.

The Chukotka tectonic collage (CH, Paleozoic and Triassic; accreted in the Late Jurassic and Early Cretaceous), which consists of passive continental-margin terranes that formed along the long-lived Neoproterozoic through early Mesozoic North American continental margin. This collage is interpreted as having been accreted to the northern Verkhoyansk-Kolyma tectonic collage in the Late Cretaceous after subsequent rifting of the North American cratonal margin in the Late Jurassic and Early Cretaceous and subsequent translation.

The South Anyui collage (SA, Permian through Early Jurassic; accreted in the Late Cretaceous), which consists of the Oloy island arc and tectonically linked subduction-zone terranes.

The Penzhina-Anadyr collage (PA, Late Jurassic and Early Cretaceous; accreted in the Late Cretaceous), which consists of the Murgal island-arc terrane and tectonically linked subduction-zone terranes to the east. This collage rims the eastern Kolyma-Omolon superterrane and Verkhoyansk-Kolyma tectonic collage and is also linked to the Uda continental-margin-arc.

The Badzhal collage (BD, Triassic through Early Cretaceous; accreted in the Late Cretaceous), which consists of the Umlekan continental-margin-arc and tectonically linked subduction-zone terranes to the east with Tethyan fauna.

The Honshu-Sikhote-Alin collage (HS, Jurassic and Early Cretaceous; accreted in the Cretaceous), which consists of fragments of island-arc, continental-margin turbidite (flysch), and subduction-zone terranes. This collage is interpreted as having formed along a transform continental margin.

The Koryak collage (KOR, Late Triassic through Cretaceous; accreted in Late Cretaceous), which consists of the Late Jurassic and Early Cretaceous Manitskiy island arc and tectonically linked subduction-zone terranes to the east.

The Sakhalin-Hokkaido collage (SK; Cretaceous; accreted in the Eocene), which consists of the Late Cretaceous flysch terranes of Sakhalin and Hokkaido Islands, and tectonically linked subduction-zone terranes to the east. This collage is interpreted as a continental-margin forearc basin and tectonically linked subduction-zone terranes that are associated with the East Sikhote-Alin continental-margin-arc.

The West Kamchatka tectonic collage (WK; mid-Cretaceous to early Tertiary; accreted in the early Cenozoic), which consists of late Paleozoic through Cretaceous subduction-zone terranes in the Russian Northeast. This collage was tectonically linked to Okhotsk-Chukotka continental-margin-arc.

The East Sakhalin collage (ES, Late Cretaceous to early Tertiary; accreted in the early Tertiary), which consists of the Late Cretaceous to middle Eocene Terpeniy-Tokoro-Nemuro-Shmidt island arc and tectonically linked subduction-zone terranes.

The Olyutorka-Kamchatka tectonic collage (OK, Late Cretaceous and Paleocene; accreted in the early Cenozoic), which consists of the Olyutorka island-arc and tectonically linked subduction-zone terranes to the east.

The East Kamchatka Peninsula tectonic collage (EP, mainly Paleocene, and accreted in the Pliocene), which consists of the Kronotskiy island arc and associated ophiolite.

Carboniferous and Permian Continental-Margin-Arcs South of the North Asia Craton and on the Sino-Korean Craton

Several major continental-margin-arcs occur on previously accreted terranes south of the North Asian craton and on the Sino-Korean craton. These arcs are interpreted as related to subduction of the late Paleozoic and early Mesozoic Solon Ocean plate beneath the North Asian and Sino-Korean cratons. The Solon Ocean lay between the Argun-Idermeg superterrane to the north (present-day coordinates) and the Sino-Korean craton to the south.

The Altay continental-margin arc (at; Devonian and early Carboniferous), which occurs on the Altay and Yenisey-Transbaikal collages. This arc is interpreted as having formed along an active continental margin in an oblique subduction zone environment.

The Gobi-Khankaisk-Daxing'anling continental-margin arc (gh, Permian) which occurs on the Argun-Idermeg superterrane, South Mongolian and Solon collages. The arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane.

The South Mongolian continental-margin arc (sm; middle Carboniferous through Triassic), which overlies and intrudes the South Mongolian and Atasbogd collages. This arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the Argun-Idermeg superterrane.

The Lugyngol continental-margin arc (lg; Permian), which occurs on the South Mongolian and Solon collages. This arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane.

The Jihei continental-margin arc (ji; Permian), which occurs on the South Mongolia-Khingan collage and intrudes the Bureya-Jiamusi superterrane and South Mongolia-Khingan collage, is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Bureya-Jiamusi superterrane and adjacent units.

The North Margin continental-margin arc (nn; Late Carboniferous to Permian), which occurs on the northeastern margin (present-day coordinates) of Sino-Korean craton. This arc is interpreted as having formed during subduction of the southern (present-day coordinates) part of Solon Ocean plate under the northeastern margin of Sino-Korean craton.

Devonian Through Early Cretaceous Continental-Margin-Arcs Along the Southeastern Margin of the North Asian Craton and Adjacent Accreted Terranes

Several major continental-margin-arcs occur along the southeastern margin of the North Asian craton or on adjacent accreted terranes. These arcs are interpreted as related to subduction of the late Paleozoic and early Mesozoic Mongol-Okhotsk Ocean plate beneath the North Asian craton and cratonal margin. The Mongol-Okhotsk Ocean lay between the North Asian craton to the north and the Argun-Idermeg superterrane to the south (present-day coordinates).

The Norovlin continental-margin arc (nr; Devonian through Early Carboniferous), which occurs on the Argun-Idermeg superterrane (Amur microcontinent - Argunsky and Idermeg passive continental-margin terranes). This arc is interpreted as having formed during subduction of the Mongol-Okhotsk Ocean plate beneath northern margin (present-day coordinates) of the Argun-Idemeg superterrane (Amur microcontinent).

The Hangay continental-margin arc (ha; Late Carboniferous to Early Permian, which occurs on the Yenisey-Transbaikal collage and Mongol-Okhotsk collage. This arc is interpreted as having formed during subduction of the northern part of Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously accreted terranes.

The Selenga continental-margin arc (se; Permian through Jurassic), which overlies and intrudes the Yenisey-Transbaikal collage and Tuva-Mongolia superterrane. This arc is interpreted as having formed during oblique subduction of the Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously accreted terranes.

The Uda-Murgal and Stanovoy continental-margin arcs (us; Jurassic and Early Cretaceous), which occur on the southern margin of the North Asian craton. These arcs are interpreted as having formed during final stage of subduction of the Mongol-Okhotsk Ocean plate.

Jurassic and Early Cretaceous Island Arcs on or Adjacent to the Kolyma-Omolon Superterrane

Two major island arcs occur along the margin of the Kolyma-Omolon superterrane:

The Uyandina-Yasachnaya island arc (uy; Late Jurassic and Early Cretaceous), which is interpreted as having formed during subduction of the Oimyakon Ocean plate between the North Asian cratonal margin and the Kolyma-Omolon superterrane. Remnants of Oimyakon oceanic crust are preserved in small obducted ophiolites along the western margin of superterrane. This Oimyakon ocean lay between the Verkhoyansk (North Asian) cratonal margin to the southwest (present-day coordinates)and the Kolyma-Omolon to the northeast.

The Oloy island arc (ol; Late Jurassic), which is interpreted as having formed on the Kolyma-Omolon superterrane during subduction of the South Anyui Ocean plate beneath this superterrane to form the South Anyui subduction-zone terrane. The South Anyui ocean formed north (present-day coordinates)of the Kolyma-Omolon superterrane.

Jurassic through Early Tertiary Continental-Margin-Arcs and Granite Belts Along the Eastern Margin of Northern Asia

A series of Jurassic through early Tertiary continental-margin arcs and granite belts occur along the eastern margin of the North Asian and Sino-Korean cratons and outboard accreted terranes to the east:

The Umlekan-Ogodzhin continental-margin arc (uo; Jurassic and Cretaceous, which occurs along the margin of the Kolyma-Omkolon superterrane. This arc is interpreted as having formed during subduction of the ancestral Pacific Ocean plate to form the Badzhal and Nadanhada terranes (parts of the Badzhal collage).

The South Verkhoyansk granite belt (sv; Late Jurassic through mid-Cretaceous), which occurs in central Russian Far east. This belt, which extends longitudinally along the central part of the South Verkhoyansk synclinorium in the Verkoyansk (North Asian) cratonal margin, is interpreted as having formed during the accretion of the outboard Okhotsk terrane.

The Main granite belt (ma; Late Jurassic), which occurs along the adjacent margins of the North Asian cratonal margin and Kolyma-Omolon superterrane. This belt is interpreted as having formed during and immediately after collision of the Kolyma-Omolon superterrane with the North-Asian cratonal margin.

The Transverse granite belt (tv; Early Cretaceous), which radiates outwards from the southwestern bend in the Kolyma-Omolon superterrane. This belt is interpreted as having formed during the late stage of accretion of the Kolyma-Omolon superterrane.

The Northern granite belt (nb; Early Cretaceous, 138 to 120 Ma), which occurs along the northwestern margin of the Kolyma-Omolon superterrane. The belt is interpreted as having formed during the subduction of oceanic crust in a closure of a small oceanic basin during the late stage of accretion of the Kolyma-Omolon superterrane.

The Khingan-Okhotsk continental-margin arc (ko; Early and mid-Cretaceous), which occurs in the Russian Southeast and consists of the Khingan-Okhotsk volcanic-plutonic belt. This arc was tectonically paired to the Early Cretaceous

Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes (part of the Honshu-Sikhote-Alin collage).

The Okhotsk-Chukotka continental-margin arc (oc; Late Cretaceous through early Tertiary), which occurs along the eastern margin of the central and northern Russian Far East. This arc is interpreted as having formed during subduction of the ancestral Pacific Ocean plate with formation of the West Kamchatka, Ekonay, and Yanranay subduction-zone terranes.

The East Sikhote-Alin continental-margin arc (ea; Late Cretaceous to early Tertiary), which occurs along the margin of southern Russian Far East. This arc is interpreted as having formed during subduction of the ancestral Pacific Ocean plate with formation of the older part of the Hidaka, the younger part of the Aniva, terrane, and the Nabilsky and Tokoro subduction-zone terranes.

Active Continental-Margin-Arcs Along the Eastern Margin of Northern Asia

Three active continental-margin arcs occur along the eastern margin of the North Asian and Sino-Korean cratons and outboard accreted terranes to the east:

The Izu-Bonin continental-margin arc (ib; Miocene through Holocene), which occurs south of southern Japan, where it consists of a volcanic arc composed chiefly of basalt to rhyolite, associated volcaniclastic rock, and intercalated hemipelagic mudstone. This arc is interpreted as having formed from subduction of the Philippine Sea Plate with the creation of the Nankai subduction zone.

The Japan continental-margin arc (ja; Miocene through Holocene), which occurs along the Japan Islands and consists of extensive Quaternary volcanic and associated rocks. This arc is interpreted as having formed during subduction of the Pacific Ocean and Philippine Sea Plates with formation of the Japan Trench and the Nankai subduction zones.

The Kuril-Kamchatka continental-margin arc (kk; Miocene through Holocene), which occurs along the Kamchatka Peninsula and the Kuril Islands and consists of the Pliocene to Quaternary Central Kamchatka volcanic belt, central Kamchatka volcanic and sedimentary basin, and the East Kamchatka volcanic belt. This arc is interpreted as having formed during subduction of the Pacific Ocean Plate with the creation of the Japan Trench subduction zone.

Transpressional Arcs (Devonian Through Cretaceous)

Four major transpressional arcs occur along the margins of the North Asian craton and previously accreted terranes to the south. These arcs are associated with a combination of strike-slip faulting and local compression and extension.

The Kema arc (ke) (Mid-Cretaceous) occurs in the Russian Southeast and consists of the Kema island arc terrane, and the Late Jurassic and Early Cretaceous Zhuravlevsk-Amur River continental-margin turbidite terrane. The arc is part of the Honshu-Sikhote-Alin collage (Jurassic and Early Cretaceous) described above. The Zhuravlevsk-Amur River continental-margin turbidite terrane and the companion Kema arc terranes are interpreted as forming along a Late Jurassic and Early Cretaceous continental-margin transform fault.

The South Siberian transpressional arc (ss; Early Devonian), which occurs in Southern Siberia and is interpreted as having formed along the southern margin of the North Asian craton and cratonal margin during Early Devonian rifting that successively evolved into a continental-margin transform margin and subsequently a convergent margin.

The Mongol-Transbaikal transpressional arc (mt; Late Triassic through Early Cretaceous), which occurs in northern Mongolia and southern Siberia and is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk Fault during and after the final closure of the Mongol-Okhotsk Ocean.

(3) The Trans-Baikal-Daxinganling transpressional arc (tr; Middle Jurassic through Early Cretaceous), which occurs in Southern Siberia, Mongolia, Northeastern China and is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk Fault during and after final closure of the Mongol-Okhotsk Ocean.

Regional Metallogenesis of Northeast Asia

Synthesis of Mineral-Deposit Models

A modern regional metallogenic analysis requires that appropriate mineral-deposit models be characterized, synthesized, and grouped for correlation with the regional tectonic processes that formed the known mineral deposits. The beginning of this type of correlation between models and tectonic processes is evident in many of the classic compilations of mineral deposits models (Eckstrand, 1984; Cox and Singer, 1986; Singer, 1993). The mineral-deposit models that were defined and described for the metallogenic analysis of Northeast Asia are listed in table 2. For this large and complex region (fig. 2), a suite of 122 mineral-deposit models was sufficient to describe the characteristic features of the 1,674 lode deposits and 75 placer districts (Obolenskiy and others, 2003 and this volume, chapter 3). The models include previous descriptions by Eckstrand (1984), Cox and Singer (1986), and Nokleberg and others (1997a), with modifications by Obolenskiy and others (2003 and this volume, chapter 3).

The mineral-deposit models listed in table 2 consist of both descriptive and genetic information that is systematically arranged to define the essential attributes of each class or type of mineral deposits; however, some models are based mainly on descriptive (empirical) information, whereby the various attributes are recognized as essential even though their relationships are unknown. For example, the basaltic native Cu mineral-deposit type, the geologic association of Cu sulfides with relatively Cu rich metabasalt or greenstone is the essential attribute. Some other mineral-deposit models are defined by genetic (theoretical) considerations, whereby the attributes are related through some fundamental geologic process. For example, the W±Mo±Be skarn deposit mineral-deposit model, the genetic process of contact metasomatism is the essential attribute. For additional information on the methodology for defining mineral-deposit models, see the discussions by Eckstrand (1984) and Cox and Singer (1986).

A major facet of the compilation and synthesis of mineral-deposit models is interpretation of the tectonic environment(s) for each model. This interpretation permits a ready perception of the geologic setting for the formation of each mineral-deposit type. The tectonic environments interpreted for the major mineral-deposit models that were used to classify deposit descriptions for the metallogenic and tectonic analysis of Northeast Asia (fig. 1) are listed in table 3. Only seven major tectonic events are interpreted for the origin of major geologic units and mineral deposits: (1) rifting; (2) sea-floor spreading; (3) continental-margin-arc and backarc; (4) island arc and backarc; (5) collision; (6) transform-continental-margin faulting and associated bimodal volcanic and plutonic belt, and (7) plume intrusion.

Summary of the Methodology of Metallogenic and Tectonic Analysis

The methodology of metallogenic and tectonic analysis for Northeast Asia (fig. 1) is illustrated in figure 3 from Nokleberg and others (2005).

The steps in this analysisare as follows.

1. A regional geologic base map is constructed. Figure 3A schematically depicts the regional geology of the Northeast Asia, with craton A representing the North Asian craton and craton B representing the Sino-Korean craton, terranes 1 through 4 representing the tectonic collages of intercratonal terranes and accretionary assemblages a through c, and postaccretionary overlap assembagles d and e, representing the major arcs overlying cratons and collages.

2. A series of mineral-deposit models appropriate for the regional geology are identified and defined, and a mineral-deposit database is compiled. In this example, the major mineral-deposit models are low-sulfide Au in shear zone and quartz vein, Au-Ag epithermal vein, porphyry Cu (+Au), bedded barite, and kuroko massive sulfide.

3. Metallogenic belts are delineated. For simplicity, in this example each metallogenic belt is assumed to contain only a single mineral-deposit type. Cratons A and B each contain distinctive, preaccretionary metallogenic belts with banded iron formation and bedded barite deposits that formed early in their geologic history. Between island-arc terranes 3 and 4 is an accretionary assemblage a, which consists of a collisional granitic pluton with a metallogenic belt of porphyry Cu deposits that formed during accretion of terrane 3 against terrane 4. Island-arc terrane 4 contains a preaccretionary belt of kuroko massive sulfide deposits that formed during marine arc volcanism. Between island-arc terranes 1 and 2 accretionary assemblage c, which contains a belt of Au quartz vein deposits that formed during accretion of terrane 1 against terrane 2. Overlying all the terranes and both cratons is postaccretionary overlap assemblage e, which contains a metallogenic belt with epithermal Au-Ag vein deposits.

4. The genesis of bedrock geologic units, structures, and contained metallogenic belts and mineral deposits is interpreted according to modern tectonic concepts, for example, are kuroko massive sulfide deposits forming in an island-arc environment, porphyry Cu and Au in shear zone and quartz vein deposits forming in a collisional environment, and epithermal Au-Ag vein deposits forming in a continental-margin igneous arc environment.

5. By carefully defining each metallogenic belt to be the geologically favorable area for a group of coeval and genetically related mineral deposits, a predictive characteristic is established within each belt for undiscovered mineral deposits.

Synthesis of Metallogenic-Belt Maps

Many metallogenic maps display major mineral deposits and (or) districts on a regional geologic base map. These maps are commonly quite complex because of a high density of deposits. To simply data presentation and increase understanding of regional patterns, the concept of a metallogenic-belt map was developed for the studies of Northeast Asia and the Circum-North Pacific (Nokleberg and others, 1997b,c; Obolenskiy and others, 2003, 2004). As an example of the power of a modern-day metallogenic-belt map, the major Archean through Mesoproterozoic metallogenic belts of Northeast Asia are shown in figure 4*A*, which includes the summary geodynamics map as a base layer. Besides displaying important summary map data, figure 4*A* also illustrates how the origins of metallogenic belts can be related to the major geologic units or structures containing the belts through the definition of a metallogenic belt, that is a group of coeval and genetically-related, significant lode and placer deposits that can be interpreted as having formed in a single major geologic or tectonic event. For additional information, summary descriptions of the major metallogenic belts in the region are provided in appendix C.

Benefits of Performing a Combined Regional Metallogenic and Tectonic Analysis

As described above, a high-quality metallogenic and tectonic analysis, including synthesis of a metallogenic and

Table 2. List of lode mineral deposit models employed for metallogenic analysis of Northeast Asia.

[Adapted from Obolenskiy and others 2003; chapter 3 this volume]

Deposit Group	Deposit Name
Deposits related to mafic and ultramafic intrusions	Anorthosite Ti-Fe-P-apatite- Diamond-bearing kimberlite Mafic-ultramafic related Cu-Ni-PGE Mafic-ultramafic related Ti-Fe(±V) Podiform chromite Zoned mafic-ultramafic Cr-PGE
Deposits related to intermediate-composition and felsic intrusions	Au skarn B (datolite) skarn Carbonate-hosted asbestos Cassiterite-sulfide-silicate vein and stockwork Co skarn Cu(±Fe, Au, Ag, Mo) skarn Fe skarn Felsic plutonic U-REE Fe-Zn skarn Fluorite greisen Granitoid-related Au vein Muscovite pegmatite Polymetallic Pb-Zn±Cu (±Ag, Au) vein and stockwork Porphyry Au Porphyry Cu (±Au) Porphyry Cu-Mo(±Au, Ag) Porphyry Mo(±W, Bi) Porphyry Sn REE-Li pegmatite Sn skarn Sn-B (Fe) skarn (ludwigite) Sn-W greisen, stockwork, and quartz vein Ta-Nb-REE alkaline metasomatite W±Mo±Be skarn W-Mo-Be greisen, stockwork, and quartz vein Zn-Pb(±Ag, Cu, W) skarn
Deposits related to alkaline intrusions	Albite syenite-related REE Alkaline complex-hosted Au Apatite carbonatite Charoite metasomatite Fe-REE carbonatite Fe-Ti(±Ta, Nb, Cu, apatite) carbonatite Magmatic and metasomatic apatite Magmatic graphite Magmatic nepheline Peralkaline granitoid-related Nb-Zr-REE Phlogopite carbonatite REE(±Ta, Nb, Fe) carbonatite Ta-Li ongonite
Deposits related to marine extrusive rocks	Besshi Cu-Zn-Ag massive sulfide Cyprus Cu-Zn massive sulfide Volcanogenic Cu-Zn massive sulfide (Urals type) Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) Volcanogenic-hydrothermal-sedimentary Pb-Zn(±Cu) massive sulfide Volcanogenic-sedimentary Fe Volcanogenic-sedimentary Mn

Table 2. List of lode mineral deposit models employed for metallogenic analysis of Northeast Asia.—Continued

[Adapted from Obolenskiy and others 2003; chapter 3 this volume]

Deposit Group	Deposit Name
Deposits related to subaerial extrusive rocks	Ag-Pb epithermal vein Ag-Sb vein Au-Ag epithermal vein Au-Kmetasomatite (Kuranakh type) Barite vein Basaltic native Cu (Lake Superior type) Be tuff Carbonate-hosted Ag-Pb Carbonate-hosted As-Au metasomatite Carbonate-hosted fluorspar Carbonate-hosted Hg-Sb Clastic sediment-hosted Hg±Sb Epithermal quartz-alunite Fluorspar vein Hg-Sb-W vein and stockwork Hydrothermal Iceland spar Hydrothermal-sedimentary fluorite Limonite Mn vein Ni-Co arsenide vein Polymetallic Ni vein Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomtite Rhyolite-hosted Sn Silica-carbonate (listvinite) Hg Sulfur-sulfide (S, FeS2) Trapp related Fe skarn (Angara-Ilim type) Volcanic-hosted Au-base-metal metasomatite Volcanic-hosted Hg Volcanic-hosted U Volcanic-hosted zeolite
Deposits related to hydrothermal-sedimentary processes	Bedded barite Carbonate-hosted Pb-Zn (Mississippi Valley type) Chemical-sedimentary Fe-Mn Evaporate halite Evaporate sedimentary gypsum Korean Pb-Zn massive sulfide Polygenic REE-Fe-Nb deposits (Bayan-Obo type) SEDEX (Sedimentary exhalative Pb-Zn) Sedimentary bauxite Sedimentary celestite Sedimentary Fe-V Sedimentary phosphate Sedimentary siderite Fe Sediment-hosted Cu Stratiform Zr (Algama Type)

Table 2. List of lode mineral deposit models employed for metallogenic analysis of Northeast Asia.—Continued

[Adapted from Obolenskiy and others 2003; chapter 3 this volume]

Deposit Group	Deposit Name
Deposits related to metamorphic processes	Au in black shale Au in shear zone and quartz vein Banded iron-formation (Algoma type) Banded iron-formation (Superior type) Clastic-sediment-hosted Sb-Au Clastic-sediment-hosted U Cu-Ag vein Homestake Au Metamorphic graphite Metamorphic sillimanite Phlogopite skarn Piezoquartz Rhodusite-asbestos Sedimentary-metamorphic borate Sedimentary-metamorphic magnesite Serpentinite-hosted asbestos Talc (magnesite) replacement
Deposits related to surficial processes	Bauxite (karst type) Laterite Ni Placer and paleoplacer Au Placer diamond Placer PGE Placer Sn Placer Ti-Zr Weathering crust and karst phosphate Weathering crust Mn(±Fe) Weathering crust REE-Zr-Nb-Li carbonatite
Exotic deposits	Impact diamond

tectonic model, will (1) greatly benefit other mineral resource studies (fig. 3), including synthesis of mineral-deposit models (Eckstrand, 1984; Cox and Singer, 1986; Singer and Cox, 1988), (2) improve prediction of undiscovered mineral depisuts as a part of quantitative mineral-resource-assessment studies (Cox, 1993; Singer, 1993, 1994), (3) assist land-use and mineral-exploration planning, (4) improve interpretations of the origins of host rocks, mineral deposits, and metallogenic belts, and (5) suggest new research.

Following are three examples of these benefits. (1) Indepth understanding of the tectonic and metallogenic origins of potential host rocks for mineral deposits may enable the prediction of undiscovered mineral deposits according to favorable host-rock geology. This capability is crucial for a mineral-resource assessment because the outlines of permissive tracts (that is, areas with a potential for undiscovered mineral-deposit types) must be drawn for each mineral-deposit type according to a favorable geologic environment. (2) Regional metallogenic and tectonic analyses, such as those we have performed for Northeast Asia and the Circum-North Pacific, enable the identification and location of continuations of ore-hosting terranes and permissive tracts around the world that were separated by various tectonic processes which have operated throughout geologic history. Suppose that a suite of metallogenic belts containing porphyry Cu deposits is hosted in various fragments of island-arc terranes that are now dispersed in a tectonic collage in the center of a continent. Tectonic analysis of the origin of the island-arc terranes and their correlations with each other will result in a grouping of these terranes and their contained metallogenic belts into an originally continuous island arc and a single large metallogenic belt. This enlargement of the host rock area and contained metallogenic belt will provide a larger dataset that should greatly improve the quality of metallogenic analysis and mineral-resource assessment. (3) An understanding of the metallogenic setting and history of host rocks and ore-forming processes is commonly important for estimating the number of undiscovered mineral deposits in a permissive tract for a mineral-resource assessment. For example, the number of volcanogenic massive sulfide

Table 3. Summary of major areas, major tectonic environments (events), and associated major lode mineral deposit models. Derived from metallogenic analyses of Northeast Asia, the Russian Far East, Alaska, and the Canadian Cordillera.

[Adapted from Nokleberg and others (2003), Scotese and others (2001), and Rodionov and others (2004)]

Areas	Tectonic Environment (event)	Major Mineral-Deposit Models (table 2)
Northeast Asia and North American cratons and cratonal margins	Rifting	SEDEX, polygenic REE, Cyprus Cu-Zn massive sulfide, volcanogenic massive sulfide, carbonate-hosted sulfide.
Ocean	Sea-floor spreading	Cyprus Cu-Zn massive sulfide, volcanogenic massive sulfide, podiform chromite.
North Asian and North American continental margins	Continental-margin arc and backarc	Porphyry, epithermal vein, polymetallic vein, skarn, greisen, pegmatite, volcanogenic massive sulfide, Besshi Cu-Zn-Ag massive sulfide.
Ocean	Island arc and backarc	Porphyry, epithermal vein, polymetallic vein, granitoid-related Au vein, skarn, zoned mafic-ultramafic Cr-PGE, mafic-ultramafic-related Cu-Ni-PGE.
North Asian and North American continental margins	Collision	Low-sulfide Au quartz vein, granitoid-related Au, porphyry, skarn, Au in black shale.
North Asian and North American continental margins	Transform continental-margin faulting and associated bimodal volcanic-plutonic belt	Zoned mafic-ultramafic Cr-PGE; W skarn, porphyry Cu-Mo($\pm$Au, Ag_, Au-Ag epithermal vein, Au quartz vein, basaltic native Cu, Cu-Ag vein.
North Asian and North American cratons	Plume intrusion	Mafic-ultramafic-related Cu-Ni-PGE and Ti-Fe($\pm$V), REE($\pm$Ta, Nb, Fe) carbonatite, skarn, metamorphic graphite, diamond-bearing kimberlite, porphyry, pegmatite.

deposits estimated in a permissive tract containing poorly exposed and poorly described mafic to felsic volcanic rocks may vary depending on whether the tract is in a volcanic forearc, axial arc, or backarc tectonic setting. Conversely, no deposits of this type might be estimated for a tract of similar rocks in an extensional cratonic setting.

Summary of Major Metallogenic Belts in Northeast Asia

The following summaries of major metallogenic belts in Northeast Asia (fig. 1) by time period are adapted from detailed descriptions of metallogenic belts by Rodionov and others (2004). Detailed descriptions of lode deposits in each belt were presented by Ariunbileg and others (2003), and summary descriptions of the major metallogenic belts in the region are presented in appendix C.

Major Archean Metallogenic Belts

The major Archean (>2.5 Ga) metallogenic belts in the region (fig. 1) are the Jidong, Liaoji, Sharizhalgaiskiy, Sutam, West Aldan belts, and Wutai (fig. 4*A*; see appendix C), all of which possess geologic units favorable for, and all contain, major stratiform banded iron-formation deposits in the (1) Sino-Korean terrane in northern China, and (2) granite-greenstone, orthogneiss, and gneiss terranes in southern Siberia that are interpreted as tectonic fragments derived from either the North Asian craton, or possibly, other cratons. Some of the banded iron-formation deposits are interpreted as having formed in an Archean backarc basin and (or) island arc. The isotopic ages of the stratiform deposits in the region range from about 3.5 to 2.5 Ga. Lesser Archean deposit types include stratiform volcanogenic massive sulfide, Au in shear-zone and quartz vein that formed during later retrograde metamorphism, and talc (magnesite) deposits that formed during later replacements. The isotopic ages of the younger

Au in shear-zone and quartz vein range from less than 1.7 to 2.5 Ga. The stratiform banded iron-formation and volcanogenic massive sulfide deposits formed early in the geologic history of the region.

Major Paleoproterozoic Metallogenic Belts

The major Paleoproterozoic (2.5 to 1.6 Ga) metallogenic belts in the region (fig. 1)are the Baydrag, Jiliaojiao, Kalar-Stanovoy, Luliangshan, Nimnyr, Qinglong, Tyrkanda-Stanovoy, and Uguy-Udokanskiy belts (fig. 4*B*; see appendix C).

Metallogenic Belts Related to Sedimentary Basins Formed on Craton or Cratonal Margins

Several belts possess geologic units favorable for major stratiform sediment-hosted deposits, including the Baydrag, Jiliaojiao, Luliangshan, Qinglong, and Uguy-Udokanskiy with banded iron-formation, sedimentary-metamorphic borate and magnesite, sediment-hosted Cu, clastic-sediment-hosted Sb-Au, and Korean Pb-Zn massive sulfide deposits. The deposits are mainly hosted in sedimentary basins in the Tuva-Mongolia superterrane, the Sino-Korean craton, and cratonal terranes derived either from the North Asian craton, or possibly other cratons. Isotopic ages of the deposits range from about 2.23 to 2.8 Ga. Favorable geologic environments for the metallogenic belts occurred in sedimentary basins on cratons or cratonal margins, and locally, in rift basins.

Metallogenic Belts Related to Rifting or Terrane Collision

Two metallogenic belts possess geologic units favorable for major deposits hosted in alkaline igneous rocks and

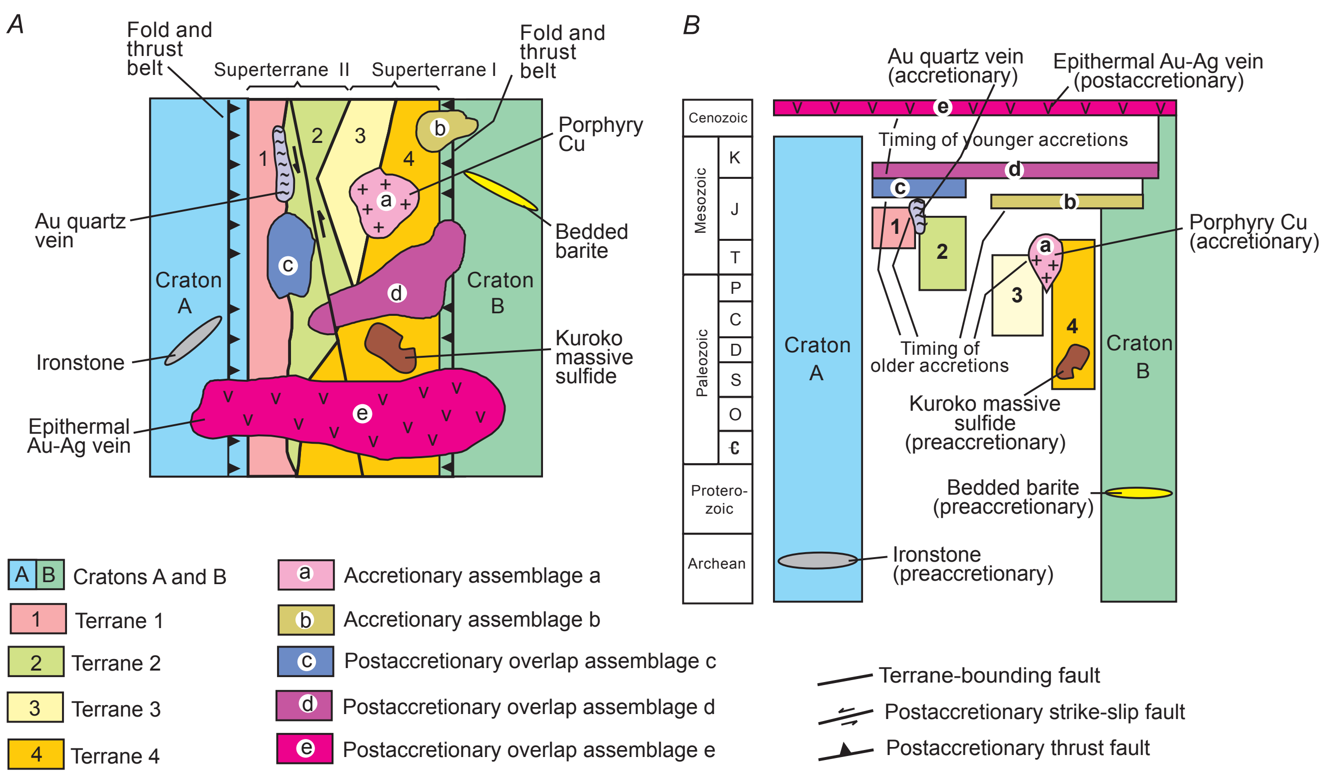

Figure 3. Schematic diagram of an orogenic belt, illustrating methodology for metallogenic analysis of cratons, terranes, accretionary assemblages, overlap assemblages, and contained metallogenic belts (fig. 1). *A*, Map view. *B*, Stratigraphic column. From Parfenov and others (1998) and Nokleberg and others (2005).

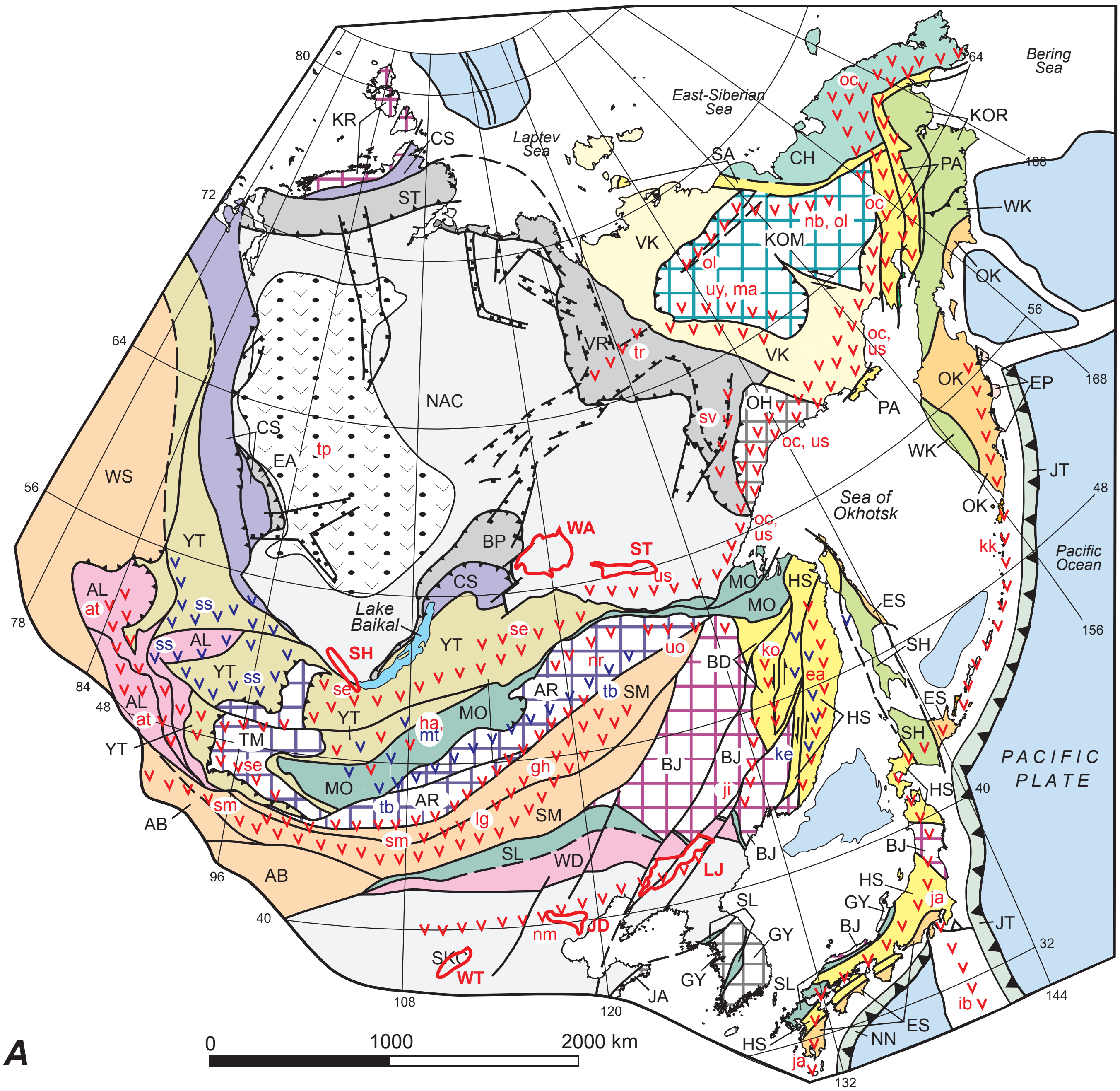

Figure 4. Generalized maps of Northeast Asia, showing locations of major metallogenic belts and major geologic units during various time periods: Archean (*A*), Paleoproterozoic and Mesoproterozoic (*B*). Neoproterozoic (*C*), Cambrian through Silurian (*D*), Devonian through Early Carboniferous (*E*), Late Carboniferous through Middle Triassic (*F*), Late Triassic through Early Jurassic (*G*), Middle Jurassic through Early Cretaceous (*H*), Cenomanian through Campanian (*I*), and Maastrichtian through Quaternary (*J*). Same symbols as in figure 2. Outlines of metallogenic belt adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (east boundary of study area) were described and interpreted by Nokleberg and others (2003). See appendix C for summary description of metallogenic belts.

carbonatite: the Nimnyr and Uguy-Udokanskiy belts apatite carbonatite, Ta-Nb-REE alkaline metasomatite, and zoned mafic-ultramafic Cr (PGE) deposits that are interpreted as formed during rifting of craton or cratonal terranes. Isotopic ages range from about 2.0 to 1.6 Ga. The igneous host rocks overlie or intrude cratonal terranes that are interpreted as derived from the North Asian craton, or possibly, other cratons.

Four metallogenic belts possess geologic units favorable for major Au in shear-zone and quartz vein deposits: the Jiliaojiao, Kalar-Stanovoy, Luliangshan, and Tyrkanda-Stanovoy. The host veins hosting the deposits intrude the North Asian and Sino-Korean cratons. These deposits are related to low-grade metamorphism and deformation that is interpreted as having occurred during terrane collision.

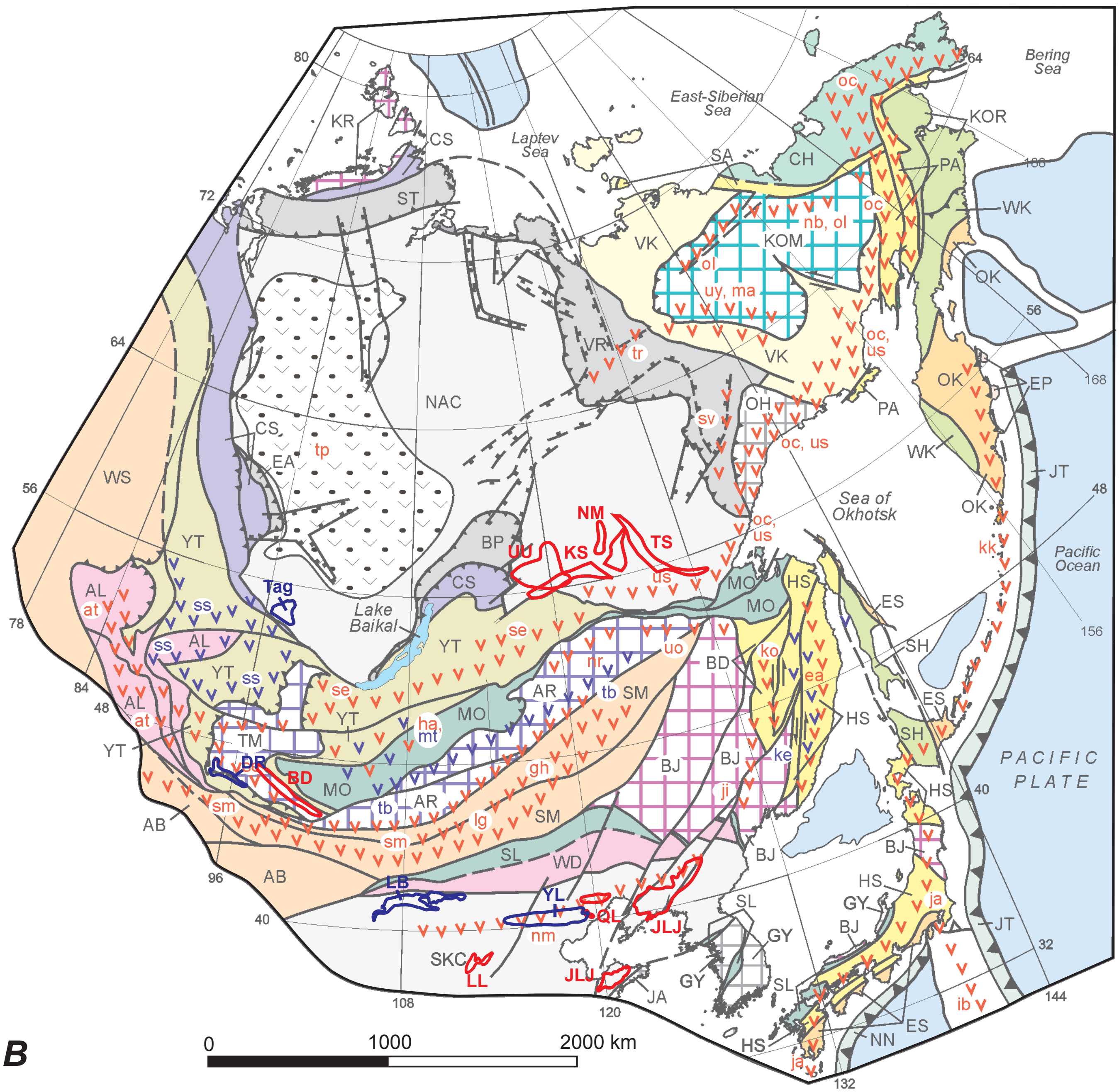

Figure 4.—Continued.

Major Mesoproterozoic Metallogenic Belts

The major Mesoproterozoic (1.6 to 1.0 Ga) metallogenic belts in the region (fig. 1) are the Darvi, Langshan-Bayan Obo, and Yanliao (fig. 4*B*; see appendix C), all of which possess geologic units favorable for major stratiform sediment-hosted deposits: the Darvi (with sedimentary bauxite and sedimentary Fe-V deposits, the Langshan-Bayan Obo with sedimentary exhalative Pb-Zn (SEDEX) and polygenic REE-Fe-Nb deposits, and the Yanliao with chemical-sedimentary Fe-Mn and sedimentary exhalative Pb-Zn (SEDEX)) deposits. The isotopic ages of deposits range from 1.4 to 1.1 Ga. Favorable geologic environments for the metallogenic belts with sediment-hosted deposits occurred in sedimentary basins in passive continental-margin rocks deposited on the Sino-Korean craton or on the cratonal units of the Tuva-Mongolia superterrane that may be derived from the North Asian craton or another craton. The sedimentary exhalative Pb-Zn (SEDEX) and polygenic REE-Fe-Nb deposits in the Langshan-Bayan Obo belt (containing the famous Bayan Obo REE-Fe-Nb Mine) are interpreted as having formed during extrusion of carbonatite magma, associated hydrothermal activity, and deposition of sedimentary overlap assemblages in a rift along the passive-continental-margin of the Sino-Korean craton.

Major Neoproterozoic Metallogenic Belts

The major Neoproterozoic (1.0 Ga to 540 Ma) metallogenic belts in the region (fig. 1) are the Angara-Pit, Baikalo-Muiskiy, Bodaibinskiy, Bokson-Kitoiskiy, Central-Yenisei, Hovsgol, Jixi, Kyllakh, Lake, Pribaikalskiy, Prisayanskiy, and Vorogovsko-Angarsk (fig. 4*C*; see appendix C).

Metallogenic Belts Related to Sedimentary Basins Formed on Cratonal Margins

Several metallogenic belts possess geologic units favorable for major stratiform sediment-hosted deposits, including the Angara-Pit with sedimentary siderite Fe and volcanogenic-sedimentary Fe deposits, the Bodaibinskiy and Central-Yenisei with Au in black shale deposits, the Bokson-Kitoiskiy with sedimentary bauxite deposits, the Hovsgol with sedimentary phosphate, volcanogenic-sedimentary Mn, and sedimentary Fe-V deposits, the Jixi with banded iron-formation deposits, the Kyllakh and Pribaikalskiy with carbonate-hosted Pb-Zn deposits, and the Vorogovsko-Angarsk with sedimentary exhalative Pb-Zn (SEDEX) and carbonate-hosted Pb-Zn (Mississippi valley type) deposits. Fossil or isotopic ages of the host rocks or deposits range from Riphean to Vendian. The deposits are hosted in sedimentary rocks deposited either on the North Asian cratonal margin (Angara Pit, Bodaibinskiy, Central-Yenisei, and Kyllakh metallogenic belts), or in basins on passive-continental-margin terranes possibly derived from this cratonal margin (Hovsgol and Vorogovsko-Angarsk metallogenic belts). Favorable geologic environments for the metallogenic belts occurred during sedimentation on continental shelves or during rifting of a continental shelf.

Metallogenic Belts Related to Island Arcs

Several metallogenic belts possess geologic units favorable for major volcanic- and (or) granite-hosted deposits, including the Baikalo-Muiskiy with volcanogenic-hydrothermal-sedimentary Pb-Zn massive sulfide deposits and the Lake with volcanogenic Cu-Zn massive sulfide (Urals type), volcanogenic-sedimentary Fe, Cu and Fe skarn, granitoid-related Au vein, mafic-ultramafic related Cu-Ni-PGE, podiform Cr, and mafic-ultramafic related Ti-Fe deposits. Favorable geologic environments for the metallogenic belts occurred in island arcs or on sea floors underlying arcs in the Baikal-Muya island-arc terrane (part of the Circum-Siberia tectonic collage), the Lake island-arc terrane (part of the Yenisey-Transbaikal collage), and island-arc terranes in the Tuva-Mongolia superterrane.

Metallogenic Belts Related to Terrane Accretion

Several metallogenic belts possess geologic units favorable for Au in shear-zone and quartz vein deposits, including the Bokson-Kitoiskiy and Central-Yenisei which are hosted in either the western part of the North Asian craton or the Yenisey-Transbaikal collage. The Bokson-Kitoiskiy metallogenic belt also contains serpentine-hosted asbestos deposits that are interpreted as having formed in the same tectonic environment. The Prisayanskiy belt is hosted in terranes derived from the North Asian craton and contains REE carbonatite, and mafic-ultramafic-related Ti-Fe deposits that are interpreted as having formed in Neoproterozoic magmatic events. The Jixi metallogenic belt contains minor Homestake Au deposits of unclear tectonic origin. Favorable geologic environments for the metallogenic belts occurred during regional metamorphism and hydrothermal alteration associated with accretion of terranes to the North Asian cratonal margin.

Major Cambrian Through Silurian Metallogenic Belts

The major Cambrian through Silurian (540 to 410 Ma) metallogenic belts in the region (fig. 1) are the Bayanhongor-1, Bedobinsk, East Liaoning, Govi-Altai, Hovd, Hunjiang-Taizihe, Jinzhong, Kiyalykh-Uzen, Kizir-Kazyr, Martaiginsk, Ozerninsky, South Khingan, and Uda-Shantar belts (fig. 4*D*; see appendix C).

Metallogenic Belts with Granitoid-Hosted Deposits Related to Continental-Margin-Arcs, Transpression Faulting, or Terrane Accretion

Several metallogenic belts possess geologic units favorable for major granitoid-hosted or granitoid-related deposits, including the Bayanhon-gor with Au in shear-zone and quartz vein, granitoid-related Au vein, Cu-Ag vein, Cu skarn deposits, the Hovd with granitoid-related Au vein, Au and Cu skarn deposits, the Kizir-Kazyr with Fe skarn and granitoid-related Au vein deposits, and the Martaiginsk with granitoid-related Au vein and Au skarn deposits. Isotopic ages of the deposits or host rocks range from 490 to 420 Ma. The Kiyalykh-Uzen metallogenic belt (with Cu, W, and Fe skarn deposits and W-Mo-Be greisen, stockwork, and quartz vein deposits, and the Martaiginsk metallogenic belt with granitoid-related Au vein and Au skarn deposits contain collisional granitoids that are interpreted as having intruded during transpressive (dextral slip) movement along the

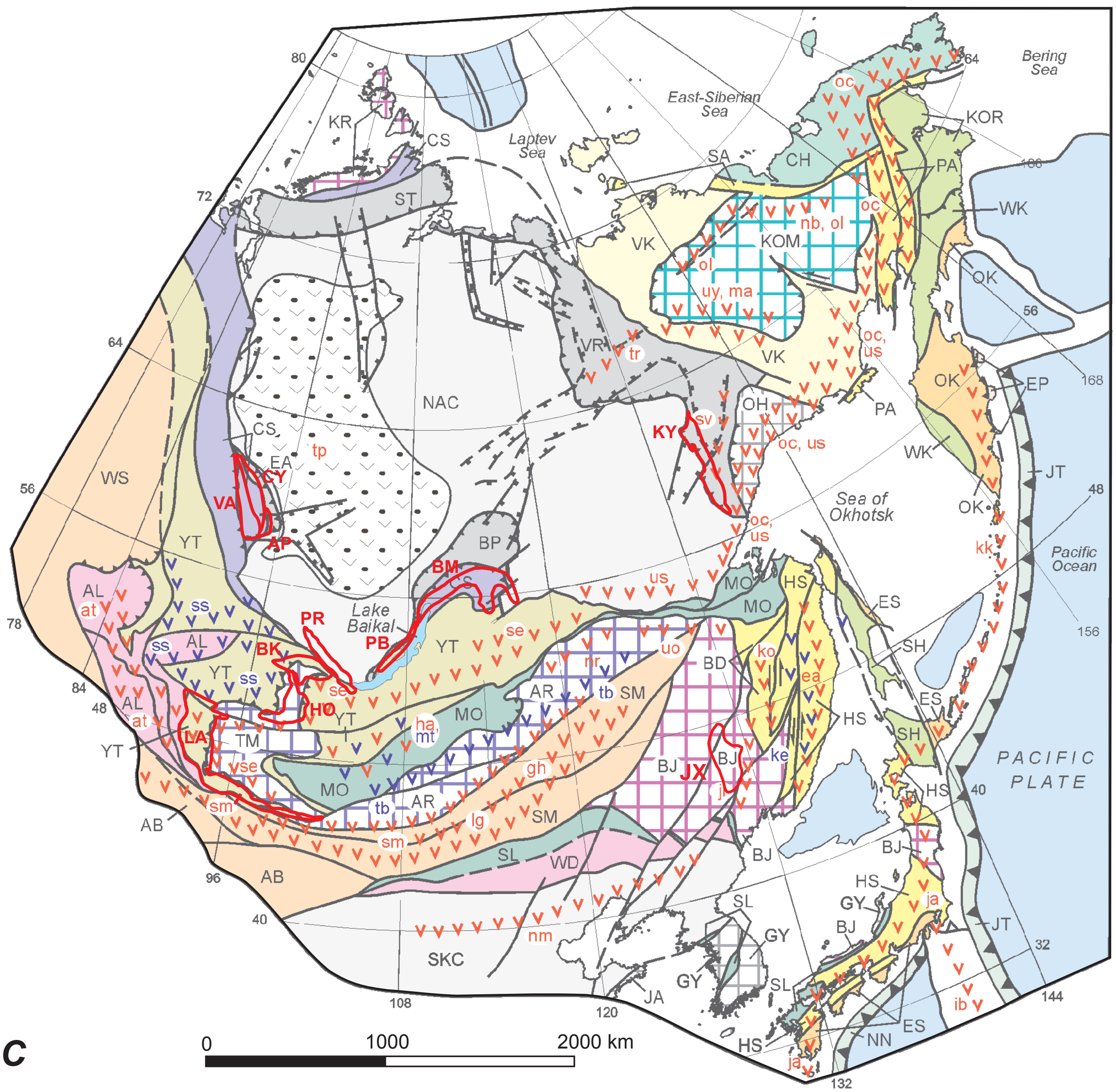

Figure 4.—Continued.

Kuznetsk Alatau Fault or during terrane accretion. Favorable geologic environments for the metallogenic belts are in the Altai and Yenisey-Transbaikal collages which are interpreted as having formed in a continental-margin-arc or associated continental-margin turbidite terranes, in a backarc basin associated with continental-margin-arc magmatism, during transform continental-margin faulting, in an island-arc, or during terrane accretion.

Metallogenic Belts with Volcanic-Hosted Deposits Related to Continental-Margin or Island Arcs

Several metallogenic belts possess geologic units favorable for major volcanic-hosted deposits, including the Govi-Altai, Ozerninsky, and Uda-Shantar with volcanogenic-sedimentary Fe, volcanogenic-sedimentary Mn, volcanogenic-hydrothermal-sedimentary massive sulfide,

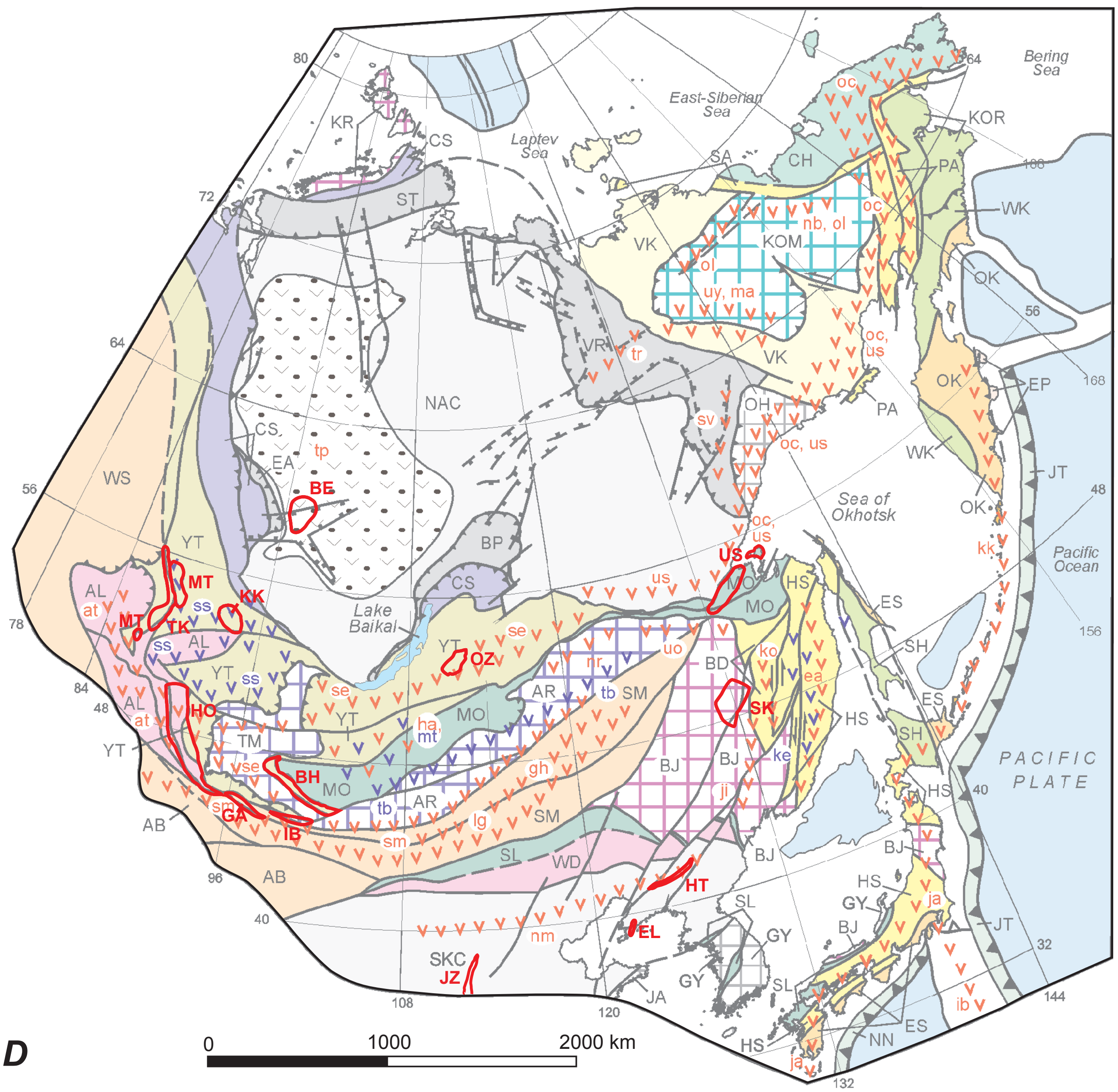

Figure 4.—Continued.

and sedimentary phosphate deposits. Fossil ages of the deposits or host rocks range from Cambrian through Silurian. The Bedobinsk metallogenic belt with sediment-hosted Cu deposits, hosted in early Paleozoic sedimentary units of the North Asia craton, is interpreted as having formed in an inland-sea basin during post-saline stage of rock deposition. Favorable geologic units for the metallogenic belts occurred in the Mongol-Okhotsk, South Mongolia-Khingan, and Yenisey-Transbaikal collages, which are interpreted as having formed either in continental-margin or island arcs or by sea floor sedimentation.

Unique Kimberlite Diamond Metallogenic Belts

Three metallogenic belts in the Sino-Korean craton possess unique favorable geologic units: the East Liaoning belt for diamond-bearing kimberlite deposits, the Hunjiang-Taizihe and Jinzhong belts for evaporite sedimentary gypsum deposits in platform sedimentary cover, the South Khingan belt for banded iron-formation deposits in continental-margin sedimentary cover. The latter two belts are interpreted as having formed during sedimentation along a cratonal margin, whereas the origin of the diamond-bearing kimberlite deposits is poorly known.

Major Devonian through Early Carboniferous Metallogenic Belts

The major Devonian through Early Carboniferous (410 to 320 Ma) metallogenic belts in the region (fig. 1) are the Bayangovi, Botuobiya-Markha, Daldyn-Olenyok, Edrengiin, Edren-Zoolon, Hongqiling, Kizhi-Khem, Mamsko-Chuiskiy, Rudny Altai, Salair, Sette-Daban, Sorsk, Tsagaan-suvarga, Udzha, Ulziit, and Yaroslavka (fig. 4*E*; see appendix C).

Metallogenic Belts Related to Continental-Margin or Island Arcs

Five metallogenic belts possess geologic units favorable for a wide variety of major granite-hosted deposits: the Altai, Deluun-Sagsai, Rudny Korgon-Kholzun, Salair, and Tsagaan-suvarga belts with volcanic-hosted metasomatite and Fe, polymetallic Pb-Zn vein and stockwork, volcanogenic Zn-Pb-Cu massive sulfide, sediment-hosted Cu, Ag-Pb epithermal vein, Fe skarn, porphyry Cu-Mo, porphyry Au, granitoid related Au vein, and mafic-ultramafic related Ti-Fe deposits. The isotopic ages of the deposits or host rocks range from Devonian through Early Carboniferous. Favorable geologic environments for the metallogenic belts occurred in the Altay continental-margin-arc and the island arc parts of the West Siberian and South Mongolia-Khingan collages.

Metallogenic Belts Related to Terrane Accretion

Several metallogenic belts possess geologic units favorable for a wide variety of major collisional granite-hosted deposits and related vein deposits, including the Bayangovi, Edren-Zoolon, Muiskiy, Ulziit, and Yaroslavka with granitoid-related Au vein, Au in shear-zone and quartz vein, fluorite greisen, Sn-W greisen, stockwork, and quartz vein, carbonate-hosted Hg-Sb deposits. Fossil or isotopic ages of the deposits or host rocks range from Devonian through Early Carboniferous (440 to 396 Ma). Favorable geologic environments for the metallogenic belts occurred in the Edren island arc and Zoolen subduction-zone terrane (both parts of South Mongolia-Khingan collage), in granitoids and veins of the Barguzin-Vitim granitoid belt intruding the Baikal-Muya island arc and the Muya metamorphic terrane (both parts of the Tuva-Mongolia superterrane), in granitoids intruding the Bureya-Jiamusi superterrane, and in vein replacements in the Govi Altai continental-margin turbidite terrane (part of the South Mongolia-Khingan collage). These granitoids and veins are interpreted as having formed during regional metamorphism and vein emplacement associated with terrane accretion and generation of anatectic granitic plutons.

Metallogenic Belts Related to Rifting

Two metallogenic belts possess geologic units favorable for a wide variety of rift-related deposits: the Sette-Daban and Udzha with sediment-hosted Cu, basaltic native Cu, REE carbonatite, and carbonate-hosted Pb-Zn. Fossil ages of the deposits or host rocks range from Devonian and Early Carboniferous. Favorable geologic units for the metallogenic belts occurred during rifting of the North Asian craton or cratonal margin.

Metallogenic Belts Related to Transpressional Faulting

Several metallogenic belts possess geologic units favorable for major vein or plutonic-hosted deposits, including the Hongqiling, Kizhi-Khem, Mamsko-Chuisky, Sorsk, and Teisk (with mafic-ultramafic related Cu-Ni-PGE, mafic-ultramafic related Ti-Fe, muscovite pegmatite, Ta-Nb-REE alkaline metasomatite, W-Mo-Be greisen, stockwork, and quartz vein, porphyry Cu-Mo and Mo, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic- and carbonate-hosted metasomatite, and Fe, Pb, and Zn skarn deposits. Fossil ages are Devonian and Early Carboniferous and isotopic ages range from 416 to 330 Ma. Favorable geologic environements for the metallogenic belts are (1) mafic and ultramafic plutons intruding and overlapping the Zhangguangcailing superterrane and the Laoling terrane, part of the Bureya-Jiamusi superterrane, (2) veins and dikes in the Mamsky and Konkudero-Mamakansky complexes intruding the Chuja paragneiss terrane, which is included in Baikal-Patom cratonal margin, and (3) the South Siberian volcanic-plutonic belt, which constitutes the South Siberian arc. All these units and deposits are interpreted as having formed during transpressional faulting and associated interplate rifting.

Unique Metallogenic Belts

Two unique metallogenic belts are hosted in Devonian diamond-bearing kimberlite intruding the North Asian craton: the Botuobiya-Markh and Daldyn-Olenyok belts. The origin of the diamond-bearing kimberlite deposits is poorly known. The unique Edrengiin metallogenic belt with volcanogenic Cu-Zn massive sulfide, volcanogenic-sedimentary Mn and Fe deposits is hosted in the Edren island-arc terrane (part of the South Mongolia-Khingan collage), and is interpreted as having formed during island-arc marine volcanism.

Major Late Carboniferous Through Middle Triassic Metallogenic Belts

The major Late Carboniferous through Middle Triassic (320 to 230 Ma) metallogenic belts in the region (fig. 1) are the Altay, Angara-Ilim, Barlaksk, Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia, Duobaoshan, Harmagtai-Hongoot-Oyut, Hitachi, Kalatongke, Kolyvansk, Kureisko-Tungsk, Maimecha-Kotuisk, Mino-Tamba-Chugoku, Norilsk, Orhon-Selenge, and Shanxi belts (fig. 4*F*; see appendix C).

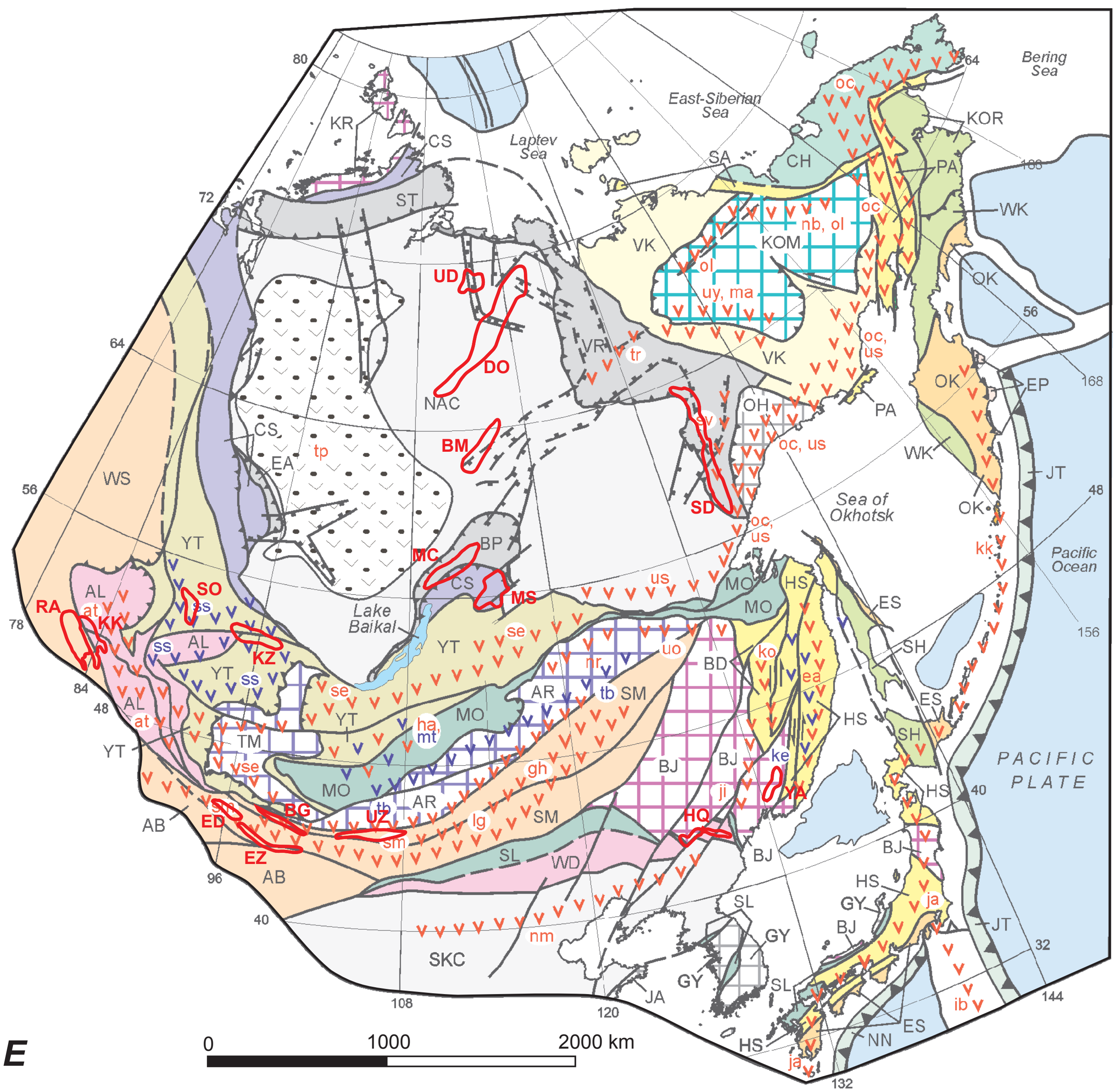

Figure 4.—Continued.

Metallogenic Belts Related to A Superplume

Four metallogenic belts possess geologic units favorable for a wide variety of major Trapp-magmatism-related deposits: the Angara-Ilim, Kureisko-Tungsk, Maimecha-Kotuisk, and Norilsk with mafic-ultramafic related Cu-Ni-PGE, Fe-Ti and phlogopite carbonatite, metamorphic graphite, basaltic native Cu (Lake Superior type), porphyry Cu-Mo, Fe skarn, and weathering crust carbonatite REE-Zr-Nb-Li deposits. Isotopic ages of the deposits or host rocks range from Devonian through Early Carboniferous. The deposits are related to replacements associated with the Tungus plateau basalt, sills, dikes, and intrusions that intrude or overlie the North Asian craton. The isotopic ages of the deposits or host rocks range from Permian through Triassic (260-200 Ma). The Norilsk metallogenic belt contains the famous mafic-ultramafic related Cu-Ni-PGE deposits in the Norilsk district in northern Siberia. Favorable geologic environments for the metallogenic belts are interpreted as related to widespread development of Trapp magmatism on the North Asian craton during intrusion of a superplume.

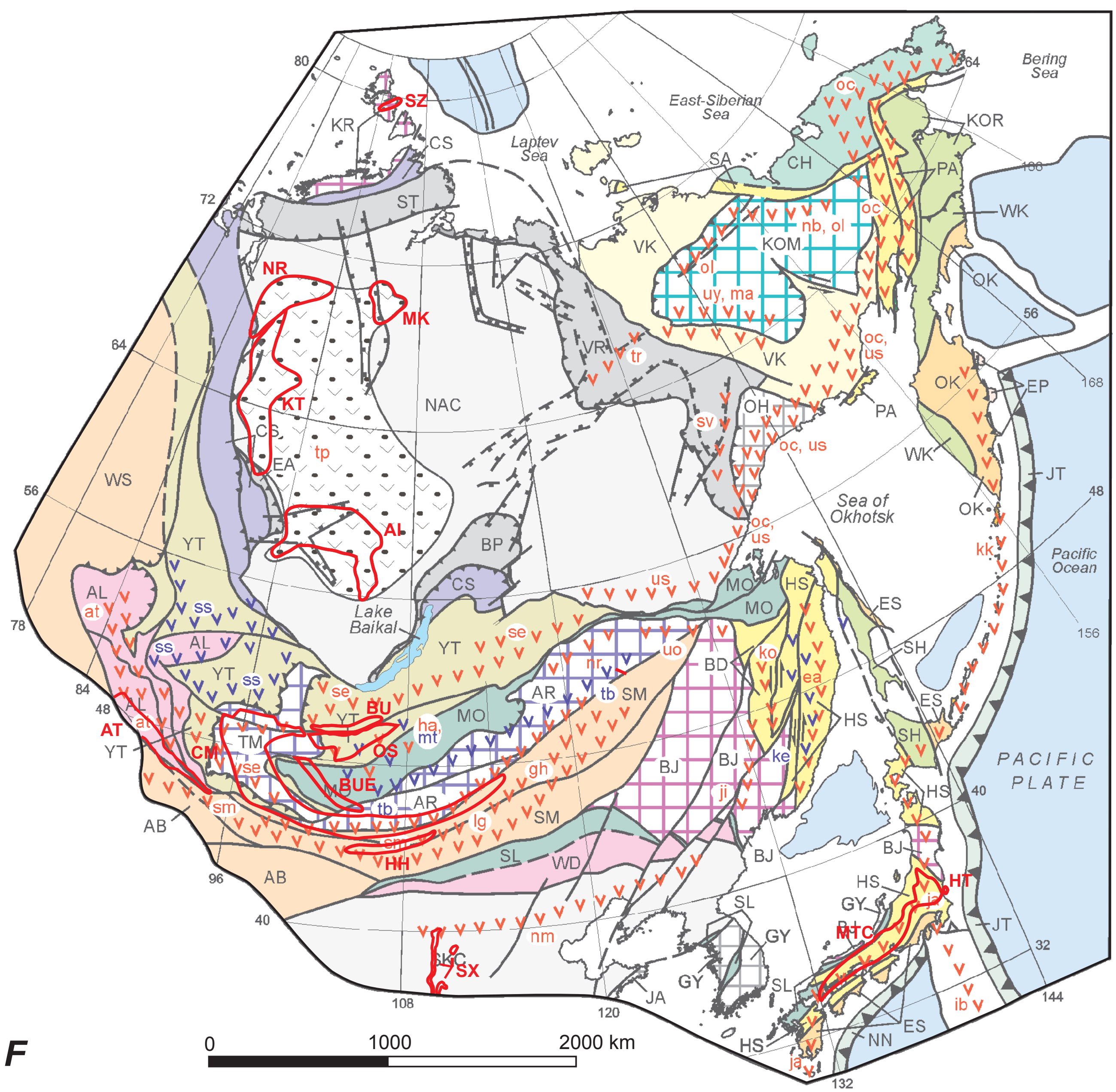

Figure 4.—Continued.

Metallogenic Belts Related to the Selenga and South Mongolian Continental-Margin-Arcs

Four metallogenic belts possess geologic units favorable for a wide variety of granitic magmatism-related deposits: the Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia and Orhon-Selenge with Fe-Zn skarn, Sn skarn, Zn-Pb, skarn, W skarn, Cu skarn, porphyry Cu-Mo, porphyry Mo, Au skarn; granitoid related Au vein, W-Mo-Be greisen, stockwork, and quartz vein, peralkaline granitoid-related, REE-Li pegmatite and basaltic native Cu deposits. The belts are hosted in granitoids in the Selenga sedimentary-volcanic plutonic belt that constitutes the Selenga continental-margin-arc that formed on the Yenisey-Transbaikal and the Tuva-Mongolia collages. Isotopic ages of the deposits or host rocks range from 240 to 285 Ma. These belts are interpreted as having formed during oblique subduction of oceanic crust of the Mongol-Okhotsk Ocean plate under the southern margin of the North Asian craton and cratonal margin and previously accreted terranes.

The Harmagtai-Hongoot-Oyut metallogenic belt with porphyry Cu-Mo and Au, granitoid-related Au, and Au-Ag epithermal Au deposits is hosted in granitoids related to the South-Mongolian volcanic-plutonic belt and is interpreted as having formed in the South Mongolian continental-margin-arc that formed along the northern (present-day coordinates) margin of the Mongol-Okhotsk Ocean.

Metallogenic Belts Related to Island Arcs

Three metallogenic belts possess geologic units favorable for a wide variety of granite- and mafic-plutonic-related deposits and volcanogenic massive sulfide deposits: the Duobaoshan, Hitachi, and Kalatongke with porphyry Cu-Mo, granitoid-related Au vein, mafic-ultramafic related Cu-Ni-PGE, volcanogenic Zn-Pb-Cu massive sulfide deposits. Isotopic ages of the igneous host rocks range from Pennsylvanian through Permian. These belts are interpreted as having formed in an island arc chain south (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. The island arcs were in the Duobaoshan terrane (part of the South Mongolia-Khingan collage), the South Kitakami terrane (part of the Bureya-Jiamusi superterrane), and the Waizunger-Baaran terrane (part of the Atasbogd collage).

Metallogenic Belt Related to Collision of Cratons

The Altay metallogenic belt with REE-Li pegmatite and muscovite pegmatite deposits is hosted in veins, dikes, and replacements related to Late Carboniferrous granitoids in the Altai volcanic-plutonic belt, which intrudes the Altai continental margin turbidite terrane. This belt is interpreted as having formed with the intrusion of collisional granite during collision of the Kazakhstan and North Asian cratons, resulting in high-grade metamorphism with crustal melting and generation of anatectic granite.

Metallogenic Belt Related to Weathering

The Shanxi metallogenic belt with sedimentary bauxite deposits is hosted in Pennsylvanian stratiform units in the upper part of the Sino-Korean platform overlapping the Sino-Korean craton and the West Liaoning terrane. This belt is interpreted as having formed during weathering of metamorphic rocks of the North China platform. The bauxite deposits are hosted in karst and lagoonal basins in a littoral-shallow sea.

Metallogenic Belt Related to Oceanic Crust

The Mino-Tamba-Chugoku metallogenic belt with volcanogenic-sedimentary Mn, podiform chromite, and Besshi massive sulfide deposits is hosted in the Mino Tamba Chichibu subduction-zone terrane (part of Honshu-Sikhote-Alin collage). This belt contains fragments of late Paleozoic and early Mesozoic oceanic crust in which these deposits originally formed.

Major Late Triassic Through Early Jurassic Metallogenic Belts

The major Late Triassic through Early Jurassic metallogenic belts in the region (fig. 1) are the Central Hentii, Delgerhaan, Govi-Ugtaal-Baruun-Urt, Harmorit-Hanbogd-Lugiingol, Kalgutinsk, Mongol Altai, North Hentii, North Kitakami, North Taimyr, and Sambagawa-Chichibu-Shimanto belts (fig. 4*G*; see appendix C).

Metallogenic Belts Related to Transpressional Arcs and Faults and to Terrane Collision

Five metallogenic belts possess geologic units favorable for a wide variety of granite-related deposits: the Central Henti, Delgerhaan, Govi-Ugtaal-Baruun-Urt, Harmorit-Hanbogd-Lugiingol, and North Hentii belts with porphyry Cu, granitoid-related Au vein, Au in shear-zone and quartz vein, Fe-Zn, Cu, Zn-Pb, Sn, and W skarn, Sn-W greisen, stockwork, and quartz vein, Ta-Nb-REE akaline metasomatite, REE carbonatite, peralkaline granitoid-related Nb-Zr-REE, and REE-Li pegmatite deposits. Isotopic ages of the host igneous rocks range from 242 to 199 Ma. These belts are hosted in the Late Triassic and Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt, which constitutes much of the Mongol-Transbaikal transpressional arc that is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk Fault during and after final closure of the Mongol-Okhotsk Ocean.

Two other metallogenic belts possess geologic units favorable for a wide variety of granite-related deposits: the Kalgutinsk and Mongol Altai belts with W-Mo-Be greisen, stockwork, and quartz vein, Ta-Nb-REE alkaline metasomatite; and Sn-W greisen, stockwork, and quartz vein deposits. Isotopic ages of the host igneous rocks range from 204 to 183 Ma. These belts are hosted in small granitoids that intruded along major transpressional fault zones (Hovd regional fault zone and companion faults) with a combination of strike-slip, extensional, and compressional displacements. The transpressional-fault zones strike northwest (present-day coordinates).

In addition, the North Taimyr metallogenic belt possesses geologic units favorable for granite-related deposits: W-Mo-Be greisen, stockwork, and quartz vein, W skarn, and porphyry Cu-Mo. Isotopic ages of the host granitoids range from 233 to 223 Ma. This belt is interpreted as having formed with the generation of granitoids during and after collision between the North Asian craton and the Kara superterrane.

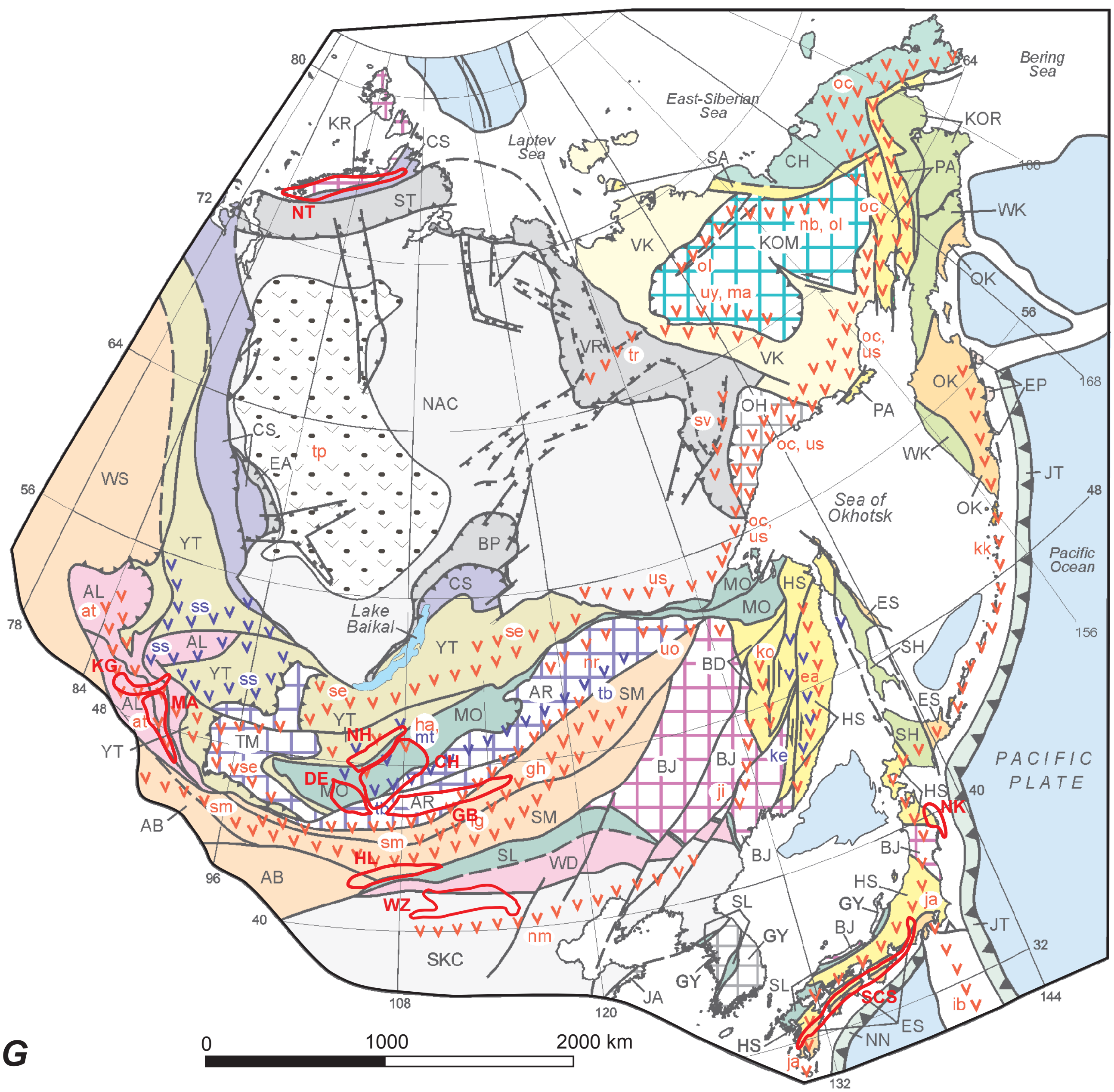

Figure 4.—Continued.

Metallogenic Belts Related to Oceanic Crust

The Sambagawa-Chichibu metallogenic belt possesses geologic units favorable for stratiform sediment-hosted deposits (Besshi Cu-Zn-Ag and Cyprus Cu-Zn massive sulfide, volcanogenic-sedimentary Mn) that are now preserved in younger subduction-zone terranes: the Mino Tamba Chichibu subduction-zone terrane (part of Honshu-Sikhote-Alin collage), the Sambagawa metamorphic terrane (part of the Honshu-Sikhote-Alin collage), and the Shimanto subduction-zone terrane (part of the Sakhalin-Hokkaido collage). The age of the host rocks is interpreted as Early Jurassic and younger. The volcanogenic-sedimentary Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor and the Besshi and Cyprus massive sulfide deposits are interpreted as having formed during submarine volcanism related to an ocean spreading ridge.

The North Kitakami metallogenic belt possesses geologic units favorable for Besshi Cu-Zn-Ag and Cyprus Cu-Zn massive sulfide, volcanogenic-sedimentary Mn deposits. This belt and deposits are hosted in the Mino Tamba Chichibu subduction-zone terrane (part of the Honshu-Sikhote-Alin collage). The volcanogenic-sedimentary Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor, and the kuroko deposits in an island arc. These deposits were subsequently incorporated into the subduction zone.

Major Middle Jurassic Through Early Cretaceous Metallogenic Belts

The major Middle Jurassic through Early Cretaceous metallogenic belts in the region (fig. 1) are the Allakh-Yun, Ariadny, Bindong, Chara-Aldan, Chybagalakh, Daxinganling, Djeltulaksky, Dzid-Selenginskiy, East Mongolian-Priargunskiy-Deerbugan, Govi-Tams, Hartolgoi-Sulinheer, Jiliaolu, Kitakami, Kondyor-Feklistov, Kular, Nerchinsky, North Bureya, North Jilin, North Stanovoy, Onon-Turinskiy, Polousny, Samarka, Shilkinsko-Tukuringrskiy, South Verkhoyansk, Taebaegsan, Tompo, Verkhne-Ingodinsky, Verkhoyansk, Yana-Adycha, and Yanshan belts (fig. 4*H*; see appendix C).

Metallogenic Belts Related to Trans-Baikalian-Daxinganling Transpressional Arc

Several metallogenic belts possess geologic units favorable for a wide variety of siliceous igneous-related deposits: the Bindong, Daxinganling, Dzid-Selenginski, East Mongolian-Priargunskiy-Deerbugan, Govi-Tamsag, Hartolgoi-Sulinheer, Nerchinsky, Onon-Turinskiy, Shilkinsko-Tukuringrskiy, and Verkhne-Ingodinsky belts with Au skarn, Au, Sn, W±Mo±Be, and Zn-Pb (±Ag, Cu) skarn, Au-Ag epithermal vein, cassiterite-sulfide-silicate vein and stockwork, fluorspar vein, granitoid-related Au vein, peralkaline granitoid-related Nb-Zr-REE, polymetallic-metasomatite, polymetallic Pb-Zn vein and stockwork, porphyry Au, porphyry Cu-Mo, Mo, and Au, clastic-sediment-hosted U, and Sn-W greisen, stockwork, and quartz vein, Ta-Nb-REE alkaline metasomatite, volcanic-hosted Au-base-metal metasomatite, carbonate-hosted Ag-Pb and Hg-Sb, volcanic-hosted zeolite, and W-Mo-Be greisen, stockwork, and quartz vein. Isotopic ages of the igneous host rocks range from 190 to 125 Ma. These belts are hosted in the major Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlaps terranes which were previously accreted to the southern (present-day coordinates) margin of the North Asian craton. The host rocks and metallogenic belts are interpreted as having formed with the major Trans-Baikalian-Daxinganling transpressional arc that formed along the major Mongol-Okhotsk suture which cuts previously accreted terranes south of the southern margin (present-day coordinates) of the North Asian craton. Displacement along this suture and formation of the arc occurred after closureof the Mongol-Okhotsk Ocean.

Metallogenic Belts Related to Accretion of the Kolyma-Omolon Superterrane and the Okhotsk Terrane

Eight metallogenic belts possess geologic units favorable for a wide variety of Au vein deposits and collisional granite-related deposits: the Allakh-Yun, Chybagalakh, Kular, Polousny, South Verkhoyansk, Tompo, Verkhoyansk, and Yana-Adycha with Au in shear-zone and quartz vein, granitoid-related Au vein, Cu and W skarn, Au in black shale, polymetallic Pb-Zn vein and stockwork, cassiterite-sulfide-silicate vein and stockwork, Sn-W and W-Mo-Be greisen, stockwork, and quartz vein, and Au-Ag epithermal vein deposits. Isotopic ages of the veins and associated granites range from Late Jurassis through Aptian. The belts and deposits are hosted in veins and granitoids (such as the Main, Northern, and South Verkhoyansk, granite belts) that intrude the Verkhoyansk (North Asian) cratonal margin and (or) the margin of the adjacent Kolyma-Omolon superterrane. The host rocks and metallogenic belts are interpreted as having formed during collision and accretion of the Kolyma-Omolon superterrane to the North Asian cratonal margin which resulted in regional metamorphism and generation of anatectic granitoids and related hydrothermal fluids. The Allakh-Yun and South Verkhoyansk metallogenic belts are interpreted as having formed immediately before accretion of the Okhotsk terrane to the North Asian cratonal margin.

Metallogenic Belts Related to the Uda-Stanovoy Continental-Margin-Arc

Three metallogenic belts possess geologic units favorable for granitoid-related deposits: the Chara-Aldan, Djeltulaksky, and North Stanovoy with granitoid-related Au vein, Au-Ag epithermal vein, Au skarn, Au in shear-zone and quartz vein, Au-K metasomatite, and charoite metasomatite deposits. Isotopic ages of the host granitoids range from Jurassic through Early Cretaceous. These metallogenic belts are interpreted as having formed during intrusion of granitoids of the Stanovoy granite belt that was part of the Uda-Stanovoy continental margin arc, which is interpreted as having formed during subduction and closure of the Mongol-Okhotsk Ocean beneath the North Asian craton to the north (present-day coordinates).

Metallogenic Belts Related to Transpressional Faulting

Four metallogenic belts possess geologic units favorable for a wide variety of transpressional granitoid-related deposits: the Jiliaolu, North Jilin, Samarka, and Yanshan with Au-Ag epithermal vein, Cu, W, and Zn-Pb W skarn, fluorspar vein, granitoid-related Au vein, polymetallic Pb-Zn vein and stockwork, polymetallic volcanic-hosted metasomatite, porphyry Cu

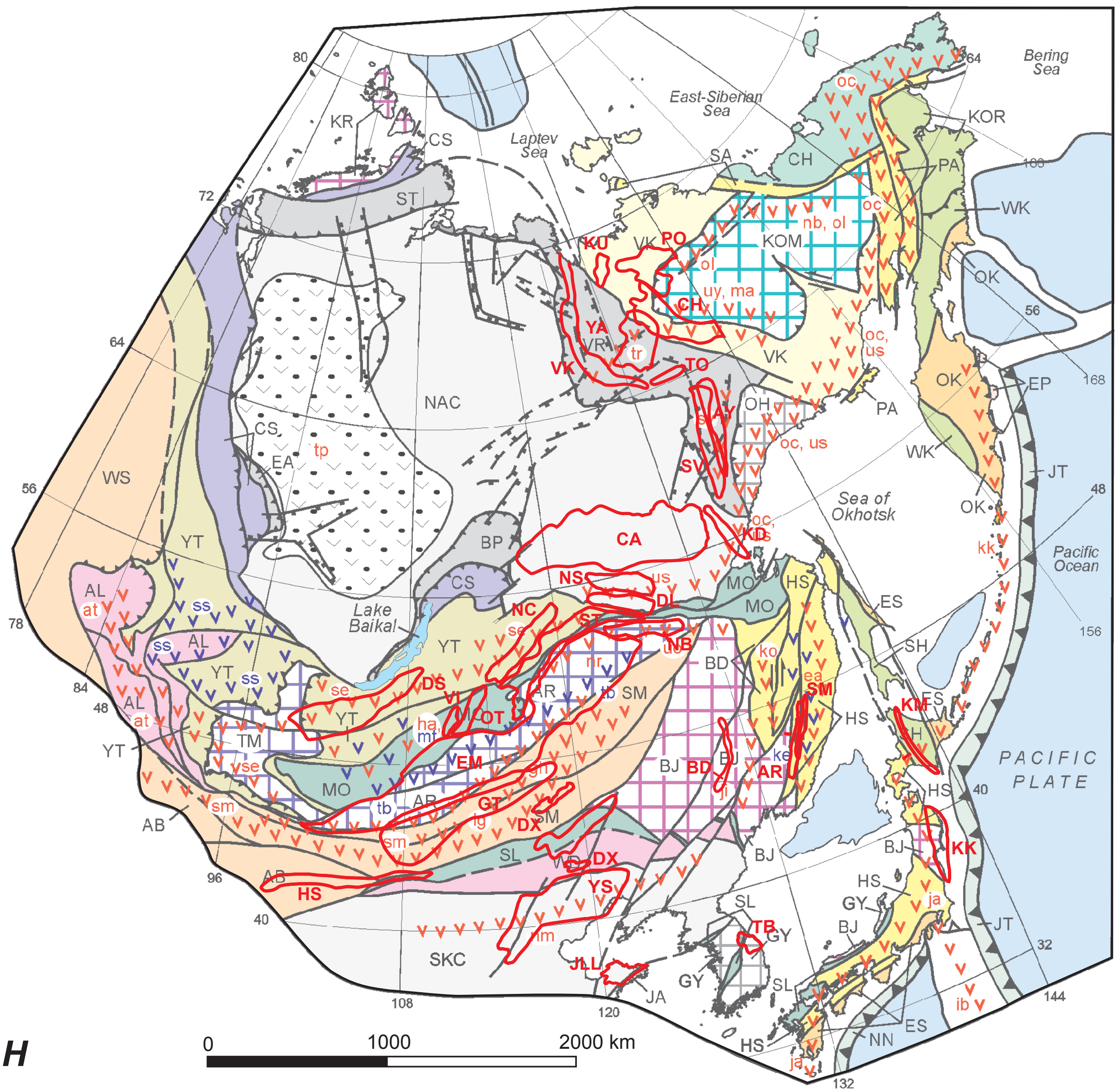

Figure 4.—Continued.

and Cu-Mo, deposits. Isotopic ages of the host granitoids range from 186 to 110 Ma. The granitoids and veins intrude either overlap assemblages on the Sino-Korean craton or the Samarka subduction-zone terrane (part of the Honshu-Sikhote-Alin collage). These metallogenic belts are interpreted as having formed during intrusion of granitoids along transpressional zones along microplate boundaries, underthrusting of the Kula oceanic ridge, and extrusion of bimodal igneous rocks along a transform continental margin or during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Ocean plate beneath the Eurasian plate.

Unique Metallogenic Belts

Five unique metallogenic belts formed during the Middle Jurassic through Early Cretaceous:

The Kondyor-Feklistov belt with zoned mafic-ultramafic Cr-PGE deposits. This belt is hosted in mafic-ultramafic intrusions and is interpreted as having formed with the intrusion of mafic-ultramafic plutons along a deep-seated fault on the North Asian cratonal margin during collision and accretion of outboard terranes.

The North Bureya belt with Au-Ag epithermal vein and granitoid-related Au vein deposits hosted in the Umlekam-Ogodzhin volcanic-plutonic belt. This belt is interpreted as having formed with the Umlekan-Ogodzhin continental-margin-arc during subduction of part of the ancestral Pacific Ocean plate.

The Ariadny belt with mafic-ultramafic-rock-related deposits hosted in Middle Jurassic and Early Cretaceous plutons that intrude the Samarka subduction-zone terrane (part of the Honshu-Sikhote-Alin collage). This belt is interpreted as having formed with the generation of ultramafic and gabbroic plutons during underthrusting of the Kula oceanic ridge and extrusion of bimodal igneous rocks along a transform continental margin.

The Taebaegsan belt with a wide assortment of granitoid-related deposits hosted in the Late Jurassic and Early Cretaceous Daebo granite. This belt is interpreted as forming during intrusion of granitoids associated with the Daebo granite that in turn are interpreted as parts of a continental-margin-arc which was linked to subduction of the ancestral Pacific Ocean plate.

The Kitakami belt with Cu skarn and granitoid-related Au deposits hosted in the Early Cretaceous Hiroshima granite belt (isotopic age of 120 to 110 Ma). This belt is interpreted as having formed during intrusion of granitoids associated with a continental-margin-arc and siliceous magmatism.

Major Cenomanian Through Campanian Metallogenic Belts

The major Cenomanian through Campanian metallogenic belts in the region (fig. 1) are the Badzhal-Komsomolsk, Central Polousny, Chelasin, Chokhchur-Chekurdakh, Eckyuchu-Billyakh, Gyeongnam, Gyeongpuk, Hidaka, Inner Zone Southwest Japan, Khandyga, Kukhtuy-Uliya, Luzhkinsky, Malo-Khingan, Pilda-Limuri, Preddzhugdzhursky, Selennyakh, Sergeevka-Taukha, South Verkhoyansk, Tumnin-Anyuy, and Upper Uydoma belts (fig. 4*I*; see appendix C).

Metallogenic Belts Related to the Okhotsk-Chukotka and East Sikhote-Alin Continental-Margin-Arcs

Seven metallogenic belts possess geologic units favorable for a wide variety of granitoid-related deposits: the Chelasin, Kukhtuy-Uliya, Luzhkinsky, Preddzhugdzhursky, Sergeevka-Taukha, Tumnin-Anyuy, and Upper Uydoma with Au-Ag epithermal vein, boron (datolite) skarn, cassiterite-sulfide-silicate vein and stockwork, granitoid-related Au vein, polymetallic Pb-Zn vein and stockwork, polymetallic volcanic-hosted metasomatite, porphyry Cu, Cu-Mo, and Mo, Cu, Sn-B, and Zn-Pb skarn, porphyry Sn, and Sn-W andW-Mo-Be greisen, stockwork, and quartz vein, and deposits. Isotopic ages of the associated granites range from mid-Cretaceous to Paleocene. These metallogenic belts and deposits are hosted in granitoids in the Okhotsk-Chukotka or the East Sikhote-Alin volcanic-plutonic belts both units are major overlap assemblages in the Russian Far East that are interpreted as parts of the extensive, nearly coeval, colinear continental-margin Okhotsk-Chukotka and East Sikhote-Alin arcs which overlie the North Asian craton and cratonal margin and previously accreted terranes to the east (present-day coordinates).

Metallogenic Belts Related to Opening of the Eurasia Basin

Several metallogenic belts possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits: the Central Polousny, Chokhchur-Chekurdakh, Eckyuchu-Billyakh, Khandyga, and Selennyakh belts (with Ag-Sb vein, Au-Ag epithermal vein, carbonate-hosted As-Au metasomatite, cassiterite-sulfide-silicate vein and stockwork, clastic sediment-hosted Hg±Sb and Sb-Au, Hg-Sb-W vein and stockwork, polymetallic Pb-Zn vein and stockwork, carbonate-hosted Hg-Sb, volcanic-hosted Hg, and Sn-W greisen, stockwork, and quartz vein deposits. Isotopic ages for the vein deposits range from 120 to 97 Ma (Aptian through Late Cretaceous). These belts and deposits are hosted in rocks of the Northern and Transverse granite belts, the Svyatoi Nos volcanic belt, and the Uyandina-Yasachnaya volcanic belt that intrude or overlie the Verkhoyansk (North Asian) cratonal margin and outboard accreted terranes. These belts are interpreted as having formed during extension related to the formation of the Eurasia Basin during initial opening of the Arctic Ocean.

Metallogenic Belts Related to the Khingan Continental-Margin-Arc

Four metallogenic belts possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits: the Badzhal-Komsomolsk, Ezop-Yam-Alin, Malo-Khingan, and Pilda-Limuri belts (with Cu skarn, porphyry Mo, granitoid-related Au vein, polymetallic Pb-Zn, porphyry Sn, rhyolite-hosted Sn, Sn-W and W-Mo-Be greisen, stockwork, and quartz vein, and cassiterite-sulfide-silicate vein and stockwork deposits. Isotopic ages for the granitoids hosting or associated with the deposits range from 100 to 75 Ma. The belts and deposits are hosted in granitoids related to the Khingan-Okhotsk volcanic-plutonic belt that is interpreted as having formed along the Khingan continental-margin-arc, which in turn is related to oblique subduction of ancestral Pacific Ocean plate and formation of the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes (parts of the Honshu-Sikhote-Alin collage).

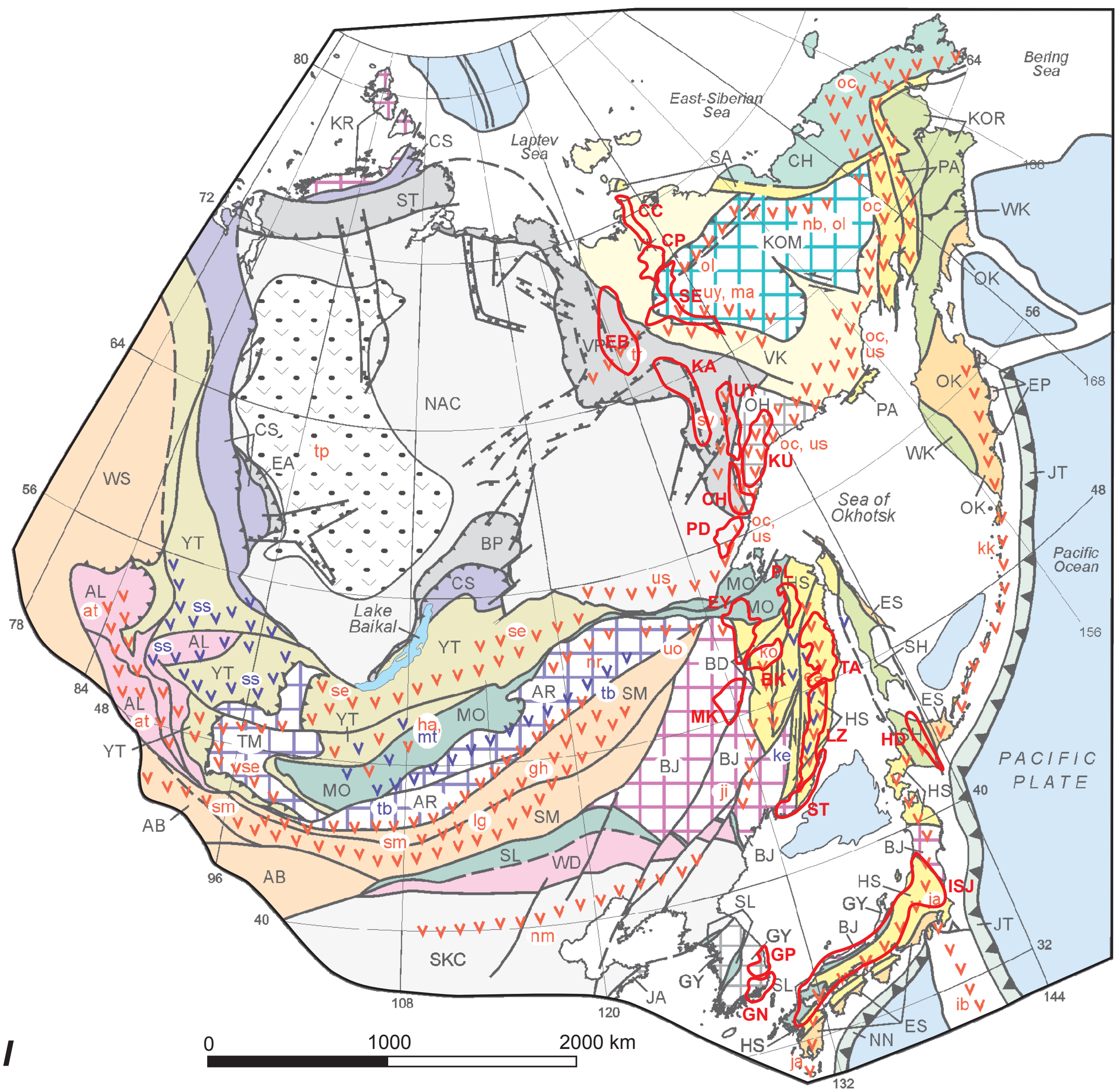

Figure 4.—Continued.

Unique Metallogenic Belts

Three unique metallogenic belts formed during the Middle Jurassic through Early Cretaceous.

The Gyeongpuk and Gyeongnam metallogenic belts with polymetallic Pb-Zn vein and stockwork, Au in shear-zone and quartz vein, porphyry Mo, W-Mo-Be greisen, stockwork, and quartz vein, Sn-W greisen, stockwork, and quartz vein, Fe skarn, and polymetallic Ni vein deposits. Isotopic ages range from the Cenomanian through Campanian. The deposits are hosted in the Cretaceous Bulgugsa granite, which intrudes the Sino-Korean craton. These belt and deposits are interpreted as having formed in a continental-margin-arc during subduction of the ancestral Pacific Ocean plate.

The Hidaka metallogenic belt with Cyprus Cu-Zn massive sulfide deposits is hosted in mid-Cretaceous to Eocene strati-form rocks that occur in tectonic fragments in the Shimanto subduction-zone terrane (part of the East Sakhalin collage). This belt is interpreted as having formed in basalt generated along the Kula-Pacific oceanic ridge, with subsequent structural incorporation of the host rocks and deposits into a subduction zone.

The Inner Zone Southwest Japan metallogenic belt with a wide variety of vein and replacement and granitoid-related deposits, including Cu, W, and Zn-Pb skarn, W-Mo-Be greisen, stockwork, and quartz vein, porphyry Mo, polymetallic Pb-Zn vein and stockwork, fluorspar vein, and metamorphic graphite deposits. The deposits are hosted in the Nohi rhyolite volcanic belt and the coeval Hiroshima granitic belt that overlie previously accreted terranes. Isotopic ages of the host rocks and deposits range from Cretaceous to Paleogene. The host rocks and deposits are interpreted as having formed during generation of granitoids along an East Asia continental-margin-arc that is tectonically linked to subduction of Kula and Pacific Ocean plates. The East Asia continental-margin-arc is interpreted as the southward extension of the East Sikhote-Alin continental-margin arc.

Major Maastrichtian Through Oligocene Metallogenic Belts

The major Maastrichtian through Oligocene metallogenic belts in the region (fig. 1) are the Kema, Lower Amur, and Popigay (fig. 4J; see appendix C). Two metallogenic belts possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits: the Kema and Lower Amur with Ag-Au epithermal vein, porphyry Cu-Mo, Cu, Au, and Mo, Au-Ag epithermal vein, epithermal quartz-alunite, and Sn-W greisen, stockwork, and quartz vein deposits. Isotopic ages for the host granitoids range from Late Cretaceous to Paleocene. These belts and deposits are hosted in granitoids of the East Sikhote-Alin volcanic-plutonic belt that is a major overlap assemblage in the Russian Far East. These belts are interpreted as parts of an extensive continental-margin-arc that formed along the eastern (present-day coordinates) margin of the North Asian craton and cratonal margin and previously accreted terranes to the east during subduction of the ancestral Pacific Ocean plate.

The unique Popigay metallogenic belt contains impact diamond deposits. The isotopic age of the deposits from tagamite (impact melt rock) and impact glasses is 35.7 Ma. This belt, which is hosted in the Popigay ring structure, is interpreted as resulting from meteoritic impact with formation of pseudotachylite, diamond, high-grade shock metamorphic minerals, and allogenic breccia.

Major Miocene Through Quaternary Metallogenic Belts

The major Miocene through Quaternary metallogenic belts in the region (fig. 1) are the Kyushu, Northeast Hokkaido, Hokuriku-Sanin, Northeast Japan, and Outer Zone Southwest Japan (fig. 4*J*; see appendix C), all five of which possess geologic units favorable for a wide variety of volcanic-related deposits, including Au-Ag epithermal vein, cassiterite-sulfide-silicate vein and stockwork, chemical-sedimentary Fe-Mn, clastic sediment-hosted Hg±Sb and Sb-Au, Ag-Sb, Hg-Sb-W vein and stockwork, limonite from spring water, Mn vein, polymetallic Pb-Zn vein and stockwork, polymetallic volcanic-hosted metasomatite, Sn and Zn-Pb skarn, Sn-W greisen, stockwork, and quartz vein, sulfur-sulfide, volcanic-hosted Hg; Ag-Sb vein, volcanogenic Zn-Pb-Cu massive sulfide, volcanogenic-sedimentary Mn, and W-Mo-Be greisen, stockwork, and quartz vein, and deposits. Isotopic ages of the host igneous rocks range from 15 to 0.3 Ma. The belts and deposits are hosted in the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that are interpreted as parts of the modern-day Japan continental-margin-arc, which is tectonically related to subduction of the Pacific Ocean and Philippine Sea plates beneath the East Asian continental margin.

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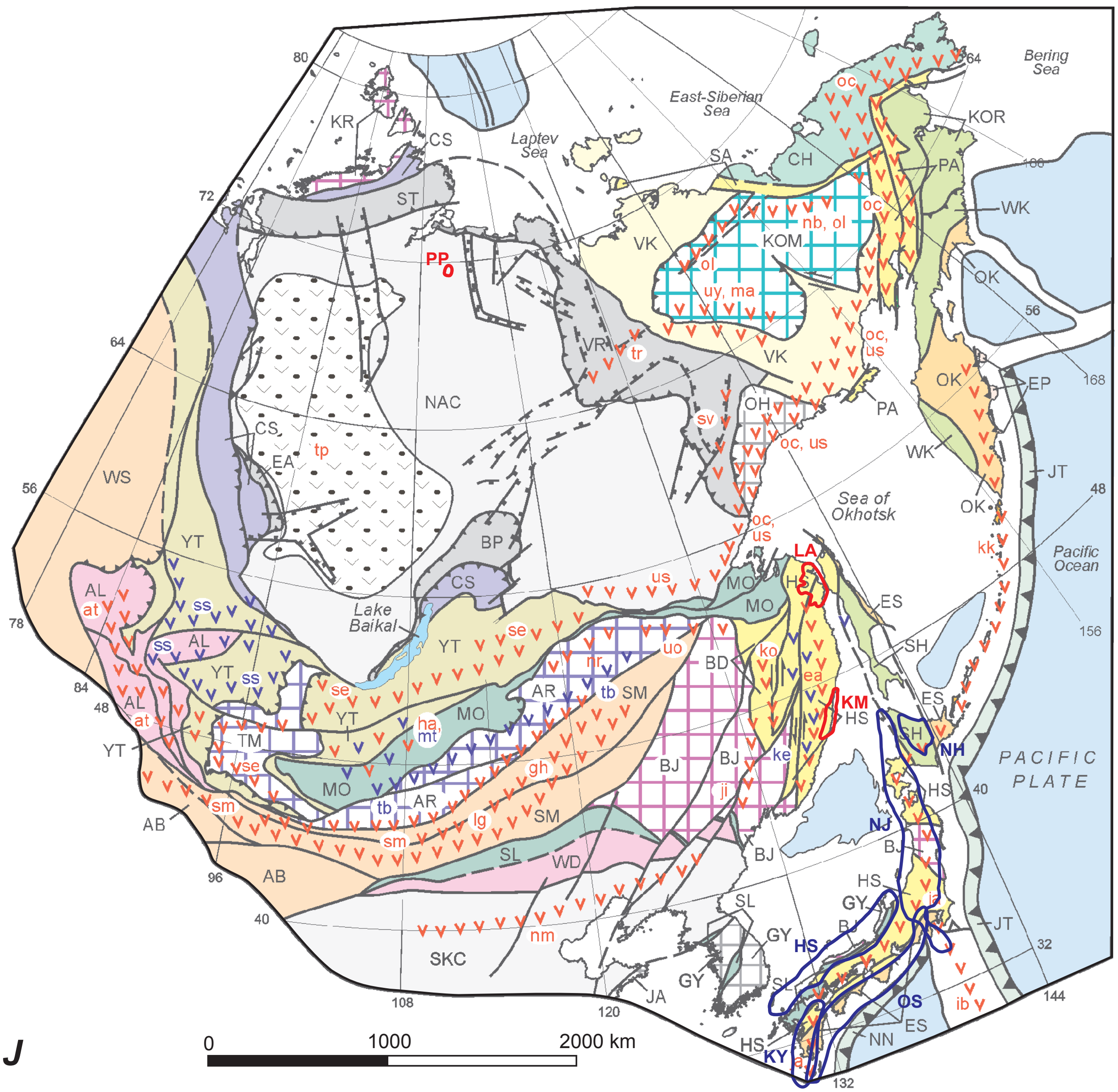

Figure 4.—Continued.

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Chapter 2

Methodology of a Combined Regional Metallogenic and Tectonic Analysis for Northeast Asia

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Introduction

The compilation, synthesis, description, and interpretation of metallogenesis and tectonics of major regions, such as Northeast Asia (eastern Russia, Mongolia, northern China, South Korea, and Japan) and the Circum-North Pacific (the Russian Far East, Alaska, and the Canadian Cordillera) require a complex methodology. The key goal for metallogenic and tectonic analysis is to define, characterize, and interpret the origin and evolution of mineralizing systems. To achieve this goal, a methodology is needed for combined regional metallogenic and tectonic analysis. The methodology, as developed in major international collaborative mineral resource studies led by the U.S. Geological Survey for the Circum-North Pacific and Northeast Asia, consists of the following steps: (1) definition of key terms; (2) compilation of a regional geologic base map that can be interpreted according to modern tectonic concepts and definitions; (3) interpretation of tectonic environments that formed the major geologic units and structures that control the origin and distribution of metallogenic belts; (4) description of significant mineral deposits (database) that enable the determination of mineral-deposit models, the relations of deposits to host rocks, and tectonic origins; (5) synthesis of mineral-deposit models that characterize the known deposits and inferred undiscovered deposits of the region; (6) compilation of a series of metallogenic belt maps on the regional geologic base map; and (7) synthesis and interpretation of a metallogenic-tectonic model.

This chapter presents an overview of the methodology for regional metallogenic and tectonic analysis, provides a theoretical example of this type of analysis, and describes an example for the Middle Jurassic through Early Cretaceous of Northeast Asia. The major sections of this chapter are: (1) definitions, compilations, and syntheses needed for a combined metallogenic and tectonic analysis; (2) a theoretical example of metallogenic and tectonic analysis; (3) description of a theoretical example of synthesizing a metallogenic-tectonic model; (4) example of a compilation of a regional-geologic base map; (5) a discussion of interpreting tectonic environments; (6) a discussion of compiling descriptions of significant mineral deposits and of synthesizing mineral-deposit models; (7) an example of compilation of a metallogenic belt map; (8) an example of a combined metallogenic-tectonic model; and (9) a description of the benefits of synthesizing a combined regional metallogenic-tectonic model.

A major goal of this chapter is to demonstrate that the methodology of regional metallogenic and tectonic analysis is a useful theoretical tool for defining, characterizing, and interpreting the origin and evolution of mineralizing systems throughout geological space and time. This methodology eliminates past problems that have limited some metallogenic and tectonic analyses, including (1) concentration of some metallogenic studies on local features of mineral deposits and districts without an understanding of their regional setting; (2) lack of integration of regional studies of host rocks, structures, and tectonic origins with respect to suites of mineral deposits; and (3) in some cases, application of a stabilistic tectonic philosophy.

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The methodology described in this chapter was developed for the international collaborative studies on the mineral resources, metallogenesis, and tectonics of Northeast Asia and the Circum-North Pacific (Russian Far East, Alaska, and the Canadian Cordillera) that were led by the U.S. Geological Survey. These studies have produced two broad types of publications. One type is a series of regional geologic, mineral deposit, and metallogenic-belt maps and companion descriptions for the regions, for example, Nokleberg and others (1998, 2004), Obolenskiy and others (2003, 2004), Parfenov and others (2003, 2004a,b), Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006). The other type of publication is a suite of metallogenic and tectonic analyses of these same regions. Major examples of this type are Scotese and others (2001), Nokleberg and others (2000, 2004, 2005), Rodionov and others (2004), and Naumova and others (2006). A summary of the major products of this project are posted on the World Wide Web at URL: http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.doc and are described in appendix A.

Relatively few combined metallogenic and tectonic analyses for large regions have been published since the 1980s. Most studies on this theme were focused on relatively smaller districts, such as that of the Maniwaki-Gracefield district in southwestern Quebec by Gauthier and Brown (1986). The major example of a regional metallogenic and tectonic analysis is that for the Circum-North Pacific (Russian Far East, Alaska, and the Canadian Cordillera) (Nokleberg and others, 1997a,b,c, 1998, 2000, 2005).

Key Terms Used In Metallogenic and Tectonic Analysis

Key terms used in the compilation, synthesis, description, and interpretation of metallogenic belts in relation to mineral deposits, metallogeny, and tectonics (Nokleberg and others, 2000, 2005) are as follows.

Accretion. Tectonic juxtaposition of terranes to a craton or cratonal margin. Accretion of terranes to one another or to a cratonal margin also produces a major change in the tectonic evolution of terranes and cratonal margins.

Amalgamation. Tectonic juxtaposition of two or more terranes before accretion to a craton or continental margin.

Composite terrane. An aggregate of terranes that is interpreted to share either a similar stratigraphic affinity or a common geologic history after accretion. An approximate synonym is *superterrane.*

Continental-margin arc terrane. Fragment of an igneous belt of coeval plutonic and (or) volcanic rocks and associated sedimentary rocks that formed above a subduction zone dipping beneath a continent. Either has or inferred to possess a sialic basement.

Craton. Chiefly regionally metamorphosed and deformed shield assemblages of Archean, Paleoproterozoic, and (or) Mesoproterozoic sedimentary, volcanic, and plutonic rocks and overlying platform successions of Paleoproterozoic, Paleozoic, and, locally, Mesozoic and Cenozoic sedimentary and lesser volcanic rocks.

Cratonal margin. Chiefly Neoproterozoic through Jurassic sedimentary rocks deposited on a continental shelf or slope. Consists mainly of platform successions. Locally has or may have had an Archean, Paleoproterozoic, and (or) Mesoproterozoic cratonal basement.

Cratonal terrane. Fragment of a craton.

Island-arc system. An island-arc terrane and tectonically linked subduction zone terranes..

Island-arc terrane. Fragment of an igneous belt of plutonic rocks and (or) coeval volcanic rocks, and associated sedimentary rocks that formed above an oceanic subduction zone. May possess a simatic basement.

Metallogenic belt. A geologic unit (area) that either contains or is favorable for containing a group of coeval and genetically-related, significant lode and (or) placer deposits. A metallogenic belt has the following characteristics: (1) is favorable for containing known or inferred mineral deposits of specific type or types; (2) may be irregular in shape and variable in size; (3) need not contain known deposits; and (4) is based on a geologic map as the primary source of information for delineation of areas that are favorable for specific deposit models. An essential part of the definition is that a belt is the geologically-favorable area for a group of coeval and genetically-related mineral-deposit models. This definition provides a predictive character for undiscovered deposits in each belt.

Metamorphic terrane. Fragment of a highly metamorphosed or deformed assemblage of sedimentary, volcanic, or plutonic rocks that cannot be assigned to a single tectonic environment because the original stratigraphy and structure are obscured. May include structural mélange that contains fragments of two or more terranes.

Mine. A site where valuable minerals or rocks have been extracted.

Mineral deposit. A site with concentrations of potentially valuable minerals for which grade and tonnage estimates have been made. Also used as a general term for any mineral occurrence or prospect.

Mineral occurrence. A site of potentially valuable minerals on which no visible exploration has occurred, or for which no grade and tonnage estimates have been made.

Oceanic crust, seamount, and ophiolite terrane. Fragment of part or all of a suite of deep-marine sedimentary rocks, pillow basalt, gabbro, and ultramafic rocks (former eugeosynclinal suite) that are interpreted as oceanic crustal sedimentary and volcanic rocks and upper mantle. Includes both inferred offshore oceanic and marginal ocean-basin rocks, minor arc-derived volcaniclastic rocks, and major marine volcanic accumulations formed at a hot spot, in a fracture zone, or along a spreading axis.

Overlap assemblage. A post accretionary unit of sedimentary or igneous rocks deposited on or intruded into two or more adjacent terranes.

Passive continental-margin terrane. Fragment of a cratonal margin.

Prospect. A site of potentially valuable minerals where excavation has occurred.

Significant mineral deposit. A mine, mineral deposit, prospect, or occurrence that is judged as being important for the metallogenesis of a geographic region.

Subduction-zone terrane. Fragment of a mildly to intensely deformed complex consisting of varying amounts of turbidite deposits, continental-margin rocks, oceanic crust and overlying units, and (or) oceanic mantle. Geologic units are interpreted to have formed during tectonic juxtaposition in a zone of major thrusting (subduction) of one lithospheric plate beneath another, generally along the margin of a continent or an island-arc terrane. May include large fault-bounded fragments with a coherent stratigraphy. Many subduction-zone terranes contain fragments of oceanic crust and associated rocks that exhibit a complex structural history in a major thrust zone, and possess blueschist-facies metamorphic assemblages. An approximate synonym is *accretionary-wedge terrane.*

Superterrane. An aggregate of terranes that is interpreted to share either a similar stratigraphic affinity or a common geologic history after accretion. An approximate synonym is *composite terrane*.

Tectonic Collage. A series of linear island-arc terranes or continental-margin arcs and tectonically-linked (companion) accretionary wedge (subduction) zones and(or) forearc and backarc basins that formed during a major tectonic event in a relatively narrow geologic timespan. Some collages may consist of fragments of cratonal margin and cratonal terranes that were amalgamated before accretion to a continent. The ages of collages with subduction-zone terranes are based on the time of active formation of the subduction zone, rather than the ages of rock units that compose to a companion subduction zone which was adjacent to and underthrust the arc.

Tectonostratigraphic terrane (terrane). A fault-bounded geologic entity or fragment characterized by a distinctive geologic history which differs markedly from that of adjacent terranes (Jones and others, 1983; Howell and others, 1985).

Turbidite-basin terrane. Fragment of a basin filled with deep-marine clastic deposits in either an orogenic forearc or backarc setting. May include continental-slope and continental-rise turbidite deposits, and submarine-fan turbidite deposits on oceanic crust. May also include minor epiclastic and volcaniclastic rocks.

Theoretical Example of Metallogenic and Tectonic analysis

A theoretical example of metallogenic and tectonic analysis is illustrated in figure 1 (from Nokleberg and others, 1998) which shows a schematic map that portrays a suite of metallogenic belts that are hosted in several geologic units including cratons, terranes, and overlap assemblages, or along major faults between terranes (fig. 1*A*), along with a series of stratigraphic columns for the geologic units (fig. 1*B*).

An orogenic belt map (fig. 1*A*), which is modeled after the major geodynamic units in Northeast Asia, cratons A and B are simplified portrayals of the North Asian craton and cratonal margin and the Sino-Korean craton, respectively. The various terranes and postaccretionary overlap assemblages on figure 1*A* the major faults cutting the terranes and overlap assemblages between the cratons and are simplified portrayals of those between the two major cratons in Northeast Asia.

The steps used in this theoretical example are as follows.

1. A regional geologic base map is constructed. In figure 1*A*, which shows a map view of an orogenic belt (consisting of two cratons and several intervening terranes), are two major cratons (A, B), several fault-bounded terranes (1, 2, 3, 4) between the two cratons, two accretionary assemblages (a,b), and three postaccretionary overlap assemblages (c,d,e).
2. A group of mineral-deposit models appropriate for the geology are identified and defined, and a mineral deposit database is prepared. In this theoretical example, the major applicable mineral-deposit models are low-sulfide Au-Ag quartz vein (orogenic gold), ironstone, Au epithermal vein, porphyry Cu, bedded barite, and kuroko massive sulfide.
3. Metallogenic belts are delineated. For simplicity in this example each belt is assumed to contain only a single mineral deposit type, and two cratons (A, B) each contain distinctive, preaccretionary metallogenic belts including ironstone and bedded barite deposits that formed early in their geologic history. Island-arc terrane 4 contains a preaccretionary metallogenic belt of kuroko massive sulfide deposits that formed during marine arc volcanism. Between terranes 1 and 2 is a postaccretionary overlap assemblage of rocks which contain a group of Au-quartz vein deposits that formed during the accretion of terrane 1 to terrane 2. Between terranes 3 and 4 is accretionary assemblage *a* that consists of a collisional granitic pluton with a porphyry Cu belt that formed during accretion of terrane 3 against terrane 4. Overlying all of the terranes and both cratons is postaccretionary overlap assemblage *e* that contains a metallogenic belt with Au-Ag epithermal vein deposits.
4. The genesis of bedrock geologic units, structures, and contained metallogenic belts and mineral deposits is interpreted using modern tectonic concepts, for example: kuroko massive sulfide deposits forming in an island-arc terrane environment; porphyry Cu and low-sulfide

Au-quartz vein deposits forming in a collisional environment; and epithermal Au vein deposits forming in a continental-margin arc environment.

5. By carefully defining each metallogenic belt to be geologically favorable for a group of coeval and genetically-related mineral deposits, a predictive characteristic is identified within each metallogenic belt for possible undiscovered deposits.

Example of a Metallogenic-Tectonic Model

The six steps for performing a combined metallogenic and tectonic analysis are illustrated in figure 2.

The construction of a regional geologic base map and a metallogenic belt overlay is illustrated in figures 2*A* and 2*B*. For the delineation of metallogenic belts, the following main principles are used (Nokleberg and others, 2005; Rodionov and others, 2004): (1) *Mineral deposit association.* Each metallogenic belt includes a single mineral deposit type or a group of spatially and genetically-related mineral deposits types. (2) *Tectonic event for formation of mineral deposits.* Each metallogenic belt includes a group of coeval and genetically related mineral deposits that formed as the result of a specific tectonic event (for example, subduction-related igneous arc, collision, accretion, rifting, and so on). (3) *Favorable geological, geochemical, and geophysical environment.* Each metallogenic belt contains host rocks, structures, geochemical anomalies or signatures, and(or) geophysical anomalies or signatures that are favorable for the occurrence of a particular suite of mineral deposit types. (4) *Geological or tectonic boundaries.* Each metallogenic belt typically is bounded by contacts with favorable stratigraphic or magmatic units, or by major faults (sutures) along which substantial translations have commonly occurred.

The components of a mineral deposit database and assignment of mineral-deposit models are listed in figure 2*C*.

The synthesis of a metallogenic-tectonic model, as listed in figure 2*D*, consists of seven steps: (1) tectonic environments for the cratons, cratonal margins, orogenic collages of terranes, overlap assemblages, and contained metallogenic belts are assigned from regional compilation and synthesis of stratigraphic, structural, metamorphic, isotopic, paleomagnetic, faunal, and provenance data (for example, Nokleberg and others, 2000; Scotese and others, 2001); (2) correlations are made among terranes, fragments of overlap assemblages, and

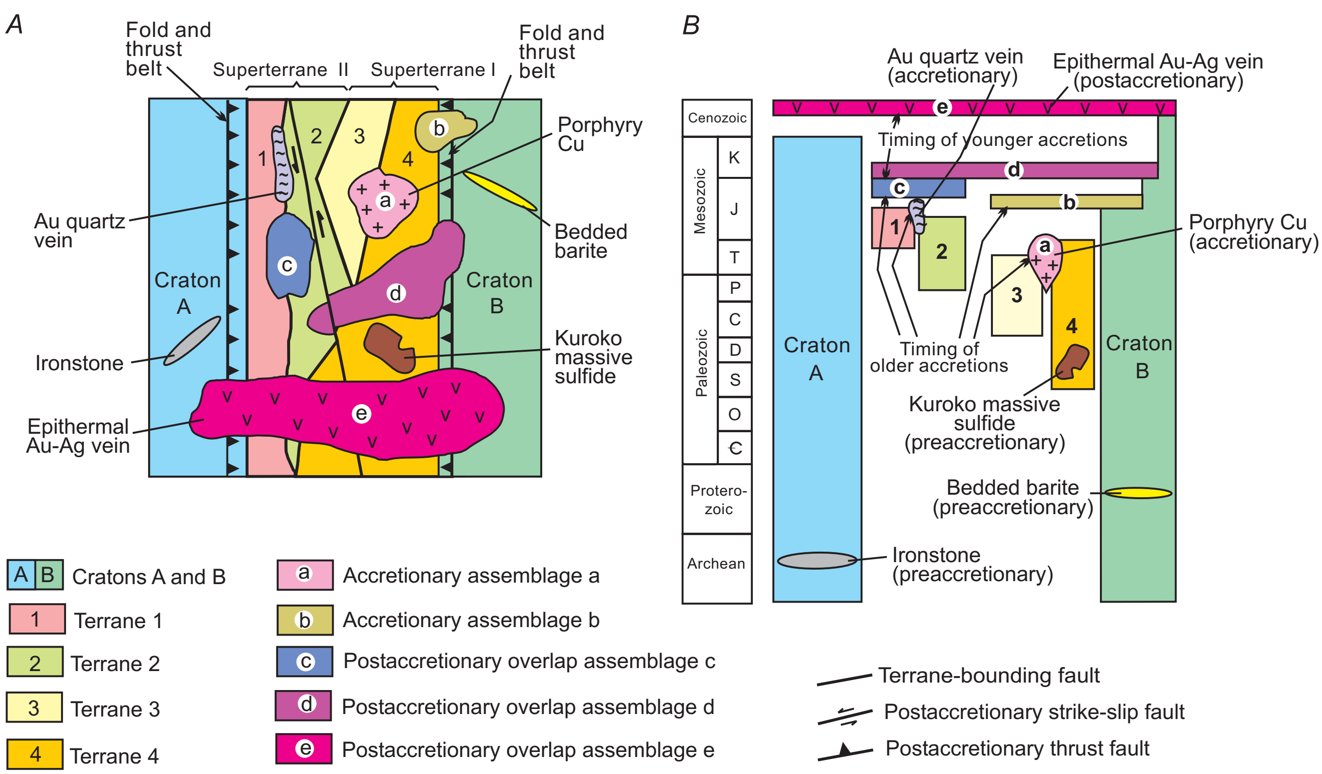

Figure 1. Schematic diagram illustrating methodology of combined regional and metallogenic and tectonic analysis of cratons, terranes, accretionary assemblages, post-accretopmaru overlap assemblages, and contained metallogenic belts. *A*. Map view of orogenic belt. *B*. Stratigraphic columns for orogenic belt. Adapted from Parfenov and others (1998)

fragments of contained metallogenic belts; (3) tectonic linkages are established between related terranes, such as an igneous-arc terrane and an associated subduction-zone terrane, for example, these linked terranes and their contained metallogenic belts, can be grouped into coeval, curvilinear arc-subduction-zone complexes that make up a tectonic collage; (4) from geologic, faunal, and paleomagnetic data, the original positions (loci) of terranes and their metallogenic belts are interpreted; (5) paths of tectonic migration of terranes and contained metallogenic belts are constructed; (6) the timings and nature of accretions of the terranes and contained collision-related metallogenic belts are determined from geologic, age, and structural data; (7) additional data for constructing the model are obtained from the geologic characteristics of postaccretionary overlap assemblages and contained metallogenic belts that overlie and stitch together the underlying and accreted or amalgamated terranes.

A simplified tectonic model that was synthesized using these data and the interpretations in parts 1-4 is illustrated in figure 2*E*.

The applications resulting from a combined metallogenic and tectonic analysis, as listed in figure 2*F*, include: (1) refining mineral-deposit models and deposit genesis; (2) improvement of assessments of undiscovered mineral resources as a part of quantitative mineral-resource assessment studies; (3) improvement of land-use and mineral exploration planning; (4) improvement of interpretations of the origins of host rocks, mineral deposits, and metallogenic belts; and (5) providing guidelines for new research.

Construction of a Regional Geologic Base Map

To compile a metallogenic-belt map for a metallogenic and tectonic analysis, a regional geologic base map must first be constructed that permits the display of metallogenic belts and their relations to host rock geology or host-rock structures (Nokleberg and others, 1997b,c; Parfenov and others, 2003, 2004a,b). To facilitate the analysis of the crustal origin and evolution of mineralizing systems, the geologic base map must be constructed at a scale that shows the major geologic data required for a synthesis that should reveal the tectonic origin of the host-rock geologic units and structures that controlled the formation of groups of mineral deposits in the metallogenic belts.

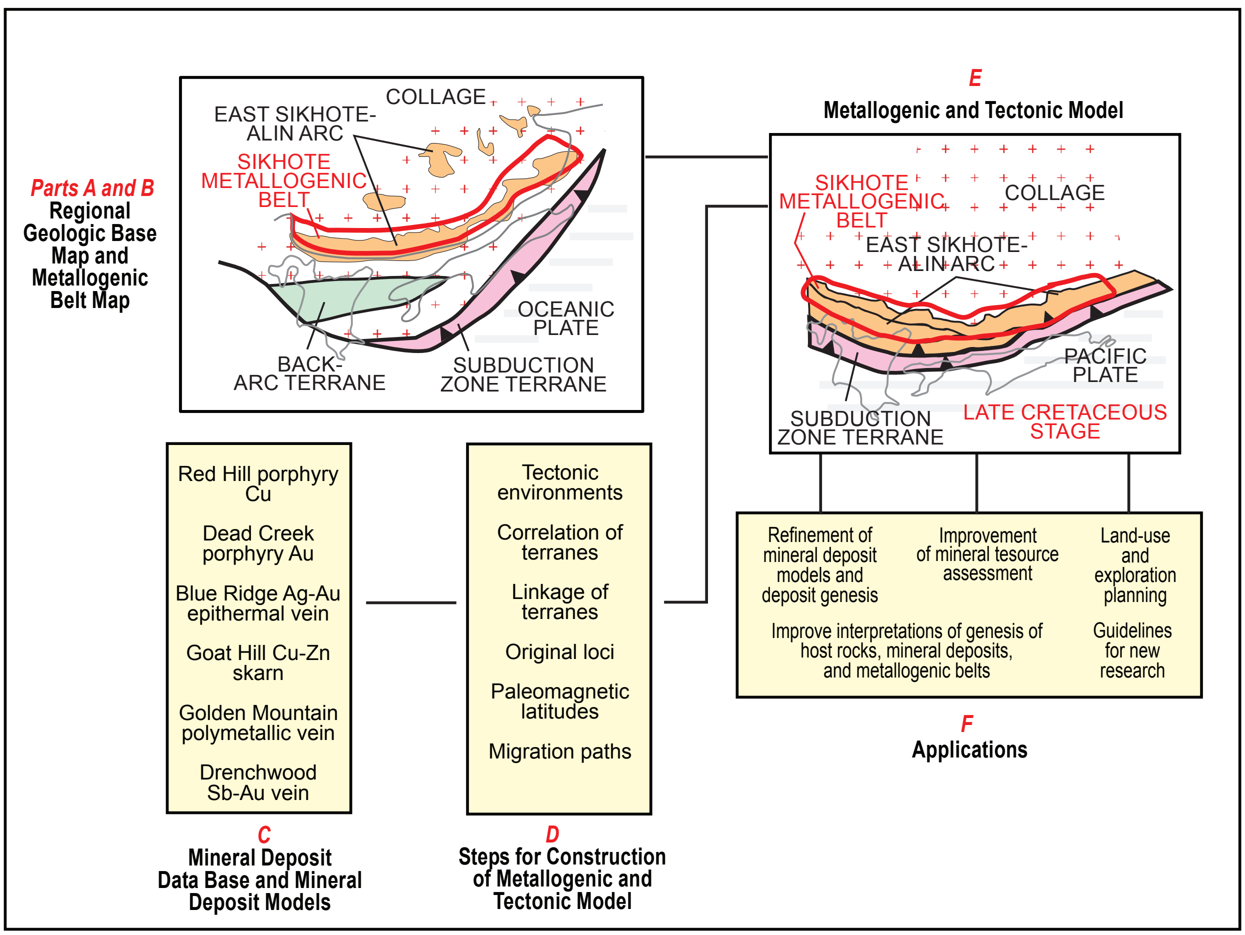

Figure 2. Major components of a metallogenic and tectonic analysis and synthesis of a metallogenic-tectonic model. *A, B,* Regional geologic base map and metallogenic belt map. *C,* Mineral deposit database and mineral-deposit models. *D,* Steps for synthesis of a metallogenic-tectonic model. *E,* Metallogenic-tectonic model. *F,* Applications.

For example. a summary geodynamics map of Northeast Asia (fig. 3; from Parfenov and others, 2003, 2004a,b) shows the host rock geology and structures that are related to the origin of metallogenic belts, including: (1) the regional surface extent of major geologic units (cratons, cratonal margins, tectonic collages of island-arc terrane, continental-margin arc, accretionary wedge, and passive continental margin terranes, volcanic and plutonic igneous arcs); (2) major fault and rift systems; and (3) active subduction zones. The regional-geologic base map should also provide descriptive data on the tectonic origins of major host-rock geologic units (for example, explanation, fig. 3) that are needed to establish geologic controls on the metallogenic belts. Figure 3 utilizes the concept of tectonic collage (see definition above) which enables: (1) depiction at small (regional) scales of the major geologic units and structures that formed in a single tectonic event; and (2) depiction of the major metallogenic belts related to the tectonic collages.

Interpretation of Tectonic Environments

For a modern metallogenic and tectonic analysis, interpretation of tectonic environments is essential for determining the origins of major geologic units and their contained mineral deposits and metallogenic belts. The interpretation of tectonic environment permits the linking of geologic origins for these sometimes disparate datasets. For the metallogenic and tectonic analyses of Northeast Asia and the Circum-North Pacific (table 1; Nokleberg and others, 1997b,c, 2000, 2005; Scotese and others, 2001; Obolenskiy and others, 2003 and this volume; Parfenov and others, 2003, 2004a,b), the major geologic units (terranes, overlap assemblages, plates), mineral deposits, mineral deposit types, and metallogenic belts, are interpreted according to the following tectonic environments: (1) craton and cratonal margin; (2) passive continental margin; (3) metamorphosed continental margin; (4) continental-margin arc and backarc; (5) island-arc terrane and backarc; (6) oceanic crust, seamount, or ophiolite related to rifting and sea-floor spreading; (7) accretionary wedge and subduction zone; (8) turbidite basin; (9) collisional; (10) transform continental-margin faulting and associated bimodal volcanic-plutonic belt; (11) plume; and (12) metamorphic. (See definitions above.) For terranes with complex geologic histories, the chosen tectonic environment is the one most prevalent during the history of the terrane. This assignment of tectonic environments should result in a higher quality interpretation for the origin of mineral deposits and metallogenic belts and for the origin of the geologic units and structures in which the deposits and belts formed.

Description of Significant Mineral Deposits and Synthesis of Mineral-Deposit models

Part of the core dataset for a combined metallogenic and tectonic analysis is a high-quality description of significant known mineral deposits (see above definition) in the region. For example, descriptions of selected major Middle Jurassic through Early Cretaceous lode deposits for Northeast Asia, adapted from Ariunbileg and others (2003), are listed in table 2 along with descriptive data that enable the determination of mineral-deposit models, age and relation of deposits and their relations to host rocks, and tectonic origins.

A modern regional metallogenic and tectonic analysis requires the construction of mineral-deposit models appropriate for the region. The models can subsequently be used to classify mines, mineral deposits, and prospects that can be interpreted as forming during various regional tectonic processes. The beginning of this type of correlation between models and tectonic processes is evident in many of classic compilations of mineral deposits models (Eckstrand, 1984; Cox and Singer, 1986; Singer, 1993). For example, mineral-deposit models employed for a large region and lists the mineral-deposit models that were defined and described for a metallogenic and tectonic analysis of Northeast Asia are listed in table 3. For this large and complex region, 122 mineral-deposit models were required to describe the characteristic features of the 1,674 lode deposits and 75 placer districts. The models include previous descriptions by Eckstrand (1984), Cox and Singer (1986), and Nokleberg and others (1997a), with modifications by Obolenskiy and others (2003, this volume).

The mineral-deposit models listed in table 3 consist both of descriptive and genetic information that is systematically arranged in order to define the essential properties of a class or type of mineral deposit. Some models, however, are based mainly on descriptive (empirical) information, whereby the various attributes are recognized as essential even though the nature of their relationships is unknown. For example, in the basaltic Cu mineral-deposit type, the empirical datum of a geologic association of Cu sulfides with relatively Cu-rich metabasalt or greenstone is the essential attribute. Some other mineral-deposit models are defined by genetic (theoretical) considerations in which case the attributes are related through some fundamental geologic process. For example, the W skarn mineral-deposit model type, the genetic process of contact metasomatism is the essential attribute. For additional information on the methodology for defining mineral-deposit models, see the discussions by Eckstrand (1984), Kirkham (1993), and Cox and Singer (1986).

Compilation of a Metallogenic-Belt Map

Many metallogenic maps that display major mineral deposits and (or) districts on a regional geologic base map are typically complex because of a high density of deposits. To simplify the data and increase understanding of regional patterns, the concept of a metallogenic belt map was developed for Northeast Asia and the Circum-North Pacific (Nokleberg and others, 1998; Obolenskiy and others, 2003, 2004). The display of metallogenic belts, as defined above, enables the depiction of major groups of coeval and genetically related, significant lode and placer deposits that can be interpreted as having formed in a single major geologic or tectonic event. A requirement of a metallogenic belt map is that the various belts can be related to major host-rock geologic units or structures as portrayed on the map and accompanying explanation. Examples of summary metallogenic belt maps for Northeast Asia are shown in the various time-stage chapters on regional metallogenic and tectonic analysis in this volume. More detailed metallogenic belt maps and companion descriptions are published by Obolenskiy and others (2003) and Rodionov and others (2004).

Benefits of Performing a Combined Regional Metallogenic and Tectonic Analysis

As described above, a high-quality, combined metallogenic and tectonic analysis can benefit other mineral resource studies, including: (1) refinement of mineral-deposit models and deposit genesis (Eckstrand, 1984; Cox and Singer, 1986; Singer and Cox, 1988; Kirkham, 1993); (2) improvement of estimates of undiscovered mineral resources as a part of quantitative mineral resource assessments (Cox, 1993; Singer, 1993, 1994); (3) improvement of land-use planning and mineral exploration; (4) improvement of interpretation of the origins of host rocks, mineral deposits, and metallogenic belts; and (5) suggestion of guidelines for future research.

Three examples of these benefits are as follows. (1) Indepth understanding of the tectonic and metallogenic origins of potential host rocks for mineral deposits enables the prediction of undiscovered mineral deposits according to favorable host rock geology. This capability is crucial because for a proper mineral resource assessment, the outlines of permissive tracts (that is, areas with a potential for undiscovered mineral deposit types) must be drawn for each mineral deposit type on the basis of knowledge of favorable geologic environments. (2) Regional metallogenic-tectonic analyses, such as those performed for Northeast Asia and the Circum-North Pacific, enable the identification and location of continuations of ore-hosting terranes and permissive tracts worldwide that have been separated by tectonic processes. For example, suppose that a suite of metallogenic belts containing porphyry Cu deposits are hosted in fragments of island-arc terranes which are now dispersed in a collage of terranes in the center of a continent. Tectonic analysis of the origin of the island-arc terranes and correlations with each other can produce a grouping of these terranes and their contained metallogenic belts into an originally continuous island arc and a single, large metallogenic belt. This enlargement of the host-rock area and its contained metallogenic belts will establish a larger dataset that can greatly improve the quality of metallogenic and tectonic analysis and mineral-resource assessment. (3) Understanding the metallogenic setting and history of host rocks and ore-forming processes often is important for estimating the number of undiscovered mineral deposits in a permissive tract. For example, the number of volcanogenic massive sulfide deposits estimated in a permissive tract containing poorly exposed and poorly described mafic to felsic volcanic rocks may vary depending on whether the tract is located in a volcanic forearc, axial-arc, or backarc tectonic setting. Conversely, no deposits of this type would be estimated for a tract of similar rocks in an extensional cratonic setting.

Summary

This chapter presents an overview of the methodology of combined regional metallogenic and tectonic analysis, including definitions, theoretical examples, and known examples for the Middle Jurassic through Early Cretaceous of Northeast Asia. It also describes how a high-quality metallogenic and tectonic analysis, and synthesis of an associated metallogenic-tectonic model, can benefit: (1) refinement of mineral-deposit models and deposit genesis; (2) improvement of estimates of undiscovered mineral resources as a part of quantitative mineral resource assessments; (3) improvement of land-use planning and mineral exploration; (4) improvement of interpretations of the origins of host rocks, mineral deposits, and metallogenic belts; and (5) suggestion of guidelines for future research. A major goal of this chapter is to demonstrate that the methodology of regional metallogenic and tectonic analysis, as summarized herein, is a powerful theoretical tool for defining, analyzing, and interpreting the crustal origin and evolution of mineralizing systems throughout geologic space and time.

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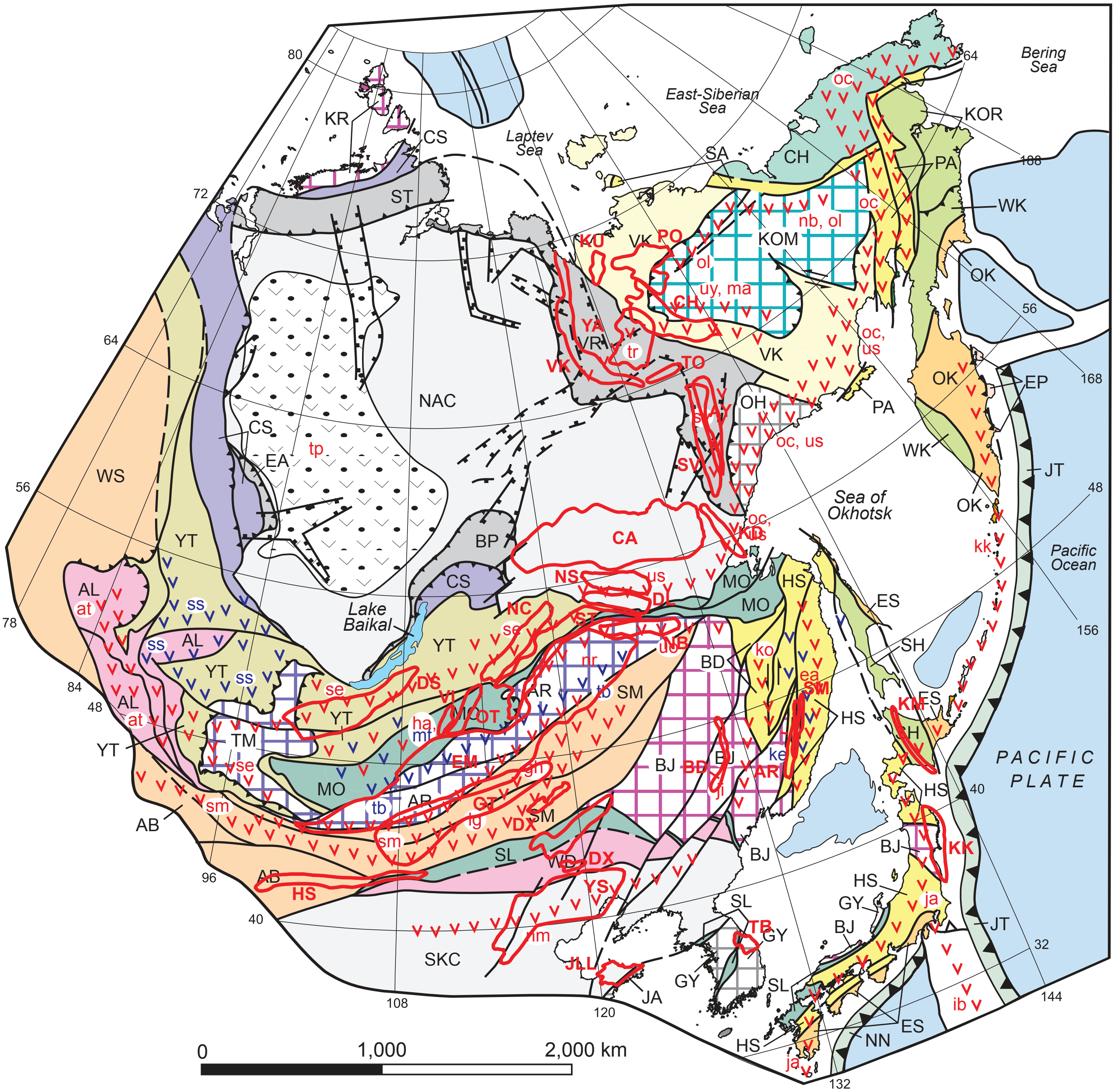

Figure 3. Summary geodynamic map of Northeast Asia showing outlines of major metallogenic belts for the Middle Jurassic through Early Cretaceous. Adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Regional geology for area east of 144ºE longitude (eastern boundary of Northeast Asia project area) as described and interpreted by Nokleberg and others (2000, 2005).

EXPLANATION

Cratons and Cratonal Margins

Cratons: NAC - North Asian (Archean and Proterozoic); SKC - Sino-Korean (Archean and Proterozoic)

Cratonal Margin: BP - Baikal-Patom (Riphean through Cambrian and older basement; EA - East Angara (Riphean and older basement; ST - South Taimyr (Ordovician through Jurassic); VR - Verkhoyansk (Devonian through Jurassic).

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

AL - Altay (Vendian to Ordovician)
WD - Wundurmiao (Riphean through Ordovician)

AB - Atasbogd (Ordovician through Permian); SM - South Mongolia-Khingan (Ordovician through Carboniferous); WS - West Siberian (Ordovician through Carboniferous)

MO - Mongol-Okhotsk (Devonian through Late Jurassic); SL - Solon (Carboniferous and Permian)

Tectonic Collages Along the Northern and Eastern Margins of North Asian and Sino-Korean Cratons

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

BD - Badzhal (Triassic through Early Cretaceous); PA - Penzhina-Anadyr (Late Jurassic and Cretaceous); HS - Honshu-Sikhote-Alin (Jurassic and Early Cretaceous); SA - South Anyui (Permian through Jurassic);

KOR - Koryak (Late Jurassic through Paleocene; SH - Sakhalin-Hokkaido (Cretaceous); WK - West Kamchatka (Mid-Cretaceous through Early Tertiary)

ES - East Sakhalin (Late Cretaceous and Early Tertiary); OK - Olyutorka-Kamchatka (Late Cretaceous to Paleocene)

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

JT- Japan Trench (including Kuril-Kamchatka trench) (Miocene through Holocene; NN - Nankai (Miocene through Holocene)

Cratonal Terranes and Superterranes

Cratonal terranes (Archean and Proterozoic): GY - Gyeonggi-Yeongnam; JA - Jiaonan; OH - Okhotsk

Late Proterozoic and Cambrian superterranes: AR - Argun-Idermeg; TM - Tuva-Mongolia

Archean through Permian superterranes: BJ - Bureya-Jiamusi; KR - Kara

Jurassic Superterrane: KOM - Kolyma-Omolon (Archean through Jurassic)

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

at - Altay arc (Devonian and early Carboniferous, 381 to 290 Ma)
ea - East Sikhote-Alin arc (Late Cretaceous through early Tertiary, 96-65 Ma)
gh - Gobi-Khankaisk-Daxing'anling arc (Permian, 295 to 250 Ma)
ha - Hangay arc (Late Carboniferous and Early Permian, 320 to 272 Ma)
ji - Jihei arc (Permian, 295 to 250 Ma)
ko - Khingan arc (Early and mid-Cretaceous)
lg - Lugyngol arc (Permian and Triassic, 295 to 250 Ma)
ma Main granite belt (Late Jurassic, 144 to 134 Ma)
nb - Northern granite belt (Early Cretaceous, 138 to 120 Ma)
nm - North Margin (Late Carboniferous and Permian, 320 to 272 Ma)
nr - Norovlin arc (Devonian and Early Carboniferous, 410 to 255 Ma)
oc - Okhotsk-Chukotka arc (Late Cretaceous and early Tertiary, 96 to 53 Ma)
ol - Oloy arc (Late Jurassic, 154 to135 Ma)
se - Selenga arc (Permian through Jurassic, 295 to135 Ma)
sm - South Mongolian arc (Carboniferous through Triassic, 320 to 203 Ma)
ss - South Siberian arc (Devonian)
sv - South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157 to 93 Ma)
tr - Transverse granite belt (Early Cretaceous, 134 to 124 Ma)
uo - Umlekan-Ogodzhin arc (Cretaceous, 135 to 65 Ma)
us - Uda-Murgal and Stanovoy arc (Jurassic and Early Cretaceous, 203 to 96 Ma)
uy - Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154 to 120 Ma)

Plume-Related Igneous Province

tp - Tungus Plateau igneous province - (Late Permian and Early Triassic, 245 Ma)

Active Arcs

ib - Izu-Bonin (late Cenozoic, 20 to 0 Ma)
ja - Japan (late Cenozoic, 23 to 0 Ma)
kk - Kuril-Kamchatka (late Cenozoic, 11 to 0 Ma)

Transpressional Arcs

ke - Kema (Mid-Cretaceous)
mt - Mongol-Transbaikal (Late Triassic through Early Cretaceous, 230 to 96 Ma)
ss - South Siberian (Early Devonian, 415 to 400 Ma)
tb - Transbaikalian-Daxinganling (Middle Jurassic through Early Cretaceous,175 to 96 Ma)

Symbols, Faults, and Contacts

Overlap-continental-margin arc
Transform-continental-margin arc
Active subduction zone
Thrust
Strike-slip fault
Fault
Contact
Riphean aulacogen
Devonian aulacogen
Modern rift system (Gakkel Ridge)
os Metallogenic belt

Figure 3.—Continued.

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Tables 1–3

Table 1. Summary of major areas, major tectonic environments (events), and associated major lode mineral-deposit models derived from metallogenic analyses of Northeast Asia, the Russian Far East, Alaska, and the Canadian Cordillera.

[Adapted from Nokleberg and others (2003), Scotese and others (2001), and Rodionov and others (2004)]

Area	Tectonic environment(s) or event(s)	Major mineral-deposit types
Northeast Asia and North American cratons and cratonal margins	Rifting	Sedimentary-exhalative Zn-Pb, polygenic REE, Cyprus massive sulfide, carbonate-hosted sulfide, various volcanogenic massive sulfide deposit types.
Ocean	Sea-floor spreading (oceanic crust, seamount, or ophiolite related to rifting)	Cyprus massive sulfide, various volcanogenic massive sulfide deposit types, podiform chromite.
North Asian and North American continental margins	Continental-margin arc intruding passive continental margin, turbidite basin, or metamorphosed continental margin. Backarc. Structurally underlain by subduction zone.	Various porphyry, epithermal vein, polymetallic vein, skarn, greisen, pegmatite, volcanogenic massive sulfide deposit types, Besshi massive sulfide.
Ocean	Island-arc terrane and backarc	Various porphyry, epithermal vein, polymetallic vein, and skarn deposit types, granitoid-related Au veinz, zoned mafic-ultramafic Cr-PGE, mafic-ultramafic related Cu-Ni-PGE.
North Asian and North American continental margins	Collision and metamorphic	Au in shear zone and quartz vein, granitoid-related Au, various porphyry and skarn types, Au in black shale.
North Asian and North American continental margins	Transform-continental-margin faulting and associated bimodal volcanic-plutonic belt	Zoned mafic-ultramafic-PGE, Cr, and Ti; W skarn, porphyry Cu-Mo, Au-Ag epithermal vein, Au in shear zone and quartz vein, basaltic native copper, Cu-Ag quartz vein.
North Asian and North American cratons	Plume intrusion into craton or cratonal margin	Mafic-ultramafic related Cu-Ni-PGE, Fe-Ti and REE carbonatite, various porphyry, pegmatite, and skarn deposit types, metamorphic graphite, diamond-bearing kimberlite.

Table 2. Examples of selected granitoid-related Au deposits for selected deposits in Northeast Asia.

[Adapted from Ariunbileg and others (2003)]

Latitude Longitude	Deposit name Country Metallogenic belt	Major metals Minor metals Deposit model	Grade and tonnage
51º 56' N 138º 47' E	Agnie-Afanas'evskoye Russia Pilda-Limuri	Au Granitoid-related Au vein	Average grade of about 25 g/t Au, maximum grade up to 1-2 kg/t Au. Mined from 1936 to 1962 with production of 12 tonnes Au.
Summary: Deposit occurs in a vein system that ranges up 0.5 km wide and up to 1.0 km long. System occurs in an anticline formed in Early Cretaceous sandstone and siltstone. Several diorite dikes occur along joints that cross host rock bedding. Veins range from 200 to 700 m long and 5 to 10 cm wide, strike northeast, and dip moderately. Veins contain mainly quartz, carbonate, feldspar, chlorite, and sericite with as much as 1% ore minerals. Ore minerals are pyrite, arsenopyrite, antimonite, chalcopyrite, sphalerite, chalcocite, and gold, and rare cassiterite, wolframite, scheelite, and molybdenite. Pyrite is dominant and forms disseminations and thin veinlets in quartz. Arsenopyrite content is less than pyrite and occurs in high-grade zones. Gold grains range from 1 to 6 mm, and occur in bunches, thin veinlets, and rare octahedron crystals in fractured quartz. Host rocks are altered near quartz veins and contain as much as 2 to 4 g/t Au. **Reference**: Moiseenko and Eyrish (1996).			
53º 27' N 126º 27' E	Pioneer Russia North Bureya	Au Granitoid-related Au vein	Average grade of 2.7 g/t Au, and 5.2 g/t Ag. Reserves of 17.1 tonnes Au, 20.1 tonnes Ag.
Summary: Deposit occurs near margin of an Early Cretaceous granodiorite intrusion in both the intrusion and in adjacent country rock that consists of contact-metamorphosed Jurassic sandstone and siltstone. Deposit consists of veins of quartz, quartz-feldspar, quartz-tourmaline and quartz-carbonate and altered zones of quartz, K-feldspar, sericite and albite. Veins and zones range from 1 to 50 m thick and have variable trends in plan view. Deposit is large and low grade and has no visible boundaries. Extent of deposit determined by geochemical sampling. Gold and Au-sulfides occur. Au deposit mineral assemblage is quartz-adularia-carbonate veins and the Au-sulfide is quartz veins with pyrite, galena, stibinite and Ag-sulfosalts. **References**: N.E. Malyamin and V.E. Bochkareva (written commun., 1990); V.N. Akatkin (written commun., 1991).			
52º 22' N 115º 33' E	Darasunskoye Russia Nerchinskiy	Au Granitoid-related Au vein	Grades ranges to a few to 300 ppm Au; average grade of 6.5 ppm Au.
Summary: Deposit consists of over 120 steeply-dipping quartz-sulfide veins that extend along strike for 1.0 to 1.2 km. Zone of veins ranges from 100 to 1,000 m thick and individual veins range from 5 to 20 cm thick. A zone of wallrock marginal to veins ranges from 0.6 to 1.5 m thick and contains disseminated sulfides. Main ore minerals are pyrite, arsenopyrite, chalcopyrite, pyrrhotite, galena, sphalerite, Pb, Cu, Ag, Bi, As, and Sb sulfosalts, tellurides, native gold, quartz, carbonates, and tourmaline. Principal economic gold-bearing mineral assemblages are: chalcopyrite-gray ore, chalcopyrite-pyrrhotite, pyrite-arsenopyrite, and sphalerite-galena. Gold occurs in arsenopyrite, pyrite, chalcopyrite, pyrrhotite, and gray ore, and is finely dispersed. Deposit occurs along the Mongol-Okhotsk and is hosted in mid- and Late Cretaceous K granodiorite-porphyry that intrudes a volcanic dome. **Reference**: Zvyagin and Sizikov (1971).			
48º 45' N 106º 09' E	Boroo Mongolia North Hentii 2	Au Granitoid-related Au vein	Average grade of 3.0 g/t Au. Resource of 40.0 tonnes Au.
Summary: Deposit is hosted by altered units of early Mesozoic gabbro, diabase, and diorite dikes. Deposit extends approximately 2.0 km along strike and ranges from 3 to 34 m thick. Ore mineral assemblages, from older to younger, are: pre-ore epidote-chlorite, quartz-sericite-albite-chlorite, gold-pyrite-arsenopyrite-K-feldspar-quartz, gold-beresite, quartz; gold-sulfide-quartz vein, and post ore calcite. Gold is fine-grained and occurs in pyrite and arsenopyrite, and as free gold in quartz veins. Main ore minerals are pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, tetrahedrite, and gold. Main gangue minerals are quartz, sericite, Fe-carbonates, calcite, albite and muscovite. **References**: Blagonravov and Shabalovskii (1977); Dejidmaa (1985).			
53º 27' N 126º 27' E	Sanshandao, Shandong Province China Jiliaolu	Au Granitoid-related Au vein	Average grade of 6.13 g/t Au. Reserves of 59 tonnes Au.
Summary: Deposit consists of stockwork greater than 10 m thick, 1000 m long, several hundred meters deep down dip. Ore body is controlled by northeast-trending faults. Deposit minerals occur in a veinlet-stockwork and are composed of electrum, native gold, pyrite, galena, sphalerite, molybdenite and quartz and sericite. Host rock alterations are silica, sericite and pyrite and local K feldspar. Four deposition stages are: pyrite-quartz, quartz-fine pyrite, quartz-base metallic sulfides, and quartz-carbonates. Gold deposition temperature is about 350 to 230° C and is related to the Cretaceous granite (with a K-Ar isotopic age of 137 to 126 Ma). **Reference**: Liu (1990).			

Table 3. List of lode mineral-deposit models employed for metallogenic and tectonic analysis of Northeast Asia.

[Adapted from Obolenskiy and others (2003, this volume)]

Group	Type
Deposits related to mafic and ultramafic intrusions	Anorthosite Ti-Fe-P apatite Diamond-bearing kimberlite Mafic-ultramafic related Cu-Ni-PGE Mafic-ultramafic related Ti-Fe (±V) Podiform chromite Serpentinite-hosted asbestos Zoned mafic-ultramafic Cr-PGE
Deposits related to intermediate and felsic intrusions	Au skarn B (datolite) skarn Carbonate-hosted asbestos Cassiterite-sulfide-silicate vein and stockwork Co skarn Cu (±Fe, Au, Ag, Mo) skarn Fe skarn Felsic plutonic U-REE Fe-Zn skarn Fluorite greisen Granitoid-related Au vein Muscovite pegmatite Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork Porphyry Au Porphyry Cu (±Au) Porphyry Cu-Mo (±Au, Ag) Porphyry Mo (±W, Bi) Porphyry Sn REE-Li pegmatite Sn skarn Sn-B (±Fe) skarn (ludwigite) Sn-W greisen, stockwork, and quartz vein Ta-Nb-REE alkaline metasomatite W±Mo±Be skarn W-Mo-Be greisen, stockwork, and quartz vein Zn-Pb(±Ag, Cu, W) skarn
Deposits related to alkaline intrusions	Albite syenite-related REE Alkaline complex-hosted Au Apatite carbonatite Charoite metasomatite Fe-REE carbonatite Fe-Ti (±Ta, Nb, Cu, apatite) carbonatite Magmatic and metasomatic apatite Magmatic graphite Magmatic nepheline Peralkaline granitoid-related Nb-Zr-REE Phlogopite carbonatite REE (±Ta, Nb, Fe) carbonatite Ta-Li ongonite

Table 3. List of lode mineral-deposit models employed for metallogenic and tectonic analysis of Northeast Asia.—Continued

[Adapted from Obolenskiy and others (2003, this volume)]

Group	Type
Deposits related to marine extrusive rocks	Besshi Cu-Zn-Ag massive sulfide Cyprus Cu-Zn massive sulfide Volcanogenic Cu-Zn massive sulfide (Urals type) Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) Volcanogenic-hydrothermal-sedimentary Pb-Zn (±Cu) massive sulfide Volcanogenic-sedimentary Fe Volcanogenic-sedimentary Mn
Deposits related to subaerial extrusive rocks	Ag-Pb epithermal vein Ag-Sb vein Au-Ag epithermal vein Au-K metasomatite (Kuranakh type) Barite vein Basaltic native Cu (Lake Superior type) Be tuff Carbonate-hosted As-Au metasomatite Carbonate-hosted fluorspar Carbonate-hosted Hg-Sb Clastic sediment-hosted Hg±Sb Epithermal quartz-alunite Fluorspar vein Hg-Sb-W vein and stockwork Hydrothermal Iceland spar Hydrothermal-sedimentary fluorite Limonite Mn vein Ni-Co arsenide vein Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite Rhyolite-hosted Sn Silica-carbonate (listvenite) Hg Sulfur-sulfide (S, FeS2) Trap related Fe skarn (Angara-Ilim type) Volcanic-hosted Au-base-metal metasomatite Volcanic-hosted Hg Volcanic-hosted U Volcanic-hosted zeolite
Deposits related to hydrothermal-sedimentary sedimentary processes	Bedded barite Carbonate-hosted Pb-Zn (Mississippi Valley type) Chemical-sedimentary Fe-Mn Evaporate halite Evaporate sedimentary gypsum Korean Pb-Zn massive sulfide Polygenic REE-Fe-Nb deposits (Bayan-Obo type) Sedimentary bauxite Sedimentary celestite Sedimentary exhalative Pb-Zn (SEDEX) Sedimentary Fe-siderite Sedimentary Fe-V Sedimentary phosphate Sediment-hosted Cu Stratiform Zr (Algama Type)

Table 3. List of lode mineral-deposit models employed for metallogenic and tectonic analysis of Northeast Asia.—Continued

[Adapted from Obolenskiy and others (2003, this volume)]

Group	Type
Deposits related to metamorphic processes	Au in black shale
	Au in shear zone and quartz vein
	Banded iron formation (Algoma type)
	Banded iron formation (Superior type)
	Clastic-sediment-hosted Sb-Au
	Cu-Ag vein
	Homestake Au
	Metamorphic graphite
	Metamorphic sillimanite
	Phlogopite skarn
	Piezoquartz
	Rhodusite-asbestos
	Sedimentary-metamorphic borate
	Sedimentary-metamorphic magnesite
	Talc (magnesite) replacement
Deposits related to surficial processes	Bauxite (karst type)
	Laterite Ni
	Placer and paleoplacer Au
	Placer diamond
	Placer PGE
	Placer Sn
	Placer Ti-Zr
	REE and Fe oolite
	Weathering crust and karst phosphate
	Weathering crust Mn (±Fe)
	Weathering crust REE-Zr-Nb-Li carbonatite
Exotic deposits	Impact diamond

Chapter 3

Mineral-Deposit Models for Northeast Asia

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Introduction

Metalliferous and selected nonmetalliferous lode and placer deposits of Northeast Asia (Eastern Russia, Mongolia, northern China, South Korea, and Japan) are herein classified into various models or types because of the complex array of mineral-deposit models in the region that are not fully described in the current literature. The mineral-deposit models used in this chapter are based on both descriptive and genetic information that is systematically arranged to describe the essential properties of a given class of deposits. Some types are descriptive whereby the various attributes are recognized as essential even though their relations are unknown, for example basaltic Cu in which the empirical datum of a geologic association of Cu sulfides with relatively Cu rich metabasalt or greenstone is the essential attribute; other types are genetic (theoretical) whereby attributes are related through some fundamental concept, for example W skarn in which the process of contact metasomatism is the genetic attribute. For additional information on the methodology of mineral-deposit models, see the discussions by Eckstrand (1984) and Cox and Singer (1986).

We use three main principles are utilized for classifying mineral deposits: (1) ore-forming processes are closely related to rock-forming processes, and mineral deposits originate as a result of mineral mass differentiation under their constant circulation in sedimentary, magmatic, and metamorphic cycles of the formation of rocks and geologic structures; (2) the classification must be understandable for the user; and (3) the classification must be open, so that new mineral deposit types can be added in the future.

The mineral-deposit models used in this volume are subdivided into four large groups according to major geologic rock-forming processes: (1) deposits related to magmatic processes; (2) deposits related to hydrothermal-sedimentary processes; (3) deposits related to metamorphic processes; and (4) deposits related to surficial processes. A separate group of exotic ore-forming processes is also defined. Each group includes several classes; for example, the group of deposits related to magmatic processes includes two classes: (1) those related to intrusive rocks; and (2) those related to extrusive rocks. The most detailed subdivisions are for deposits related to magmatic processes because they are the most abundant in the region. In this classification, lode deposit models that share a similar origin, such as magnesian and (or) calcic skarn or porphyry deposits, are grouped together under a single genus with several types (or species) within the genus.

This chaper was prepared by a large group of Russian, Chinese, Mongolian, South Korean, Japanese, and U.S. geologists who are members of a joint international project on Major Mineral Deposits, Metallogenesis, and Tectonics of Northeast Asia conducted by the Russian Academy of Sciences, the Mongolian Academy of Sciences, the Mongolian

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National University, the Mongolian Technical University, the Mineral Resources Authority of Mongolia, the Geological Research Institute, Jilin University, the China Geological Survey, the Korea Institute of Geoscience and Mineral Resources, the Geological Survey of Japan, and the U.S. Geological Survey. More information about major goals and all publications produced by the project is contained in the introduction to this volume (see chap. 1). The major publications for this project are: (1) a compilation of significant metalliferous and selected nonmetalliferous lode deposits and selected placer districts in Northeast Asia (Ariunbileg and others, 2003); (2) a series of mineral-deposit location and metallogenic-belt maps of Northeast Asia (Obolenskiy and others, 2003a,b, 2004; Nokleberg and others, 2004); (3) a description of the metallogenic belts in Northeast Asia (Rodionov and others, 2004); and (4) a Geographic Information Systems (GIS) spatial data compilation of all these maps, descriptions, and databases (Naumova and others, 2006). A summary of the major publications of this project is posted on the World WideWeb at URL: http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.doc and provided in Appendix A.

Classification of Mineral Deposits

Three main principles are utilized for classifying mineral deposits in this study: (1) ore-forming processes are closely related to rock forming processes (Obruchev, 1928), and so mineral deposits originate as thae result of mineral mass differentiation under their constant circulation in sedimentary, magmatic, and metamorphic cycles of formation of rocks and geological structures (Smirnov, 1969); (2) the classification must be understandable for the user; and (3) the classification must be open, so that new mineral-deposit types can be added in the future (Cox and Singer, 1986).

The classification below is a further development of the mineral deposit classifications by Smirnov (1969), Eckstrand (1984), Cox and Singer (1986), Kirkham (1993), and Nokleberg and others (1997). In Smirnov (1969)'s classification, the mineral deposits are grouped into six hierarchical levels of metallogenic taxons, according to such stable features as: (1) environment of formation of host and genetically-related rocks, (2) genetic features of the deposit, and (3) mineral and (or) elemental composition of the ore. The six hierarchical levels are as follows.

1. Group of deposits.
2. Class of deposits.
3. Clan of deposits.
4. Family of deposits.
5. Genus of deposits.
6. The deposit types (models).

A hierarchial ranking of mineral deposit models according to these levels is listed in table 1; for simplicity, this classification in this table omits the family and genus levels.

The mineral-deposit models used in this volume (table 1) are subdivided into four groups, according to major geologic rock-forming processes: (1) deposits related to magmatic processes; (2) deposits related to hydrothermal-sedimentary processes; (3) deposits related to metamorphic processes; and (4) deposits related to surficial processes. A separate group of exotic ore-forming processes is also defined. Each group includes several classes. For example, the group of deposits related to magmatic processes includes two classes: (1) those related to intrusive rocks; and (2) those related to extrusive rocks; each class includes several clans and so on. The most detailed subdivisions are for deposits related to magmatic processes because they are the most abundant type in the region. In the classification below, lode deposit types that share a similar origin, such as magnesian and (or) calcic skarn, or porphyry deposits, are grouped together under a single genus with several types (or species) within the genus.

Some of the mineral-deposit models below differ from the published descriptions; for example, the Bayan Obo deposit was described previously as carbonatite-related. However, modern isotopic, mineralogic, and geologic data recently obtained by Chinese geologists have resulted in a new interpretation of the origin of this deposit. These new data indicate that the Bayan Obo deposit consists of minerals which formed during Mesoproterozoic sedimentary-exhalative (*SEDEX*) processes, along with coeval metasomatic activity, and sedimentary diagenesis of dolomite, and alteration. The SEDEX process consisted of both sedimentation and metasomatism. Later deformation, especially during the Caledonian orogeny, further enriched the ore. Thus, the Bayan Obo mineral-deposit type is herein described as related to SEDEX processes, not to magmatic processes, although magmatic processes also played an important role in deposit formation. Consequently, this deposit model is part of the family of polygenetic carbonate-hosted deposits. Similar revisions were made for carbonate-hosted Hg-Sb and other mineral-deposit models.

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text.

- Deposits related to magmatic processes
  - Deposits related to intrusive magmatic rocks
    - I. Deposits related to mafic and ultramafic intrusions
      - A. Deposits associated with rift related differentiated mafic-ultramafic complexes
        - Mafic-ultramafic-related Cu-Ni-PGE
        - Mafic-ultramafic-related Ti-Fe(±V)
        - Zoned mafic-ultramafic Cr-PGE
      - B. Deposits associated with ophiolitic complexes
        - Podiform chromite
        - Serpentinite-hosted asbestos
      - C. Deposits associated with anorthosite complexes
        - Anorthosite Ti-Fe-P-apatite
      - D. Deposits associated with kimberlite
        - Diamond-bearing kimberlite
    - II. Deposits related to intermediate-composition and felsic intrusions
      - A. Pegmatite
        - Muscovite pegmatite
        - REE-Li pegmatite
      - B. Greisen and quartz vein
        - Fluorite greisen
        - Sn-W greisen, stockwork, and quartz vein
        - W-Mo-Be greisen, stockwork, and quartz vein
      - C. Alkaline metasomatite
        - Ta-Nb-REE alkaline metasomatite
      - D. Skarn (contact metasomatic)
        - Au skarn
        - B (datolite) skarn
        - Carbonate-hosted asbestos
        - Co skarn
        - Cu(±Fe, Au, Ag, Mo) skarn
        - Fe skarn
        - Fe-Zn skarn
        - Sn skarn
        - Sn-B (Fe) skarn (ludwigite)
        - W±Mo±Be skarn
        - Zn-Pb(±Ag, Cu, W) skarn
      - E. Porphyry and granitoid pluton-hosted deposit
        - Cassiterite-sulfide-silicate vein and stockwork
        - Felsic plutonic U-REE
        - Granitoid-related Au vein
        - Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork
        - Porphyry Au
        - Porphyry Cu(±Au)
        - Porphyry Cu-Mo(±Au, Ag)
        - Porphyry Mo(±W, Bi)
        - Porphyry Sn

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text. —Continued

III. Deposits related to alkaline intrusions
- A. Carbonatite-related deposits
  - Apatite carbonatite
  - Fe-REE carbonatite
  - Fe-Ti(±Ta, Nb, Cu, apatite) carbonatite
  - Phlogopite carbonatite
  - REE (±Ta, Nb, Fe) carbonatite
- B. Alkaline-silicic intrusion-related deposits
  - Alkaline complex-hosted Au
  - Peralkaline granitoid-related Nb-Zr-REE
  - Albite syenite-related REE
  - Ta-Li ongonite
- C. Alkaline-gabbroic intrusion-related deposits
  - Charoite metasomatite
  - Magmatic and metasomatic apatite
  - Magmatic graphite
  - Magmatic nepheline

Deposits related to extrusive rocks

IV. Deposits related to marine extrusive rocks
- A. Massive sulfide deposits
  - Besshi Cu-Zn-Ag massive sulfide
  - Cyprus Cu-Zn massive sulfide
  - Volcanogenic Cu-Zn massive sulfide (Urals type)
  - Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types)
- B. Volcanogenic-sedimentary deposits
  - Volcanogenic-hydrothermal-sedimentary Pb-Zn (±Cu) massive sulfide
  - Volcanogenic-sedimentary Fe
  - Volcanogenic-sedimentary Mn

V. Deposits related to subaerial extrusive rocks
- A. Deposits associated with mafic extrusive rocks and dike complexes
  - Ag-Sb vein
  - Basaltic native Cu (Lake Superior type)
  - Hg-Sb-W vein and stockwork
  - Hydrothermal Iceland spar
  - Ni-Co arsenide vein
  - Silica-carbonate (listvinite) Hg
  - Trapp-related Fe skarn (Angara-Ilim type)
- B. Deposits associated with felsic to intermediate-composition extrusive rocks
  - Au-Ag epithermal vein

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text. —Continued

			Ag-Pb epithermal vein
			Au K metasomatite (Kuranakh type)
			Barite vein
			Be tuff
			Carbonate-hosted As-Au metasomatite
			Carbonate-hosted fluorspar
			Carbonate-hosted Hg-Sb
			Clastic-sediment-hosted Hg±Sb
			Epithermal quartz-alunite
			Fluorspar vein
			Hydrothermal-sedimentary fluorite
			Limonite
			Mn vein
			Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite
			Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite
			Rhyolite-hosted Sn
			Sulfur-sulfide (S, FeS_2)
			Volcanic-hosted Au-base-metal metasomatite
			Volcanic-hosted Hg
			Volcanic-hosted U
			Volcanic-hosted zeolite
Deposits related to hydrothermal-sedimentary processes			
	VI. Stratiform and stratabound deposits		
		Bedded barite	
		Carbonate-hosted Pb-Zn (Mississippi Valley type)	
		Sediment-hosted Cu	
		Sedimentary exhalative (SEDEX) Pb-Zn	
		Korean Pb-Zn massive sulfide	
	VII. Sedimentary rock-hosted deposits		
		Chemical-sedimentary Fe-Mn	
		Evaporate halite	
		Evaporate sedimentary gypsum	
		Sedimentary bauxite	
		Sedimentary celestite	
		Sedimentary phosphate	
		Sedimentary Fe-V	
		Sedimentary Fe-siderite	
		Stratiform Zr (Algama type)	
	VIII. Polygenic carbonate-hosted deposits		
		Polygenic REE-Fe-Nb (Bayan-Obo type)	
Deposits related to metamorphic processes			

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text. —Continued

	IX. Sedimentary-metamorphic deposits	
		Banded iron-formation (Algoma type)
		Banded iron-formation (Superior type)
		Homestake Au
		Sedimentary-metamorphic borate
		Sedimentary-metamorphic magnesite
	X. Deposits related to regionally metamorphosed rocks	
		Au in black shale
		Au in shear zone and quartz vein
		Clastic-sediment-hosted Sb-Au
		Cu-Ag vein
		Piezoquartz
		Rhodusite-asbestos
		Talc (magnesite) replacement
		Metamorphic graphite
		Metamorphic sillimanite
		Phlogopite skarn
Deposits related to surficial proceses		
	XI. Residual deposts	
		Bauxite (karst type)
		Laterite Ni
		Weathering-crust Mn (±Fe)
		Weathering-crust and karst phosphate
		Weathering-crust REE-Zr-Nb-Li carbonatite
	XII. The depositional deposits	
		Placer and paleoplacer Au
		Placer diamond
		Placer PGE
		Placer Sn
		Placer Ti-Zr
Exotic deposits		
	Impact diamond	

Deposits Related to Intrusive Magmatic Rocks

I. Deposits Related to Mafic and Ultramafic Intrusions

A. Deposits Associated with Rift-related Differentiated Mafic-Ultramafic Complexes

Mafic-Ultramafic-Related Cu-Ni-PGE (Eckstrand, 1984; Page, 1986c; Dyuzhikov and others, 1988)

Mafic-ultramafic-related Cu-Ni-PGE deposits consist of magmatic Cu-Ni sulfide deposits in differentiated layered mafic-ultramafic intrusions that generally occur in a cratonic setting commonly in association with intracontinental rifts and flood basalts. Mafic and ultramafic phases of layered intrusive complexes include peridotite, pyroxenite, gabbro, norite, picrite, troctolite, gabbro, and diabase. The deposits may occur either in the footwall below the main intrusion or near the bottom of the intrusion. Conformable layers or lenses commonly occur in a local depression or embayment, at or near the base of the host intrusion. Minerals are massive sulfides, sulfide-matrix breccias, interstitial sulfide networks, and disseminated sulfides. In well-preserved deposits, the rich areas of deposit minerals occur close to the base, and are overlain by sparse disseminated sulfides. Sulfide veins and dissemination commonly penetrate footwallrocks. Minerals are complex, contain Ni and Cu along with PGE, Co, Se, Te, and Au, and include pentlandite, chalcopyrite, cubanite, millerite, pyrrhotite, various PGE minerals, pyrite, sphalerite, and marcasite in association with plagioclase, hypersthene, augite, olivine, hornblende, biotite, quartz, and a variety of alteration minerals. The main deposit minerals are syngenetic with the host intrusions. The depositional environment consisted of emplacement of multiple ore-bearing mafic magmas (probably mantle derived) in upper-crustal levels in tensional environments associated with rifting. Contamination of the magma was an important factor for sulfur saturation and formation of a sulfide phase. Examples of this mineral-deposit type are Norilsk I and II (fig. 1) and Talnakh, Russia; and Hongqiling, Jilin Province, China, Kalatongke; and Xinjiang, China.

Mafic-Ultramafic Related Ti-Fe (±V) (Lee and others, 1965; Eckstrand, 1984; Page, 1986a; Sinyakov, 1988)

Mafic-ultramafic related Ti-Fe (+V) deposits consist of layers and lenses, and disseminated titanomagnetite or V-magnetite, with minor amount of ilmenite and chromite, in differentiated gabbroic intrusions. Host rocks are mainly

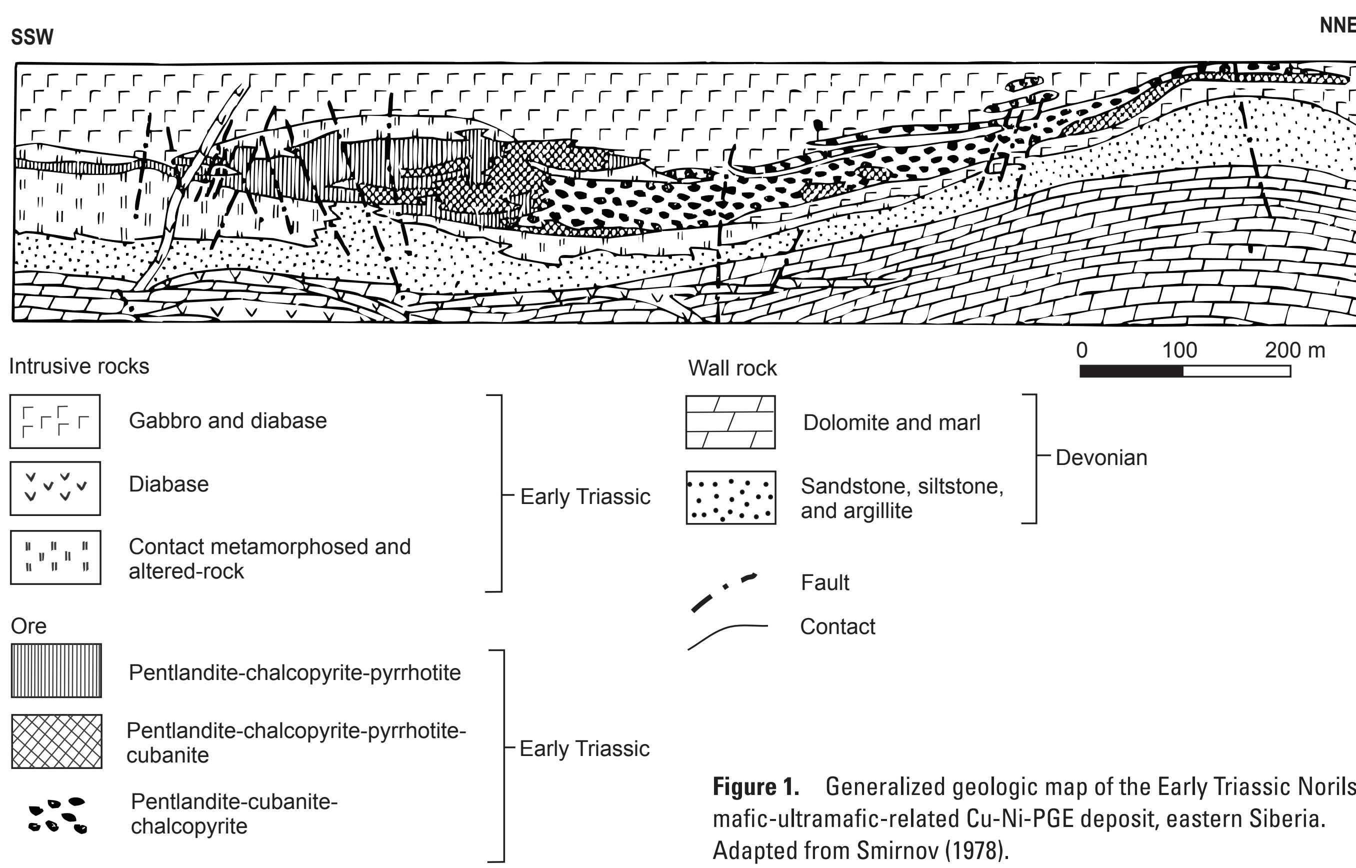


Figure 1. Generalized geologic map of the Early Triassic Norilsk mafic-ultramafic-related Cu-Ni-PGE deposit, eastern Siberia. Adapted from Smirnov (1978).

norite, gabbronorite, dunite, harzburgite, peridotite, pyroxenite, troctolite, anorthosite, gabbro, and diabase. The deposit minerals occur near the tops of intrusions as stratiform or irregular bodies consisting of disseminated and interstitial Fe-Ti-V oxide minerals. Pipes and ilmenite-rich veins may cut layers. Massive ore is generally more important economically than disseminated ore. The principal ore minerals are titanomagnetite and (or) V-magnetite; asociated minerals are ilmenite, hematite, spinel, and sulfides (pyrite, pyrrhotite, chalcopyrite). Rock-forming minerals are plagioclase, olivine, pyroxene, apatite, and sphene, as well as Fe-Ti oxide phases that formed by crystal settling or filter pressing during crystallization of anorthosite or gabbro magmas, thereby forming syngenetic layers and segregations, as well as massive oxide autointrusions in partially solidified gabbro and genetically related host rocks. The depositional environment consisted of intrusions of gabbro-anorthosite, dunite-pyroxenite-gabbroic and gabbro-diabasic magmatic associations with magmatic layering of host intrusions. Mafic-ultramafic rocks commonly intrude granitic gneiss, or volcanic-sedimentary rocks. An association exists between the ore-bearing, layered plutons and deep-fault zones. The deposits are generally Precambrian but may be as young as Tertiary. Locally, the Precambrian deposits may be highly metamorphosed with occurrence of deposits in hornblende schist as at the Soyonpyong deposit on the Korean Peninsula, where the depositional environment consisted of stratiform to irregular mafic to ultramafic plutons in continental margin or island arcs. Examples of this mineral-deposit type are Kavakta (fig. 2) and Lysanskoye, Russia, and Damiao, Hebei Province, China.

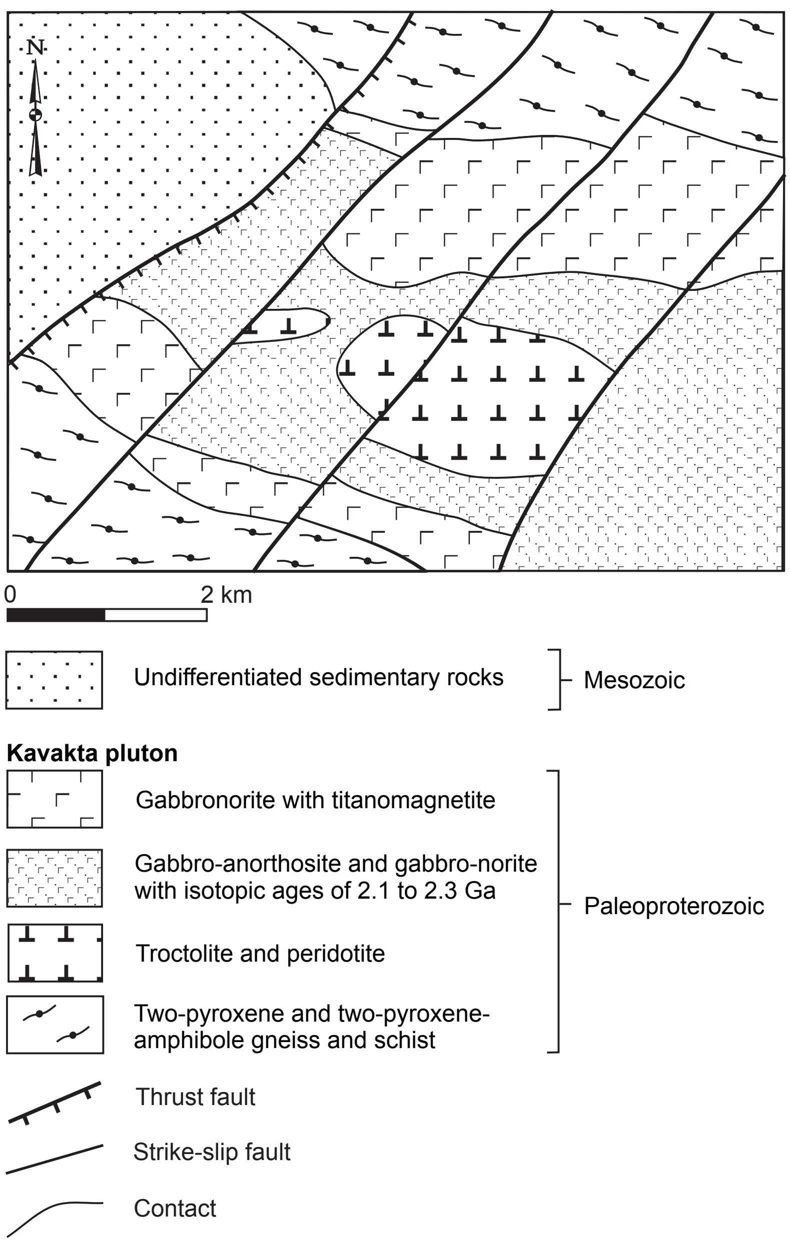


Figure 2. Generalized geologic map of the Paleoproterozoic Kavakta mafic-ultramafic related Ti-Fe(V) deposit, Yakutia, Russia. Adapted from Stogniy (1998).

Zoned Mafic-Ultramafic Cr-PGE (Page and Gray, 1986; Kosygin and Prikhod'ko, 1994; Malich, 1999)

Zoned mafic-ultramafic Cr-PGE deposits consist of zoned ultramafic to mafic plutons containing Cr and PGE minerals. The central part of the pluton is generally composed of dunite and the peripheral parts consist of pyroxenite, koswite, and rare gabbro. The zoned plutons are commonly intruded by sills and dikes of gabbro, diorite, monzonite, and various alkaline rocks. The mafic and ultramafic rocks composing the pluton, as well as the host metamorphosed sedimentary-calcareous rocks, may be locally altered to feldspar-pyroxene metasomatite and skarn. The deposit minerals in the zoned plutons are chromite, native PGE, various PGE minerals and alloys, and Ti-V-magnetite, with local accessory pentlandite, pyrrhotite, bornite, and chalcopyrite. The deposit minerals generally occur in dunite in the top-central part of the pluton. Small to large (up to 3 kg and more) platinum nuggets may occur in peripheral placer deposits. The depositional environment consisted of zoned mafic to ultramafic plutons that formed the lower parts of island-arc or continental margin arc systems. An example of this mineral-deposit type is at Kondyor, Russia (fig. 3).

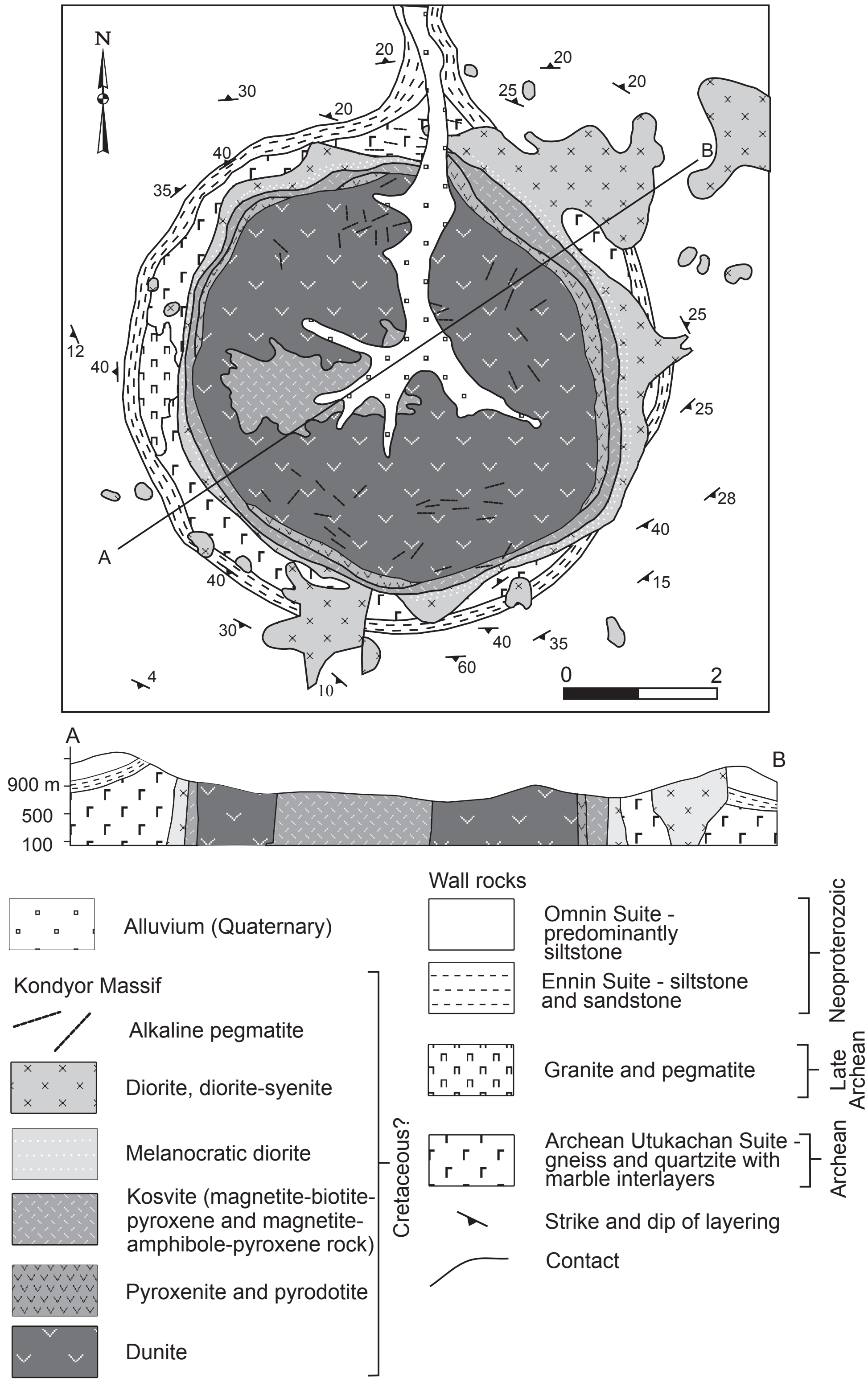


Figure 3. Generalized geologic map of the Early Cretaceous Kondyor zoned mafic-ultramafic Cr-PGE deposit, Russian Southeast. Adapted from G.V. Andreev, A.A. El'yanov, and A.N. Mil'to, written commun., 1974).

B. Deposits Associated with Ophiolitic Complexes

Podiform Chromite (Eckstrand, 1984; Albers, 1986)

Podiform chromite deposits consist of pods or lenses of chromite in the ultramafic parts of ophiolite complexes (alpine peridotites) that may locally be intensely faulted and dismembered. The host rocks are mainly dunite and harzburgite, commonly serpentinized, with local troctolite. The principal ore mineral is chromite with associated olivine, pyroxene, serpentine, magnetite, clinopyroxene, and plagioclase, as well as magnetite and PGE minerals and alloys. The deposits generally consist of lenticular bodies of massive to heavily disseminated chromite.; tabular, rod-shaped and irregular bodies may also occur. Nodular textures and foliation and banding are common. A specific deposit may consist of several individual pods, commonly in linear zones or, in some places, in echelon arrays. The depositional environment consisted of magmatic cumulates in elongate magma pockets along oceanic ridges or the basal parts of island arcs. Examples of this mineral-deposit type are Khalzan uul and Sulinheer group, Mongolia;, Hegenshan 3756, Inner Mongolia, China; and Ganbi, Japan.

Serpentinite-Hosted Asbestos (Cho and others, 1970; Zolojev, 1975; Eckstrand, 1984; Page, 1986b)

Serpentinite-hosted asbestos deposits consist of chrysotile developed in stockworks in serpentinized olivine-rich ultramafic rocks that consist mainly of harzburgite, dunite, wehrlite, and pyroxenite. The serpentinized ultramafic rocks may be locally intruded by pegmatite dikes, as in the central Korean Peninsula. Associated minerals are magnetite, brucite, talc, and tremolite. The major deposits occur in allochthonous bodies of serpentinized ophiolitic or alpine ultramafic rocks in Phanerozoic orogenic belts. The depositional environment consisted of ultramafic rocks that form the basal part of ophiolite sequences obducted onto a continental margin, or parts of a subduction-zone complex. Examples of this mineral-deposit type are Molodezhnoye and Sayanskoye, Russia, and Ikh nart, Mongolia.

C. Deposits Associated with Anorthosite Complexes

Anorthosite Ti-Fe-P-Apatite (Sang and Shin, 1981; Kosygin and Kulish, 1984; Force, 1986a; Jeong and others, 1998)

Anorthosite Ti-Fe-P-apatite deposits occur in anorthosite plutons composed of andesine and andesine-labradorite. The anorthosite plutons are highly alkalic and are associated with gabbro, ferrodiorite, syenite, alkalic granite, and, in some places, mangerite. The plutons generally intrude granulite-facies country rocks. Principal deposit minerals are apatite, titanomagnetite, and ilmenite that occur either: (1) as disseminations near melanocratic gabbro, pyroxenite, and dunite along the margins of the anorthosite pluton; or (2) as rich apatite (nelsonite) veins in tectonically weak zones; lesser associated minerals are ilmenite and magnetite. The depositional environment consisted of intrusion into the basal part of a continental crust or craton under hot, dry conditions. Examples of this mineral-deposit type are Dzhaninskoe, Gayumskoe, and Maimakanskoe, Russia.

D. Deposits Associated with Kimberlite

Diamond-Bearing Kimberlite (Zhang and Xu, 1995; Khar'kiv and others, 1997)

Diamond-bearing kimberlite deposits consist of pipes and dikes made of kimberlite breccia. The deposits occur mostly near secondary branches of giant, deep, long, extensional faults in a stable craton, for example, the Tanlu Fault belt in the eastern part of the North China platform. The pipes are rounded or elongated with diameters of few hundred meters. In the North Asian craton, the kimberlite pipes range in age from Devonian through early Tertiary. Within a few hundred meters of the surface, the pipe is commonly funnel-shaped, and at greater depths (down to about 1,500 m), is cylindrical, and at still greater depths may have the shape of a feeder dike. The kimberlite dikes generally range from 0.3 to 20 m wide, are 100 to 800 m long and several hundred meters long downdip. Most kimberlites are concentrated in fields, generally less than 1 ha in area and from several kilometers to 20 km apart. The kimberlite breccia consists of fragments of sedimentary cover rocks, including limestone, sandstone, shale, schist, granulite, and gneiss that are parts of Precambrian cratonal basement, as well as dunite, garnet lherzolite, garnet saxonite, picotite lherzolite, massive phlogopite, diamond–bearing ultramafic rocks, eclogite, spinel-rich and spinel-free ultramafic rocks, and pyroxenite. The ultramafic and associated rocks are interpreted as mantle derived. Inclusions of Phanerozoic sedimentary cover and cratonal basement rocks are abundant at the margins of kimberlite pipes and dikes which commonly contain inclusions of mantle-derived minerals that range from 1 to 10 cm across, including Cr-pyrope and picotite. The breccia is cemented by tuff with xenocrysts of altered olivine (group I), pyrope, picroilmenite, Cr spinel, Cr diopside, and rare large (maximum 2 cm) diameter) grains of gem-quality zircon. The minerals are embedded in a carbonate-serpentine matrix including olivine II, picroilmenite II, Cr-spinel II, phlogopite, and perovskite. Secondary minerals, such as serpentine, carbonate, and chlorite, compose the bulk of the kimberlite in both the upper and lower parts of pipes; rare minerals are Cr-diopside, picrotanite, morssanite, rutile, oysanite, and zircon. Kimberlite intrudes under hypabyssal conditions, as indicated by typically massive structures and pseudomorphs of coarse olivine crystals scattered in a fine-grained matrix of phlogopite, serpentine, calcite, and perovskite. Only parts of kimberlite pipes and dikes contain industrial diamonds. Indicator minerals for diamond in kimberlite are Cr-diopside and picotite and associated diamond placer deposits. The depositional environment consisted of kimberlite magma interpreted as forming during deep-level subduction of oceanic crust and mantle metasomatism in cratonal regions. The kimberlite magmas are erupted along various shear-fault systems to near-surface levels during uplift of the craton; subsequent younger uplift resulted in the erosion of the kimberlite and exposure of the root systems, including pipes and dikes. Examples of this mineral-deposit type are Ingashinskoye, Mir (fig. 4), and Yubileinaya, Russia.

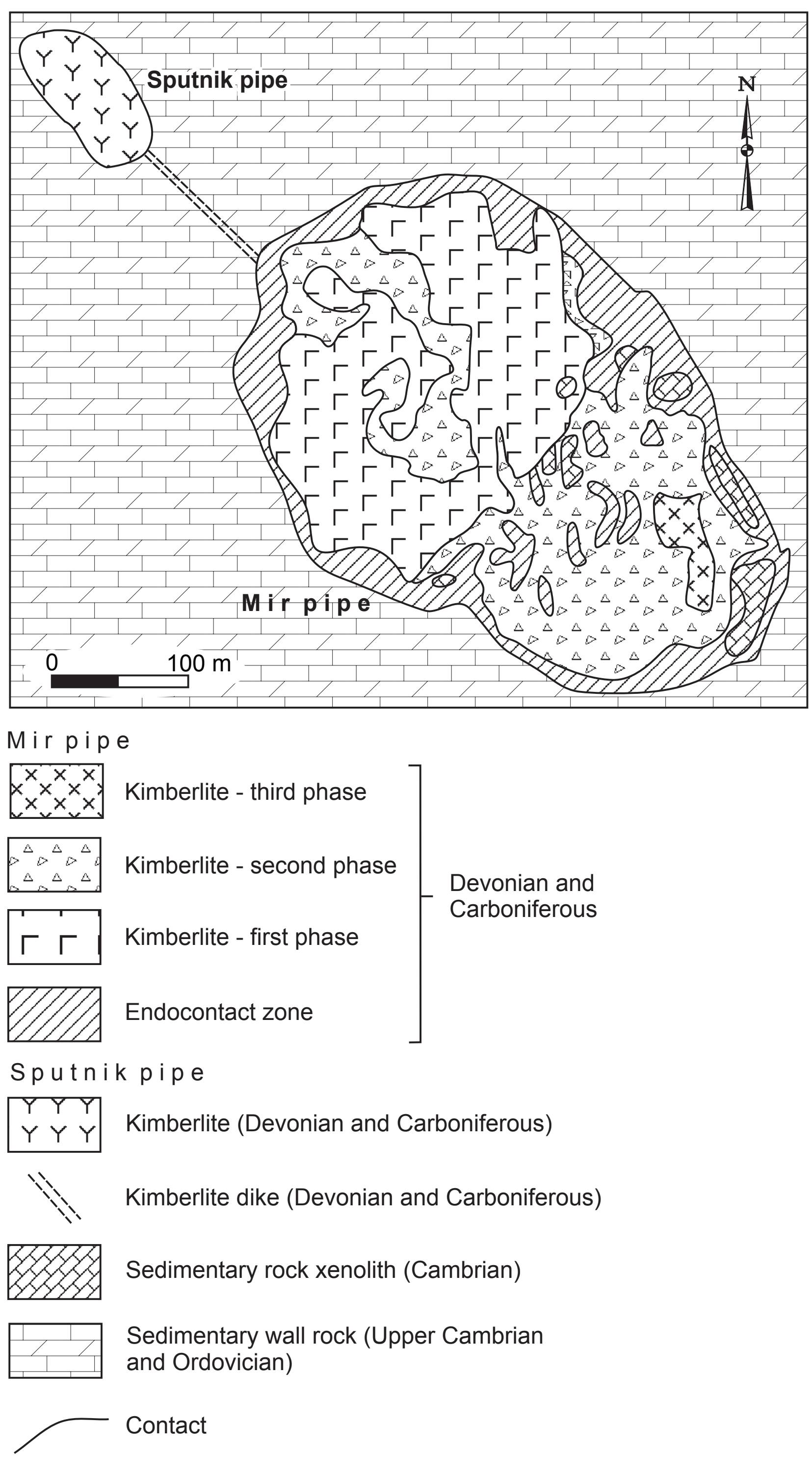


Figure 4. Generalized geologic map of the Devonian through Carboniferous Mir diamond-bearing kimberlite deposit, Yakutia, Russia. Adapted from Khar'kiv, Zinchuk, and Zuev (1997).

II. Deposits Related to Intermediate-Composition and Felsic Intrusions

A. Pegmatite

Muscovite Pegmatite (Sokolov, 1970; Chesnokov, 1975; Vasil'eva, 1983)

Muscovite pegmatite deposits consist of pegmatite veins containing high-quality foliated muscovite that occurs in schist that is metamorphosed to amphibolite facies. Pegmatite veins are generally concentrated in apical parts of large granite-migmatite domes and are mainly confined to horizons of Al-silicate rocks (for example, biotite-muscovite granite gneiss, two-mica schist). Groups or fields of pegmatite veins may be hosted in the hinge areas of anticlines and flexures in schist that are multiply deformed. The shape of the deposits is diverse, and crosscutting dikes with numerous tongues are dominant. The pegmatite minerals are plagioclase (oligoclase, oligoclase-andesine), microcline-perthite, quartz, biotite, muscovite, tourmaline, and rare beryl and almandine garnet. Veins with plagioclase, plagioclase-microcline, and microcline are dominant. High-grade muscovite typically occurs in quartz masses that contain corroded feldspar crystals. The depositional environment consisted of pegmatite fields in regional metamorphic and granitic belts that occur along the periphery of ancient cratons. Many muscovite pegmatite fields, some with REE minerals (including allanite, apatite, bastnaesite, cerite, fluorite, monazite, titanite, tourmaline, topaz, xenotime, and zircon) occur in some pegmatite belts and may extend for several hundred kilometers. Examples of this mineral-deposit type are Chuyskoye, Lugovka, Mamsko-Chuiskiy (fig. 5), Sogdiondonskoye, and Vitimskoye, Russia.

REE-Li Pegmatite (Lee, 1959; Kovalenko and Koval, 1984; Kim, and Park, 1986; Rundqvist, 1986; Zagorskiy and others, 1997; Lin and others, 1994)

REE-Li pegmatite deposits consist of two subtypes. The first subtype consists of REE spodumene granite pegmatite that is mainly associated with two-mica granite. The pegmatite deposits generally occur along the exocontact zones of granitic intrusions, generally within 1 to 3 km of contacts and intrude metamorphosed carbonaceous and clastic rocks. Pegmatite bodies are commonly clustered in elongate belts along regional faults. Many pegmatite veins occur along feather joints. Two morphologic types of pegmatite bodies are defined: (1) elongate and persistent veins and vein systems that occur at depth; and (2) single and small vein-shaped bodies. Major minerals are albite, oligoclase, spodumene, quartz, microcline, muscovite, beryl, helvite, columbite-tantalite, fluorite, tourmaline, cassiterite, and zircon; lesser minerals are various sulfides, including pyrite, molybdenite, and galena. The major REE minerals include allanite, apatite, bastnaesite, cerite, fluorite, monazite, titanite, tourmaline, topaz, xenotime, and zircon. The principal metal is Li along with associated Ta, Nb, Sn, Be, Mo, and W. Mineral zonation is typical in large pegmatite bodies. The Keketuohai pegmatite No. 3 (Xinjiang Province, China) consists of a large cupola-like body that is about 250 m long, 150 m wide, and 250 m high.

The second subtype consists of REE pegmatite that is mainly associated with calc-alkaline, Li-F leucocratic granite. Three varieties are defined: (1) Li-mica pegmatite; (2) muscovite (muscovite-albite) pegmatite; and (3) muscovite-microcline pegmatite. The first two varieties are Ta bearing, and the third contains cassiterite and wolframite. Li-mica pegmatite contains Ta-Nb minerals, cassiterite, Li-mica, quartz, albite, microcline, apatite, tourmaline, topaz, and

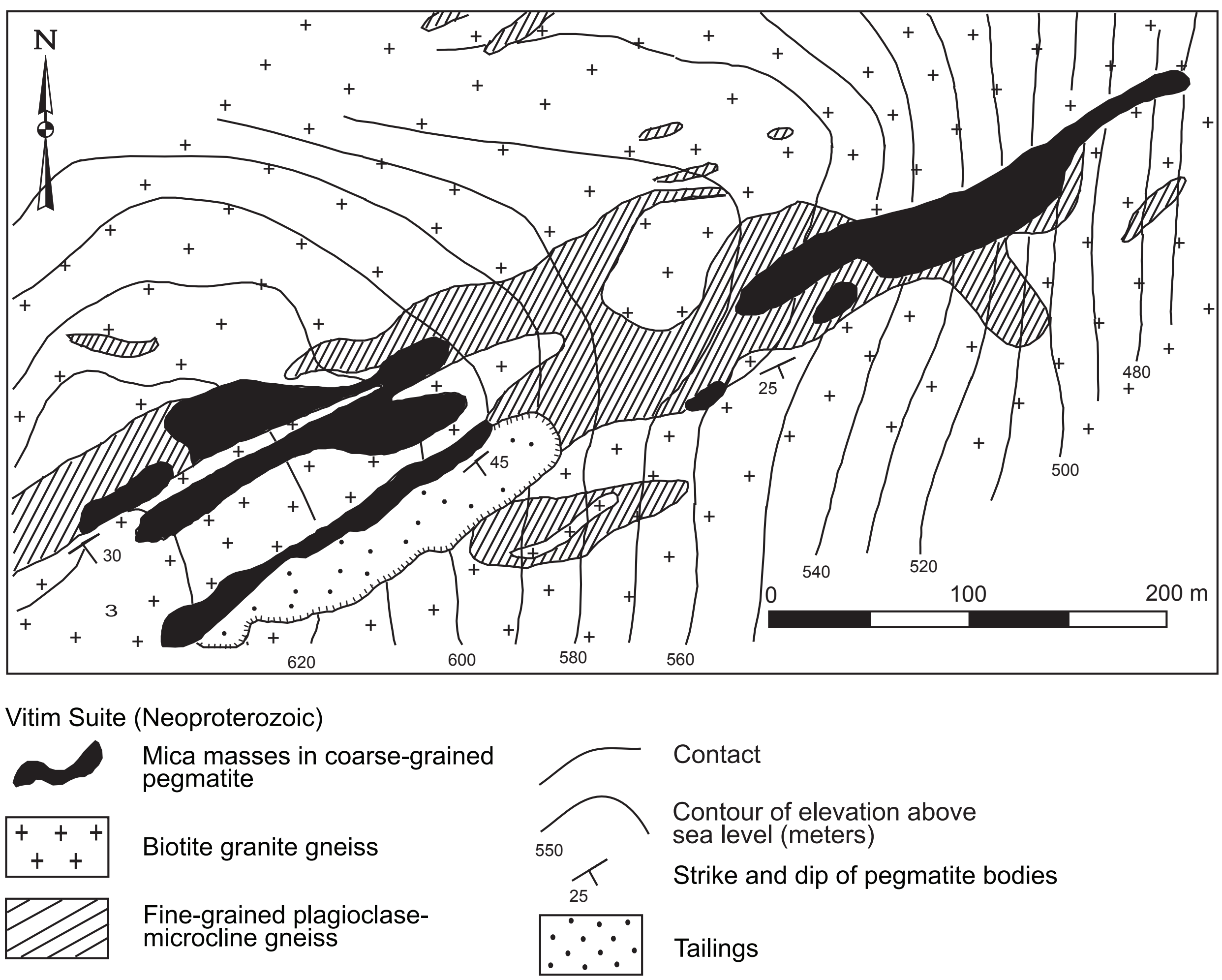


Figure 5. Generalized geologic map of the Devonian through Early Carboniferous Mamsko-Chuiskiy muscovite pegmatite deposit, TransBaikal, Russia. Adapted from Markov (1937).

beryl; and muscovite-albite pegmatite contains columbite, tantalite, quartz, albite, microcline, and muscovite. Muscovite-microcline pegmatite includes cassiterite, wolframite, quartz, microcline, and muscovite. REE-Li pegmatite deposits form dikelike or lenticular bodies that range from a few meters to hundreds of meters in length, and from 1 to 10 m width. Associated Li-Sn-Be pegmatite contains Li-mica, and Ta and Sn-W minerals. The depositional environment consisted of REE-Li pegmatite and associated granitic rocks in postaccretionary intrusions that postdate the peak of batholith emplacement. Associated granite is mainly calc-alkaline and Li-F leucogranite and related, coeval volcanic and subvolcanic rocks. Examples of this mineral-deposit type are Vishnyakovskoye, Russia; and Keketuohai (fig. 6), Kelumute, and Xinjiang, China.

B. Greisen and Quartz Vein

Fluorite Greisen (Govorov, 1977)

Fluorite greisen deposits consist of fine-grained, dark-violet rocks composed of fluorite (from 63 to 66 volume percent) and micaceous minerals, mainly muscovite (25 to 35 volume percent), along with lesser ephesite and phlogopite; subordinate minerals are (in decreasing order) tourmaline, sellaite, cassiterite, topaz, sulfides, and quartz. The deposits generally occur in veins in gneiss (as on the Korean Peninsula), or in limestone or marble (as in the Khanka area, Russian Southeast). The veins in limestone or marble occur concordant to limestone layers, and form lenticular and

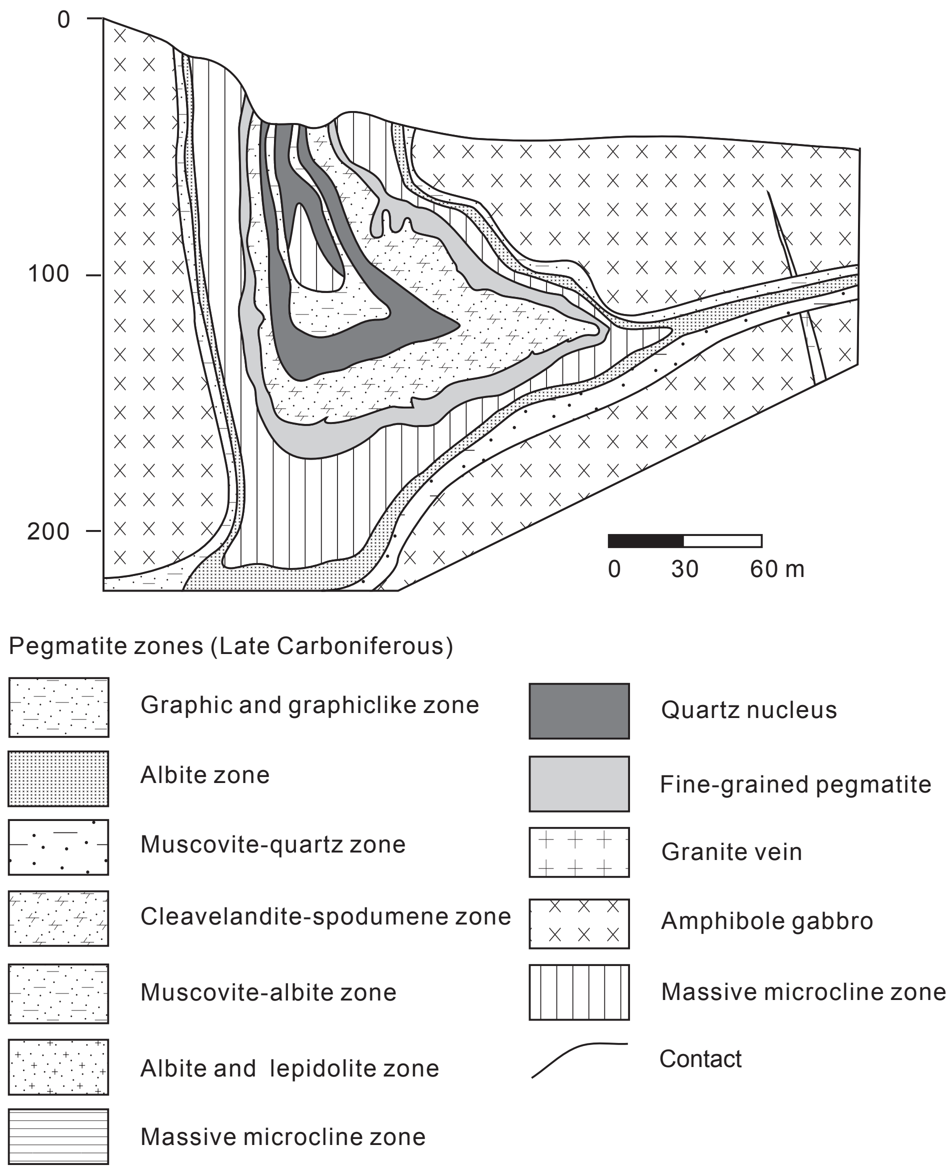


Figure 6. Generalized geologic map of the Late Carboniferous Altay REE-Li-pegmatite Kehketuohai deposit, northern China. Adapted from Lin and others (1994).

flame-shaped bodies of apocarbonate greisen that occurs in limestone intruded by Li-F, S-type granite. Metasomatic rocks replacing limestone occur at and above contacts with granitic intrusions. Muscovite-quartz pegmatite veins containing molybdenite-cassiterite-diopside, vesuvianite-diopside-andradite, and scapolite skarn also occur near intrusive contacts; these veins are interpreted as having formed before fluorite-mica greisen. B isotopic analysis of tourmaline indicates a primary evaporite source (V.V. Ratkin, written commun., 1994), suggesting that deep-seated evaporites in zones of granitic magma generation were the source of fluorine. Alternatively, some fluorine may be derived from the volatile phase of granitic magma. Scarce quartz and the absence of paragenetic calcite suggest an extremely high fluorine activity in silica-poor solutions. The depositional environment consisted of thick clastic limestone sequences or carbonate gneiss in cratonal or continental-margin terranes that were intruded by continental-margin-arc plutonic rocks. Examples of this mineral-deposit type are Preobrazhenovskoye and Voznesenka-II (fig. 7), Russia.

Sn-W Greisen, Stockwork, and Quartz Vein (Rodionov and others, 1984; Reed, 1986b)

Sn-W greisen, stockwork, and quartz vein deposits consist of disseminated cassiterite, cassiterite- and wolframite-bearing veinlets in stockworks, lenses, pipes, and breccia in granite that has been altered to greisen. The granite is mainly biotite and (or) muscovite leucogranite emplaced in mesozonal to epizonal environments. The deposits are commonly associated with cupolas and domes of silicic and ultra-silicic, F-enriched rocks of late-stage, fractionated granitic magmas. The deposits generally consist of simple to complex quartz-cassiterite±wolframite and rare sulfides in fissure fillings or replacement lodes that occur in or near felsic plutonic rocks. The veins are associated with mineralized greisen zones. Main deposit minerals are cassiterite, wolframite, arsenopyrite, scheelite, rare molybdenite, beryl, and pyrite wit associated chalcopyrite, various Bi-minerals, and rare galena, stannite, and sphalerite. Mineralogic and metal zonation may occur on a small scale (within single veins or vein systems) and (or) on a larger scale (within ore districts). An inner zone of cassiterite±wolframite is commonly bordered by Pb, Zn, Cu, and Ag sulfides. The depositional environment generally consisted of mesozonal to epizonal (hypabyssal) silicic plutons containing felsic dike swarms, and the typical tectonic environment consisted of zones of accreted terranes that intruded late-stage to postorogenic granitoids which ascended from deep-seated magmatic chambers. Examples of this mineral-deposit type are Deputatskoye and Zimnee (fig. 8), Russia, and Mungon-Ondur and Tugalgatain nuruu, Mongolia.

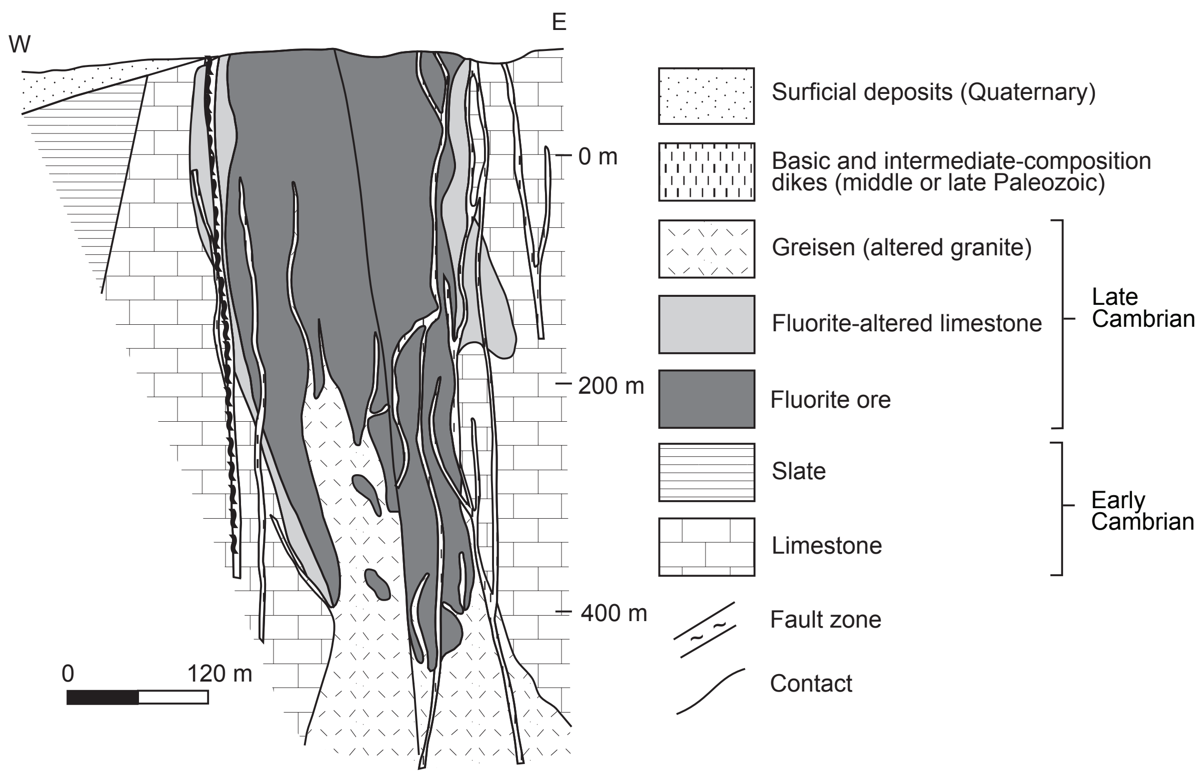


Figure 7. Generalized geologic map of the Late Cambrian though Devonian Voznesenka-II fluorite greisen deposit, Russian Southeast. Adapted from Ryazantzeva (1998).

W-Mo-Be Greisen, Stockwork, and Quartz Vein (Kim and Koh, 1963; Malinovskiy, 1965; Kuznetsov and others, 1966; Sotnikov and Nikitina, 1971; Park and others, 1980; Cox and Bagby, 1986; Kolonin, 1992)

W-Mo-Be greisen, stockwork, and quartz vein deposits consist of veins and stockworks of W, Mo-W, and Be-Mo-W minerals that occur within endo- and exocontact zones of multistage granitoid intrusions. The deposits generally occur in cupolas and domes of silicic and ultrasilicic granitic rocks and the deposits consist of elongate quartz veins and vein systems, stockworks, and greisen cupolas. Quartz-scheelite stockworks are common in exocontact zones and disseminated wolframite and molybdenite occur in greisen, quartz veins, and veinlets. Other minerals are bismuthinite, pyrite, pyrrhotite, arsenopyrite, bornite, chalcopyrite, scheelite, cassiterite, beryl, galena, sphalerite, and various Bi minerals; gangue minerals are quartz, muscovite, K-feldspar, fluorite, lepidolite, and rare tourmaline. Veins occur at the upper-level apices of granitic plutons, including alaskite, and in peripheral zones of contact-metamorphosed sandstone and shale. Associated hydrothermal alteration includes greisen with albite, and rare chlorite and tourmaline with Li, Nb, and Ta minerals. The deposits may be associated with Sn-W vein and Sn greisen deposits. The depositional environment consisted of tensional fractures in epizonal granitoid plutons that intruded sedimentary or metasedimentary rocks, and the typical tectonic setting consisted of anatectic granitic plutonic belts related to collisional zones and (or) interplate strike-slip-fault zones. Examples of this mineral-deposit type are Dzhidinskoe (fig. 9) and Okunevskoye, Russia, and Lednikovy-Sarmaka, Ondortsagan, and Tsunkheg, Mongolia.

C. Alkaline metasomatite.

Ta-Nb-REE Alkaline Metasomatite (Solodov and others, 1987)

Ta-Nb-REE alkaline metasomatite deposits concist of Ta-, Nb-, and REE-bearing alkaline metasomatite that replaces multistage alkali REE granites and host rocks that are generally composed of marble, gneiss, or amphibolite. The

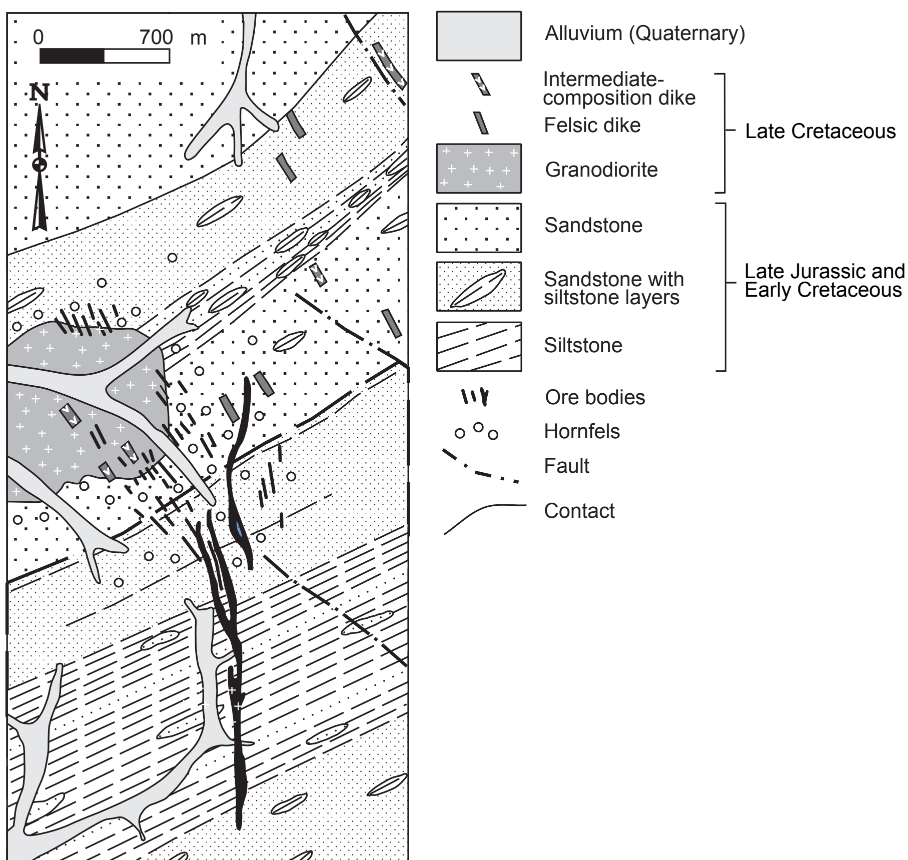


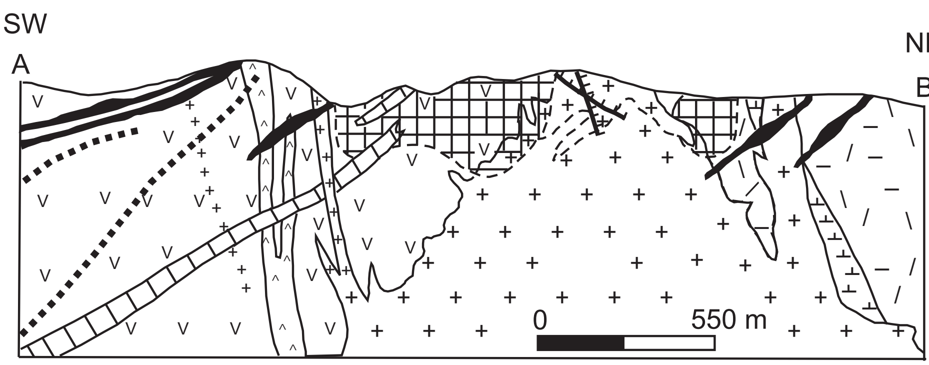
Figure 8. Generalized geologic map of the mid-Cretaceous through early Tertiary Luzhkinsky Sn-W greisen, stockwork, and quartz vein deposit, Russian Southeast. Adapted from A.N. Ivakin and V.V. Orlovsky (written commun, 1978).

deposits are composed of fine- and medium-grained quartz-albite-microcline. Ta-Ni minerals (for example, columbite and pyrochlore), zircon, and thorite are widespread along with REE minerals. Columbite and zircon are of practical significance. Important accessory minerals are REE minerals, including gagarinite, yttrofluorite, monazite, bastnaesite, and xenotime. Mineral zonation of metasomatic bodies is characteristic. Complex multistage metasomatic processes, which occur in the apical part of granite massive and in rocks within shear zones, consisted of microcline, albite, muscovite, and silica alterations. Relatively rich deposits occur in columns and lenticular planar bodies that extend to depths of hundreds of meters. The deposits consistute a unique resource of Ta, Ni, Zr, Hf, and Th, along with Li, REE, and U. The depositional environment consisted of deposit-hosting intrusions and metasomatic deposits that occur along major shear zones connected with intraplate and continental-marginal rift and strike-slip faults. Examples of this mineral-deposit type are Katuginskoye, Ulug-Tanzek (fig. 10), and Zashikhinskoe, Russia, and Khalzanburegtei, Mongolia.

D. Skarn (Contact Metasomatic)

Au Skarn (Hwang and Kim, 1963; Vachrushev, 1972; Theodore and Hammarstrom, 1991)

Au skarn deposits consist of veinlet-disseminated and masses of Au-sulfides that are superimposed on hydrothermally altered calc-silicate and Mg-silicate skarn. The various skarns replace carbonates and coeval volcanic rocks along intrusive contacts with andesite stocks, diorite, granodiorite, granite, and granite porphyry. The deposits are generally small and irregular but may persist at the depth. Minerals are garnet, pyroxene, wollastonite, vesuvianite, magnetite, epidote, actinolite, quartz, pyrite, chalcopyrite, bornite, sphalerite, and native gold. Gold formed simultaneously with or after deposition of sulfides, sometimes in association with hydrothermal alteration that formed epidote, chlorite, and silica. The depositional environment consisted of contacts of calcareous-volcanic sequences intruded by gabbrodiorite-granitic complexes in continental margin or island-arc systems. Examples of this



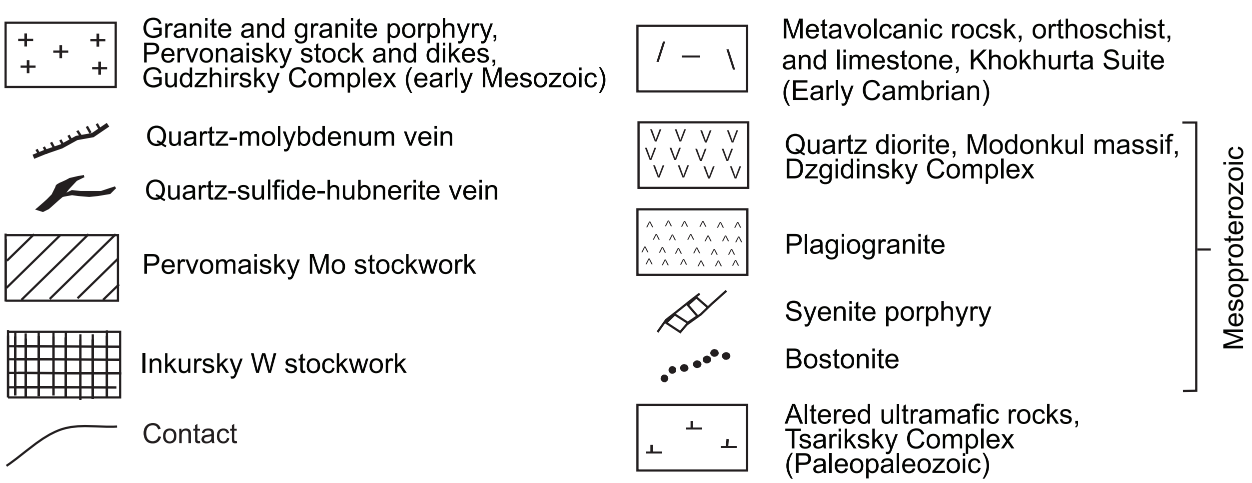


Figure 9. Generalized geologic map of Middle Jurassic through Early Cretaceous Dzhidinskoe W-Mo-Be greisen, stockwork, and quartz vein deposit, Russia. Adapted from Ignatovich (1961).

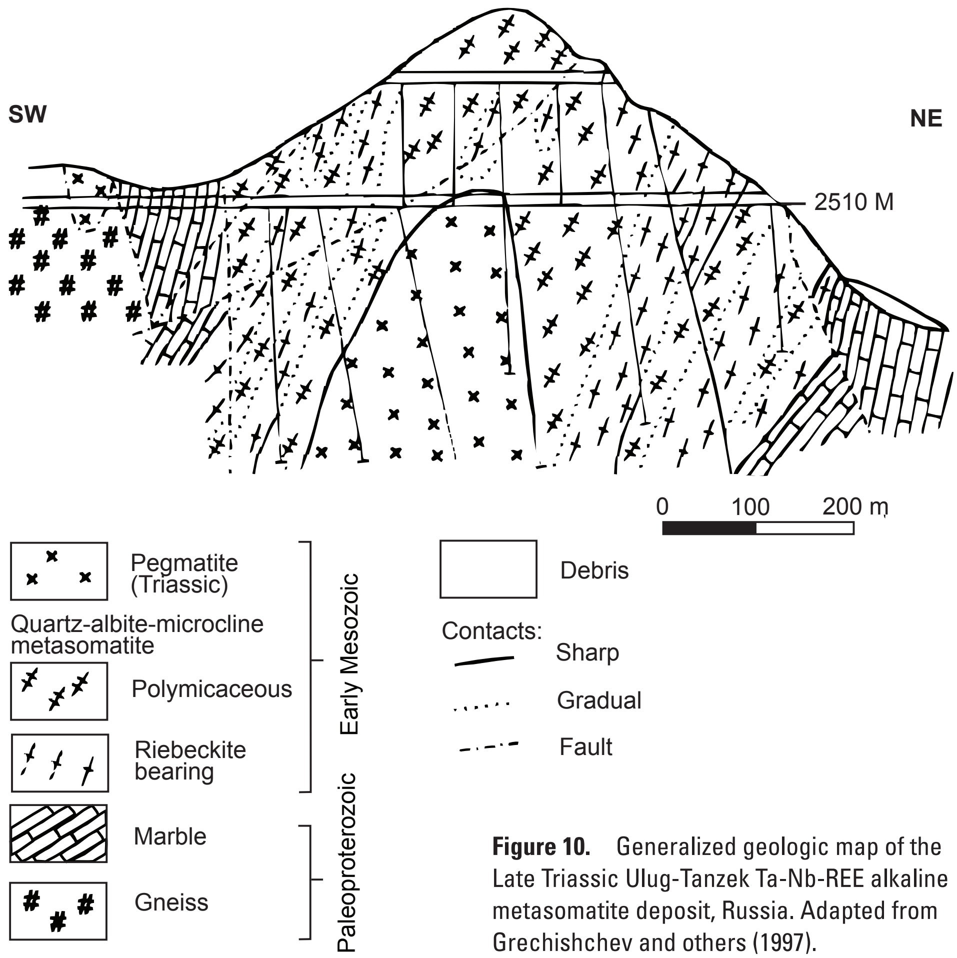


Figure 10. Generalized geologic map of the Late Triassic Ulug-Tanzek Ta-Nb-REE alkaline metasomatite deposit, Russia. Adapted from Grechishchev and others (1997).

mineral-deposit type are Boltoro, Mongolia, and Andryushkinskoe and Sinyukhinskoye, Russia.

B (Datolite) Skarn (Nosenko and others, 1990; Ratkin and others, 1992; Ratkin and Watson, 1993)

B (datolite) skarn deposits consist of danburite and datolite skarn associated with garnet-hedenbergite-wollastonite skarn. The skarn is interpreted as having formed during successive metasomatic replacement of limestone by wollastonite, grossularite-andradite, and hedenbergite and by danburite, datolite, axinite, quartz, and calcite. The deposits are characterized by thin-banded wollastonite that forms kidney-shaped aggregates of pyroxene and datolite in walls of paleohydrothermal cavities in marble. The hydrothermal cavities occur to depths of 500 m from the paleosurface, above a metasomatic zone of wollastonite and grossularite. The central part of these cavities (0.5 to 50 m across) is filled with danburite druse. Danburite formed after a second, B metasomatism, and boron was redeposited at higher paleogypsometric levels in datolite associated with garnet-hedenbergite skarn. Genesis of neighboring Pb-Zn deposits is associated with formation of the later skarn. B isotopic data suggest that the source of dissolved boron was a deep-seated granitoid intrusion. The depositional environment consisted of early formation of grossular-wollastonite skarn, followed by formation of thin-banded wollastonite aggregates with datolite and danburite simultaneously with eruption of a postaccretionary ignimbrite sequence that overlay an accretionary wedge complex containing large limestone xenoliths (dimensions of 0.5 by 2.0 km) in a highly deformed siltstone and sandstone matrix. The only example of this deposit type is the large Dalnegorsk boron mine (fig. 11) in the Russian Southeast that constitutes the main source of boron in Russia.

Carbonate-Hosted Asbestos (Wrucke and Shride, 1986)

Carbonate-hosted asbestos deposits occurs along the contacts between mafic dikes and sills that intruded silicified carbonates. Major rock types are serpentinite, diabase, gabbro, chert-bearing dolomite, and marl. The deposits are commonly stratiform, lensoid, or irregular, and are concordant with the host carbonates. The industrial minerals are serpentine asbestos, massive serpentine, calcite, and dolomite. Varied and distinct metasomatic structures also occur. Major alteration minerals are serpentinite, talc, tremolite, diopside, and carbonate. Alteration zoning is not apparent. The deposition environment was metasomatism associated with mafic intrusions into impure carbonates. The deposits may be of any age, but in Northeast Asia they are mainly Mesoproterozoic. The tectonic environment was mafic plutons forming parts of continental-margin arcs. The best example of this mineral-deposit type is at Chaoyang, Liaoning Province, China.

Co Skarn (Nekrasov and Gamyanin, 1962; Bakharev and others, 1988; Lebedev, 1986)

Co skarn deposits occur along the contacts between siltstone and limestone during contact metamorphism associated with intrusion of granodiorite, syenite-diorite, and granite plutons and small intrusions (stocks and dikes) of alkali gabbro. The skarn typically consists of pyroxene and grossularite-andradite garnet and lesser axinite and scapolite. The deposits consist of small masses of Co-pyrite, sulfoarsenides, and arsenides along with gersdorffite, arsenopyrite, lollingite, and cobaltite. Native gold occurs in association with Bi and Te minerals, including native bismuth, joseite, hedleyite, and bismuthine. Examples of this mineral-deposit type are Karagem and Vladimirovskoye, Russia.

Cu (±Fe, Au, Ag, Mo) Skarn (Cox and Theodore 1986; Nokleberg and others, 1997)

Cu (±Fe, Au, Ag, Mo) skarn deposits consist of chalcopyrite, magnetite, and pyrrhotite in calc-silicate skarn that replaces carbonates along intrusive contacts with plutons ranging in composition from quartz diorite to granite and from diorite to syenite. Zn-Pb-rich skarn generally occurs farther from the intrusion, whereas Cu- and Au-rich skarn generally occur closer. Major minerals are pyrite, hematite, galena, molybdenite, sphalerite, and scheelite. Mineralization is multistage. The deposit type is commonly associated with porphyry Cu-Mo deposits. The depositional environment consisted mainly calcareous sedimentary sequences intruded by felsic to intermediate-composition granitic plutons that form parts of continental-margin arcs. Examples of this mineral-deposit

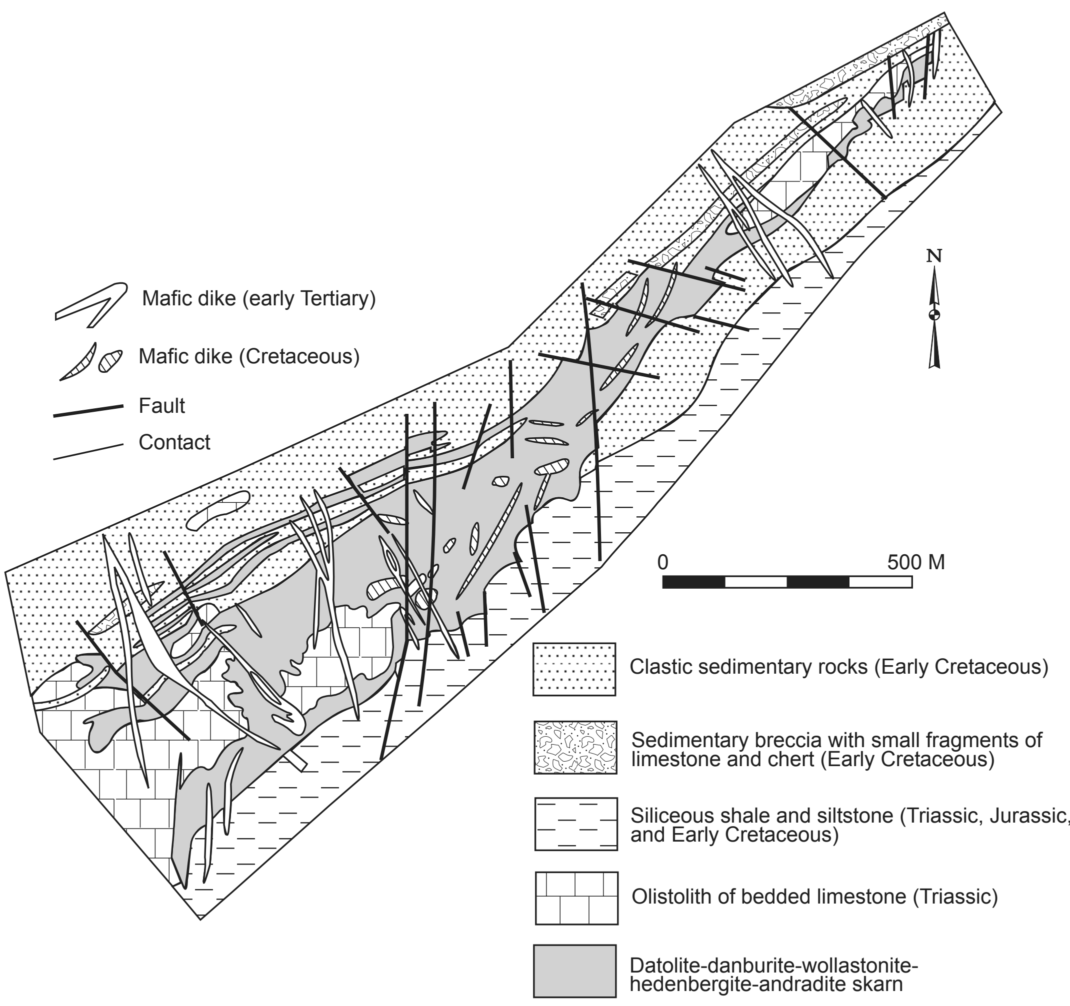


Figure 11. Generalized geologic map of the Late Cretaceous through early Tertiary Dalnegorsk boron (datolite) skarn deposit. Adapted from Ratkin (1991).

type are Boltoro, Kuma, and Muromets, Russia, Khokhbulgiin khondii, Mongolia, and Kamaishi, Japan (fig. 12).

Fe Skarn (Mazurov, 1985; Cox, 1986d; Sinyakov, 1988)

Fe skarn deposits consist of dispersed magnetite in calc-silicate or Mg- silicate skarn that replaces carbonates, tuffaceous carbonates, or calcareous clastic rocks near the contact of intrusive rocks range vary from gabbro and diorite to granodiorite and granite. Coeval volcanic rocks occur locally. Associated minerals are relatively rare chalcopyrite, pyrite, and pyrrhotite. Metasomatic replacements consist of a wide variety of calc-silicate and related minerals. The main skarn minerals are Mg-silicates, calc-silicates, albite, scapolite, chlorite, and amphibole. The depositional environment consisted of metavolcanic and metasedimentary sequences, including dolomite, dolostone, and rare limestone that were intruded by gabbro to granite in island arcs, continental marginal arcs, or rifted continental margins. Examples of this mineral-deposit type are Abakanskoye, Beloretskoye, Inskoye, Lavrenovskoye, Tabratskoye, and Timofeevskoe, Russia, and Tomor tolgoi (fig. 13), Mongolia.

Fe-Zn Skarn (Bakhteev and Chizhova 1984; Podlessky and others, 1984, 1988)

Fe-Zn skarn deposits consist of sphalerite and associated minerals in calcic skarn that typically occurs along the pre-intrusive tectonic-lithologic contacts between uplifted blocks of calcareous metasedimentary rocks intruded by granitoids. The intrusive rocks are mainly potassic subalkaline granite and leucogranite. The skarn occurs in lenses or in layers, and range from tens to hundreds of meters in thickness and several hundreds meters along strike. The intrusive rocks display little or no alteration. Major minerals are sphalerite and magnetite, and lesser chalcopyrite, hematite, bismuthinite, molybdenite, pyrite, and galena. Gangue minerals are andradite-grossularite garnet, hedenbergite, magnetite, epidote, and feldspar. Typical and common zonation consists of epidote-feldspar, epidote-andradite, andradite-magnetite, andradite-pyroxene-magnetite, and pyroxene-magnetite. Typical retrograde minerals are actinolite, quartz, calcite, and chlorite. Fe and Zn mineral distribution is irregular and occurs mostly in garnet and garnet-pyroxene skarn. Pb/Zn/Cu ratios are about 0.2/4.5/0.1. The deposit typically exhibits four stages of mineralization: garnet-pyroxene

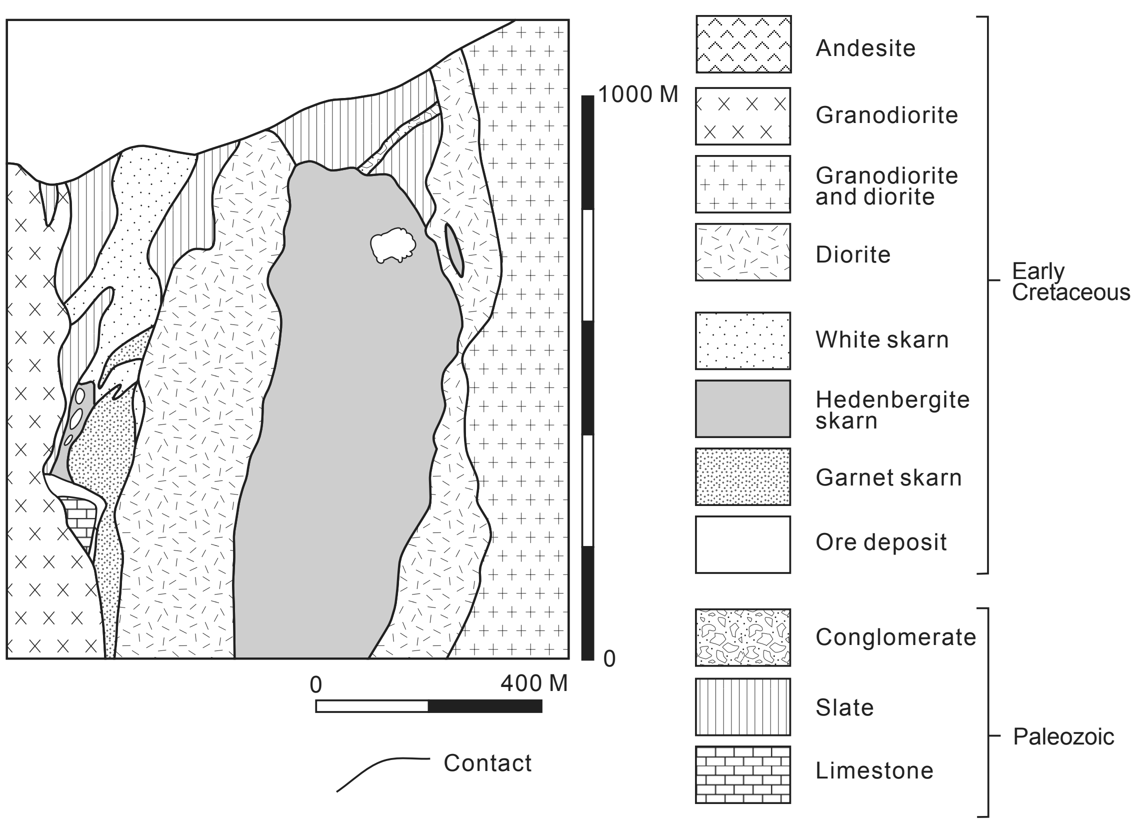


Figure 12. Generalized geologic map of the Early Cretaceous Kamaishi Cu(±Fe, Au, Ag, Mo) skarn deposit, Japan. Adapted from Nittetsu Mining Co. (1981).

skarn, andradite-magnetite aposkarn, sulfide, and quartz-carbonate. The depositional environment consisted of metamorphosed calcareous rock sequences including dolomite, dolostone, and rare limestone that were intruded by granitoids in island or continental marginal arcs. Examples of this mineral-deposit type are Khol khudag, Tumurte, and Tumurtiin-Ovoo, Mongolia, and Jinling, Shandong Province, China.

Sn Skarn (Reed, 1986c; Nokleberg, and others, 1997)

Sn skarn deposits consist of Sn, W, and Be minerals in skarn, veins, stockworks, and greisens near intrusive contacts between generally epizonal(?) granitic plutons and limestone. The deposit minerals include cassiterite, and local scheelite, sphalerite, chalcopyrite, pyrrhotite, magnetite, and fluorite. Alteration consists of greisen near granite margins, and metasomatic andradite, idocrase, amphibole, chlorite, chrysoberyl, and mica in skarn. The depositional environment consisted of epizonal granitoid plutons that intruded calcareous sedimentary or metasedimentary rocks and the typical tectonic setting was backarc granitoids interpreted as having formed in continental-margin arcs, or anatectic granitoids in collisional zones and (or) interplate strike-slip-fault zones. Examples of this mineral-deposit type are Haobugao and Huanggan, Inner Mongolia, China.

Sn-B (±Fe) Skarn (Ludwigite Type) (Lisitsin, 1984; V.I. Shpikerman in Nokleberg and others, 1997)

Sn-B (±Fe) skarn (ludwigite type) deposits consist of metasomatic replacement of dolomite by mainly ludwigite and magnetite adjacent to granitoids. Ludwigite constitutes as much as 80 percent of the deposits, and Sn occurs as an isomorphic admixture in ludwigite. Other minerals are magnetite, suanite (Mg_2B_5O), ascharite, kotoite, datolite, harkerite, monticellite, fluoroborite, clinohumite, calcite, periclase, forsterite, diopside, vesuvianite, brucite, garnet, axinite, phlogopite, serpentine, spinel, and talc. The deposits consist of limestone metasomatically replaced by pyroxene-garnet-calcite skarns that is commonly altered to greisen to form Sn skarn. Mg and associated calcic skarn generally form near highly irregular (convoluted) contacts of granite plutons and in large xenoliths of carbonates. The depositional environment consisted of epizonal granitoid plutons that intruded calcareous sedimentary or metasedimentary rocks, and the typical tectonic setting consisted of backarc granitoids forming in continental-margin arcs, or of anatectic granitoids in collisional zones and (or) along interplate strike-slip-fault zones. No notable examples of this deposit type occur in the region.

W±Mo±Be Skarn (Beus, 1960; Kuznetsov and others, 1966; Cox, 1986j)

W±Mo±Be skarn deposits consist of scheelite and (or) scheelite-helvite in pure or altered (greisen or silica alteration) calc-silicate skarn that replaces carbonates or calcareous sedimentary rocks, along or near intrusive contacts with quartz diorite to granite plutons. Skarn forms irregular and vein-shaped bodies and layers. Associated minerals are molybdenite, pyrrhotite, sphalerite, bornite, pyrite, and magnetite. Two subtypes are defined: (1) scheelite skarn containing disseminated W minerals and (2) scheelite-helvite skarn with disseminated W and Be minerals. Skarn typically contains garnet, vesuvianite, pyroxene, epidote, actinolite fluorite, helvite, scheelite, beryl, quartz, muscovite, and rare sulfides. Replacement of wallrocks consists of a wide variety of calc-silicate and related metasomatic minerals. Scheelite also occurs in quartz-topaz and quartz-mica greisen interpreted as having formed by replacement of skarn. The depositional environment consisted of contact zones along the margins of granitic intrusions in continental-margin or island arcs, or adjacent to anatectic granitoids intruding

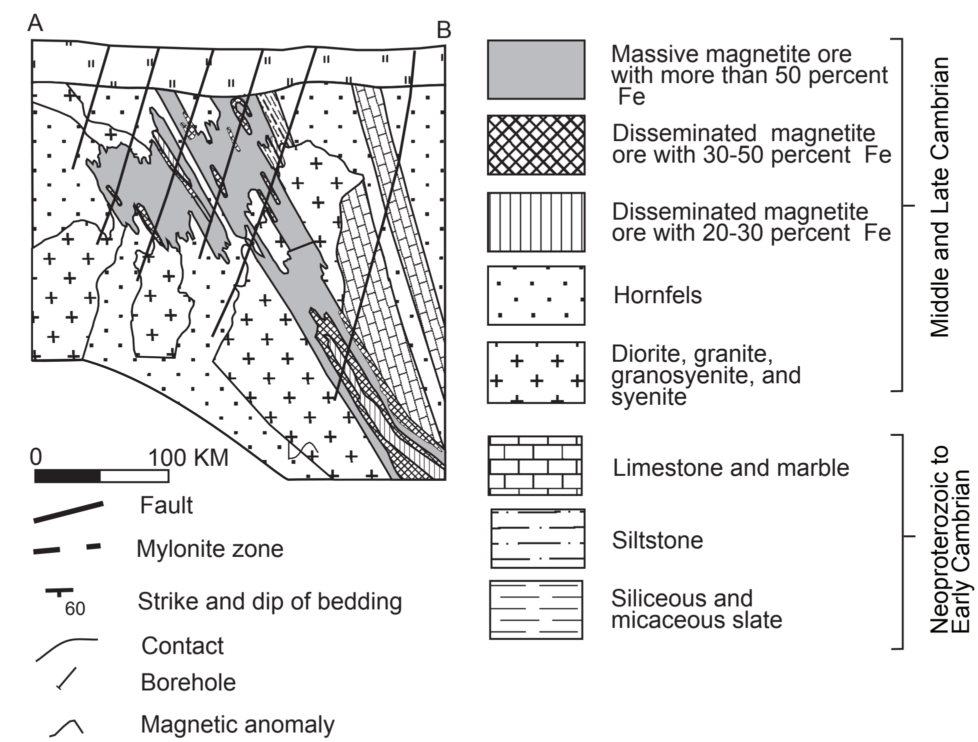


Figure 13. Generalized geologic map of the Middle through Late Cambrian Tomor tolgoi Fe skarn deposit, Mongolia. Adapted from (Marinov, Khasin, and Khurts (1977).

collisional zones. Examples of this mineral-deposit type are Lermontovsky and Vostok 2 (fig. 14), Russia, and Sangdong, South Korea.

Zn-Pb (±Ag, Cu, W) Skarn (Cox, 1986k; Eckstrand, 1984; Nokleberg, and others, 1997)

Zn-Pb (±Ag, Cu, W) skarn deposits consist of sphalerite and galena in calc-silicate skarn that replaces carbonates or impure calcareous sedimentary rocks along intrusive contacts with plutons varying in composition from quartz diorite to granite and from diorite to syenite. Zn-Pb-rich skarns generally occur farther from the intrusion relative to Cu- and Au-rich skarns. The deposits may occur at a considerable distance from the source granitic intrusion. Associated minerals are pyrite, chalcopyrite, hematite, magnetite, bornite, arsenopyrite, and pyrrhotite. The deposits vary from stratiform skarn that occurs parallel to limestone bedding near plutonic contacts, to discordant bodies that commonly occur at lithologic and structural contacts at some distance from pluton and dike contacts. The deposits are rather narrow but may extend downdip to 1-km depth and they may be controlled by ring faults around volcanic-tectonic depressions. The depositional environment consisted of mainly calcareous sedimentary sequences intruded by felsic to intermediate-composition granitic plutons in continental margin arcs. Examples of this mineral-deposit type are Savinsky 5, Russia (fig. 15); Baiyinnuoer and Xiaoyingzi, Inner Mongolia;, Huanren, Liaonig Province, China, and Kamioka Tochibora, Japan.

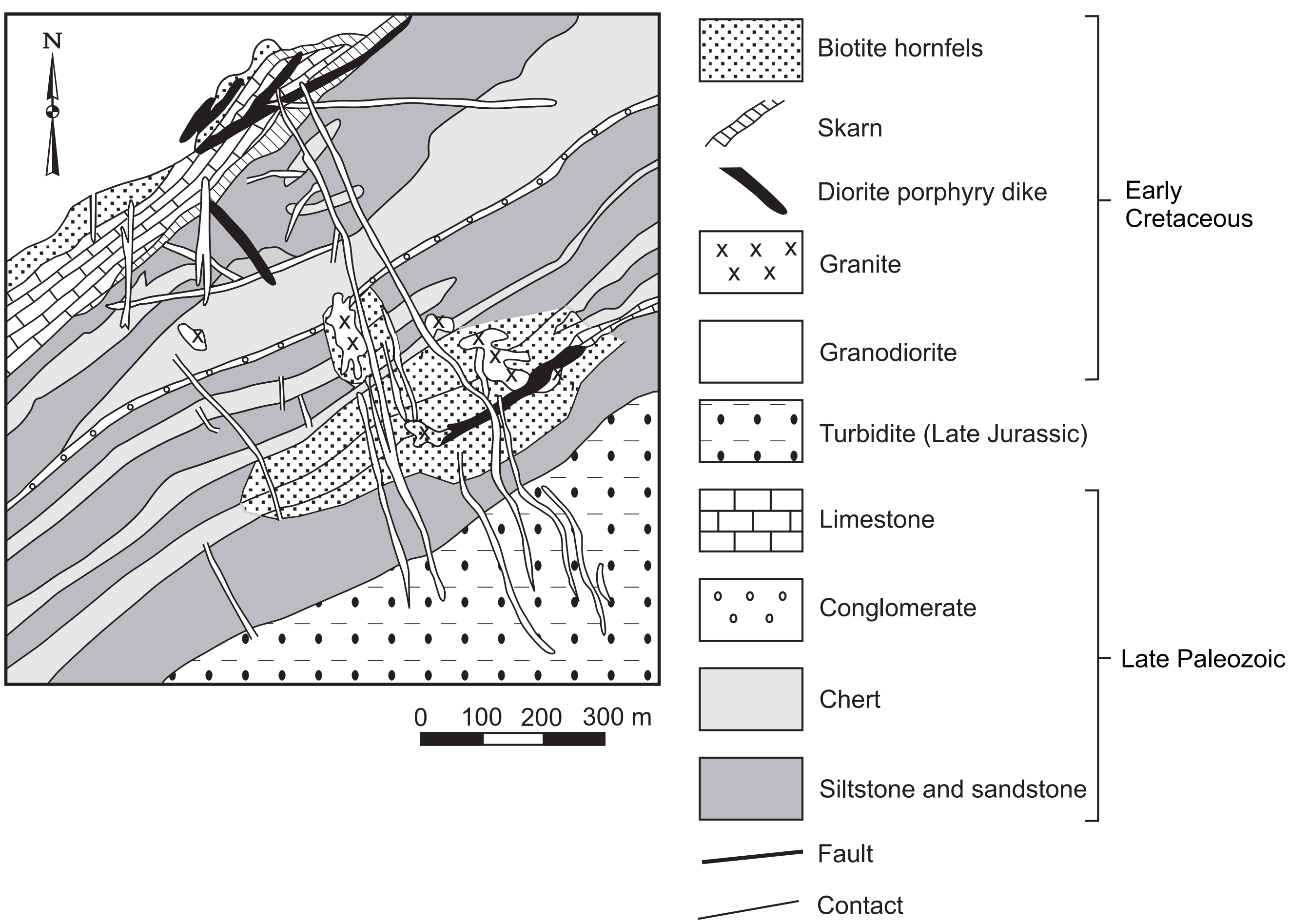


Figure 14. Generalized geologic map of the Early Cretaceous through mid-Cretaceous Vostok 2 W±Mo±Be skarn deposit, Russian Southeast. Adapted from Stepanov (1977).

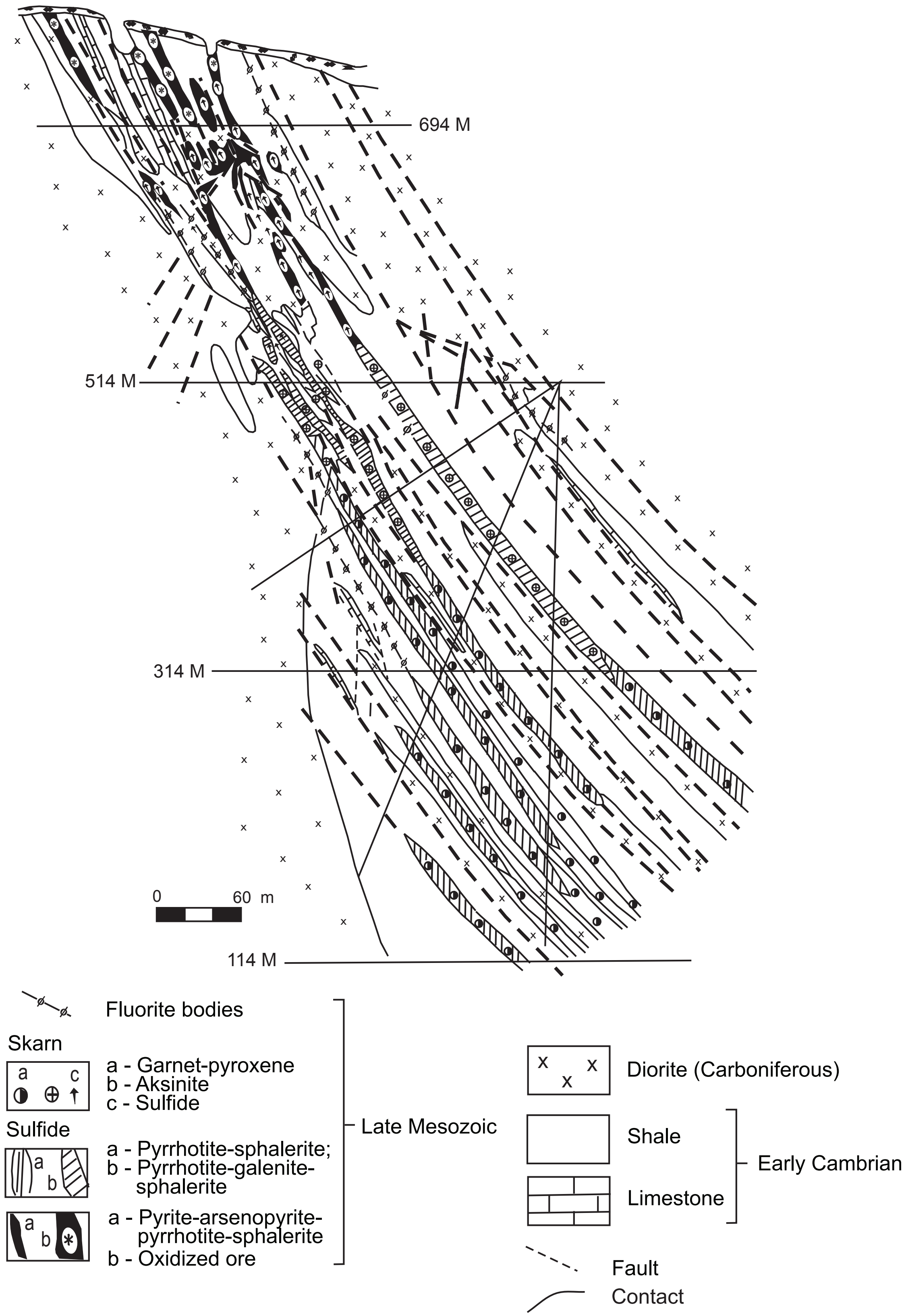


Figure 15. Generalized geologic map of the Middle Jurassic through Early Cretaceous Savinsky 5 Zn-Pb(Ag, Cu, W) skarn deposit, TransBaikal, Russia. Adapted from Arkhangelskaya (1963).

E. Porphyry and Granite Pluton-Hosted Deposits

Cassiterite-Sulfide-Silicate Vein and Stockwork (Kim and Shin, 1966; Lugov and others, 1972; Ontoyev, 1974; Seminsky, 1980; Togashi, 1986; S.M. Rodionov, this study)

Cassiterite-sulfide-silicate vein and stockwork deposits consist of linear zones, veins, and stockworks containing cassiterite, wolframite, scheelite, and various sulfides in a gangue of quartz with siderophyllite, tourmaline, sericite, and chlorite. The deposits occur in or adjacent to hypabyssal multistage intrusive massifs (stocks and laccoliths), subvolcanic bodies that intrude sedimentary, volcanic or metamorphic rocks. Associated intrusive rocks range in composition from gabbro through diorite and granodiorite to granite. The deposits typically contain abundant simple and complex veins and zones that are controlled by large crosscutting faults, or occur in various elements of concentric or radial faults surrounding volcanic-plutonic complexes. Stock with greisen is relatively older and scarce. Many deposits commonly contain stockwork minerals of the same composition as veins and zones. Minerals are cassiterite, arsenopyrite, chalcopyrite, galena, sphalerite, pyrite, pyrrhotite, scheelite, wolframite, fluorite, native bismuth, argentite, native gold, bismuthine, and complex sulfosalts; gangue minerals are quartz, tourmaline, sericite, chlorite, and rare muscovite and feldspar. Typical alteration assemblages are quartz-tourmaline, quartz-siderophillite, quartz-sericite, and quartz-chlorite. High-sulfide (cassiterite-sulfide) and low-sulfide (cassiterite-silicate) deposits may also occur. Several stages of mineralization may be evident with horizontal zonation. The depositional environment consisted of backarc zones of continental-margin arcs. Examples of this mineral-deposit type are Deputatskoye, Khapcheranga (fig. 16), Sherlovogorskoye, and Ulakhan-Egelyakh, Russia.

Felsic Plutonic U-REE (Nokleberg and others, 1997)

Felsic plutonic U-REE deposits consist of disseminated U, Th, and REE minerals in fissure veins and alkalic granite dikes in or along the margins of alkalic and peralkalic granitic plutons, or in granitic plutons, including granite, alkalic granite, granodiorite, syenite, and monzonite. The deposit minerals include allanite, thorite, uraninite, bastnaesite, monazite, uranothorianite, xenotime, and some with galena and fluorite. The depositional environmentconsisted mainly of the margins of epizonal to mesozonal granitic plutons in the backarc zones of continental-margin arcs. Examples of this mineral-deposit type are Chergilen, Diturskoe, and Neozhidannoye, Russia.

Granitoid-Related Au Vein (Eckstrand, 1984; Firsov, 1985; Cherezov and others, 1992)

Granitoid-related Au vein deposits consist of fissure veins and veinlet-stockwork zones containing disseminated gold and and some sulfides that generally occur in small, complex granitic intrusions. Plutonic rocks consist mainly of calc-alkalic and subalkalic diorite, granodiorite, and granite. The deposits may consist of disseminated gold that occurs at the apices of plutons, or in contact metamorphic aureoles. Minerals are native gold, Au-bearing telluride, and sulfides, and associated quartz, tourmaline, muscovite, sericite, chlorite, feldspar, carbonates, and fluorite. Disseminated sulfides in wallrocks, especially arsenopyrite, are commonly enriched in Au and Ag. Alteration to berizite-listvenite is common, with the formation of quartz, sericite, tourmaline, and chlorite. The depositional environment consisted of epizonal plutons that intruded miogeoclinal sedimentary rocks, some of which were regionally metamorphosed and deformed before intrusion. The plutons commonly occur in backarcs of a continental-margin arcs. The deposits display a similar mineralogy and chemical environment and are commonly associated with polymetallic vein deposits containing disseminated Au-bearing sulfides. Examples of this mineral-deposit type are Boroo, Mongolia (fig. 17), Linglong, Shandong Province, Sanshandao, Xincheng, Shandong Province, China; and Tuanjiegou, Heilongjiang Province, China.

Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork (Hwang and Kim, 1962; Moon, 1966; Cox, 1986e; Wang, 1989; Mironov and others, 1989; Tian and Shao, 1991)

Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork deposits consist of quartz-carbonate veins containing base metal sulfides and associated Ag-minerals and gold. The deposits are related to hypabyssal bodies that intruded volcanic, sedimentary, and metamorphic rocks, including interbedded calcic siltstone, siliceous marble, and rhyolite. The intrusions range in composition from calcalkaline to alkaline diorite to granodiorite, and from monzonite to monzogranite and occur in small plutons and dike swarms. Some deposits are controlled by faults along contacts between host rocks and felsic intrusions and range from stratiform or vein to lensoid. The deposits are locally large and are concordant with the bedding of host rocks (for example, Au-Ag polymetallic vein deposits in Jilin Province, China). Au vein deposits are generally sulfide poor (total sulfide content less than 5 percent), and generally occur in masses, disseminations, or veinlets. Minerals are native silver, galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, arsenopyrite, argentite, Ag sulfosalts, native gold, and Cu and Sn sulfides. Vein minerals are quartz, carbonate, barite, and fluorite. Metallic zoning is very common and consists of Pb, Zn (Au and Ag) at depth, Au, Ag (Pb, Zn) at middle horizons, and Ag (Au) at upper levels. Similar metallic zoning patterns also occur horizontally. Alteration consists of wide propylitic zones, and narrow sericite and argillite zones. For Au vein deposits, the most intense host-rock alterations are silica and berizite (pyrite+sericite+carbonate) alterations. Silica alteration commonly occurs adjacent to deposit minerals, and successive outward are are sericite and propylite alterations. Alteration zones range from several tens to 100 meters in width. The depositional environment consisted of zones of

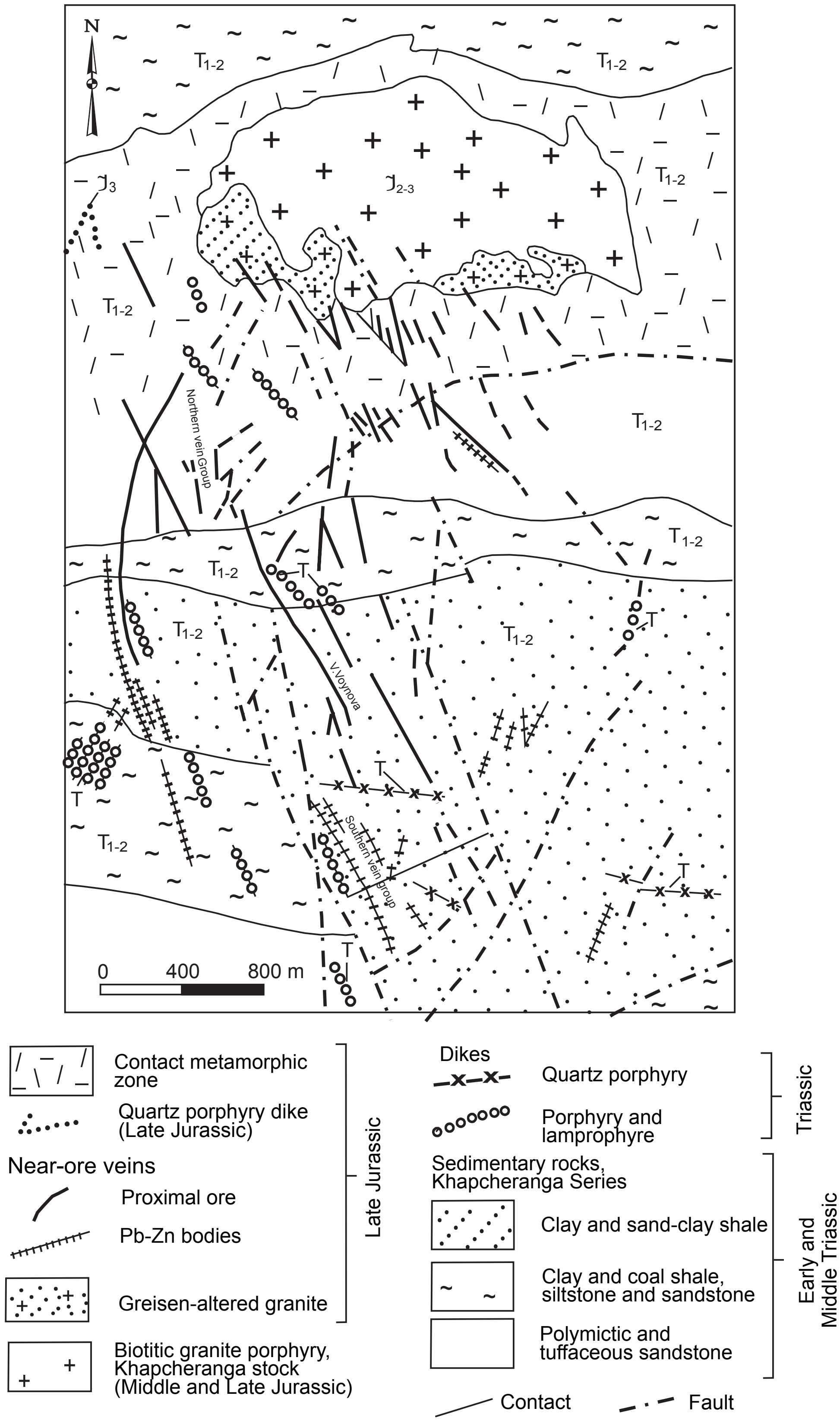


Figure 16. Generalized geologic map of the Middle Jurassic through Early Cretaceous Khapcheranga cassiterite-sulfide-silicate vein and stockwork deposit, TransBaikal, Russia. Adapted from Ontoev (1974).

local domal uplift in continental margin arc and island-arc volcanic-plutonic belts. Examples of this mineral-deposit type are Kuolanda, Prognoz, and Tsav (fig. 18), Russia, Khartolgoi, Mongolia; and Lianhuashan, Inner Mongolia and Meng'entaolegai, Inner Mongolia, China.

Porphyry Au (Fogelman, 1964, 1965; Eckstrand, 1984; Gamyanin and Goryachev, 1990, 1991; Sillitoe, 1993b; Dejidmaa, 1996)

Porphyry Au deposits consist of stockwork zones and disseminated gold with local sulfides that generally occur in simple to complex granitic intrusions, or in breccia pipes associated with volcanic-plutonic complexes. Related intrusive rocks are calc-alkalic and subalkalic granodiorite or granite. Breccia, if present, contains fragments of host rocks (flows, tuffs, granitoids, and sedimentary rocks), and other hypabyssal and subvolcanic rocks. Minerals are native gold, Au-bearing tellurides, and sulfides; accessory minerals are quartz, tourmaline, muscovite, sericite, chlorite, feldspar, carbonates, and fluorite. Two subtypes are defined: (1) a low-sulfide subtype with chalcedony veins and (2) a high-sulfide subtype with abundant disseminated sulfides. Within breccia pipes, gold generally occurs in the cement (matrix) as disseminations or stringer disseminations, along with disseminated sulfides (pyrite, sphalerite, galena, arsenopyrite, and chalcopyrite). Disseminated sulfides in wallrocks, especially arsenopyrite, are commonly enriched in Au and Ag. Host rocks exhibit chlorite, argillite, and quartz alteration. Advanced argillic alteration is widespread in the shallow parts of deposits; sericite alteration is typically minor. Stock and associated volcanic rocksrange in composition from low-K calc-alkalic through high-K calc-alkalic to K-alkalic. The deposits are commonly associated with polymetallic vein, Au-Ag epithermal vein, and porphyry Cu deposits. The depositional environment consisted of subduction-related continental-margin or island arcs with

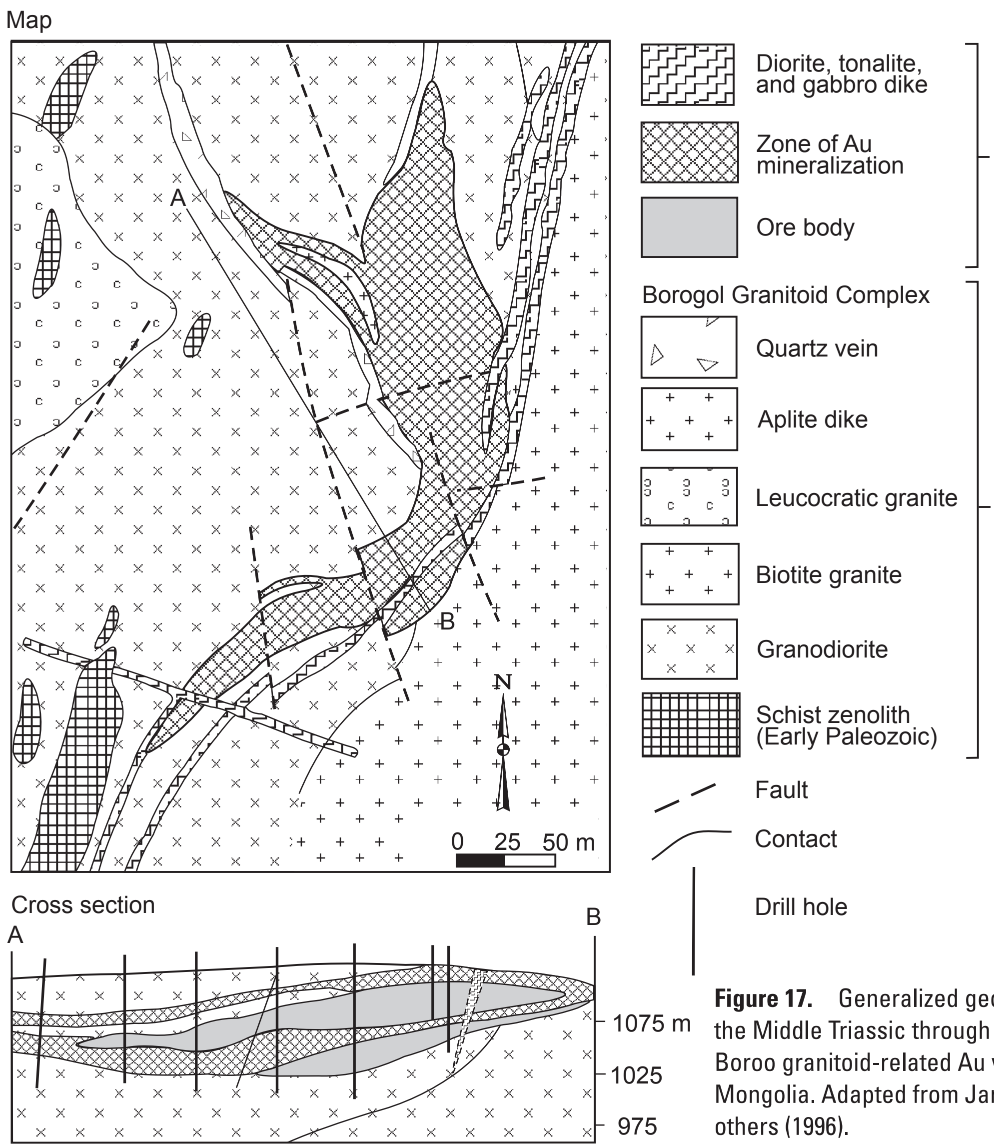


Figure 17. Generalized geologic map of the Middle Triassic through Middle Jurassic Boroo granitoid-related Au vein deposit, Mongolia. Adapted from Jargalsaihan and others (1996).

composite epizonal porphyry stocks that intruded coeval volcanic piles and adjacent passive continental-margin sedimentary rocks, some of which were regionally metamorphosed and deformed before intrusion. Examples of this mineral-deposit type are Ara-Ilinskoe, Russia, Delmachik, Russia, and Naozhi, Jilin Province, China.

Porphyry Cu (± Au) (Cox, 1986g; Sukhov and Rodionov, 1986; Evstrakhin, 1988)

Porphyry Cu (± Au) deposits consist of stockwork veinlets and rare veins of chalcopyrite, bornite, and magnetite in porphyry intrusions and coeval volcanic rocks. The host intrusive rocks vary in composition from tonalite and monzogranite to syenite and monzonite. Coeval volcanic rocks consist of dacite and andesite flows and tuffs. High-K, low-Ti volcanic rocks (shoshonite) may also be common. Minerals are chalcopyrite and bornite with associated magnetite, pyrite, rare native gold, electrum, sylvanite, and hessite, and rare PGE minerals; gangue minerals are quartz, K-feldspar, biotite, sericite, and chlorite, and rare actinolite, anhydrite, calcite, and clay minerals. A general, systematic alteration consists of (1) an inner zone of quartz, biotite, rare K-feldspar, chlorite, actinolite, and anhydrite; (2) an outer alteration zone of propylitic minerals; and (3) late-stage quartz-pyrite-white mica-clay minerals that overprint early feldspar alteration. The deposit mineral veinlets and mineralized fractures are closely spaced. The deposits are generally cylindrically or bell-shaped and are centered on a volcanic-intrusive center. Highest-grade ore commonly occurs at the level where stock divides into branches. The depositional environment consisted of subduction-related continental margin or island arcs with porphyry stocks, dikes, and large-scale breccia intruding coeval volcanic rocks nearby volcanic center and adjacent passive-continental-margin sedimentary rocks. Granitoids hosting the deposits generally intruded durint the waning stage of a volcanic cycle. Examples of this mineral-deposit type are Khongoot and Oyu Tolgoi (fig. 19), Mongolia, and Xiaoxinancha, Jilin Province, China.

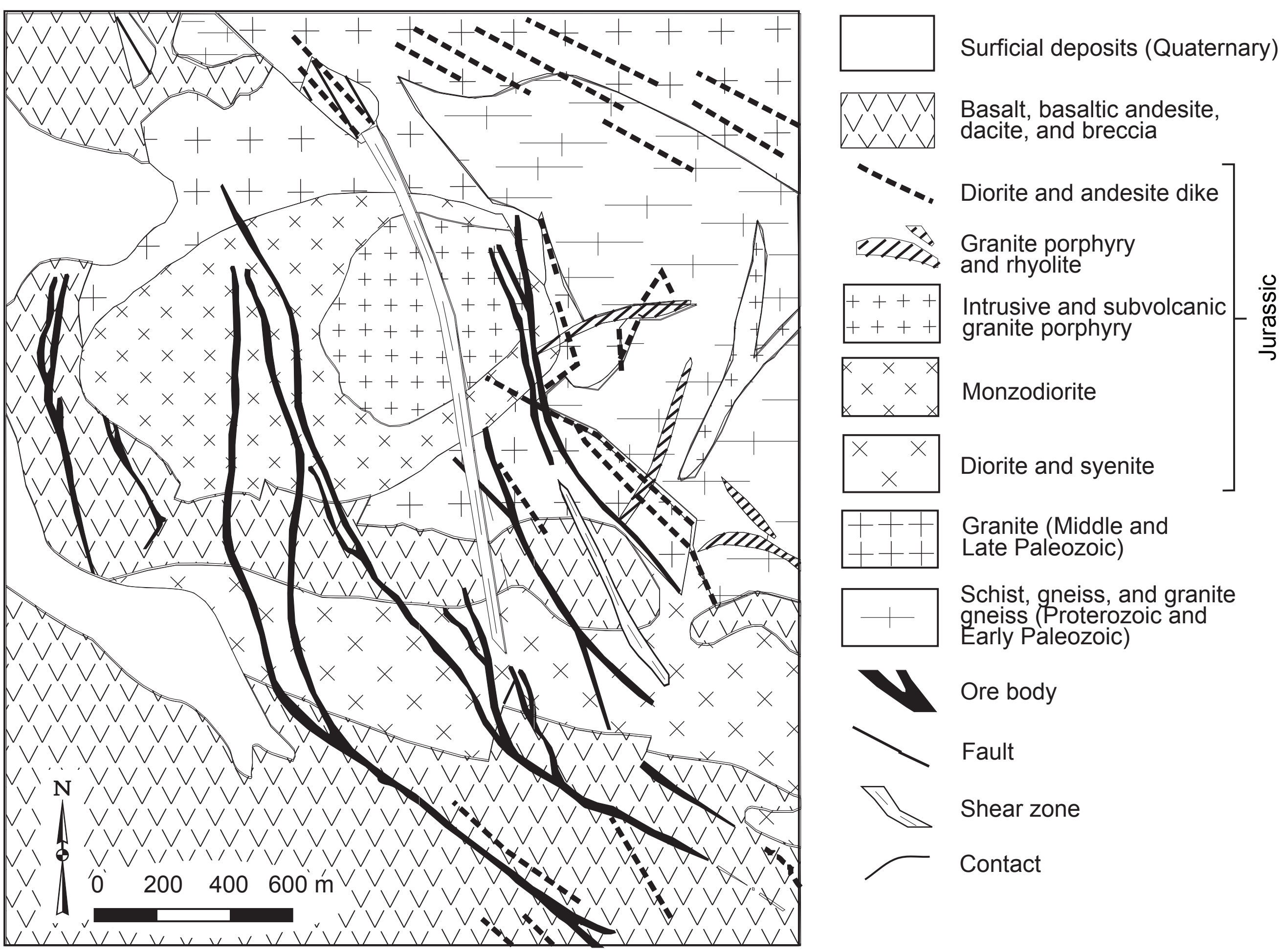


Figure 18. Generalized geologic map of the Middle Jurassic through Early Cretaceous Tsav polymetallic Pb-Zn±Cu(±Ag, Au) vein and stockwork deposit, Mongolia. Adapted from Jargalsaihan and others (1996).

Porphyry Cu-Mo (± Au, Ag) (Sotnikov and others, 1977, 1985; Cox, 1986h; Sukhov, and Rodionov, 1986; Nokleberg and others, 1997)

Porphyry Cu-Mo (± Au, Ag) deposits consist of stockwork veinlets and veins of quartz, chalcopyrite, and molybdenite in or near porphyritic intrusions. The host igneous rocks are felsic and calc-alkalic, predominantly tonalite to monzogranite plutons occurring mainly in stocks that intrude granitic, volcanic, or sedimentary rocks. Breccia pipes (including pebble breccia) and dikes are common. Veinlets and veins contain mainly quartz and carbonates. Minerals are chalcopyrite, molybdenite, pyrite, sphalerite, Ag-rich galena, and gold; alteration minerals are quartz, K-feldspar, sericite, and biotite or chlorite. Anhydrite occurs in the deeper levels of the deposits. Most deposits exhibit varying degrees of hypogene alteration, including sodic, potassic, and phyllic alteration. The earlier mineralization stage commonly starts with alkaline metasomatism (microclinization), followed by metasomatic deposition of molybdenite and later overprinting by

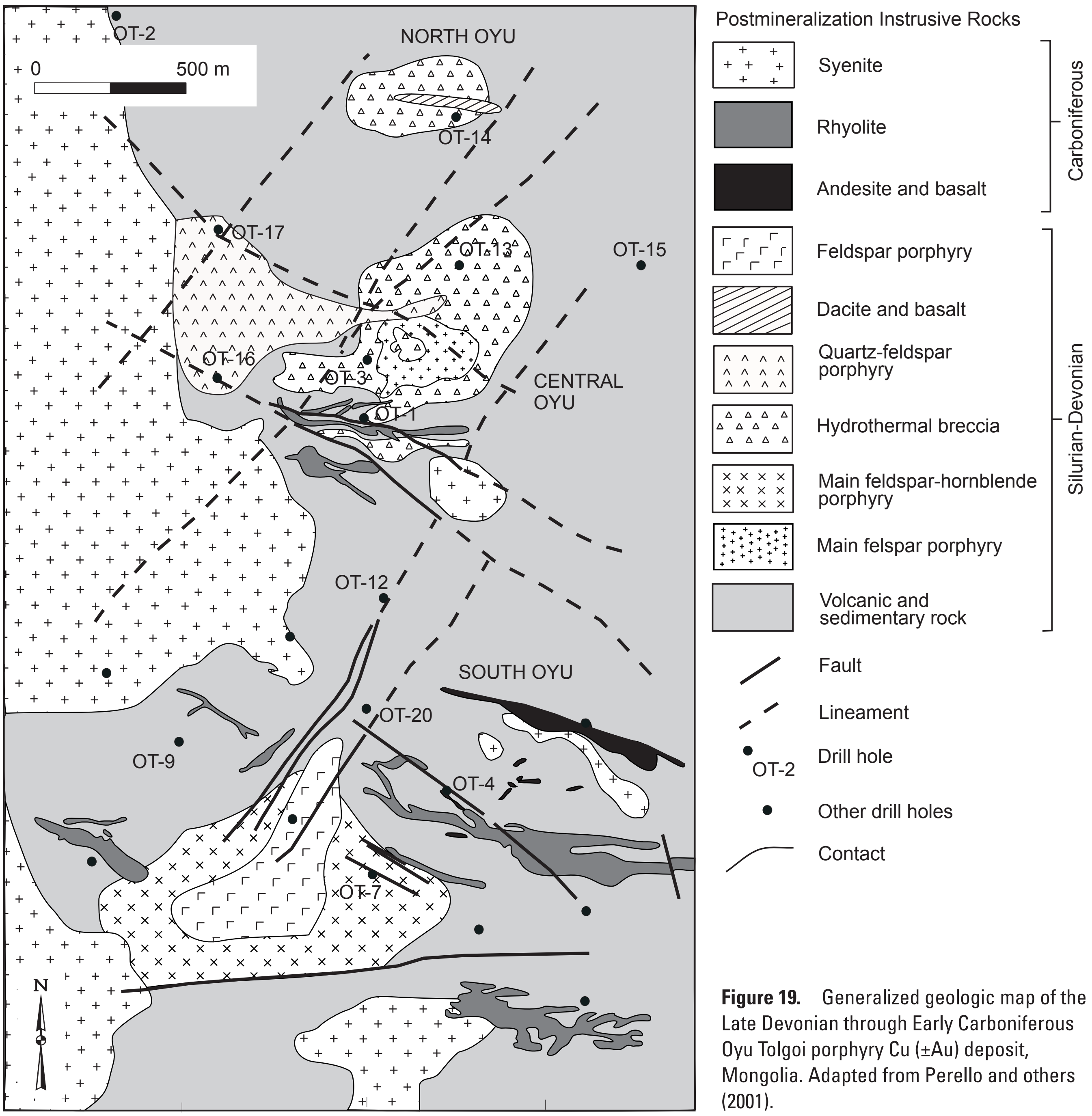


Figure 19. Generalized geologic map of the Late Devonian through Early Carboniferous Oyu Tolgoi porphyry Cu (±Au) deposit, Mongolia. Adapted from Perello and others (2001).

sericite alteration with subsequent deposition of Cu sulfides, sometimes in open-space filling veins and veinlets. Alteration zones, from inner to outward, are sodic-calcic, potassic, phyllic, and argillic to propylitic. Widespread, episodic development of abundant joints in intrusions and wallrocks is typical. The depositional environment consisted of shallow porphyry intrusions that were contemporaneous with abundant dikes, faults, and breccia pipes associated with andesite stratovolcanoes in the backarc zones of subduction-related continental-margin or island arcs. Examples of this mineral-deposit type are Erdenetiin Ovoo (fig. 20) and Tsagaan Suvarga, Mongolia, Duobaoshan, Heilongjiang Province and Wunugetushan, Inner Mongolia, China.

Porphyry Mo (± W, Sn, Bi) (Sotnikov and others, 1977, 1985; Theodore, 1986; Pokalov, 1992; Ludington, 1986; Nokleberg, and others, 1997)

Porphyry Mo (± W, Sn, Bi) deposits consist of quartz-molybdenite stockwork in felsic porphyries and adjacent country rock. The porphyries range in composition from granite-rhyolite, (>75 percent SiO_2) to tonalite, granodiorite, and monzogranite. Radial silicic dikes and small breccia pipes are common. Associated minerals are pyrite, scheelite, and chalcopyrite, rare cassiterite, wolframite, and tetrahedrite; gangue minerals are quartz, K-feldspar, biotite, calcite, and white mica. Some deposits are high F, and have larger

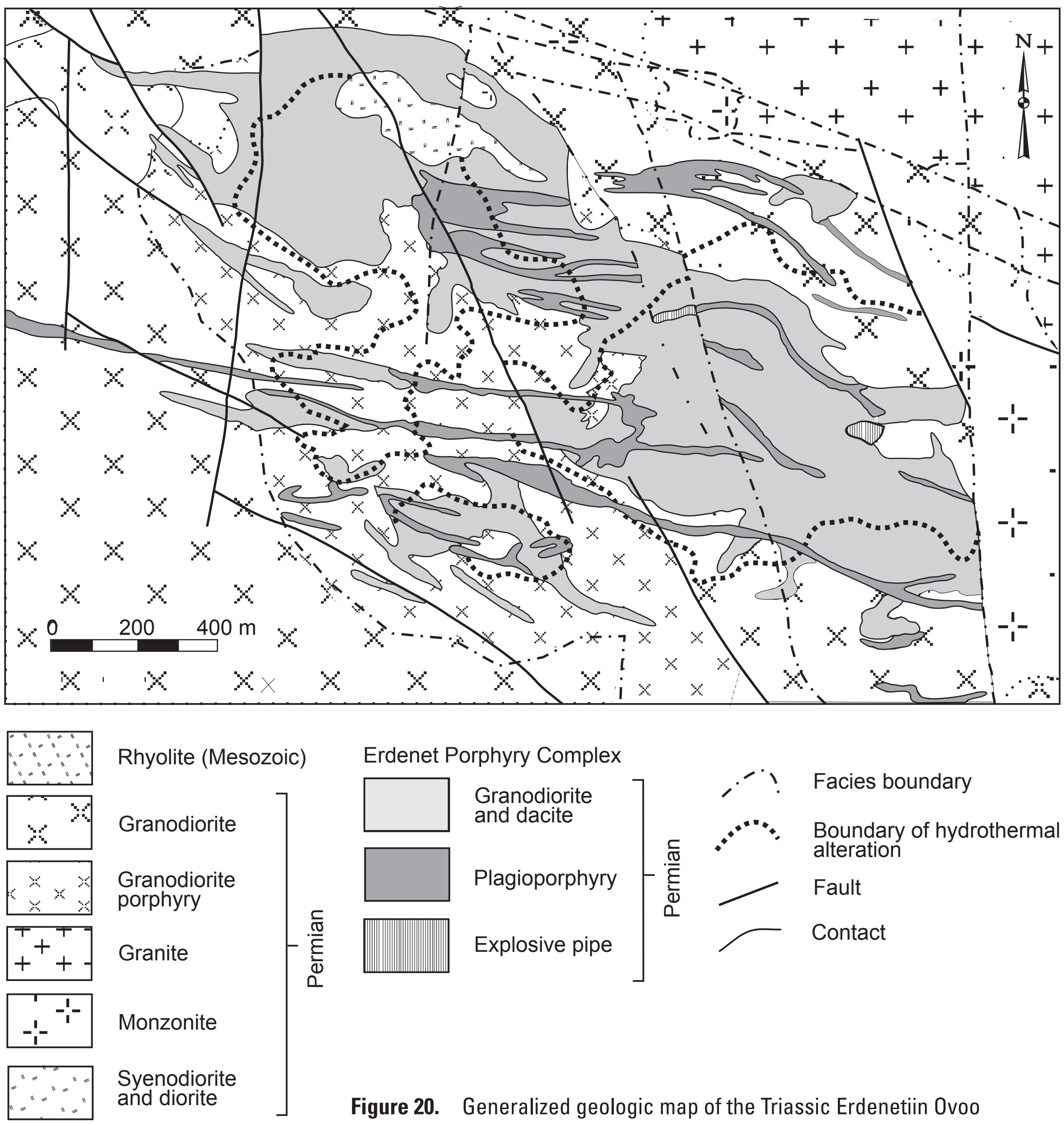


Figure 20. Generalized geologic map of the Triassic Erdenetiin Ovoo porphyry Cu-Mo deposit, Mongolia. Adapted from Gavrilova and others (1989).

tonnages and higher average grades than the low-F deposits hosted in quartz monzonite. Alteration consists of potassic grading outward to propylitic, sometimes with phyllic and argillic overprints. Intense quartz and quartz-feldspar veins are typical for F-rich deposits. Minor greisen veins may occur below the ore body. According to mineralogy and tectonic setting, two subtypes are defined: (1) high-grade, rift-related deposits with multistage F-rich, highly evolved granite to rhyolite stocks that constitute a high-silica, alkalic rhyolite suite; and (2) low-grade, continental-margin arc-related deposits hosted in F-poor, calc-alkalic stocks or plutons that form a differentiated monzogranite suite. The high-grade, F-rich deposits are also associated with intraplate alkaline igneous rocks. The depositional environment consisted of shallow, epizonal porphyry intrusions in the backarc zones of subduction-related, continental-margin arcs that were built on thick continental crust. Examples of this mineral-deposit type are Birandzha, Melginskoye, Metrekskoye, Sorskoye (fig. 21), and Zhirekenskoye, Russia; and Daheishan 2, Jilin Province, China; and Lanjiagou, Liaoning Province, China.

Porphyry Sn (Reed, 1986a; Rodionov, 1990; Nokleberg and others, 1997)

Porphyry Sn deposits consist mainly of cassiterite and associated minerals in stockworks, veinlets, and disseminations that occur in complex, subvolcanic, multiphase granitic plutons, granitic porphyry or quartz porphyry stocks, and subvolcanic and volcanic rhyolite breccias, and as well as in coeval volcanic rocks and surrounding clastic rocks. The subvolcanic host rocks range in composition from intermediate to silicic (quartz-latite, dacite, rhyodacite); cogenetic volcanic rocks consist of calc-alkaline pyroclastic rocks and lava (quartz-latite to rhyodacite). Closely related intrusions are mainly strongly-altered and brecciated quartz porphyry. Magmatic-hydrothermal breccia and extensive metasomatic propylitic and phyllic alterations are typical, accompanied by quartz, tourmaline, sulfides, and sericite. Minerals are cassiterite, quartz, pyrrhotite, pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, stannite, wolframite, muscovite, sericite, chlorite, albite, adularia, siderite, rhodochrosite, calcite, topaz, fluorite, sulfostannates, and Ag and Bi minerals. Alteration zones, from interior to periphery, are

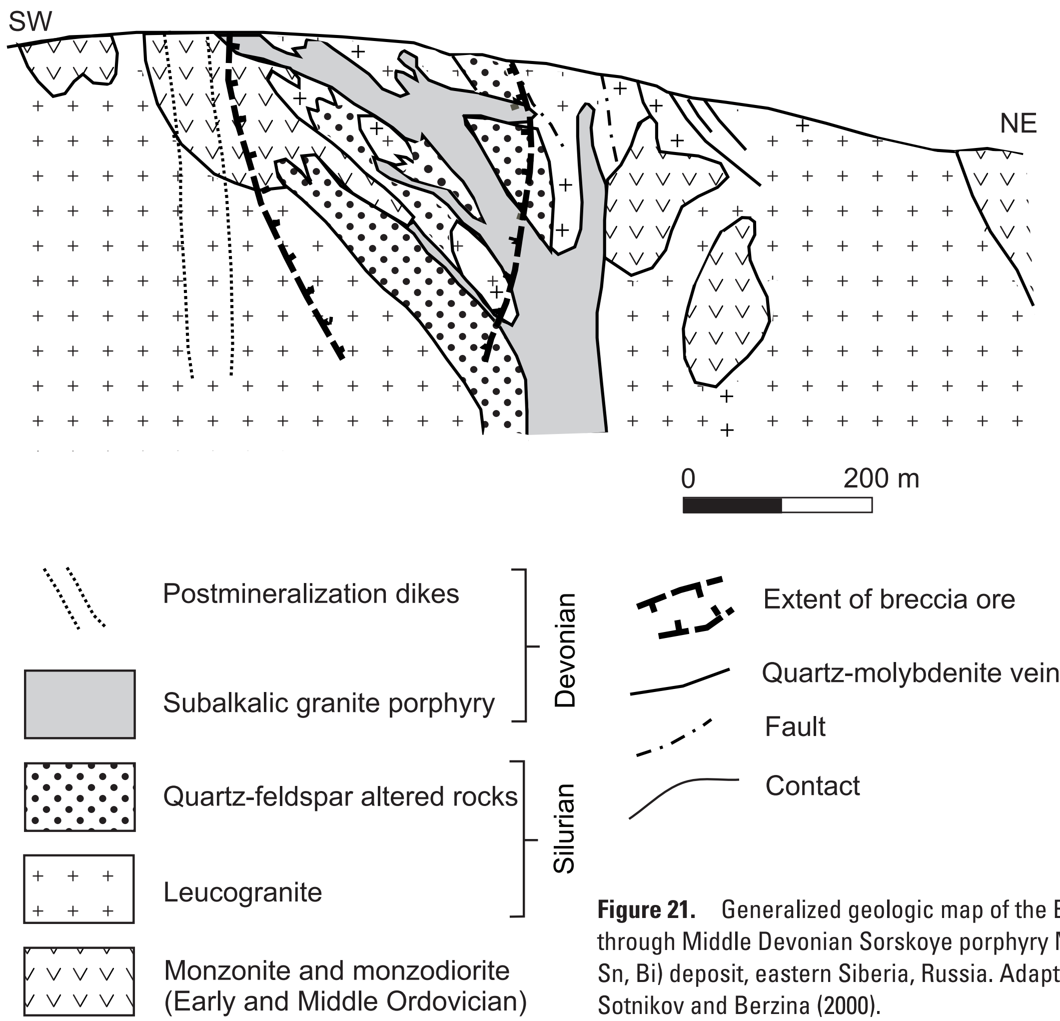


Figure 21. Generalized geologic map of the Early through Middle Devonian Sorskoye porphyry Mo(±W, Sn, Bi) deposit, eastern Siberia, Russia. Adapted from Sotnikov and Berzina (2000).

tourmaline (±adularia), phyllic, propylitic, and argillic. Some deposits exhibit a quartz-tourmaline core with a peripheral zone of sericite. The deposits are commonly associated with Sn- and Ag-bearing polymetallic veins. The depositional environment consisted mainly of shallow subvolcanic stocks emplaced from 1 to 3 km beneath or within vents of stratovolcanoes in the backarc zones of subduction-related continental-margin arcs. Examples of this mineral-deposit type are Mokhovoye, Mopau, Surkho, Yantarnoe, and Zvezdnoe, Russia.

III. Deposits Related to Alkaline Intrusions

A. Carbonatite-Related Deposits

Apatite Carbonatite (Smirnov, 1982; Entin and others, 1991)

Apatite carbonatite deposits consist of apatite-carbonate, apatite-quartz-carbonate, martite-apatite-quartz-carbonate assemblages, martite-apatite-carbonate, and apatite-carbonate-quartz assemblages in asymmetric early- and late-stage stocks. Early-stage carbonatites form veins, vein zones, and stockworks in mafic complexes intruded into crystalline basement. The veins range from a few centimeters to 30-40 m wide and from a few meters to 500 m long, rarely as much as 1.5 km. Early-stage apatite carbonatite contains apatite, carbonates (calcite, dolomite), K-feldspar, phlogopite, martite, and serpentine. Apatite occurs as large (maximum of 20 cm diameter) acicular crystals with coarse cracks filled with breakdown products, including mica, serpentine, and martite. Intergrowths of martite, serpentine, and phlogopite, and serpentine and martite that rim apatite grains are common. Apatite may also contain microcrystals of monazite. Late-stage carbonatite, which occurs as dikes and stocks intruding the early-stage carbonatite, consists of dolomite, anhydrite, apatite, quartz, chlorite, minor barite and martite, and rare tourmaline, fluorite, and sulfate-apatite. Typically intergrowths of apatite and hematite, visually resembling jaspilite, are replaced by apatite, martite, and carbonates. Apatite in late-stage carbonatite occurs as subparallel acicular crystals in a carbonate matrix, lacks coarse cracks, and is intergrown with martite, serpentine, and phlogopite; carbonate inclusions are insignificant. The depositional environment consisted of generation of alkalic mafic magmas during rifting of cratons or cratonal terranes. An example of this mineral-deposit type is at Seligdar, Russia.

Fe-REE Carbonatite (Kim and others, 1965; Nevskiy and others, 1972; Sinyakov, 1988; Park and Hwang, 1995)

Fe-REE carbonatite deposits consist of magnetite, calcite, hematite, limonite, chalcopyrite, pyrite, siderite, rhodochrosite, apatite, REE minerals, fluorite, barite, and siderite. The deposits occur in complex featherjoint systems associated with large faults. Host rocks are alkali mafic magmas that intrude mainly gneiss-schist complexes and clastic sedimentary rocks. Hornblendite dikes occur locally (for example, Hongcheon mine, Korean Peninsula). Minerals are siderite, barite, fluorite, hematite, magnetite, bastnaesite, parisite, REE minerals, and sulfides. REE minerals also occur in siderite, barite, and fluorite. Extensive hydrothermal alteration consists of ankerite-calcite-siderite metasomatite. Ore-bearing breccia zones form steeply dipping columns. The deposit minerals form complex mixtures of magnetite, monazite, apatite, and strontianite that occur in carbonates mostly composed of Fe-rich dolomite, ankerite, and siderite with anomalous P, Sr, Nb, La, Ce, Nd, Sm, and Ba contents. Apatite is associated with magnetite, dolomite, strontianite, and barite. Also occurring is REE monazite that forms myrmekitic intergrowths with dolomite and strontianite. Minor chalcopyrite and molybdenite occur as disseminations in ore and carbonaceous host rocks. Magnetite and monazite are commonly fractured by cataclastic deformation. Pyrite is a common sulfide in alteration zones. The deposits range in structure from breccia to massive to locally banded. High Fe deposit minerals are interpreted as forming during hydrothermal replacement of argillaceous sedimentary rocks. The depositional environment consisted of generation of alkalic mafic magmas during rifting of craton or cratonal terranes. Examples of this mineral-deposit type are Karasugskoye and Ulatayskoye, Russia.

Fe-Ti (±Ta, Nb, Fe, Cu, Apatite) Carbonatite (A.A. Frolov in Pokalov, 1984; Singer, 1986a)

Fe-Ti (±Ta, Nb, Fe, Cu, apatite) carbonatite deposits consist of ferrous carbonatite spatially and genetically related to circular alkali-ultramafic plutons that tend to occur adjacent to deep fault zones. Zoned plutons are characteristic and consist of dunite, pyroxenite, jacupirangite, melteigite, ijolite, urtite, nepheline syenite, and carbonatite. Two subtypes are defined: perovskite-titanomagnetite and apatite-magnetite. The first subtype consists of pyroxenite and dunite with disseminations, branches, lenses, and veinlets of minerals, mianly titanomagnetite, perovskite, olivine, and pyroxene. The second subtype consists of magnetite, apatite, baddeleite, pyrochlore, forsterite, calcite, dolomite, phlogopite, clinohumite, zircon, and Cu-Ni sulfides. The deposits commonly occur in linear or ring-shaped veins, pipelike bodies, and stockworks that occur in both the central and in peripheral parts of plutons. The depositional environment consisted of generation of alkalic mafic-ultramafic magmas during rifting of cratons or cratonal terranes. Examples of this mineral-deposit type are Esseiy 1, Gulinskoye 1, Iriaas 1, and Kugda 1, Russia.

Phlogopite Carbonatite (Eckstrand, 1984; Epstein, 1994)

Phlogopite carbonatite deposits consist of phlogopite bodies and disseminations hosted in alkalic ultramafic plutons. Phlogopite occurs in carbonatite in association with autoreactional skarns. Both endoskarn and exoskarn occur. endoskarn consists of metasomatic ijolite and nepheline-pyroxene rock; and exoskarn consists of melonite-pyroxene, calcite-diopside, diopside-wollastonite-calcite, and calcite-magnetitem pegmatite masses. Phlogopite also occurs in (1) veins and lenses of garnet, nepheline, and pyroxene; (2) disseminations in carbonate-diopside rock; and (3) veins in dunite. The deposits are zoned with (1) a peripheral zone composed of garnet-pyroxene-nepheline pegmatoid rock; (2) a core vein zone composed of apatite-pyroxene and calcite-phlogopite rock. Phlogopite distribution is irregular. The depositional environment consisted of a carbonatite-alkali-ultramafic complex that intruded along major faults during intracraton rifting. This deposit type is associated with Fe-Ti carbonatite and REE-Ta-Nb carbonatite deposits. Examples of this mineral-deposit type are Gulinskoye 3 and Odikhincha 1, Russia.

REE (±Ta, Nb, Fe) Carbonatite (Smirnov, 1969; Nevskiy and others, 1972; Samoilov and Kovalenko, 1983; Eckstrand, 1984; Sinyakov, 1988; Epstein, 1994; Kovalenko and Yarmolyuk, 1995)

REE (±Ta, Nb, Fe) carbonatite deposits consist of stockworks, metasomatic veins, breccias, columnar bodies, and lenses of various size containing REE, Ta-Nb, and Fe minerals in complexly zoned alkalic ultramafic carbonatite igneous complexes that occur in (1) zoned pluglike stocks, (2) lopolith-type conical massifs, (3) circular or semi-circular structures, and linear dikes occurring in conical and radial faults, and (4) complexly shaped intrusions combining the three previous structures. The complexes tend to cluster near major faults. The zoned carbonatite complexes and stocks commonly contain two or more of the following rock types: pyroxenite, gabbro, urtite, ijolite, foyaite, nephelinite, alkaline syenite, carbonatite melanephelinite, melaleucitite, phonolite, trachyte, eruptive trachyte breccia with a carbonatite matrix, latite, trachybasalt, and syenite. The carbonatites generally consist of various assemblages of augite-diopside-calcite, forsterite-calcite, aegirine-dolomite, aegirine-ankerite, calcite, and ankerite. Zonation consists of a central zone of carbonatite, a medial zone of ultramafic rocks, and a peripheral zone of ijolite and nepheline syenite; the zonation sequence may be locally reversed or complex. Igneous and nearby host rocks are commonly intensively altered, along with the obscuration of the distinction between igneous and country rocks. Alteration assemblages include combinations of pyroxene, feldspar, nepheline, alkaline amphibole, ankerite, calcite, siderite, magnetite, apatite, and bastnaesite. Minerals, which occur in alkaline metasomatic rock, are pyrochlore, baddeleyite, perovskite, knopite, dysanalite, synshysite, bastnaesite, parisite, zircon, monazite, columbite, apatite, yttrialite, melanocerite, yttrotitanite, hydrothorite, siderite, barite, strontianite, fluorite, hematite, magnetite, celestine, cerrusite, apatite, monazite, and sulfides. REE's also occur in siderite, barite, and fluorite. The depositional environment consisted of intrusion of alkalic mafic magma during rifting of cratons or cratonal terranes. Examples of this mineral-deposit type are Beloziminskoye, Gornoye Ozero (fig. 22), and Gulinskoye 2, Russia, and Mushgai hudag, Mongolia.

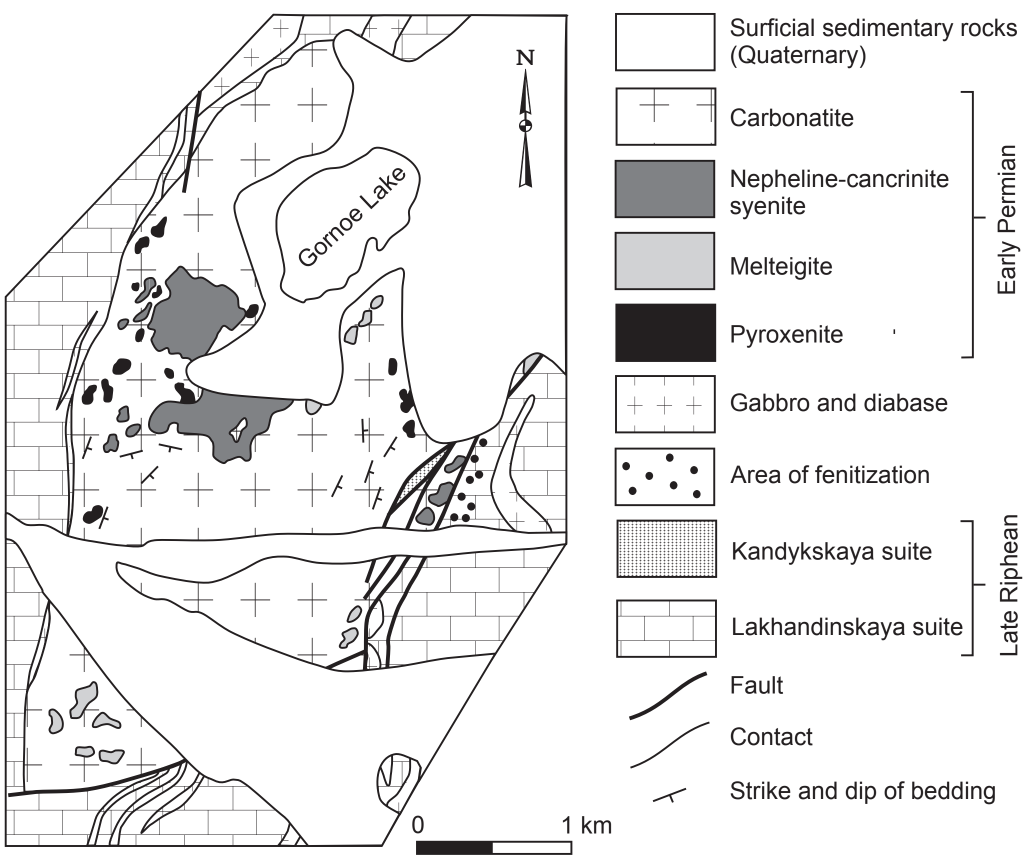


Figure 22. Generalized geologic map of the Middle Devonian through Early Carboniferous Gornoye Ozero REE (±Ta, Nb, Fe) carbonatite deposit, Russian Southeast. Adapted from Korostylyov (1982).

B. Alkaline-Silicic Intrusions-Related Deposits

Alkaline Complex-Hosted Au (Song and others, 1996; Shi and Xie, 1998)

Alkaline complex-hosted Au deposits occur in alkaline igneous complexes and peripheral country rocks. Three subtypes are defined: (1) most common Au-bearing potassic and silica-altered rocks; (2) more common, Au quartz veins associated with potassium alteration envelope; and (3) less common Au quartz veins. Minerals, which comprise less than 3 percent of the host rock, are mainly gold and pyrite, and lesser magnetite, chalcopyrite, galena, altaite, and others; gangue minerals are mainly quartz and lesser feldspar, sericite, chlorite, epidote, and others. Gold ranges in fineness ranges from 935 to 978. Wallrocks are altered to K-feldspar, silica, pyrite and sericite. The host alkaline igneous complex (for example at Dongping, Hebei Province, China) consists of alkali feldspar syenite, alkali feldspar quartz syenite, pyroxene-hornblende-alkali feldspar syenite, pyroxene-hornblende syenite, and hornblende-alkali-feldspar syenite. Alkaline complexes occur in elongated zones that typically intrude Archean metamorphic gneiss along major faults. The depositional environment consisted of intrusion of alkalic mafic magma during rifting or strike-slip faulting of cratons or cratonal terranes. Examples of this mineral-deposit type are Akalakhinskoye, Russia, Dongping (fig. 23) and Hougou Chicheng, Hebei Province, China.

Peralkaline Granitoid-Related Nb-Zr-REE (Vladykin, 1983; Kovalenko and others, 1985, 1995)

Peralkaline granitoid-related Nb-Zr-REE deposits consist of peralkaline granitic rocks containing REE-Zr-Nb minerals that generally occur in the apical parts of cupolas, generally in association with highly fractionated magmatic phases, including peralkaline pegmatite. The host granite is composed of K-feldspar, quartz, albite, arfvedsonite, aegirine, fluorite, and various REE minerals, such as elpidite, gittinsite, zircon, pyrochlore, monazite, REE fluorcarbonate, and polylitihonite. Alteration consists of replacement by epidote, orthoclase, and postmagmatic albite. The deposits are generally hosted in microcline-albite granite and metasomatic rocks composed of quartz, albite, pyroxene, and microcline. Quartz-epidote metasomatite contains zircon, fergusonite, allanite, chevkinite and titanite in veinlike zones; fergussonite and zircon with REE's and Y also occur. Accessory minerals are amphibole, magnetite, zircon, epidote, ilmenite, fluorite, beryl, chevkinite, pyrite, and galena. Associated deposit types are REE pegmatite and quartz-fluorite veins. The depositional environment consisted of intrusion of peralkaline granitic rock into miogeoclinal or island arc assemblages. Examples of this mineral-deposit type are Ulaantolgoi, Mongolia and China, and Baerzhe, Inner Mongolia, China.

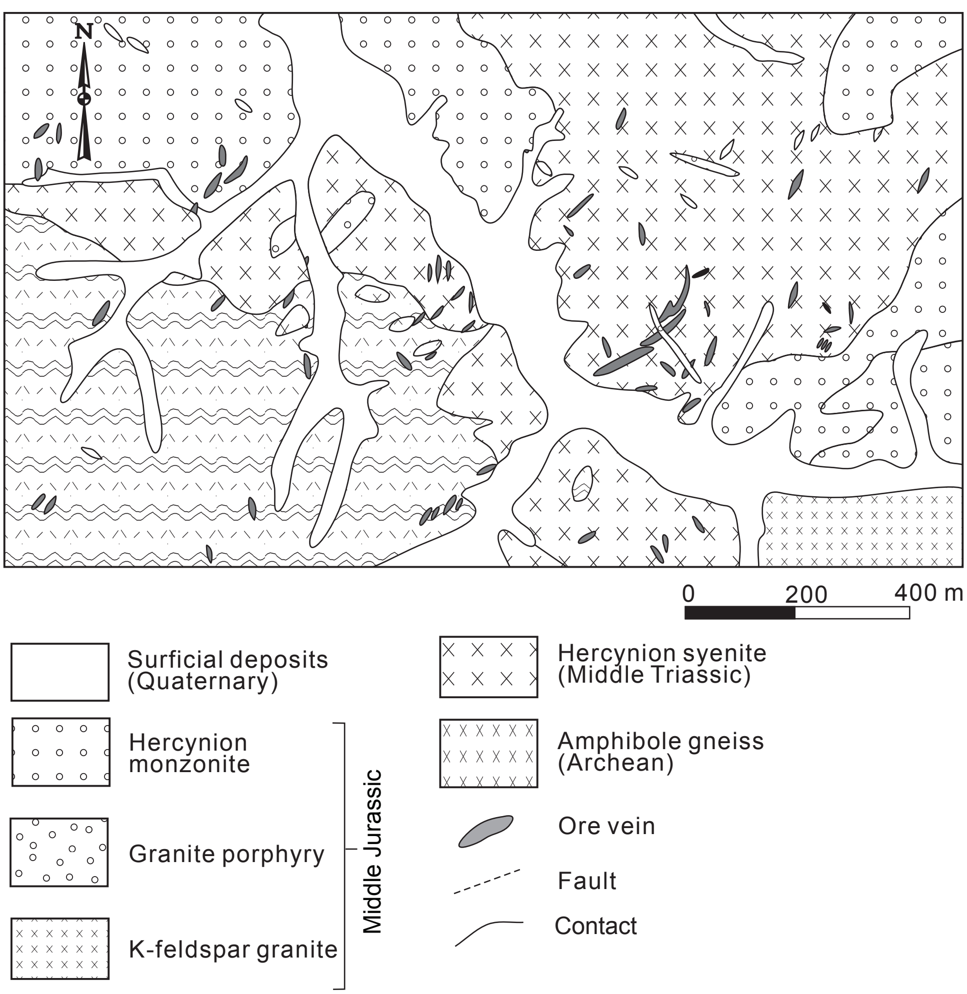


Figure 23. Generalized geologic map of the Middle Jurassic Dongping alkaline complex-hosted Au deposit, northern China. Adapted from Song and Zhao (1996).

Albite Syenite-Related REE (Andreev and others, 1994; Kempe and others, 1994; Kovalenko and Yarmolyuk, 1995)

Albite syenite-related REE deposits occur in (1) endocontacts of alkaline plutons composed of metasomatically altered alkaline syenite (nordmarkite) and (2) peralkaline volcanic rocks (comendite, pantellerite, peralkaline trachydacite, trachyrhyolite and trachybasalt) intruded by REE-albite nepheline syenite. Minerals are various REE-Zr-Nb minerals. An example of this deposit type is at Maikhan Uul, Mongolia.

Ta-Li Ongonite (Kovalenko and others, 1971; Kovalenko and Kovalenko, 1986)

Ta-Li ongonite deposits are subdivided into volcanic and plutonic facies. The igneous rocks are porphyritic with phenocrysts of albite, quartz, K-feldspar, topaz, and Li-fengite in a fine-grained matrix of REE minerals. Main minerals contain Ta, Rb, Nb, Be, Li, and Sn. Plutonic ongonite is rich in Ta (maximum of 130 ppm with an average concentration of 88 ppm), and Li (average concentration of 2,780 ppm), and Rb (average concentration of 2,380 ppm). Volcanic ongonite (for example, Teg Uul, Mongolia) contains less REE's (average concentrations of 37 ppm Ta, 170 ppm Nb, 1,040 ppm Rb, and 90 ppm Be) and occurs in large bodies, including volcanic cones, stratified bodies, and sheets. Igneous rocks contain an average of 0.05 to 0.8 percent Li, 0.5 to 5.0 percent Zr, and 0.3 to 4.5 percent REE. High Li, Be, Sn, and Zn contents are characteristic. The Teg Uul deposit, Mongolia, is large (over 1 km^2) and composed of a tuff unit that ranges from 10 to 20 m in thickness. Associated rocks are late Mesozoic rhyolite and ongorhyolite that occur in volcanic necks. Other examples of this mineral-deposit type are Ulkanskoe, Russia, and Ongon Khairkhan, Mongolia.

C. Alkaline-Gabbroic Intrusion-Related Deposits

Charoite Metasomatite (Konev and others, 1996)

Charoite metasomatite deposits consist of breccia-like, veinlike, stratified bodies of charoite hosted in Archean and Proterozoic fenitized gneiss, quartz sandstone, and dolomite. Charoite is interpreted as having formed during the final intrusive stage of ultrapotassic alkaline syenite; however, interpretations vary about its genesis. One interpretation is a metasomatic origin and the other interpretation is magmatism that resulted in charoite metasomatic replacement of host rocks Mineral composition is diverse, ranging from almost monomineralic charoite to complex mixtures of aegirine, pectolite, K-feldspar, quartz, tinaksite, fedorite, canasite, and calcite. As many as 50 minerals are known in the deposits. Morphology consists of dense monoliths with shell-like fractures, pegmatoid, coarse-crystalline, schistose, and gneissic. Charoite ranges in color from purple to brown, and to colorless. Charoite composition is similar to canasite and the chemical formula is $(Na, K)_5Ca[(OH,F)_3]Si_{10}O_{25}$ with Ba and Sr. The only example of this mineral-deposit type is at Murunskoe, Russia.

Magmatic and Metasomatic Apatite (Arkhangelskaya, 1964; Litvinovsky and others, 1998)

Magmatic and metasomatic apatite deposits consists of two subtypes: magmatic deposits and metasomatic apatite deposits. The first subtype occurs in sheeted plutonic or stratiform complexes with alternating, conformable lenses, plates, and dikes that are composed of medium- and coarse-grained alkaline gabbro, melanocratic alkaline gabbro, or alkaline-feldspar syenite. Apatite is concentrated in alkaline gabbro (average 4 percent P_2O_5) and forms equally spaced tabular grains, short prisms, needles, discrete cumulate minerals, poikilitic inclusions in pyroxene and amphibole, phenocrysts in microgabbro dikes, and lenses and nests with hornblende and titanomagnetite. Hornblende-feldspar pegmatite also occurs with numerous apatite inclusions. Host rocks for the intrusions are commonly gneissic granite and gneiss.

The second subtype consists of large metasomatite zones in zoned plutons of alkaline nepheline syenite and pseudoleucite syenite containing as much as 19 percent K_2O and 23 percent Al_2O_3. The metasomatite mainly occurs along syenite contacts and in linear fracture zones. Early stage melanocratic metasomatite consists of ijolite, fayalite, and micaceous shonkinite. The melanocratic metasomatite bodies varies from several meters, to dozens to hundreds of meters thick and from dozens to hundreds of kilometers long. Melanocratic metasomatite is enriched in Ca, Mg, Fe, and P with a high apatite content of 3 to 10 percent. Apatite is unevenly distributed; deposits rich in apatite consist of pyroxene, biotite, apatite, orthoclase, nepheline, plagioclase, magnetite (locally up to 10 to 20 percent), and sphene. Apatite content ranges from 5 to 10 to 80 percent. Apatite-rich areas, as much as several dozen square meters in area, occur in synnyrite that contains mainly apatite with lesser orthoclase, biotite, pyroxene, and magnetite. The depositional environment of both subtypes consisted of intrusion of alkaline syenite magma during rifting or strike-slip translation of cratons or cratonal terranes. Examples of this mineral-deposit type are Murunskoe, Oshurkovskoye, and Synnyrskoye, Russia, and Fanshan, Hebei Province, China.

Magmatic Graphite (Lobzova, 1975; Eremin, 1991)

Magmatic graphite deposits consist of masses of graphite in alkaline plutonic rocks, including syenite and nepheline syenite. The graphite occurs in irregular lenses, stocks, and veins. The host rock limestone forms complex xenoliths in the marginal parts of the alkaline plutons. Altered rock is skarn and fenite that occur in, or adjacent to contact zones. Banded deposit minerals consist of alternating graphite and graphite-pyroxene-calcite layers; associated minerals include feldspar, apatite,and aegirine. Examples of this mineral-deposit type are Kureiskoye 2, Russia, Guangyi, Muling, and Yangbishan, Heilongjiang Province, China.

Magmatic Nepheline (A.N. Sucharina, in Kuznetsov, 1982)

Magmatic nepheline deposits consist of high-grade nepheline minerals hosted in alkalic gabbro that intrudes orogenic zones and accreted terranes. The deposits and intrusive host rocks occur along or adjacent to major fault zones. Host rocks for the ore-bearing intrusions are mainly carbonates and carbonaceous pyroclastic rocks. Minerals are urtite containing as much as 90 percent nepheline that occur in dikes and complex alkalic gabbro plutons; associated minerals are titanaugite and lesser apatite, aegirine-augite, titanomagnetite, and pyrrhotite. Examples of this mineral-deposit type are Dahu-Nurskoye and Kharlinskoye, Russia, and Beltesin gol, Mongolia.

IV. Deposits Related to Marine Extrusive Rocks

A. Massive Sulfide Deposits

Besshi Cu-Zn-Ag Massive Sulfide (Cox, 1986c; Slack, 1993, M. Ogasawara, this study)

Besshi Cu-Zn-Ag massive sulfide deposits consist of thin sheets of massive to well-laminated pyrite, pyrrhotite, chalcopyrite and sphalerite, and sulfides with lesser magnetite, galena, bornite, and tetrahedrite. Gangue minerals are quartz, carbonates, albite, white mica, and chlorite. The deposits occur in thick sequences of clastic sedimentary rocks and intercalated basalt, which is volumetrically subordinate to the sedimentary rocks. Thinly laminated chert and black shale occur locally. Wallrocks may include sericite and chlorite schist, coticule, tourmalinite, and albitite lenses that commonly form stratabound bodies or envelopes around massive sulfides, and may extend as much as 5 to 10 meters into adjacent host rocks. Coticule, tourmalinite, and albitite lenses may occur as stratiform layers that extend laterally for hundreds of meters beyond the massive sulfide deposit. Wallrocks exhibit hydrothermal alteration and (or) chemical sedimentation that was coeval with deposition of the massive sulfides. Alteration is sometimes difficult to recognize because of subsequent metamorphism. The deposits typically consist of stratiform lenses and sheetlike accumulations of semi-massive to massive sulfides. Footwall feeder zones may occur. The type example is the Besshi deposit in southwestern Japan that occurs in the Sambagawa metamorphic terrane. The depositional environment consisted of submarine hot springs related to the deeper zones of submarine basaltic volcanism along spreading oceanic ridges or backarc spreading centers, possibly in areas where a spreading oceanic ridge occurs near a continental margin that is supplying clastic detritus. Examples of this mineral-deposit type are Besshi (fig. 24), Iimori, Kune, Makimine, Minenosawa, and Shimokawa, Japan.

Cyprus Cu-Zn Massive Sulfide (Eckstrand, 1984; Singer, 1986b)

Cyprus Cu-Zn massive sulfide deposits consist of massive sulfides in submarine, predominantly mafic tholeiitic or calc-alkaline volcanic rocks that occur in ophiolite sequences or greenstone belts. Minerals are mainly pyrite, chalcopyrite, and sphalerite, and lesser marcasite and pyrrhotite. Sulfides occur in pillow basalt associated with tectonized dunite, harzburgite, gabbro, sheeted diabase dikes, and fine-grained sedimentary rocks that form part or all of an ophiolite assemblage. Locally beneath massive sulfide bodies is a stockwork composed of pyrite, pyrrhotite, minor chalcopyrite, and sphalerite. Some sulfides may be brecciated and recemented. Alteration in the stringer zone consists of abundant quartz, chalcedony, chlorite, and lesser illite and calcite. Some deposits are overlain by Fe-rich and Mn-poor ochre. The depositional environment consisted of submarine hot springs along an axial graben in oceanic or backarc spreading ridges, or hot springs related to submarine volcanoes in seamounts. Examples of this mineral-deposit type are Mainskoye, Russia, Nergui, Mongolia, and Okuki, Japan.

Volcanogenic Cu-Zn Massive Sulfide (Urals type) (Borodaevskaya and others, 1985)

Volcanogenic Cu-Zn massive sulfide (Urals type) deposits consist of massive to disseminated Zn-Cu sulfide minerals hosted in island-arc volcanic belts. The volcanic rocks consist of bimodal rhyolite and basalt, andesite, dacite, and rhyolite with subordinate felsic rocks. Ore-controlling structures are volcanotectonic depressions, calderas, domes, and synvolcanic faults. The most widespread are lens-shaped deposits that are concordant with host rocks. Less abundant deposits are funnel-shaped or T-shaped deposits. Apophyses of massive sulfides in lenses in footwalls may grade downward into discordant stringers. Multilevel deposits are typical. Minerals are mainly pyrite, chalcopyrite, and sphalerite with minor galena, tennantite, tetrahedrite, and bornite; gangue minerals are quartz, sericite, chlorite, and carbonate. The volcanic and sedimentary host rocks are widely altered. The root-zones consist of sericite-quartz metasomatite grading upward and outward into quartz-sericite-chlorite and quartz-carbonate-sericite-chlorite with albite and epidote zones. Silica, epidote, and hematite alterations are widespread above deposits. Sulfides are zoned with Cu and Zn enrichment from footwall to hanging-wall and from core to periphery. Most minerals are massive but locally may be banded or brecciated, or may occur in stringers on the flanks of deposits. Formation of thick gossan in weathering zones of deposits is typical. The depositional environment consisted of an ensimatic island arc constructed on oceanic crust containing differentiated basalt and other volcanic rocks. The deposit type is a variant of Cyprus Cu-Zn massive sulfide deposits. Examples of this mineral-deposit type are Khariuzikhinskoye 1, Russia, and Borts Uul, Mongolia.

Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) (Lambert and Sato, 1974, Jakovlev, 1978; Singer, 1986c)

Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) deposits consist of Zn-Pb-Cu massive sulfides hosted in marine felsic to intermediate-composition volcanic, pyroclastic, and bedded volcanic and sedimentary rocks.

The deposits consist typically of massive stratiform and stockwork parts. The massive stratiform part is typically oval shaped in plan view and is underlain by a stockwork part; the stockwork part is typically funnel shaped, commonly occurs in silicified rhyolite, and is interpreted as a feeder zone for hydrothermal fluids. From stratigraphic bottom to top, the deposits are characterized by the following zones: (1) siliceous stockwork ore (pyrite-chalcopyrite-quartz), (2) yellow ore (stratiform pyrite-chalcopyrite), (3) black ore (stratiform sphalerite-galena-chalcopyrite-pyrite-barite), (4) barite ore, and (5) thin beds of ferruginous chert. Lenticular or irregular masses of gypsum and (or) anhydrite may also occur. Main minerals are pyrite, sphalerite, galena, chalcopyrite, and lesser tennantite, tetrahedrite, bornite, electrum, stromeyerite, argentite, native silver, and enargite; other minerals are barite, gypsum, anhydrite, calcite, dolomite, quartz, chlorite, and sericite. The stratigraphic footwall and locally the stratigraphic hanging wall are hydrothermally altered. Sericite, montmorillonite, and Mg-chlorite alteration envelops stratiform deposits. Associated with the stockwork

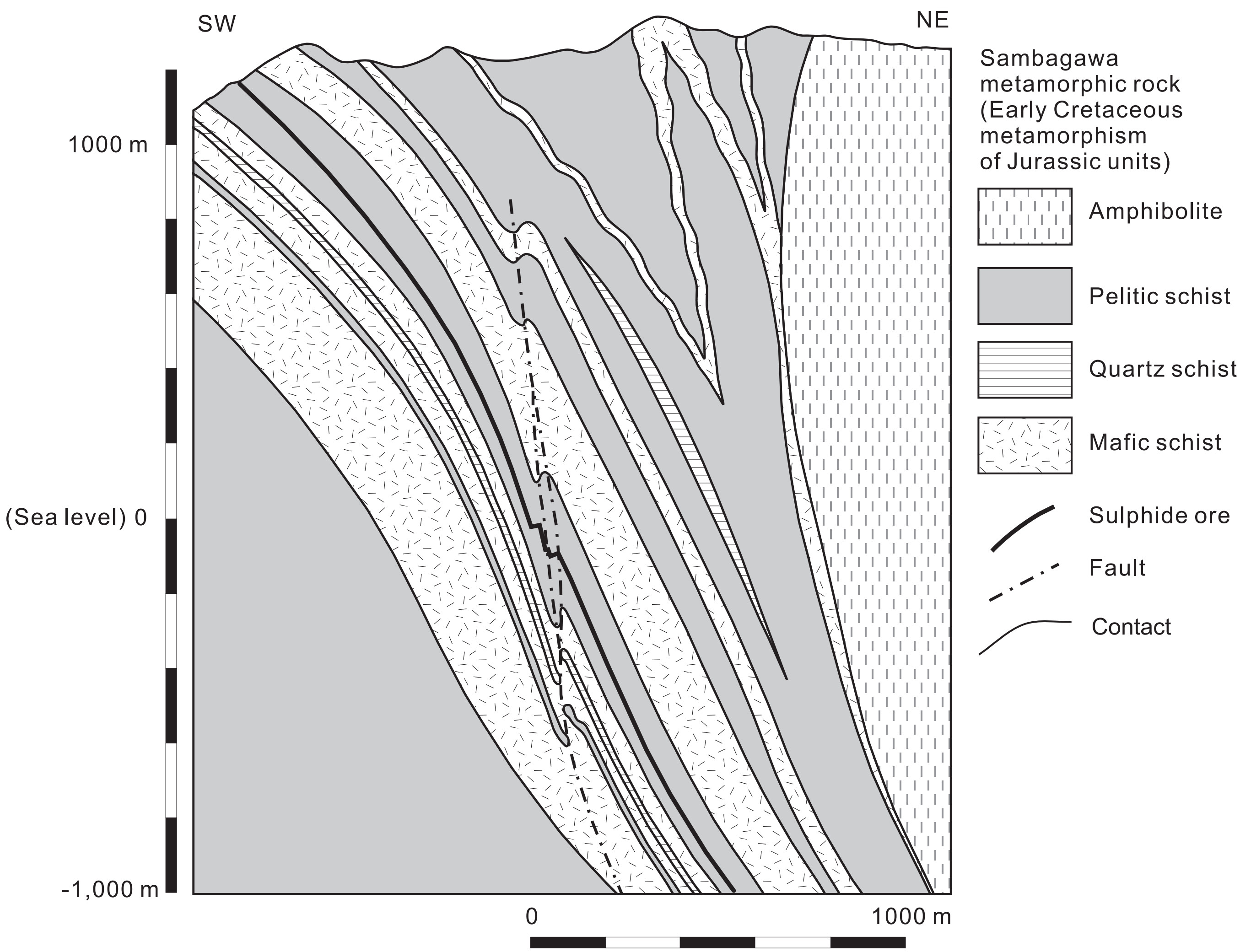


Figure 24. Generalized geologic map of the Early Jurassic through Campanian Besshi Cu-Zn-Ag massive sulfide deposit, Japan. Adapted from Sumitomo Metal Mining Co. (1981).

is quartz, sericite, and Mg-chlorite alteration. The Kuroko-type deposits in the Hokuroku area, northeastern Japan, formed in the middle Miocene during backarc rifting. The depositional environment consisted of discharge of solutions from high temperature submarine hydrothermal systems onto or near the sea floor along continental-margin or island arcs or backarc basins; discharge sites were fracture controlled. Examples of this mineral-deposit type are Khotoidokh and Korbalihinskoye (fig. 25), Russia.

B. Volcanogenic-Sedimentary Deposits

Volcanogenic-Hydrothermal-Sedimentary Pb-Zn, (±Cu) (Distanov, 1977; Distanov and others, 1982a,b; Eckstrand, 1984)

Volcanogenic-hydrothermal-sedimentary Pb-Zn, (±Cu) deposits consist of massive to stratiform Pb-Zn sulfide deposits of hydrothermal-sedimentary origin hosted in basinal assemblages of clastic, volcanic, and carbonates that are intruded by shallow basaltic magmas. Sulfides occur in basins in rhythmic, multistage sheets or layers that are hosted in tuffaceous, clastic, carbonate, and black shale. The deposits exhibit lateral and concentric zoning, massive to layered structures, and little or no wallrock hydrothermal alteration. Mineral aggregates are well laminated and consist of fine-grained quartz and sulfides, or quartz, siderite, and sulfides. The sulfides are Pb-Zn-rich, with little or no Cu. Main minerals are pyrite, sphalerite, galena, minor chalcopyrite arsenopyrite, tetrahedrite, burnonite, and pyrrhotite; gangue minerals are quartz, siderite, calcite, and ankerite. Rhythmic layers are typical, and sedimentary sulfide breccia is locally widespread. Two subtypes are defined: slightly metamorphosed (Ozernoje type) and highly metamorphosed (Kholodninskoje type). Metamorphism resulted in recrystallization and partial redistribution of minerals and

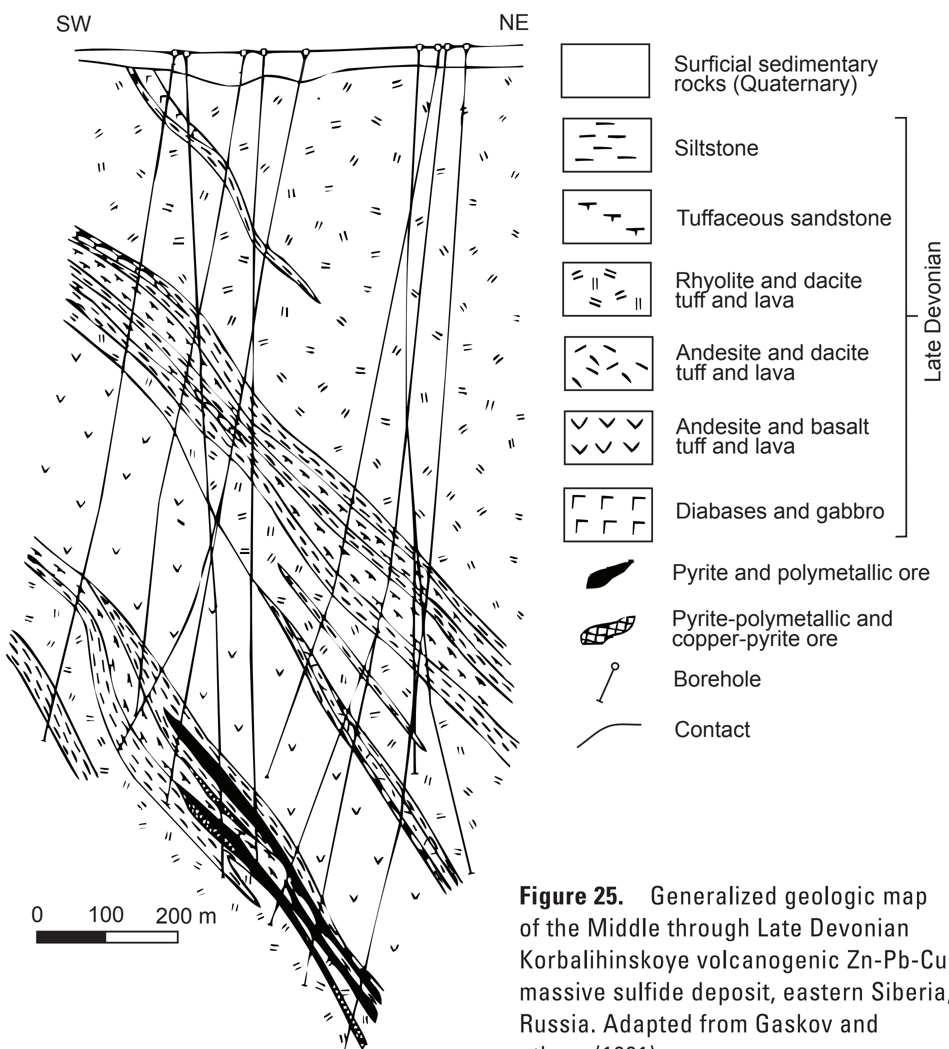
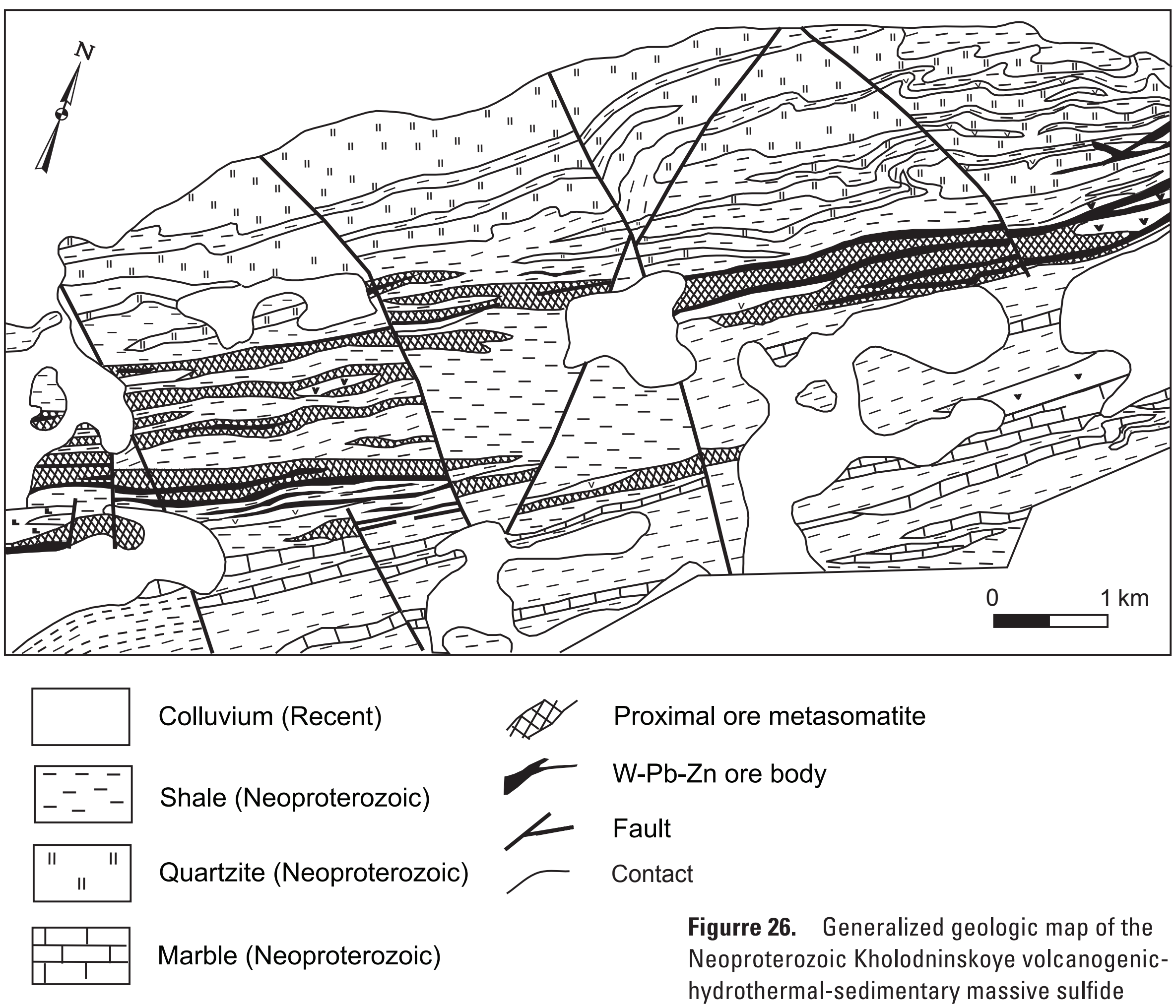


Figure 25. Generalized geologic map of the Middle through Late Devonian Korbalihinskoye volcanogenic Zn-Pb-Cu massive sulfide deposit, eastern Siberia, Russia. Adapted from Gaskov and others (1991).

changes in texture and structures but did not significantly influence the scale of deposit. The depositional environment consisted of either continental-margin rifting or intra-island-arc basins. Deep-seated faults are interpreted having formed conduits for mafic magmatism and hydrothermal systems. Basinal depressions are a deposit control and also resulted in burial of the deposits. Examples of this mineral-deposit type are Kholodninskoye (fig. 26) and Ozernoye 2, Russia, and Xiaoxilin, Heilongjiang Province, China.

Volcanogenic-Sedimentary Fe (Eckstrand, 1984; Sinyakov, 1988)

Volcanogenic-sedimentary Fe deposits consist of sheeted magnetite-hematite accumulations in volcanogenic and sedimentary sequences. The deposits are stratiform, and beds of iron formation are interlayered with volcanic rock, greywacke, and shale. The deposits occur from near to far from extrusive centers in submarine volcanic belts associated with deep fault systems and rift zones. The volcanic rocks are mainly siliceous with lesser mafic rocks, including rhyolite, siliceous porphyry, trachyrhyolite, trachyandesite, and basalt that are interlayered with pyroclastic, sedimentary, and siliceous exhalative rocks and metamorphic analogs. Main minerals are magnetite, hematite, siderite, Mn-siderite, pyrite, and pyrrhotite; associated minerals are chert, quartz, Fe-silicates, Fe-carbonates, chlorite, amphibole, biotite, feldspar, and chalcopyrite. Mineral distribution is a function of primary sedimentary facies. Oxide, silicate, carbonate, and sulfide facies commonly consist of thin, alternating layers or beds of silica and Fe-rich minerals interbedded with clastic sedimentary and volcanic rocks. Two subtyptes are defined: unmetamorphosed hematite-magnetite and metamorphosed



Figurre 26. Generalized geologic map of the Neoproterozoic Kholodninskoye volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn(±Cu), TransBaikal, Russia. Adapted from Distanov and others (1982).

actinolite-magnetite. Metamorphic-mineral assemblages reflect the mineralogy of primary sedimentary facies. Some studies of the Fe skarn deposits in Altai-Sayan, Russia, and elsewhere suggest metamorphic derivation from volcanogenic-sedimentary Fe deposits. The depositional environment consisted of eruption of siliceous with lesser mafic volcanic rock in fault-controlled marine basins associated with island arcs, backarcs, or rifts. Examples of this mineral-deposit type are Belokitatskoye, Eloguiskoye, Gar, Kholzunskoye, Turukhanskoye, and Udorongovskoye, Russia.

Volcanogenic-Sedimentary Mn (Watanabe and others, 1970; Varentsov and Rakhmanov, 1978; Koski, 1986)

Volcanogenic-sedimentary Mn deposits consist of sheets and lenses of braunite, hausmannite, rhodochrosite, and oxidized braunite intercalated with shale, chert, jasper, limestone, marine basalt flows, mafic tuff, spilite, and siliceous keratophyre. The mafic volcanic host rocks differ from normal tholeiitic basalt in their relatively higher content of K, Na, and Ti. The deposits generally occur in sequences with abundant chert and sedimentary rocks, rather than in sequences dominated by volcanic rock; are commonly associated with volcanogenic Fe deposits; and may contain complex oxidized ferromanganese minerals. Abundant secondary Mn oxides (todorokite, psilomelane, amorphous MnO_2) typically occur at the surface and along fractures. Deposits in Japan are mainly hosted in chert in a Jurassic accretionary-wedge complex and do not contain volcanic rocks; however, a volcanogenic-sedimentary origin is interpreted. The depositional environment consisted of marginal basins associated with island arcs or young intraplate rift basins. Examples of this mineral-deposit type are Bidzhanskoe (Kabalinskoe), Mazulskoye, and Usinskoye, Russia, and Saihangol, Mongolia.

V. Deposits Related to Subaerial Extrusive Rocks

A. Deposits Associated with Mafic Extrusive Rocks and Dike Complexes

Ag-Sb Vein (Borisenko and others, 1992)

Ag-Sb vein deposits consist of siderite and quartz-siderite veins and vein systems containing Ag-sulfosalts hosted in carbonaceous clastic black shale sequences that are commonly contact metamorphosed. The main minerals are Sb-, Cu-, Pb-, and Ag sulfosals, including tetrahedrite, freibergite, schwatzite, chalcostibite, zinkenite, jamesonite, boulangerite, and Bi sulfosalts, chalcopyrite, antimony, arsenopyrite, and pyrite. The main gangue minerals are siderite, quartz, calcite, ankerite, barite, and fluorite. Associated carbonate and argillic alteration may have occurred. The depositional environment consisted of accumulation of black shale near fault-controlled basins and backarc basins in interplate rift zones. The mineral deposit type is commonly associated with epithermal vein deposits. Examples of this mineral-deposit type are Kyuchyus, Russia, and Asgat, Mongolia (fig. 27).

Basaltic Native Cu (Lake Superior type) (Lee and Kim, 1966; Eckstrand, 1984; Kutyrev, 1984; Cox, 1986b)

Basaltic native Cu (Lake Superior type) deposits consist of stratabound disseminated Cu minerals in basalt lava erupted into shallow coastal-marine basins, and less onto subaerial oceanic volcanic islands. The volcanic rocks are generally interbedded with red sandstone, conglomerate, and siltstone. The basalt is generally potassic or alkalic and may include shoshonite and trachybasalt. Major minerals are native copper, chalcocite, bornite, chalcopyrite, and native silver, both in the matrix of, and as amygdules in the porous roofs of basalt flows, and in veinlets within the basalts. Minerals occur as disseminations, stringers, lenses, and irregular patchy accumulations. Wallrocks are altered mainly to epidote, calcite, chlorite, and zeolite. The largest deposits generally are concordant or peneconcordant and occur along specific rock types, such as amygdaloidal flow-top breccia, pyroclastic tuff and breccia, and interlayered conglomerate, carbonaceous sandstone, and siltstone; smaller deposits occur as veins or irregular stringer zones in fissures and faults, and in fault breccias. The depositional environment consisted of continental, rift-related, flood-basalt sequences, and continental-margin and island arcs. This mineral-deposit type is commonly associated with sediment-hosted Cu deposits. Examples of this mineral-deposit type are Arylakhskoye, Russia, and Zuunturuu gol, Mongolia.

Hg-Sb-W Vein and Stockwork (Scheglov, 1959; Borovkov and Gaivoronsky, 1995)

Hg-Sb-W vein and stockwork deposits consist of small veins and stockworks of low-temperature, hydrothermal chalcedony-like quartz, and ferberite-scheelite, stibnite, and cinnabar. The deposits occur in Neoproterozoic and Paleozoic metamorphic rocks (shale and quartzite) along major fractures or crosscutting faults in schist, in platy stockwork with pseudostratification. The deposits occur far from intrusive bodies and are associated with deep faults along the edges of late Mesozoic intermountaine basins, or are associated with Late Cretaceous explosive extrusive siliceous volcanism. Minerals are ferberite and local stibnite, cinnabar, scheelite, pyrite, chalcopyrite, sphalerite, siderite, fluorite, native sulfur, and lesser pyrolusite; gangue minerals are chalcedony-like quartz, fine-grained quartz, and hydromica. Three subtypes are defined: (1) ferberite, stibnite, and cinnabar; (2) scheelite; and (3) stibnite and ferberite. The deposit textures are breccia, kidney-shaped, colloform, and banded. Scarce hydromica wallrock alteration may occur. Examples of this mineral-deposit type are Ryushoden and Yamatosuigin, Japan.

Hydrothermal Iceland Spar (Kievlenko, 1974)

Hydrothermal Iceland spar deposits consist of low temperature hydrothermal Iceland spar that occurs in crystalline

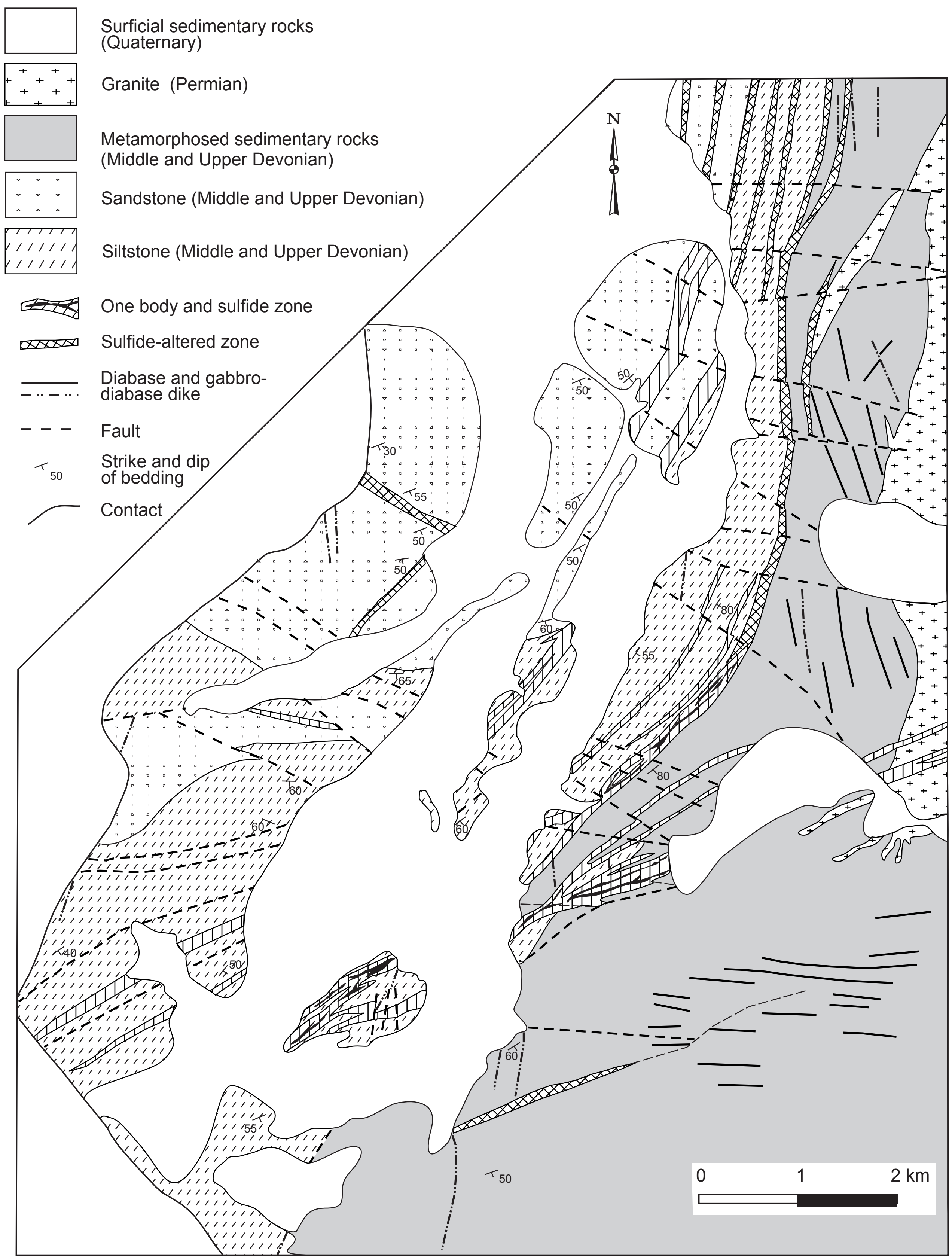


Figure 27. Generalized geologic map of the Early and Middle Jurassic Asgat Ab-Sb vein deposit, Mongolia. Adapted from Borisenko and others (1986).

masses in traps in pillow basalt, amygdaloidal basalt, tuffaceous rocks and subvolcanic dolerite. Iceland spar occurs in cavities, fractures, and fissures in basalt and dolerite, and in fractures in tuff; associated minerals are zeolite, analcite, chalcedony, chlorite, montmorillonite, and hydromica. Alteration to chlorite and montmorillonite may occur. Examples of this mineral-deposit type s are Khrustalnoye and Skala Suslova, Russia.

Ni-Co Arsenide Vein (Krutov, 1978; Borisenko and others, 1984; Eckstrand, 1984)

Ni-Co arsenide vein deposits consist of carbonate and quartz-carbonate-chlorite veins containing Ni-Co arsenides and Cu, Bi, and Ag sulfosalts. Another name is five-metal (Ag-Co-Ni-Bi-U) arsenide ore association. The deposits occur along steeply dipping vein and vein systems in deep-seated faults and conjugate fractures in association with basalt and alkalic basalt dikes. Host rocks are mainly siltstone, shale, schist, mafic and felsic volcanic rocks, contact metamorphic rocks, and relatively older mafic and ultramafic granitoids. Minerals are Ni-Co-Cu-Ag-Bi arsenides, sulfoarsenides, and sulfosalts including skutterudite, smaltite, chloanthite, safflorite, rammelsbergite, nickeline, gersdorfite, argentite, and native silver; gangue minerals are dolomite, calcite, ankerite, quartz, barite, fluorite, and chlorite. Two subtypes are defined: Ni-Co arsenide and Cu-Co sulfoarsenide-sulfosalt. The first subtype exhibits colloform and incrustate structures, and the second subtype exhibits disseminated and streaky-disseminated structures. Minor zones of talc-carbonate-chlorite alteration, and quartz-carbonate-hydromica metasomatic alteration occur in the wallrock. The depositional environment consisted of hydrothermal fluids ascending deep faults and fractures in intraplate areas undergoing tectonic and magmatic reactivation. Examples of this mineral-deposit type are Hovu-Aksinskoye, Russia, and Teht, Mongolia.

Silica-Carbonate (Listvinite) Hg (Kuznetsov, 1974; Obolenskiy, 1985; Rytuba, 1986b)

Silica-carbonate (listvinite) Hg deposits consist of cinnabar and associated minerals along contacts of serpentinite, siltstone, graywacke, and limestone that occur in major thrust zones. Minerals are mainly cinnabar, stibnite, pyrite, realgar, orpiment, arsenopyrite, and some Ni and Co minerals; gangue minerals are mainly dolomite, breunnerite, and ankerite in association with quartz, calcite, dickite, fuchite, and talc. The deposits occur in masses, veins, and disseminations in irregular lenses, in veins in crush breccia and mylonite zones, and in adjacent sedimentary rocks. Cinnabar is closely associated with silica-carbonate (listvinite) and argillic alteration. The depositional environment consisted of zones of thrust faults containing lenses of serpentinite, ultramafic rocks, and graywacke. The deposits generally occur in subduction-zone terranes and are commonly reactivated by younger interplate movement. Examples of this mineral-deposit type are Chagan-Uzunskoye and Krasnogorskoye 1, Russia.

Trapp-Related Fe Skarn (Angara-Ilim type) (Mazurov and Bondarenko, 1997)

Trapp-related Fe skarn (Angara-Ilim type) deposits consist of magnesian magnetite skarn formed during mafic trapp magmatism. The deposits occur mainly in the North Asia craton in connection with late Paleozoic and early Mesozoic tectonism and magmatism. Spatial distribution of the deposits is controlled by deep basement faults, trapp magmatic centers, and occurrence of dolomite and evaporate sequences in lower parts of the crust. The occurrence of evaporite and Ca-Na brines are important. Four subtypes are defined: (1) steeply dipping ore shoots containing brecciated skarn in diatreme, (2) gently dipping, stratabound deposits occurring under dolerite sills and interlayered sills in calcareous rock, (3) steeply dipping veins, and (4) layered deposits in caldera depressions. The main deposits occur in explosion pipes that extend to depths of 1,000 to 1,200 m. Calc-silicate and Mg-silicate skarn are widespread, along with epidote, chlorite-amphibole, serpentine-chlorite, and calcite metasomatite. The main part of magnesian magnetite deposits is associated with hydrothermal alteration. The deposits contain halite, anhydrite, typical oolitic hematite, and magnetite that occur in lenses in massive and banded ore. The depositional environment consisted of intrusion of Trapp-related mafic magma into evaporate horizons with brine. Examples of this mineral-deposit type are Kapaevskoye, Korshunovskoe, Nerjundinskoye, and Rudnogorskoe, Russia.

B. Deposits Associated with Felsic to Intermediate Extrusive Rocks and Dike Complexes

Au-Ag Epithermal Vein (Berger, 1986a; Mosier and others, 1986b; Park and others, 1988; Sillitoe, 1993a; Yurgenson and Grabeklis, 1995; Hedenquist and others, 1996; Nokleberg and others, 1997; Rodionov and Khanchuk, 1997; Yan and others, 2000)

Au-Ag epithermal vein deposits consist of gently to steeply dipping quartz veins, stockworks, and disseminations hosted mainly in volcanic rocks. Associated igneous rocks are commonly subaerial, calc-alkaline, volcanic rock (andesite, dacite, and rhyolite, as well as porphyritic shoshonite dikes or alkalic igneous rocks in continental-crustal sequences (> 20 km thick) and in island arcs. Two subtypes are defined - low sulfidation Au-Ag epithermal vein and high sulfidation Au epithermal vein. The subtype includes the Comstock Au, Creede, and Sado epithermal vein deposits, which contain electrum, native gold, pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, arsenopyrite, tellurides, and pyrargyrite; gangue minerals are quartz, adularia, illuite, calcite, and chalcedony. Fine-grained chalcedony-like quartz, grading into chalcedony, occurs in laminated and thin-banded colloform textures. The deposits are typically open-space-filling veins. Hydrothermal alteration adjacent to veins consists of illite and smectite. The deposits are interpreted as having formed from low sulfidation hydrothermal solutions with a neutral pH.

The second subtype contains disseminated native gold, pyrite, and enargite-luzonite that occur in silicified (vuggy) quartz bodies and in zones of quartz-alunite (advanced argillic) alteration and replacement. Other deposit minerals are precious-metal tellurides, covellite, tennantite, tetrahedrite, chalcopyrite, sphalerite, and galena. The occurrence of high-sulfidation sulfosalts, such as enargite and luzonite, and relatively high sulfidation tennantite characterizes this subtype. Replacements are also common. Gangue minerals are mainly quartz, alunite, kaolinite, pyrophyllite, diaspore, illite, and barite that also occur in peripheral alteration zones. The deposits are interpreted as having formed from acidic and oxidized hydrothermal fluids. Closely related mineral-deposit types are epithermal quartz-alunite Au, acid-sulfate Au, and enargite Au.

Locally, Au-Ag epithermal vein deposits may occur in volcanic-tectonic grabens associated with strike-slip faults. Associated porphyry deposits may occur. The deposits may be overlain by either barren areas, acid-leached zones, or silicified horizons. The deposits are associated with felsic volcanic centers that formed over sedimentary rocks or older volcanic and plutonic rocks. The depositional environment consisted of subduction-related continental-margin or island arc generally within 100 km of active volcanic fronts. Subduction-related magmatism and associated hydrothermal activity tended to shift trenchward over time. Examples of this mineral-deposit type are Chaganbulagen and Erentaolegai, Inner Mongolia, China; and Hishikari (fig. 28), Konomai, Kushikino, and Sado, Japan.

Ag-Pb Epithermal Vein (Batjargal and others, 1997; Dorjgotov and others, 1997)

Ag-Pb epithermal vein deposits consists o quartz-sulfide veins and mineralized zones in various rock types intruded by mafic dikes. The deposits extend along strike for several hundreds meters, extend downdip to 300 m, and are as much as several tens of meters thick. Two subtypes are defined: quartz-carbonate-sulfide and carbonate-sulfide. Major minerals are galena, arsenopyrite, stibnite, and Ag minerals, with subordinate chalcopyrite, sphalerite, cinnabar, and pyrite. Gangue minerals are quartz, siderite, chalcedony, kaolin, calcite, barite, and fluorite. Main wallrock alterations are quartz, chalcedony, kaolinite, and chlorite. The deposits exhibit three major stages: quartz-galena, quartz-fluorite, and quartz-carbonate. The depositional environment consisted of intrusion of mafic dikes along active, deep-seated faults in areas of rifting of continental-margin arcs. Examples of this mineral-deposit type are Boorch and Dulaan khar uul, Mongolia.

Au K-Metasomatite (Kuranakh type) (Kazarinov, 1967; M.B. Boradoevskaya and I.S. Rozhkov in Smirnov, 1974; Fredericksen, 1998; Fredericksen and others, 1999)

Au potassium metasomatite deposits occur along contacts between lamprophyre dikes with calcareous rocks and sandstone adjacent to high-angle faults. Host rocks may be underlain by Precambrian metamorphic rocks. The hydrothermal activity, that formed the metasomatite was associated with igneous activity that resulted in intrusion of dike swarms and (or) small plugs and sills of bostonite, microgabbro, and minette. Gold is spatially related to dikes and may occur in both early and late stages. The deposits consist of several subhorizontal, blanket- or ribbon-like bodies, as much as several dozen meters thick, that occur mainly along, and (or) locally above or below contacts between calcareous footwallrocks and overlying clastic rocks along narrow, long fault zones. Two subtypes are defined: quartz-adularia and quartz replacing adularia. Main deposit minerals are quartz, pyrite, marcasite, native gold, silver, bismuth, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite, carbonate, and barite. Gold occurs with pyrite, arsenopyrite, sphalerite, and galena; however, total sulfides constitute only a few percent of the total rock mass. The deposits are intensely oxidized and only traces of arsenopyrite and pyrite occur. Gold occurs primarily as grains smaller than 5 microns, commonly in friable grains of porous goethite. Fluid-inclusion studies indicate homogenization temperatures of 80° to 220°C, averaging from 110° to 160°C. Mineralization was controlled by interpolate-rifting structures. In many places, the deposits are complicated by karst formation, which resulted in formation of secondary rubble ore and surficial weathering of ore and gold. The depositional environment consisted of intrusion of lamprophyre into passive continental margins during rifting. Examples of this mineral-deposit type are Kuranakh, Russia, and Hadamengou, Inner Mongolia and Wulashan, Inner Mongolia, China.

Barite Vein (Marinov, Khasin, and Khurts, 1977)

Barite vein deposits consist of quartz-barite and barite veins and veinlets in stockwork in quartz porphyry, diabase, porphyry, tuff, and biotite granite. The deposits commonly occur along contacts of volcanic and sedimentary rocks, commonly in association with fluorite deposits. Examples of this mineral-deposit type are Chapsordag and Taptan-Turazy, Russia and Bayan Khoshuu, Mongolia.

Be Tuff (Kovalenko and Koval, 1984)

Be tuff deposits consist of bedded and graded-bedded tuff containing fragments of ongorhyolite, rhyolite, quartz, feldspar, fluorite, and Be-bearing bertrandite. Be content averages about 0.05 percent. The depositional environment consisted of extrusive centers with rhyolite and ongorhyolite. Examples of this mineral-deposit type are Dorvon Dert and Teg uul, Mongolia.

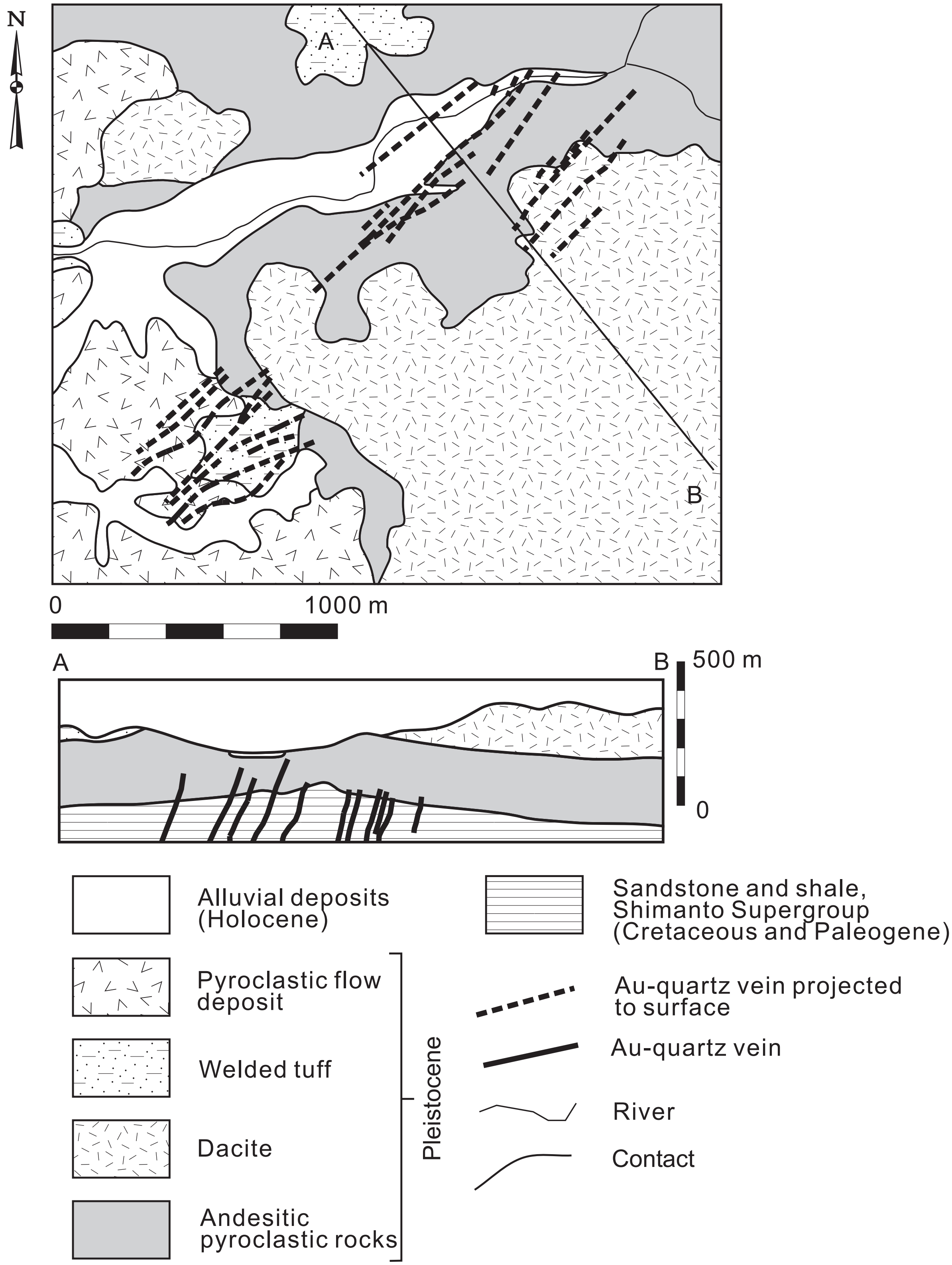


Figure 28. Generalized geologic map of the Pliocene through Quaternary Hishikari Au-Ag epithermal vein deposit, Japan. Adapted from Ibaraki and Suzuki (1993).

Carbonate-Hosted As-Au Metasomatite (Smirnov, 1961, Zavorotnykh and Titov, 1963)

Carbonate-hosted As-Au metasomatite deposits consist of quartz veins, vein zones, and lenses, nests, and veins in metasomatite bodies in limestone that is intruded by dikes of granite porphyry, granodiorite porphyry, diorite porphyry, or lamprophyre. Major minerals are arsenopyrite, pyrite, minor galena, sphalerite, marcasite, and chalcopyrite, and local gold; main gangue minerals are quartz, calcite, and dolomite. Wallrock alteration consists of quartz, dolomite, ankerite, serpentine, chlorite, sericite, talc, and kaolinite. The deposits generally contain galena, and sphalerite. The depositional environment consisted of intrusion of granite porphyry or lamprophyre into miogeoclinal sequences during continental collisions. Examples of this mineral-deposit type are Gurulevskoe and Oktjabrskoye, Russia.

Carbonate-Hosted Fluorspar (Ivanova, 1974; Bulnaev, 1995)

Carbonate-hosted fluorspar deposits consist of cocrystallized quartz and fluorite metasomatite that occurs in sheets, mineralized fracture zones, or veins in sequences of shale, limestone, and dolomite which form small xenoliths in granitoid plutons. The deposits exhibit gradational contacts with host rocks and consist of fine-grained bands, spots, and masses of fluorite, quartz, and calcite with relic dolomite, limestone, and carbonaceous rocks. The deposit layering is concordant with layering in host rock. The deposit margin generally contains quartz, fluorite, and calcite druse; calcite forms festoon ore with numerous layers. Shale contains mainly fluorite stringers. Breccia zones occur along contacts of rocks of contrasting lithology. The deposits are associated with hydrothermal veins that intrude various aluminosilicate rocks. The depositional environment consisted of intrusion of granite into shale, limestone, and dolomite in continental-margin arcs. Examples of this mineral-deposit type are Egitinskoye (fig. 29) and Urgen 2, Russia.

Carbonate-Hosted Hg-Sb (Smirnov and others, 1976; Obolenskiy, 1985)

Carbonate-hosted Hg-Sb deposits consist of stratabound lenses and nests in dolomite-limestone breccia and in layers in siliceous carbonates and jasperoid (silicified, dolomitized carbonate breccia) intercalated with clay and coal-clay shale. The sedimentary rocks are cut by dikes of quartz porphyry, diabase, and lamprophyre. The calcareous host rocks were subsequently altered to dolomite and brecciated during diagenesis and karst formation. Other wall-rock alterations consist of jasperoid, and quartz and calcite veinlets. The deposit type is commonly confined to thrust zones and localized under impermeable clay layers; clear boundaries do not occur. Major minerals are cinnabar and stibnite, and lesser pyrite, marcasite, sphalerite, stibnite, realgar, and orpiment, and rare chalcopyrite, cassiterite, arsenopyrite, chalcostibite, kermesite, servantite, gold, schwatzite, aktascite, galkhaite, and fluorite. The depositional environment consisted of an epithermal system in deep-fault zones in passive-continental-shelf margins and interplate rifts. Examples of this mineral-deposit type are Aktashskoye and Kelyanskoye, Russia.

Clastic-Sediment-Hosted Hg±Sb (Kuznetsov, 1974; Smirnov, Kuznetsov, and Fedorchuk, 1976; Khasin and Suprunov, 1977)

Clastic-sediment-hosted Hg±Sb deposits consist of simple and complex ladder and concordant carbonate-quartz and quartz veins and veinlets, and mineralized breccia. Host rocks are terrigenous and volcanic-terrigenous rocks in accretionary-wedge terranes, including flysch composed of siltstone, shale, sandstone, and conglomerate. Wallrocks are altered to quartz, carbonate, pyrite, and rare argillite and sericite. Minerals are cinnabar, pyrite, stibnite, arsenopyrite, chalcopyrite, and rare gold, galena, sphalerite, tetrahedrite, realgar, orpiment, native arsenic, native mercury, and Sb oxides that occur in disseminations, nests, and stringers. Stibnite and Sb oxides locally form Sb deposits without mercury. Gangue minerals are mainly quartz, carbonates, and dickite. The deposits occur in stockworks, lenses, layers, irregular bodies, breccia, and simple and (or) complex veins in fault zones that are associated with regional strike-slip faults and in some thrust fault zones. In thrust-fault zones, extensive alteration occurs, and the zones generally contain vertical quartz-carbonate veins of high-grade Sb and moderate-grade Au. The deposit types may occur in linear fold belts with ladder and concordant carbonate-quartz veins with higher Au than Sb grade. The deposits are structurally controlled by fracture sets and feathering major faults, anticlines, and domes, and commonly contain several ore horizons that occur in saddle-shaped veins and bodies; associated igneous rocks are mainly rare alkalic basalt dikes. The depositional environment consisted of low-temperature hydrothermal fluids that originated in deep magmatic chambers. Examples of this mineral-deposit type are Zagadka and Zvyozdochka, Russia.

Epithermal Quartz-Alunite

Epithermal quartz-alunite deposits occur in volcanic cones, caldera ring fractures, and areas of igneous activity underlain by sedimentary evaporate; associated rocks are felsic hypabyssal intrusions and volcanic rocks, including dacite, quartz latite, rhyodacite, and rhyolite. Large deposits occur in zones of intensely altered host rocks. Early-stage, high temperature mineral assemblage is quartz-alunite-pyrophyllite with corundum, diaspore, andalusite, and zunyite. Depending on extent of alunite, deposits are zoned with an inner zone of quartz-alunite, a surrounding intermediate zone of quartz-alunite-kaolinite-montmorillonite, and an outer zone of pervasive chlorite-calcite from propylitic alteration. Ammonium-bearing clay may occur. The deposit type is closely related to epithermal Au, porphyry Cu, and polymetallic volcanic-hosted metasomatite deposit type. An example of this mineral-deposit type is Iskinskoe (Askum), Russia.

Fluorspar Vein (Ivanova, 1974; Bulnaev, 1976)

Fluorspar vein deposits consist of fluorspar in steeply-dipping veins and brecciated zones and, less commonly, of metasomatite in carbonates, granite, and volcanic and volcanic-sedimentary sequences. Main mineral assemblages are quartz-fluorite, quartz-calcite-fluorite, barite-quartz-calcite-fluorite, and pyrite-marcasite-fluorite; minerals are fluorspar and quartz with barite, calcite, pyrite, marcasite, and clay. Argillic hydrothermal alteration is common in aluminosilicate host rocks, and silicification is common in limestone. The deposits are structurally controlled by fractures and breccia and form linear belts related to intraplate rifting in reactivated areas. Some deposits occur in volcanic belts in continental-marginal arcs, mainly in trachyrhyolite and trachybasalt of subaerial volcanic-plutonic belts. The depositional environment consisted of either along the flanks or in the inner parts of volcanic rift depressions. Examples of this mineral-deposit type are Naranskoye, Russia and Anas, Berkh 1, Bujgar, Bilkh-Uul, and Chuluut tsagaan del, Mongolia.

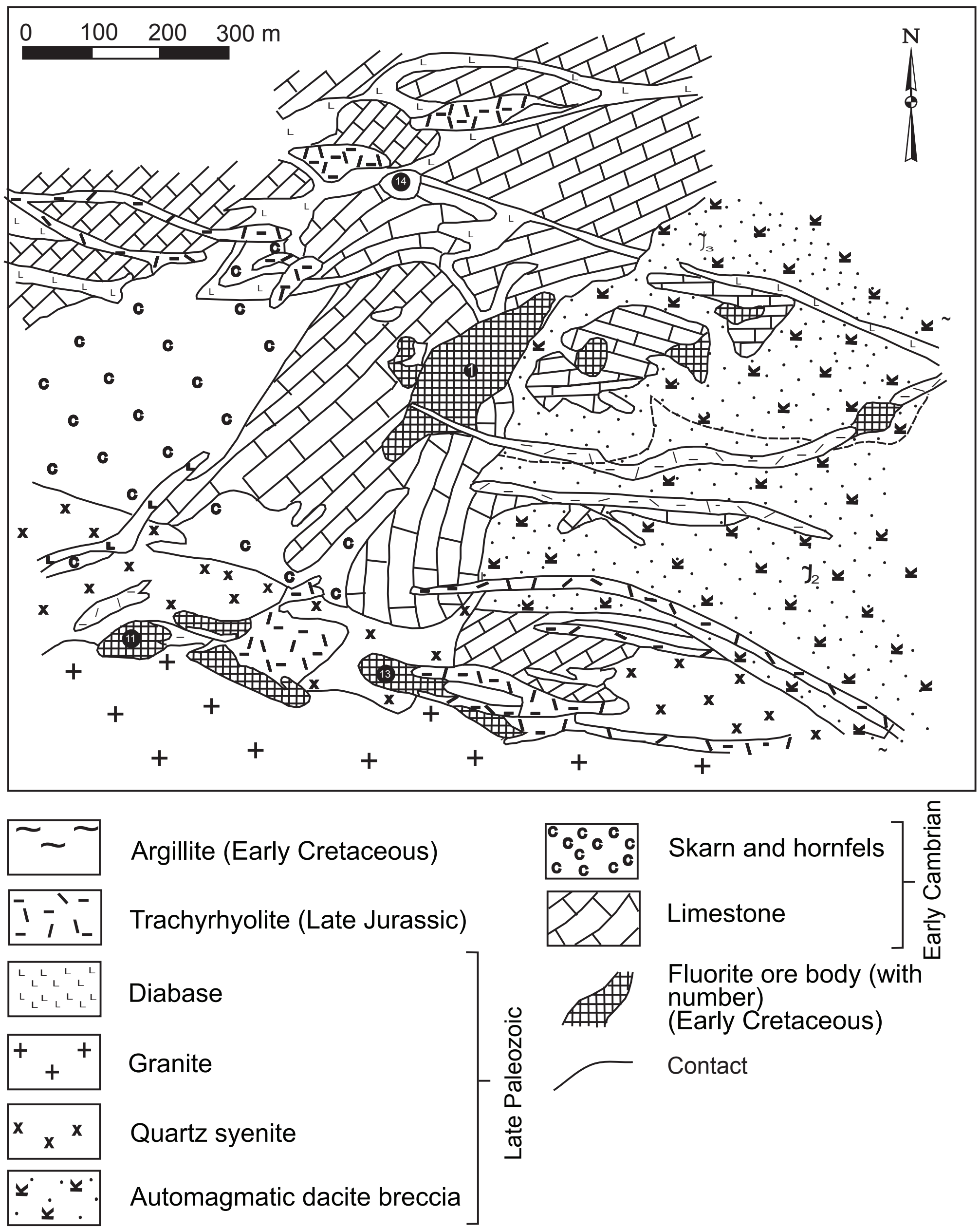


Figure 29. Generalized geologic map of the Middle Jurassic through Early Cretaceous Egitinskoye carbonate-hosted fluorspar deposit, TransBaikal, Russia. Adapted from Bulnaev (1995).

Hydrothermal-Sedimentary Fluorite (Cheng and others, 1994)

Hydrothermal-sedimentary fluorite deposits consist of multilayered fluorite and associate minerals that occur conformably in layered volcanic and sedimentary rocks, including limestone, slate, rhyolite, and dacite. Minerals occur in layers, bands, and breccia. Major deposit mineral is fluorite with minor clay and carbonates. The homogenization temperature of fluid inclusions in fluorite is about 85 to 270° C. Quartz grains are both angular and rounded, suggesting that the fluorite formation was related to volcanism. The depositional environment consisted of late Paleozoic volcanic island arcs. Examples of this mineral-deposit type are Aobaotu and Sumochaganaobao, Inner Mongolia, China.

Limonite from Spring Water (Shiikawa, 1970)

Limonite deposits consist of bedded limonite formed on mountain slopes and in valleys in areas of volcanic activity, with Fe precipitation from acidic ferruginous spring water associated with volcanic activity. The deposits are principally composed of aggregates of amorphous and (or) crystalline hydrated Fe_2O_3. Main mineral is goethite with lesser hydrohematite, akaganeite, lepidocrocite, xanthosiderite, and stilpnosiderite; jarosite, scorodite, and siderite may also occur, along with clays, including kaolinite and hydrated halloysite. Some deposits exhibit megascopic and microscopic textures and structures that are pseudomorphs after various plants, indicating that a biochemical process caused Fe_2O_3 precipitation from spring water. The deposit forms by chemical precipitation during neutralization of acidic water containing ferrous sulphate. Examples of this mineral-deposit type are Gumma and Tokushunbetsu, Japan.

Mn Vein (Mosier, 1986a)

Mn vin deposits occur as Mninerals in epithermal veins that occur along faults and fractures in subaerial volcanic rocks Host rocks are rhyolite, dacite, andesite, and basalt flows, tuffs, breccia, and agglomerate. Minerals are rhodochrosite, manganocalcite, calcite, quartz, chalcedony, barite, and zeolite that occur in veins, masses, stringers, and disseminations. Kaolinite alteration is most common. The depositional environment consisted of penetrative-fracture systems in volcanic centers in continental-margin arcs. Examples of this mineral-deposit type are Inakuraishi, Jokoku, and Yakumo, Japan.

Polymetallic (Pb, Zn ± Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite (Distanov, 1977)

Polymetallic (Pb, Zn ± Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposits consist of hydrothermal-metasomatic polymetallic sulfides that occur in volcanic and sedimentary rocks. Intensely deformed and sheared rocks are the most favorable replacement site. The deposits consist of complex lenses and stockworks containing massive, vein, and disseminated minerals. Host rocks are commonly felsic to mafic extrusive rocks, tuff, and volcanic rocks, most commonly hypabyssal quartz rhyolite and dacite porphyry intrusions and diabase porphyry dike swarms. Metasomatic alteration is intensive and consists of quartz-sericite, quartz-sericite-chlorite metasomatite, and silica and barite alterations. Aluminosilicates are more extensively altered. Three subtypes are defined: (1) barite-polymetallic, (2) pyrite-polymetallic, and (3) Cu-sulfide epigenetic. Early-stage pyrite and barite-sulfide-polymetallic minerals, and late-stage quartz-carbonate-sulfides are typical. Main minerals are mainly pyrite, sphalerite, galena, tennantite, tetrahedrite, chalcopyrite, and lesser arsenopyrite, bornite, electrum, argentite, magnetite, hematite, and native gold; gangue minerals are barite, quartz, carbonate, albite, sericite, chlorite, and rare fluorite. Main ore controlling structures are shears in deep-level fault zones in basement. Steep fault zones locally are important. The deposits are associated with small porphyry intrusions and mafic dikes. The depositional environment consisted of active continental-margin arcs built on zones of accreted terranes. Examples of this mineral-deposit type are Krasnogorskoye 2 (fig. 30), Salairskoye, and Urskoye district, Russia, and Jiawula, Inner Mongolia, China; and Sanmen, Jilin Province, China.

Polymetallic (Pb, Zn, Ag,) Carbonate-Hosted Metasomatite (Gorzhevskiy and others, 1970; Morris, 1986; Sinyakov, 1994)

Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposits consist of hydrothermal-metasomatic polymetallic Pb-Zn minerals hosted mainly in limestone and dolomite. The deposits and districts are controlled by folds and fractures, with major faults, companion fractures, and shear zones. The deposits are structurally complicated, including layered, lenticular, and commonly vein, stock, or pipelike bodies. Major mineral assemblages are galena-sphalerite; boulangerite-galena-arsenopyrite; and sphalerite-pyrite. Abundant pyrite and Pb-Sb sulfides are typical. The deposit minerals occur in masses, layers, and breccia. Associated magmatic rocks are small intrusions and dikes of quartz porphyry, granite porphyry, and lamprophyre. The depositional environment consisted of active continental-margin arcs built on carbonate sequences overlying continental crust. Examples of this mineral-deposit type are Leiba, Lugovoye, and Vozdvizhenskoye, Russia.

Rhyolite-Hosted Sn (Reed and others, 1986)

Rhyolite-hosted Sn deposits consist of cassiterite and wood tin that occur in discontinuous veinlets and stockworks and in disseminations in rhyolite flow-dome complexes. Other minerals are hematite, cristobalite, fluorite, tridymite, opal, chalcedony, adularia, and zeolite; accessory minerals are topaz, fluorite, bixbyite, pseudobrookite, and beryl. Associated wallrock alteration minerals are mainly cristobalite, fluorite, smectite, kaolinite, and alunite. Host rhyolite commonly contains more than 75 percent SiO_2 and is K-rich. Controlling fracture and breccia zones occur in the most permeable, upper parts of flow-dome complexes. The depositional environment consisted of felsic volcanic rocks erupted onto continental crust. An example of this mineral-deposit type is at Dzhalinda, Russia.

Sulfur-Sulfide (S, FeS_2) (Vlasov, 1976; Mukaiyama, 1970; M. Ogasawara, this study)

Sulfur-sulfide deposits consist of three subtypes: (1) sublimation, consisting of surficial sulfur deposited from gas and solution; (2) sedimentary, consisting of lacustrine deposits formed in volcanic craters; and (3) replacement, the most valuable subtype, consisting of replacement metasomatic sheets and irregular bodies in porous and fractured rocks. All three subtypes are genetically and spatially associated with andesite. Minerals are generally diverse and consist mainly of sulfur and pyrite, with lesser variable realgar, orpiment, metacinnabar, stibnite, sphalerite, and molybdenite. Sulfide content increases with depth and grades into massive sulfide. Host rocks generally are hydrothermally altered to opal, pyrite, alunite, and kaolinite. Example of this mineral-deposit type are Kusatsu-Shirane, Matsuo, and Shojingawa, Japan.

Volcanic-Hosted Au-Base-Metal Metasomatite (Kormilitsyn and Ivanova, 1968; Sanin and Zorina, 1980; Tauson, Gundobin, and Zorina, 1987)

Volcanic-hosted Au-base-metal metasomatite deposits consist of metasomatic listvinite-beresite zones containing sulfides. The zones, which occur in propylitically altered trachyandesite and latite are intruded by small stockworks and dikes of diorite porphyry, granodiorite porphyry, and granite porphyry, extend as far as several kilometers along strike, are as much several hundred meters thick, and exhibit gradational boundaries with volcanic host rocks. The deposits occur in pipes, nests, lenses, veins, and echelonlike fractures; both continuous veins and disseminations occur. Massive deposits are uncommon, but contain 60 to 80 percent pyrite, galena, and sphalerite along with sulfosalts, quartz, and dolomite. The deposits range in texture from massive through layered, densely disseminated, and spotted, to colloform. Veinlets and disseminations form haloes around the massive deposit minerals, but generally form independent bodies with an irregular distribution of sulfides. The following mineral assemblages are recognized: (1) tourmaline and pyrite, and local arsenopyrite, chalcopyrite, and gold; (2) pyrite,

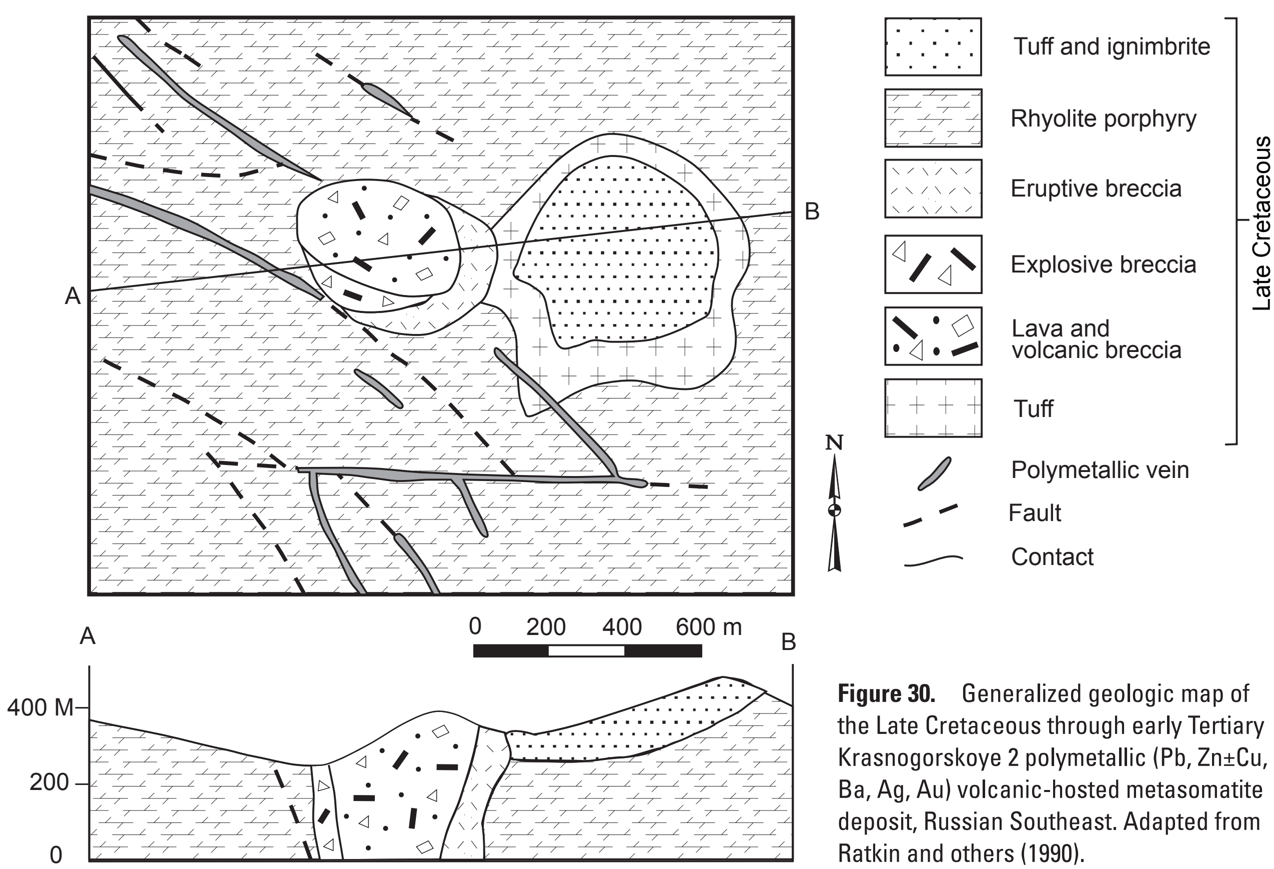


Figure 30. Generalized geologic map of the Late Cretaceous through early Tertiary Krasnogorskoye 2 polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposit, Russian Southeast. Adapted from Ratkin and others (1990).

galena, and sphalerite with gold, quartz, and carbonates; (3) sulfosalts (fahl ore, tetrahedrite, schwatzite, tennantite, cleiophane), gold, and dolomite; and (4) realgar-stibnite with gold, Hg-barite, and stibnite. Gold is finely dispersed and occurs in sulfides. The depositional environment consisted of intrusion of intermediate-composition to siliceous granitoids into the hypabyssal parts of collisional zones and extrusion of associated andesite and latite. Examples of this mineral-deposit type are Shirokinskoye (fig. 31), Russia; Bupyoung, South Korea; and Yixingzai, Fanshi, Shanxi Province, China.

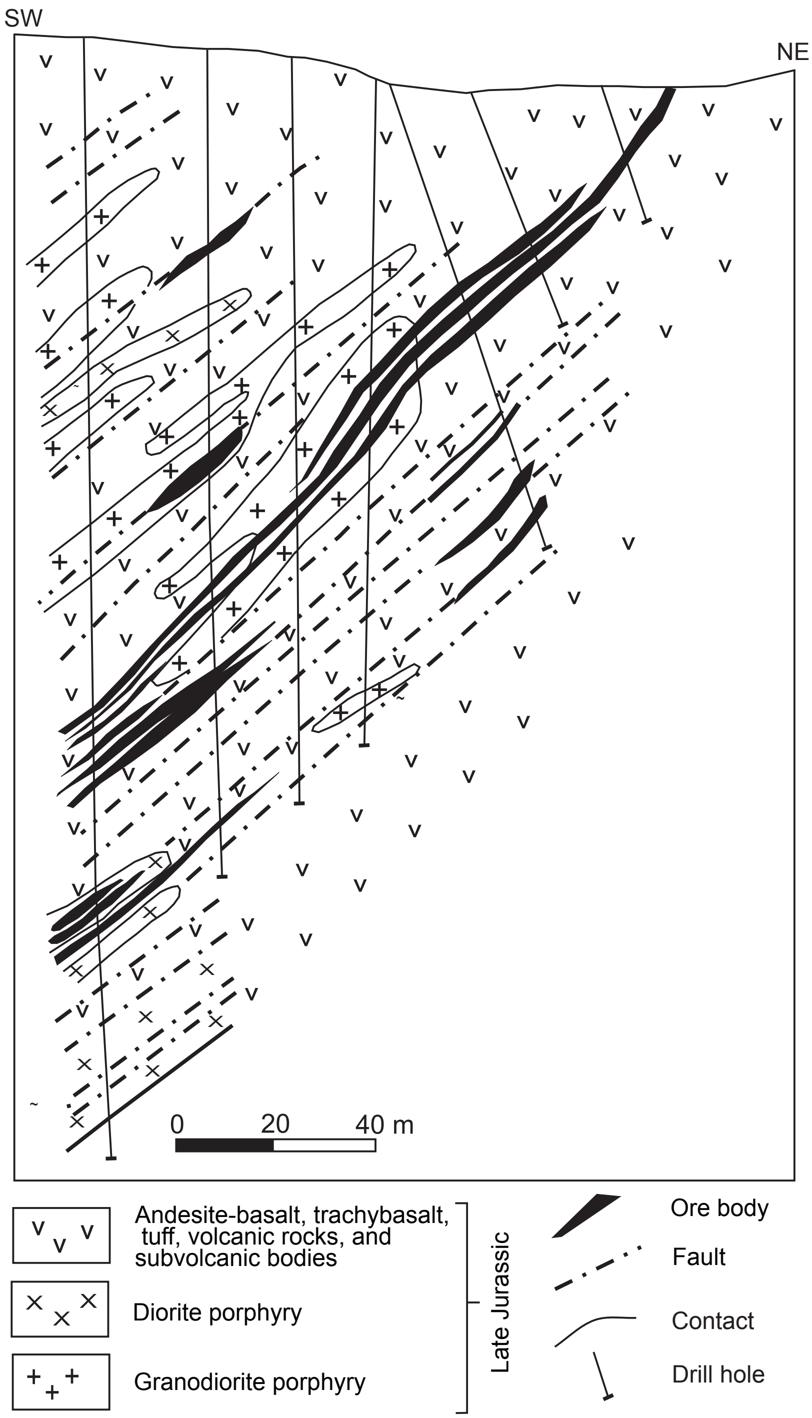


Figure 31. Generalized geologic map of the Middle Jurassic through Early Cretaceous Shirokinskoye volcanic-hosted Au-base-metal metasomatite deposit, TransBaikal, Russia. Adapted from Zorina (1980).

Volcanic-Hosted Hg (Kuznetsov, 1974; Babkin, 1975; Smirnov, Kuznetsov, and Fedorchuk, 1976)

Volcanic-hosted Hg deposits consist of disseminated and local masses of cinnabar in veinlets and breccia in layers, lenses, and irregular bodies. The deposits are hosted in felsic, and lesser intermediate-composition and mafic volcanic rocks or along contacts between subvolcanic intrusive and volcanic rocks. Other common minerals are stibnite, pyrite, and marcasite, with subordinate or rare arsenopyrite, hematite, lead, Zn and Cu sulfides, tetrahedrite, schwatzite, Ag sulfosalts, gold, realgar, and native mercury; gangue minerals are mainly quartz, chalcedony, hydromica, kaolinite, dickite, alunite, carbonate, chlorite, and solid bitumen. Minerals may occur in multiple layers. Wallrocks may be altered to propylite and argillite with various combinations of quartz, sericite, kaolinite, and epidote. Mercury was deposited mainly during intense metasomatic replacement and, to a lesser extent, in open fissures and voids. The depositional environment consisted of tectonic boundaries of major volcanic depressions and calderas related to active continental margin arcs and interplate rifts. This deposit type is similar to the hot-spring Hg model of Rytuba (1986a). Examples are Dogdo and Terligkhaiskoye, Russia, and Itomuka, Japan.

Volcanic-Hosted U (Bagby, 1986)

Volcanic-hosted U deposits consist of U minerals in pervasive fractures and breccias that occur along the margins of shallow intrusives. Common minerals are coffinite, uraninite, and brannerite; other minerals are pyrite, realgar-orpiment, leucoxene, molybdenite, fluorite, quartz, adularia, and barite. Uraninite is commonly encapsulated in silica. Common host rocks are high-silica alkali rhyolite, potassic trachyte, and peralkaline and peraluminous rhyolite, altered to kaolinite, montmorillonite, and alunite. Wallrocks are altered to silica and adularia. The deposits occur in subaerial to subaqueous, near-surface volcanic complexes that are associated with shallow intrusive rocks. The depositional environment consisted of continental rifts and associated calderas. Examples of this mineral-deposit type are Dornod and Gurvanbulag, Mongolia.

Volcanic-Hosted Zeolite (Gottardi and Galli, 1985; Zhamoitsina and others, 1992)

Volcanic-hosted zeolite deposits consist of concordant beds and lenses of zeolite-altered tuff in epicontinental basins and lacustrine volcanic and sedimentary rock sequences. The deposits were formed by replacement of siliceous tuff, and volcanic breccia composed of trachyrhyolite and trachydacite. Minerals are clinoptilolite, mordenite, and lesser heulandite, analcime, montmorillonite, quartz, calcite, adularia, and hydromica. Clinoptilolite and mordenite occur in siliceous tuff, and fillipsite and analcime occur in mafic tuff. Diagenetic and sedimentary zeolite are widespread. Zeolites were formed by isochemical alteration of porous vitric tuff permeated by low-temperature water of normal salinity and alkalinity. Zeolite beds are homogeneous and zoned as a function of temperature gradient. The depositional environment consisted of volcanic depressions in epicontinental volcanic belts or continental margin arcs. Examples of this mineral-deposit type are Pezasskoye, Russia, and Tsagaantsav, Mongolia.

Deposits Related to Hydrothermal-Sedimentary Processes

VI. Stratiform and Stratabound Deposits.

Bedded Barite (Orris, 1986)

Bedded barite deposits consist of stratiform, massive, and nodular barite interbedded with marine chert and calcareous sedimentary rocks, mainly dark chert, shale, mudstone, and dolomite. The deposits are commonly associated with Zn-Pb sedimentary exhalative (SEDEX) massive sulfide deposits. Alteration consists of secondary barite veining and local, weak to moderate sericite replacement. Associated minerals are minor witherite, pyrite, galena, sphalerite, quartz, and carbonate. The depositional environment consisted of epicratonal marine basins or embayments, commonly with smaller local restricted basins. Examples of this mineral-deposit type are Martyuhinskoye, Sorminskoye, and Tolcheinskoye, Russia.

Carbonate-Hosted Pb-Zn (Mississippi Valley Type) (Eckstrand, 1984; Briskey, 1986b; Ponomarev and Zabirov, 1988)

Carbonate-hosted Pb-Zn deposits consist of stratabound Pb- and Zn-sulfides hosted in carbonates with both primary and secondary porosity that commonly formed on reefs on paleotopographic highs. The deposits are hosted mainly in dolomite and limestone, but are locally hosted in sandstone, conglomerate, and calcareous shale. Minerals are mainly galena, sphalerite, pyrite, marcasite, dolomite, calcite, and barite, with minor chalcopyrite, siegenite, bornite, tennantite, bravoite, digenite, covellite, and arsenopyrite. Alteration consists of regional dolomitization. Also common is disseminated secondary carbonate gangue, massive in some places, that occurs in coarsely crystalline aggregates. The deposits are highly irregular in shape, stratiform or commonly discordant a local scale but stratabound on a district scale. Minerals occur mainly in open-space fillings in highly brecciated dolomite. Sphalerite commonly exhibits a colloform texture. The deposits commonly occur at the margins of clastic basins, generally on orogenic foreland carbonate platforms. Some deposits occur in carbonate sequences in foreland thrust belts bordering foredeeps of platforms. Few are associated with rift zones. The depositional environment consisted of areas of shallow-water marine carbonate with prominent facies controlled by reefs growing on the flanks of paleotopographic basement highs. The deposit type may also be associated with sedimentary-exhalative Pb-Zn (SEDEX) deposits. Examples of this mineral-deposit type are Mayskoye 1 and Sardana, Russia, and Chaihe, Liaoning Province, China.

Sediment-Hosted Cu (Narkelun and others, 1977; Yakovlev, 1977; Eckstrand, 1984; Sotnikov and others, 1985; Cox, D.P., 1986i; Lurie, 1988)

Sediment-hosted Cu deposits consist of stratabound, disseminated Cu sulfides in reduced red-bed sequences with green or gray shale, siltstone, and sandstone, thinly laminated carbonates and evaporates, and local channel conglomerate. Main minerals are chalcocite, bornite, chalcopyrite, pyrite, galena, and sphalerite, and lesser carrollite, Co-pyrite, betekhtinite, native copper, Ag, and Ge minerals. Sulfides are commonly zoned both vertically and laterally in the following sequence upward and outward from the base of the ore body: (1) chalcocite and bornite; (2) bornite-chalcopyrite; (3) chalcopyrite and pyrite; and (4) galena and sphalerite. Sulfides may be weathered to malachite, azurite, chrysocolla, and atacamite. Secondary downdip chalcocite enrichment is common. The genetic model is sedimentary concentration of minerals in red-bed sequences with extraction of Cu from basement rocks or underlying sedimentary rocks by subsurface brines probably derived from evaporates followed by transportation through oxidized beds and precipitation in anoxic sediment. The depositional environment consisted of epicontinental shallow-marine basins or intracontinental rifts along continental margin platforms. Examples of this mineral-deposit type are Pravo-Ingamakitskoye, Sakinskoye, and Udokan (fig. 32), Russia.

Sedimentary-Exhalative Pb-Zn (SEDEX) (Brisky, 1986a; Ponomarev, 1987)

Sedimentary-exhalative Pb-Zn (SEDEX) deposits consist of stratiform massive to disseminated sulfides occurring in sheets or lenses that are conformable with host rocks that consist of carbonates, clastic carbonates, and siliceous carbonates, including limestone and dolomite, and lesser marl, calcareous shale, siltstone, sandstone, and chert. Minerals are mainly galena, sphalerite, pyrrhotite, pyrite, Mg-Fe carbonates, and lesser sulfides and sulfosalts, barite, and fluorite. Minerals typically are finely crystalline. Metamorphosed deposits are coarsely crystalline and massive. Minerals occur in bands, laminae, masses, breccia, streaks, and disseminations. SEDEX silica-siderite and silica-ankerite-sideroplesite is associated with sulfide layers, and diagenetic dolomite is also common. Common depositional sites are interpreted as local synsedimentary depressions, synclines, and paleoslopes. Meager to no association of minerals with volcanism is evident in most areas. Minor volcanic rocks, mainly tuff and breccia, occur in host rocks in some deposits. Extensive hydrothermal alteration may occur near vents, including stockwork and disseminated sulfides, silica, albite, and chlorite. Hydrothermal activity is interpreted to have occurred in association with growth faults between major crustal blocks. The depositional environment consisted of late Proterozoic through late Paleozoic carbonate-rich, fine-grained clastic sedimentary rocks forming in shallow-marine basins undergoing pericratonal platform subsidence along microcontinent margins. Examples of this mineral-deposit type are Gorevskoye (fig 33), Russia; Dongshengmiao, Huogeqi, and Jiashengpan, and Tanyaokou, Inner Mongolia, China.

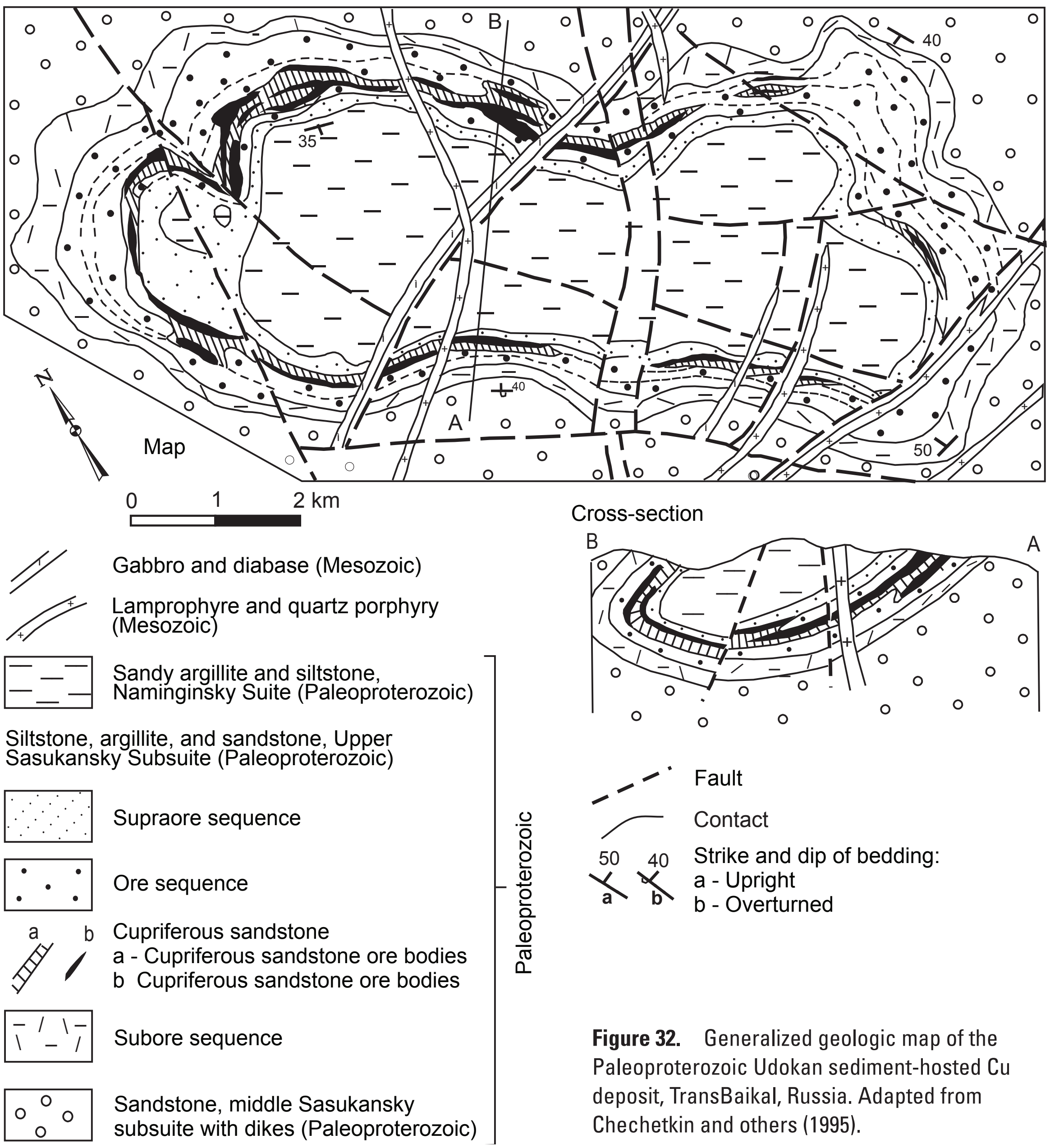


Figure 32. Generalized geologic map of the Paleoproterozoic Udokan sediment-hosted Cu deposit, TransBaikal, Russia. Adapted from Chechetkin and others (1995).

Korean Pb-Zn Massive Sulfide (V.V. Ratkin in Nokleberg and others, 1997)

Korean Pb-Zn massive sulfide deposits consist of Pb- and Zn-sulfides in carbonates, mainly limestone and dolomite, and lesser marl. Minerals are mainly pyrite, galena, sphalerite, fluorite, and magnetite, mainly in lenses and beds conformable to bedding in host rocks; magnetite also forms layers interbedded with sulfides, fluorite, and carbonates. Little to no hydrothermal alteration has occurred; mainly diagenetic alteration in carbonates and associated rocks. This mineral deposit type is intermediate SEDEX and carbonate-hosted Pb-Zn (Mississippi Valley) deposit types. Examples are the Voznesenskoe and Chernyshevskoe mines, Russian Southeast. The depositional environment consisted of typically late Proterozoic through early Paleozoic carbonate-rich sedimentary rocks in basins that overlap folded metamorphic complexes. Examples of this mineral-deposit type are Voznesenka-I, Russia (fig. 34), and Huanggoushan, Jilin Province; and Qingchengzi, Liaoning Province, China.

VII. Sedimentary-Hosted Deposits

Chemical-Sedimentary Fe-Mn (Hwang and Reedman, 1975; Philippova and Vydrin, 1977; Zaitsev and others, 1984; Zhong and Yao, 1987; Ye and others, 1994)

Chemical-sedimentary Fe-Mn deposits consist of sheets and lenses of massive to disseminated Fe and Mn oxides and carbonates that in sedimentary and clastic carbonates, including limestone and dolomite. Minerals are magnetite, hematite, siderite, pyrolusite, hausmannite, braunite, and rhodochrosite (including Ca-rhodochrosite and Fe-rhodochrosite). Ore layers consist of sedimentary chert, quartzite, quartz-sericite-chlorite schist, and clastic carbonates. According to mineralogy and Fe and Mn grade, three subtypes are defined: (1) Fe, (2) Fe-Mn, and (3) Mn. Mn beds commonly occur in the middle to upper part of a progressive sequence within a transitional zone between clastic rocks and chemical precipitations; some Mn

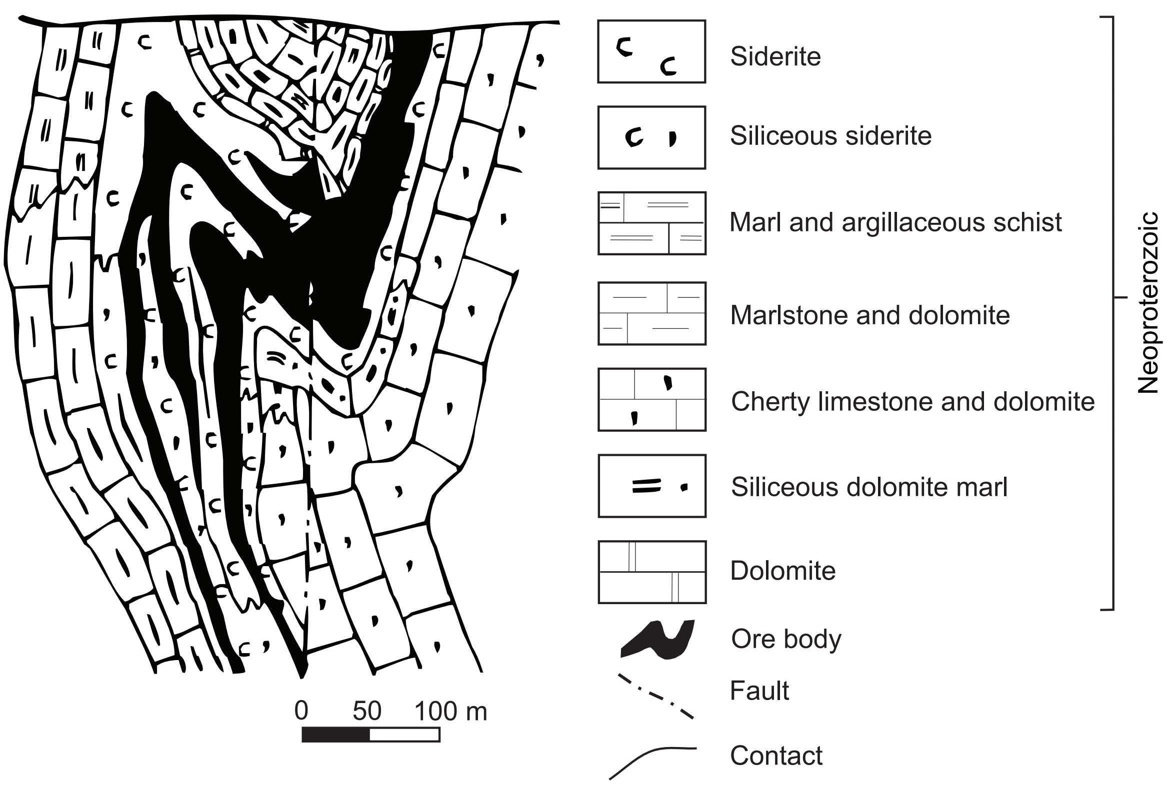


Figure 33. Generalized geologic map of the Early Neoproterozoic Gorevskoye sedimentary exhalative (SEDEX) Pb-Zn deposit, Eastern Siberia. Adapted from Saraev (1999).

beds may occur in the middle to lower parts of a retrogressive sequence. Mn-bearing carbonate commonly occurs in shale or mudstone. However, some Mn carbonate occurs in sandstone and red shale. On the North China platform, a group of B-Mn deposits of to the third Mn subtype is characterized by Mn-boracite; minerals are mainly Mn-boracite, rhodochrosite, Ca-rhodochrosite, and ankerite. In Northeast China, a group of deposits hosted in mudstone, dolostone, and dolomitic limestone that are part of the Mesoproterozoic Jixian System, are named the Jixian type of B-Mn deposit, including: (1) a group of late Paleoproterozoic Fe oxide (Fe siderite) deposits (Xuanlong type of Fe deposit); and (2) a group of late Mesoproterozoic Fe-Mn deposits (Wafanzhi type of Mn deposit) on the North China Platform. Another example is the Khovsgol carbonate basin located in northern Mongolia where Fe, Fe-Mn, and Mn occurrences are associated with sedimentary phosphate, allunite, and V deposits at the same stratigraphic level but without a regular spatial distribution. Associated with

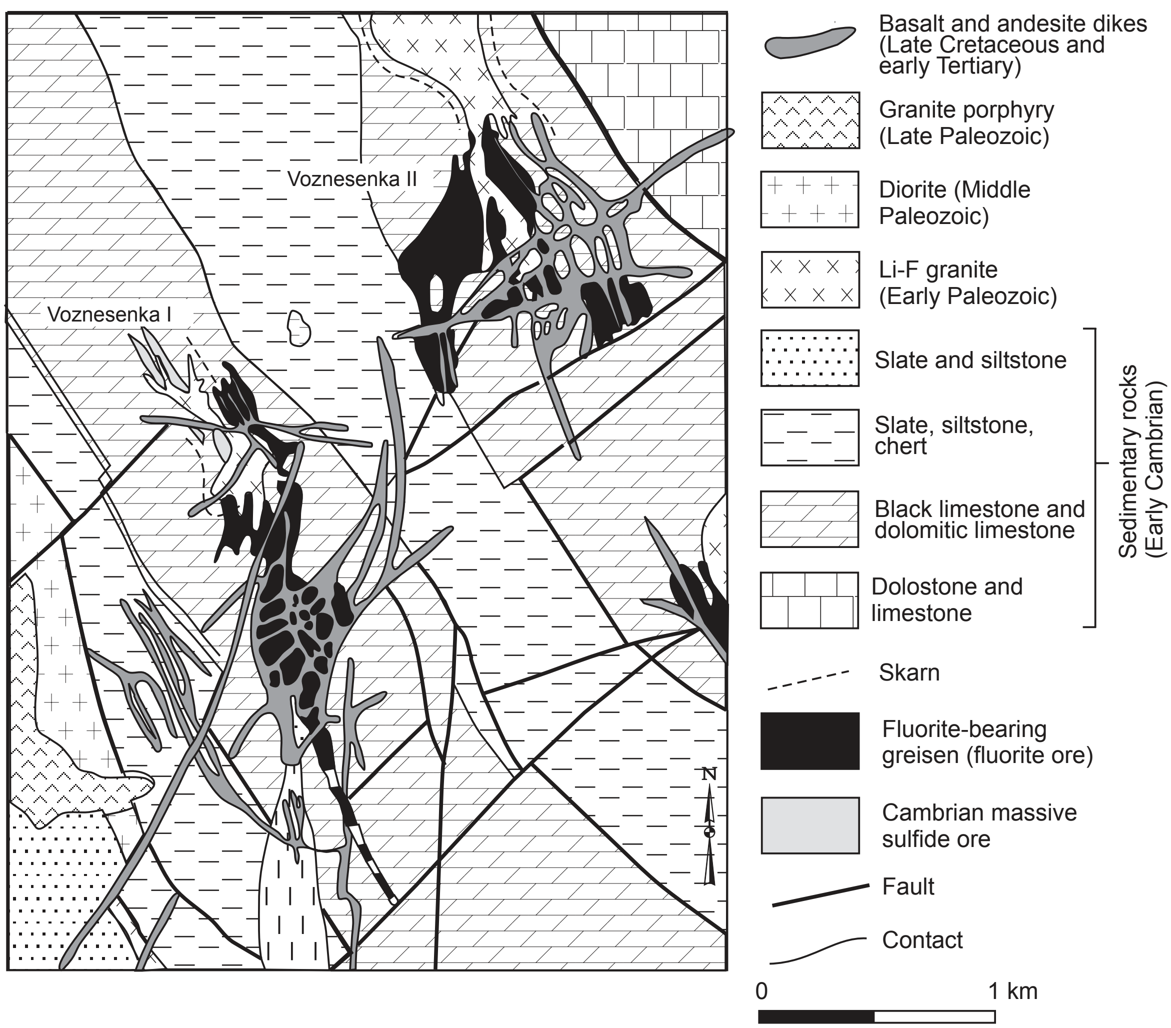


Figure 34. Generalized geologic map of the Cambrian Voznesenka I Korean Pb-Zn massive sulfide deposit, Russian Southeast. Adapted from Ratkin (1995).

extensive phosphate deposits are also low-grade sedimentary Fe, Mn, and Al deposits. The depositional environment consisted of formation of sheets and lenses of massive to disseminated Fe and Mn oxides and carbonates in an epicontinental marine environment. The deposit type may be associated with sedimentary gypsum, and alunite, and rare barite and bauxite deposits. Examples of this mineral-deposit type are Dongshiuchang, Tiejin Province, China; Pangjiapu, Hebei Province, China; and Wafangzi, Liaoning Province, China.

Evaporate Halite (Kleiner and others, 1977)

Evaporate halite deposits consist of halite that occurs mainly in Middle through Late Devonian reef limestone, dolomite, calcareous breccia, arkose, siltstone, diabase, agglomerate, and tuff. Minerals are gypsum, halite, anhydrite, and lesser carbonates, vanthoffite, and sylvinite. The deposits occur in beds that vary from 9 to 50 m thick. Halite is generally smoky, shiny pink, and coarse-grained. Halite bearing beds, which vary from 100 to 600 m, occur mainly in anticlines. Largest known deposits are Shuden-Uul and Davst-Uul in northern part of the Mongolian Altay Range. The depositional environment consisted of formation during continental-margin rifting or along transform-continental-margin boundaries. Examples of this mineral-deposit type are Davst uul and Shuden uul, Mongolia.

Evaporate Sedimentary Gypsum (Kleiner and others, 1977; Yuan others, 1982; Ganbaatar, 1999)

Evaporate sedimentary gypsum deposits occur in evaporite carbonate sequences of supratidal (sabkha) facies in semienclosed sedimentary basins. Two main types of evaporite sequence occur: carbonate and cataclastic. The deposits are multilayered and range in shape from bedded through stratiform to lensoid. The deposits gradually thicken from the margins to the center of a basin. Major minerals are gypsum, anhydrite, and lesser brogniartine, K- and Mg-halite, and native sulfur; gangue minerals are calcite, dolomite, magnesite, native sulfur, clay, and minor halite, authigenic quartz, and chalcedony. Gypsum content is as much as 98 percent. The deposits commonly exhibit idiomorphic, mosaic, and granular textures. The deposit minerals occur in masses, bands, beds, laminae, stockwork, breccia, and bioturbation zones. From the margin to the center of a basin, the common facies are sandstone (conglomerate), mudstone, gypsum, halite, and K- and Mg-halite that occur in circular zones. The deposit-forming materials are derived from weathering the of surrounding rocks, dissolution of ancient halite deposits, or deep brines, volcanic hydrothermal fluids, or marine water. Local later alteration during diagenesis and dissolution may form gypsum veins. The deposit indicators include shallow-water deposition of mudstone and marl with mudcracks. On the North China platform, the deposits are mainly hosted in Cambrian and Late Ordovician epicontinental rocks. The depositional environment consisted of intense evaporation of brine in enclosed or semi-enclosed subsiding basins in a dry climate. Examples of this mineral-deposit type are Baruun Tserd, Mongolia and Taiyuan, Shanxi Province, China.

Sedimentary Bauxite (A.N. Sucharina, in Kuznetsov, 1982)

Sedimentary bauxite deposits consist of bauxite beds hosted in carbonaceous and clastic rocks that form in marine or continental environments. Two subtypes are defined: carbonaceous and clastic. The first subtype, which occurs in neritic marine deposits along passive continental margins, is characterzied by thick, rift-related carbonates with interformational stratigraphic breaks, interlayered with thin (as much as a few meters thick) bauxite horizons. Metamorphosed equivalent consists of diaspore that forms at andalusite-sillimanite facies. The second subtype occurs in clastic sequences as a result of weathering of aluminosilicate rocks and minerals and redeposition in a peneplain environment. Main minerals are gibbsite and gibbsite-kaolinite. The deposits, which range from tens to about 100 m in thickness, are generally flat lying, may be linear or lenticular, and may form in karsts underneath layered deposits. Examples of this mineral-deposit type are Ke’er, Re’er, Shigong, and Xiaoyi, Shanxi Province, China.

Sedimentary Celestite (Yakovlev, 1986)

Sedimentary celestite deposits consist of thin layers and concretions of celestite in sandstone and mudstone. The major mineral is celestite. The depositional environment consisted of formation of continental lacustrine sedimentary rocks in grabens during late-stage continental rifting. Examples of this mineral-deposit type are Dugshih hudag and Horgo uul, Mongolia.

Sedimentary Phosphate (Eckstrand, 1984; Mosier, 1986a,b; V.L. Librovich, in Rundqvist, 1986)

Sedimentary phosphate deposits consist of phosphorite in mainly clastic volcanic silica-carbonates. Phosphate layers may be monomineralic. Major textures and structures are finely laminated (locally aphanitic), oolitic, streaky disseminated, and brecciated; associated rocks are marl, shale, cherty limestone, and dolomite. Volcanic rocks may also occur. The depositional environment consisted of a marine sedimentary basin connected to the open sea, with local upwelling zones over continental-shelf rocks along passive or active continental margins. Examples of this mineral-deposit type are Belkinskoye and Seibinskoye 2, Russia, and Burenhan and Hubsugul, Mongolia.

Sedimentary Fe-V (Oh and Hwang, 1968; Eckstrand, 1984; Sinyakov, 1988; Poznaikin and Shpilikov, 1990)

Sedimentary Fe-V deposits consist of chemical-sedimentary strata containing layered oolitic brown ironstone and (or) V-bearing chert, carbonaceous shale, and chert horizons. Fe deposits occur in mudstone, argillite, black shale, ferruginous sandstone, glauconite sandstone, limestone, and manganiferous and phosphatic shale and sandstone; V deposits occur in cherty-carbonaceous shale with interlayered siliceous shale, carbonaceous and calcareous shale, mudstone, siltstone, chert, and rare limestone. Chert horizons may contain sedimentary quartzite. Massive beds commonly range from 2 to 25 to 30 m in thickness and are interbedded with shale, sandstone, and gritstone. Minerals are mainly hematite, goethite, siderite, and chamosite; associated minerals are calcite, ankerite, various clay minerals, clastic quartz, pyrite, and phosphatic fossil debris. Fe content in ore beds is irregular and ranges from 20 to 45 percent. The deposits are rich in P_2O_5 and V_2O_5. V grade ranges from 0.01 to 1.0 percent. The depositional environment consisted of deposition of ironstone in neritic basins, lagoons, and estuaries under oxygenated to euxinic conditions. Examples of this mineral-deposit type are Kolpashevskoye, Russia, and Hitagiin gol, Mongolia.

Sedimentary Fe Siderite (Rundqvist, 1986)

Sedimentary Fe siderite deposits consist of layers and lenses of siderite in the upper part of a coal series. The deposits are hosted in sandstone and argillite containing siderite oolites and concretions. Siderite content is as much as 80 to 90 percent. Associated matrix minerals are chlorite, hydromica, quartz, and feldspar. Ore layers ranges from 0.1 to 2 m in thickness. This deposit type is of little economic importance. Examples of this mineral-deposit type are Barandatskoye, Ishimbinskoye, Nizhne-Angarskoye, and Parabel-Chuziks-koye, Russia.

Stratiform Zr (Algama Type) (Bagdasarov and others, 1990; Nekrasov and Korzhinskaya, 1991; Zalishchak and others, 1991)

Stratiform Zr deposits consist of hydrozircon and baddeleyite in lenses and veins that occur mainly in a layer of cavernous dolomite marble, as much as 40 m thick. The ore occurs as breccia composed of fragments of metamorphic quartz and dolomite cemented by hydrozircon and baddeleyite aggregate; baddeleyite also occurs as loose aggregates formed by weathering of primary ore. Some caverns in the dolomite contain colloform, sinter-type aggregates of hydrozircon and baddeleyite, but breccia texture predominates. The cavern walls are coated with metamorphic quartz. The host dolomite is not hydrothermally altered. A large deposit occurs in the northern part of the Khabarovsk province, Russia and is hosted mainly in subhorizontal dolomite marble that, along with other miogeoclinal sedimentary rocks, constitutes the Neoproterozoic and early Paleozoic sedimentary cover of the Stanovoy block of the North Asian craton; its origin is speculative. According to B. Zalischak (written commun., 1992), the type Algama deposit in Russia was formed by discharge of hydrothermal solution along a layer of porous dolomite; sudden pressure fall resulted in a blast. A U-Pb isotopic age of about 100 Ma was obtained on hydrozircon (J.N. Aleinikoff, written commun., 1993).

VIII. Polygenetic Carbonate-Hosted Deposits

Polygenic REE-Fe-Nb (Bayan-Obo Type) (Kim and others, 1959; Chao and others, 1992; Cao, 1994; Lin and others, 1994; Ren and others, 1994; Zhang and Tang, 1994; Bai and others, 1996; Pan, 1996; Tu Guangzhi, 1996, 1998)

The major example of a polygenetic REE-Fe-Nb deposit is the Bayan-Obo superlarge REE-Fe-Nb deposit in China (fig. 35), which contains reserves of as much as 70 percent of the world's REE resource. The deposit, which occurs in Mesoproterozoic clastic rocks and Mg-carbonates, consists of layered to lenticular bodies that are generally concordant with the host dolomie. The deposit contains about 170 minerals, including 60 Nb, REE, Ti, Th, Fe minerals, and principal Fe minerals are hematite, magnetite, and siderite. Principal REE minerals are monazite, parisite, huanghoite, and cerapatite; principal Nb-Ta minerals are niobite, aeschynite, fersmite, and pyrochlore. Two subtypes are d Nb-REE-Fe subtype A, and Nb-REE subtype B. Subtype A ore varieties are massive, banded, vein-disseminated (aegirine type), disseminated and laminated (riebeckite type), and massive and disseminated (biotite and dolomite types). Subtype B ore varieties are disseminated muscovite, aegirine, and diopside rich. The deposit consists of several blocks: a northern block with abundant ferrous minerals, blocks with abundant REE minerals with lesser ferrous minerals, and blocks with both ferrous and REE minerals. The deposit type contains well-developed hydrothermal alterations, including riebeckite, aegirine, fluorite, and biotite alterations, especially Mg skarn in the contact zone between dolomite and granite.

Several genetic interpretations exist. Tu (1998) reported Rb-Sr- and Sm-Nd-isotopic compositions and Nb/Ta ratios indicating that REEd and Nb are mantle derived. The current controversy is about the timing and mechanism of ore formation; dome studies suggest a relation to carbonatite magma (Bai, 1996), whereas other studies suggest that the metasomatism formed REE, Nb, Th, and Fe minerals and that the deposit is epigenetic (Chao, 1992). Recent isotopic studies of the country rocks and of ore and gangue minerals (Cao, 1994, Ren, 1994, Zhang, 1994) indicate mainly Mesoproterozoic and Caledonian ages, suggesting formation in the Mesoproterozoic and strong reworking in the early Paleozoic, possibly with partial introduction of new REE minerals (Ren, 1994, Cao, 1994, Pan, 1996). Tu Guangzhi (1996, 1998) interpreted a Mesoproterozoic SEDEX event in which metasomatic activity, diagenesis, and alteration of dolomite were synchronous and mineals were subsequently enriched during Caledonian deformation. The general interpretation is that the deposit formed in a rift zone along the north edge of North China craton.

Another example of a polygenetic REE-Fe-Nb deposit is at Yangyang, Korea, which consists of magnetite in a polymetamorphosed contact deposit hosted in Precambrian biotite gneiss and a younger syenite intrusion. The western part of the syenite contains many lenticular xenoliths of calc-silicate rock, tactite, and amphibolite formed from metasomatized impure limestone. Magnetite occurs in the syenite in close association with tactite or amphibolite and locally in in lenticular masses as xenoliths, or intruded by syenite dikes. The main mineral is magnetite in masses, plates, or brittle zones; gangue minerals include hornblende, epidote, and biotite. This deposit is interpreted as a polymetamorphosed contact deposit in which a primary contact-metasomatic magnetite was intruded by syenite.

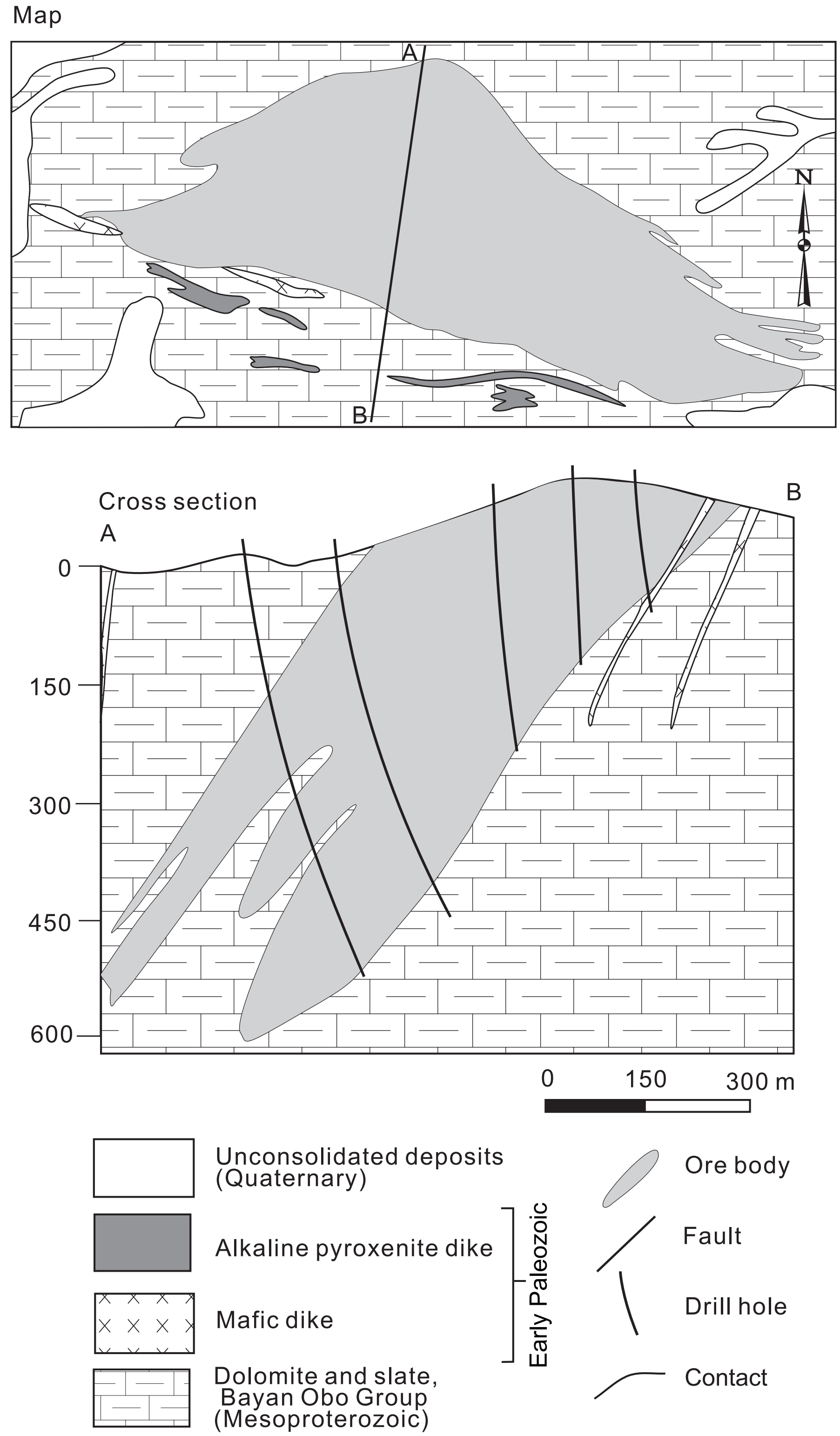


Figure 35. Generalized geologic map of the Mesoproterozoic Baiyan Obo polygenetic REE-Fe-Nb deposit deposit, northern China. Adapted from Li (1993).

Deposits Related to Metamorphic Processes

IX. Sedimentary-Metamorphic Deposits

Banded Iron formation (Algoma type) (Zhang and others, 1984;Yan, 1985; Zhang and others, 1985; Cannon, 1986)

Banded iron formation (Algoma type) deposits consist of Fe minerals hosted mainly in Archean ferrous quartzite beds and Fe-rich mafic to felsic volcanic, volcanoclastic, and clastic rocks. The deposits are typically interlayered on a centimeter scale with quartzite and Fe-rich beds. The deposits may be metamorphosed to varying degrees. At a lower metamorphic grade, main minerals are mainly magnetite, hematite, ilmenite, maghematite, fine-grained quartz, amphibole, and biotite; mineral composition, texture, and structures vary with metamorphic grade. With increasing metamorphism, minerals coarsen and Fe grade increases; at granulite facies minerals are magnetite, quartz, hypersthene, diopside, amphibole, ilmenite, plagioclase, garnet, and biotite. The deposits are widespread in the early Precambrian basement of the Sino-Korean craton and are a major source of iron in North China. Local enrichment associated with regional or contact metamorphism is associated with granitoid intrusion. In comparison with Superior-type deposits, the depositional environment of Algoma-type deposits consisted of tectonically mobile marine volcanic belts in small volcanic-sedimentary basins. Some the deposits are spatially associated with volcanogenic Zn-Cu massive sulfides, Homestake Au, and Au in shear zone and quartz veins deposits. Examples of this mineral-deposit type are Nanfen, Liaoning Province, China; Sijiaying, Hebei Province, China; Gongchangling, Anshan, Liaoning Province, Shanyangping and Yangchaoping, Daixian County, Shanxi Province, China.

Banded Iron Formation (Superior type) (Eckstrand, 1984; Cannon, 1986; Sinyakov, 1988)

Banded iron formation (Superior type) deposits consist of ferrous minerals in quartzite beds of mainly Paleoproterozoic age. The deposits consist mainly of banded, Fe-rich sedimentary rocks, generally of great lateral extent, that typically are interlayered on a centimeter scale with siliceous (chert) and Fe-rich beds. Iron-formation and host rocks commonly exhibit sedimentary textures typical of shallow-water deposition in tectonically stable regions. Main minerals are magnetite, hematite, fine-grained quartz, Fe silicates, and Fe carbonates. Many deposits are isoclinally folded and thrust faulted. The deposits are commonly metamorphosed to varying degrees, or weathered and enriched by supergene processes. Supergene deposits may be localized in irregularities along paleoerosional surfaces. The end product of weathering is Fe hydroxides and high-grade supergene hematite. The depositional environment consisted of stable shallow-water marine basins, commonly on stable continental shelf or intracratonic basin formed on ancient cratons and microcontinents. Examples of this mineral-deposit type are Bakcharskoye, Kostenginskoe, Nelyuki, Olimpiyskoe, Sutarskoye, and Tarynnakh (fig. 36), Russia, and Yuanjiachun, Shanxi Province, China.

Homestake Au (Berger, 1985b)

Homestake Au deposits are mainly hosted in metamorphosed banded iron-formation. The deposits commonly occur in thin laminae, concordant lenses, or veins in Fe-rich, siliceous, and carbonate rocks.

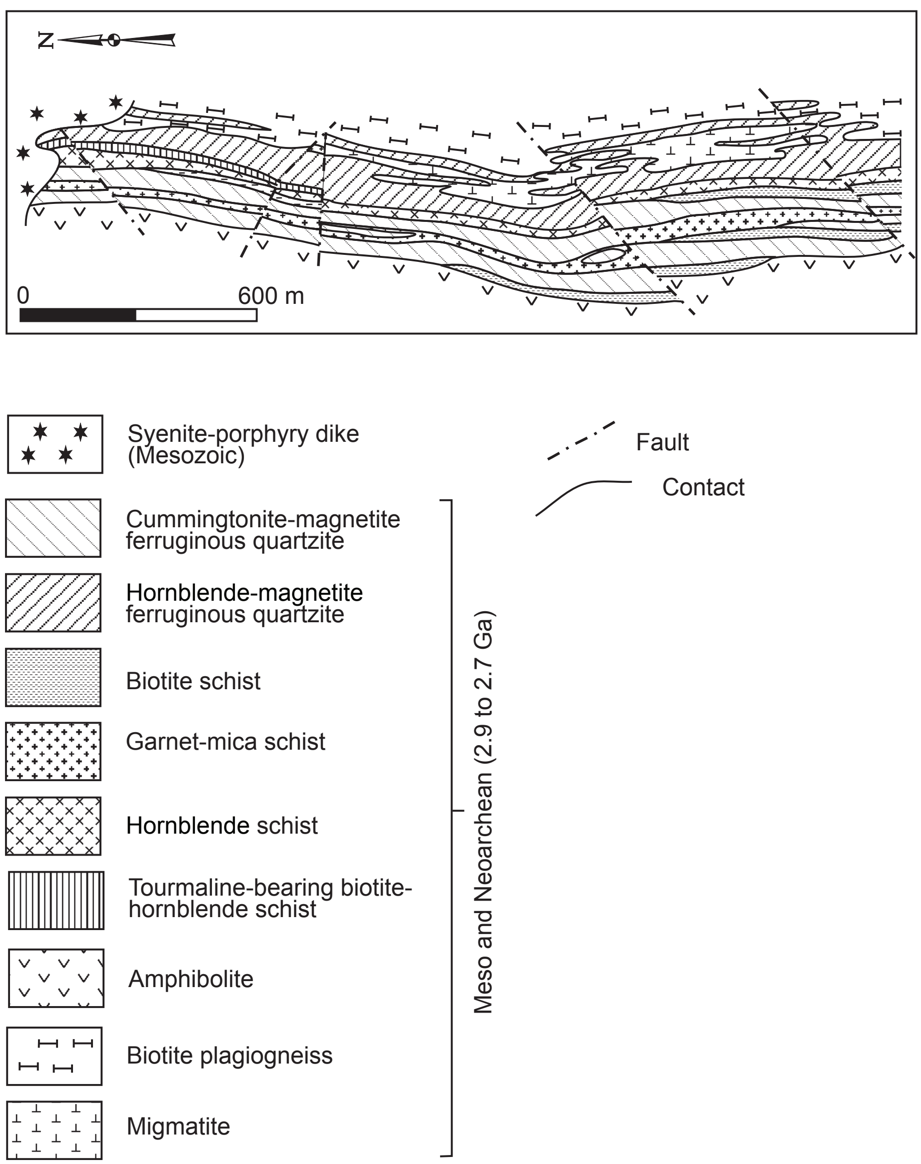


Figure 36. Generalized geologic map of the Archean through Paleoproterozoic Tarynnakh banded-iron formation deposit, Yakutia, Russia. Adapted from Gorelov and others (1984).

Main minerals are native gold, pyrite, pyrrhotite, arsenopyrite, magnetite, sphalerite, and chalcopyrite, with local tetrahedrite, scheelite, wolframite, molybdenite, fluorite, and actinolite. Banded Fe oxides are commonly replaced by pyrite and pyrrhotite. Main alteration minerals are chlorite and tourmaline. Associated deposits are volcanogenic massive sulfice (Kuroko), Algoma banded iron formation, and Au in shear zone and quartz vein deposits. Genesis is debated, but this mineral deposit type is generally interpreted as having formed during marine volcanism or late-stage hydrothermal activity. An example of this mineral-deposit type is at Dongfengshan, Heilongjiang Province, China.

Sedimentary-Metamorphic Borate (Peng and others, 1993)

Sedimentary-metamorphic borate deposits consist of two subtypes: metasedimentary and hydrothermal subtypes. The first subtype is conformably hosted in stratiform Mg carbonates (mainly magnesite), with suanite [$Mg_2(B_2O_5)$] as the main ore mineral, along with magnesite. The second subtype consists of stratiform Mg silicates in breccia or deformed bands, and is the more important of the two subtypes. Breccia fragments contain laminated, fine-grained forsterite and diopside in a matrix of suanile and magnesite. Ludwigite ($(MgFe)_2Fe_3$+$(BO_3)O_2$) occurs mainly in the second subtype that is Fe rich. Both subtypes, especially the second, may be altered, with replacement of forsterite by serpentinite, phlogopite, and other minerals, and of suanite to szaibelyite [$MgBO_2(OH)$]. Hydrothermal alteration is closely associated with intrusion of granitic rocks and pegmatite. Deposits of the second subtype in eastern Liaoning, northeastern China are hosted in a Paleoproterozoic volcanic-sedimentary sequence, metamorphosed to amphibolite facies, that contains tourmaline, albite, and microcline and exhibits a spatial distribution suggesting an evaporite rift-related genesis. Examples of this mineral-deposit type are Wengquangou (fig. 37) and Zhuanmiao, Liaoning Province, China.

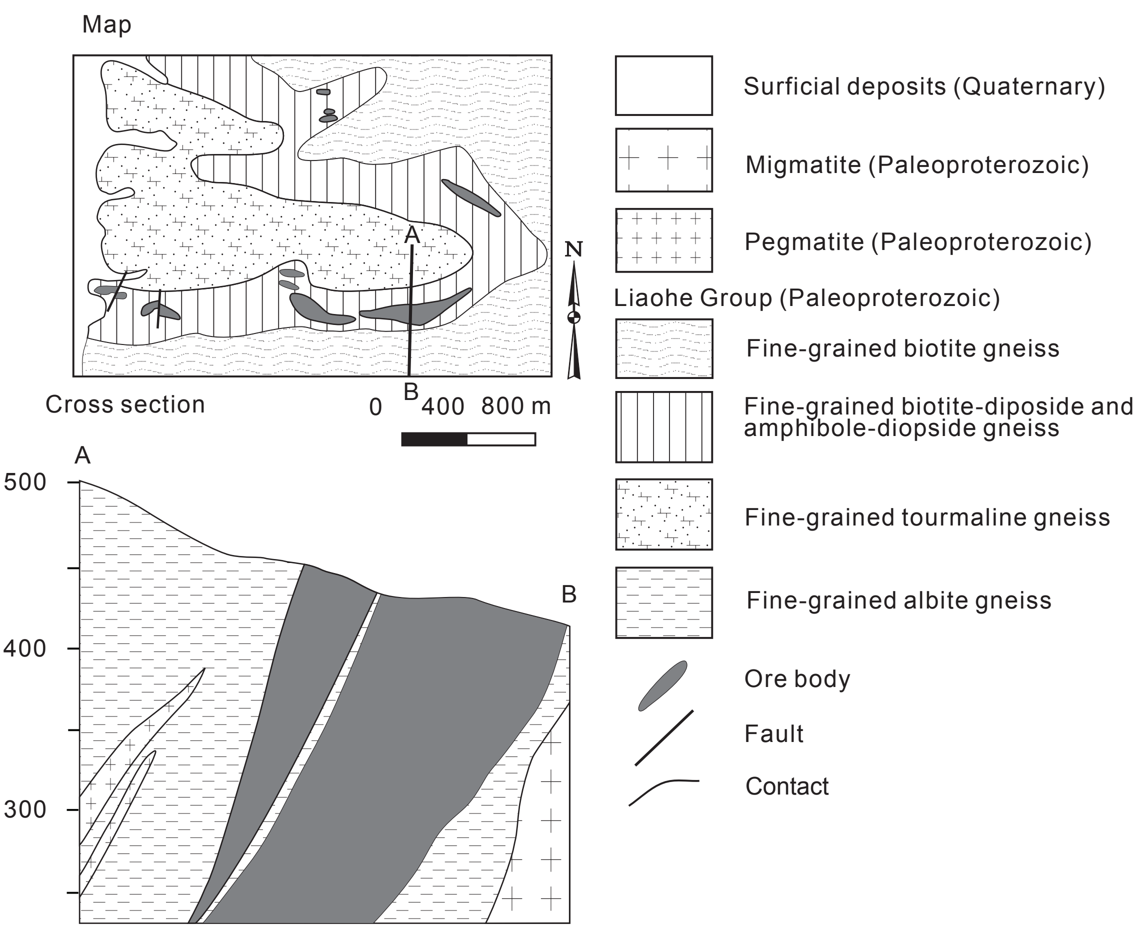


Figure 37. Generalized geologic map of the Late Paleoproterozoic Wengquangou sedimentary-metamorphic borate deposit, northern China. Adapted from Jiang and others (1994).

Sedimentary-Metamorphic Magnesite (Zhang and others, 1984; Li and Zhu, 1992)

Sedimentary-metamorphic magnesite deposits consist of magnesite in beds ranging from 200 to 2,000 m in length and from 30 to 300 m width. The deposits are mainly hosted in Paleoproterozoic carbonates, and generally dolomite marble. The deposits contain sedimentary textures, including ripple marks, and mud cracks, and local metasomatic textures. Minerals are mainly massive with lesser banding. The major mineral is medium- to coarse-grained magnesite, along with lesser talc, tremolite, dolomite, and chlorite and rare calcite, Fe-dolomite, rhodochrosite, Fe-magnesite, siderite, garnet, pyrite, serpentinite, sphalerite, chalcopyrite, magnetite, apatite, and hematite. Maximum MgO content of magnesite is 47 percent. The depositional environment consisted of Paleoproterozoic rifting in a littoral, shallow-marine sedimentary basin. Possible subsequent lower-greenschist- to amphibolite-facies metamorphism and intensive deformation may have resulted in recrystallization of minerals, crystallization of siderite, and formation of lenticular metasomatic deposits. Examples of this mineral-deposit type are Biderin gol, Mongolia, and Xiafangshen and Xiaoshengshuisi, Liaoning Province, China.

X. Deposits Related to Regionally Metamorphosed Rocks

Au in Black Shale (Kazakevich and 1972; Buryak, 1980, Kanovalov, 1985)

Au in black shale deposits consist of stringers, disseminations, and veins that occur in Riphean sequences composed of alternating layers of folded black phyllite or shale, sandstone, limestone, siltstone, and argillite. Microfolds and longitudinal shear zones in anticlines are an important control. Gold occurs in conformable zones as disseminations. Highest Au content is in horizons and lenses of carbonaceous shale. Au-quartz veins occur in upper horizons as relatively thin bodies that pinch out downdip. Minerals constitute a low-sulfide quartz assemblage of mainly pyrite and arsenopyrite with scarce sphalerite, galena, and chalcopyrite. Rare PGE minerals may occur. Peripheral haloes, that are low in gold, contain disseminated pyrite and arsenopyrite. The deposits are polygenic and polychronous. Gold initially accumulated during deposition of the host rocks, and was redistributed and concentrated during dynamic metamorphism and infiltration of ore-bearing fluid. Examples of this mineral-deposit type are Mangazeika 2, Olympiada, and Sukhoy Log (fig. 38), Russia.

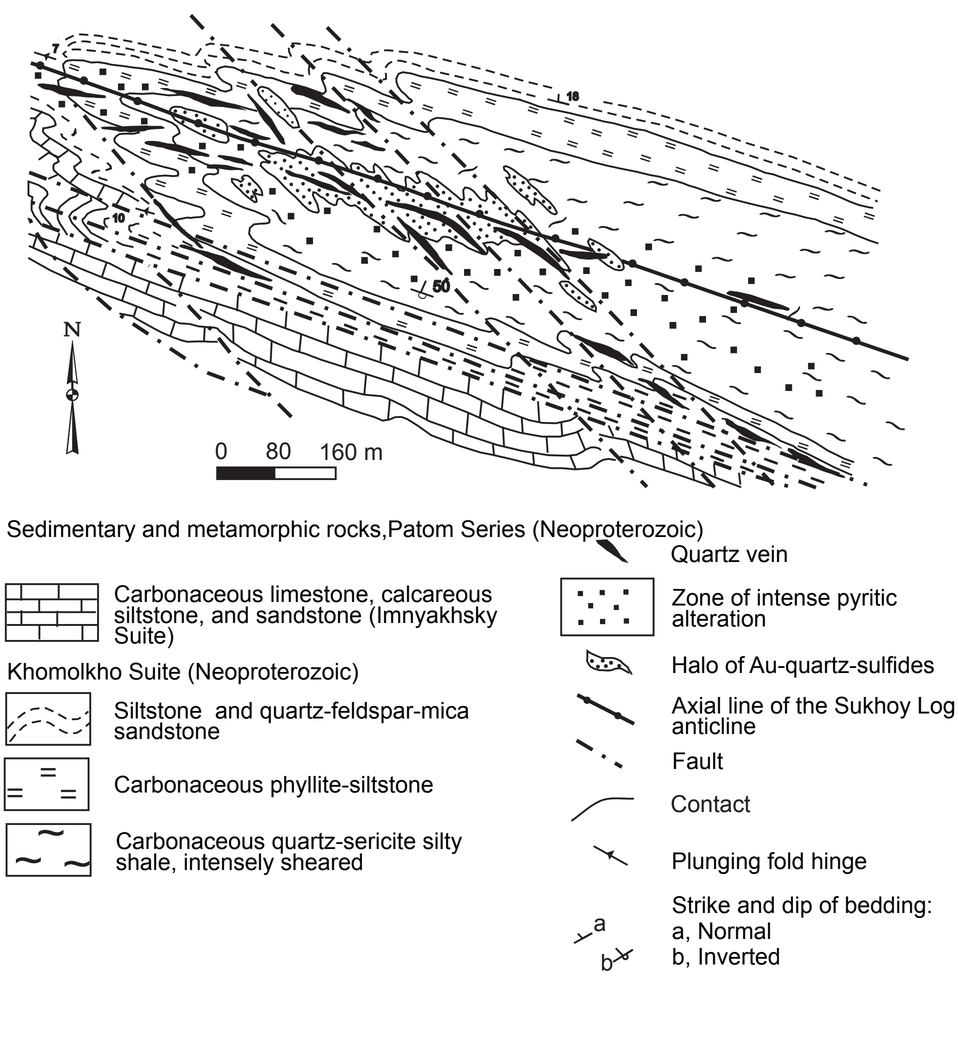


Figure 38. Generalized geologic map of the Devonian through Early Carboniferous Sukhoy Log Au in black shale deposit, TransBaikal, Russia. Adapted from Buryak (1982).

Au in Shear Zone and Quartz Vein (Berger, 1986c)

Au in shear zone and quartz vein deposits includes low-sulfide Au quartz vein, turbidite-hosted, concordant-vein, and shear-zone Au deposits. The deposits consist of gold in massive, persistent quartz veins that are hosted in regionally metamorphosed volcanic rock, and in metamorphosed graywacke, chert, and shale. Veins are generally late synmetamorphic to postmetamorphic and locally cut granitic rocks. Associated minerals are minor pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, pyrrhotite, and sulfosalts; alteration minerals include quartz, siderite, albite, and carbonates. The depositional environment consisted of low-grade metamorphic belts associated with continental margin arcs or collisional (anatectic) zones, or along transform continental margins. Examples of this mineral-deposit type are Nezhdaninka and Zun-Kholba (fig. 39), Russia, and Jiapigou, Jilin Province, China; Jinchangyu, Hebei Province, China; and Paishanlou, and Liaoning Province, China.

Clastic-Sediment-Hosted Sb-Au (Distanov and others, 1977; Berger, 1978, 1993; Indolev and others, 1980)

Clastic-sediment-hosted Sb-Au deposits consist of stibnite and associated minerals that occur in simple, lenticular, and ladder veins and in reticulate veins and veinlets, sometimes with subconformable disseminations. Main minerals are stibnite, berthierite, pyrite, arsenopyrite, and gold, with subordinate sphalerite, galena, chalcopyrite, tetrahedrite, chalcostibite, scheelite, pyrrhotite, marcasite, gudmundite,

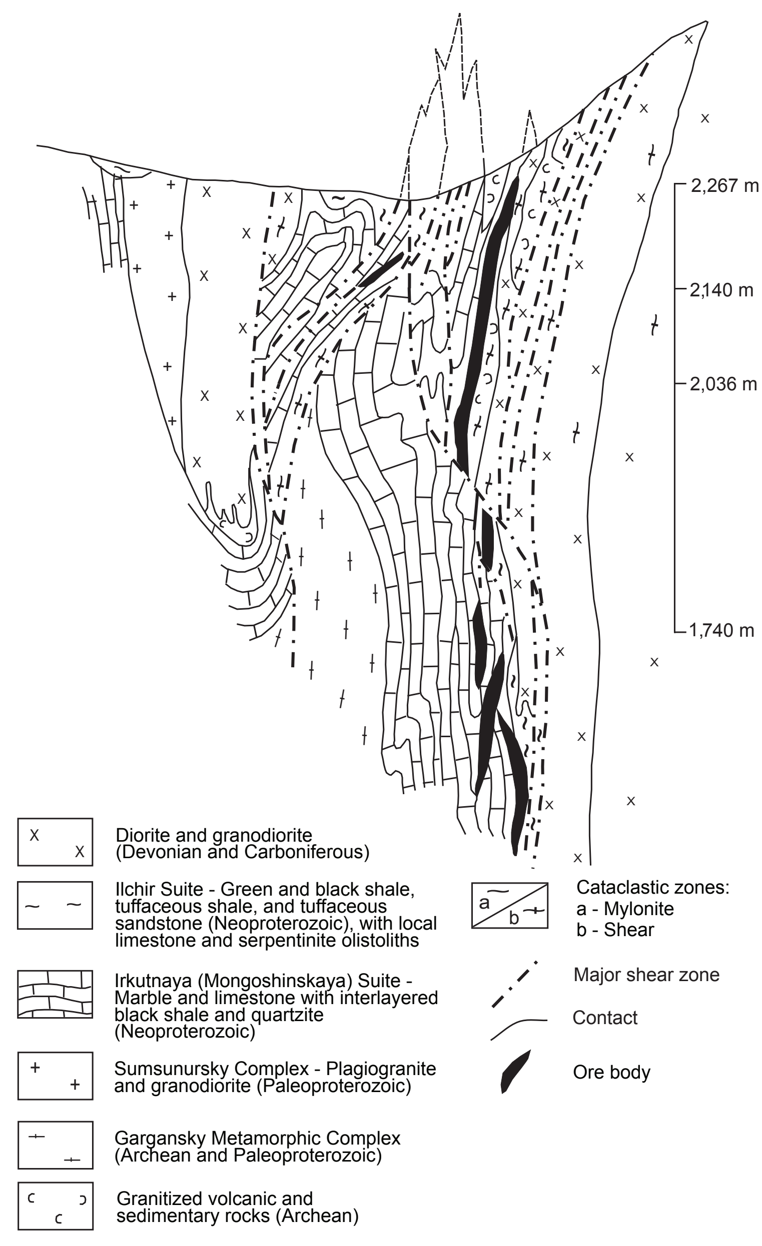


Figure 39. Schematic cross section of the Neoproterozoic through Silurian Zun-Kholba Au in shear zone and quartz vein deposit, TransBaikal, Russia. Adapted from Mironov and others (1995).

gersdorffite, native antimony, and native silver; gangue minerals are mainly quartz and lesser ankerite, calcite, dolomite, siderite, donbassite, sericite, and gypsum. Wallrocks are altered to varying combinations of quartz, carbonates, sericite, and pyrite. The host rocks for these deposits are (1) Proterozoic and Paleozoic greenschist derived from mafic volcanic and volcanic-clastic rocks; (2) interbedded carbonaceous black shale and volcaniclastic rocks; (3) or to a lesser extent, retrogressively-metamorphosed granitic rocks. The depositional environment consisted of strongly deformed fold belts that formed along intracratonic-rift troughs or in reactivated pericratonic-platform subsidences on a passive continental margin. The deposit type is controlled by linear zones of folds and mylonites that are associated with regional strike-slip faults, and are associated with low-grade greenschist facies regional metamorphism, suggesting a hydrothermal-metamorphic origin. The deposit type may also be associated with Au-quartz vein deposits. Examples of this mineral-deposit type are Sentachan, Russia (fig. 40), and Ichinokawa, Japan.

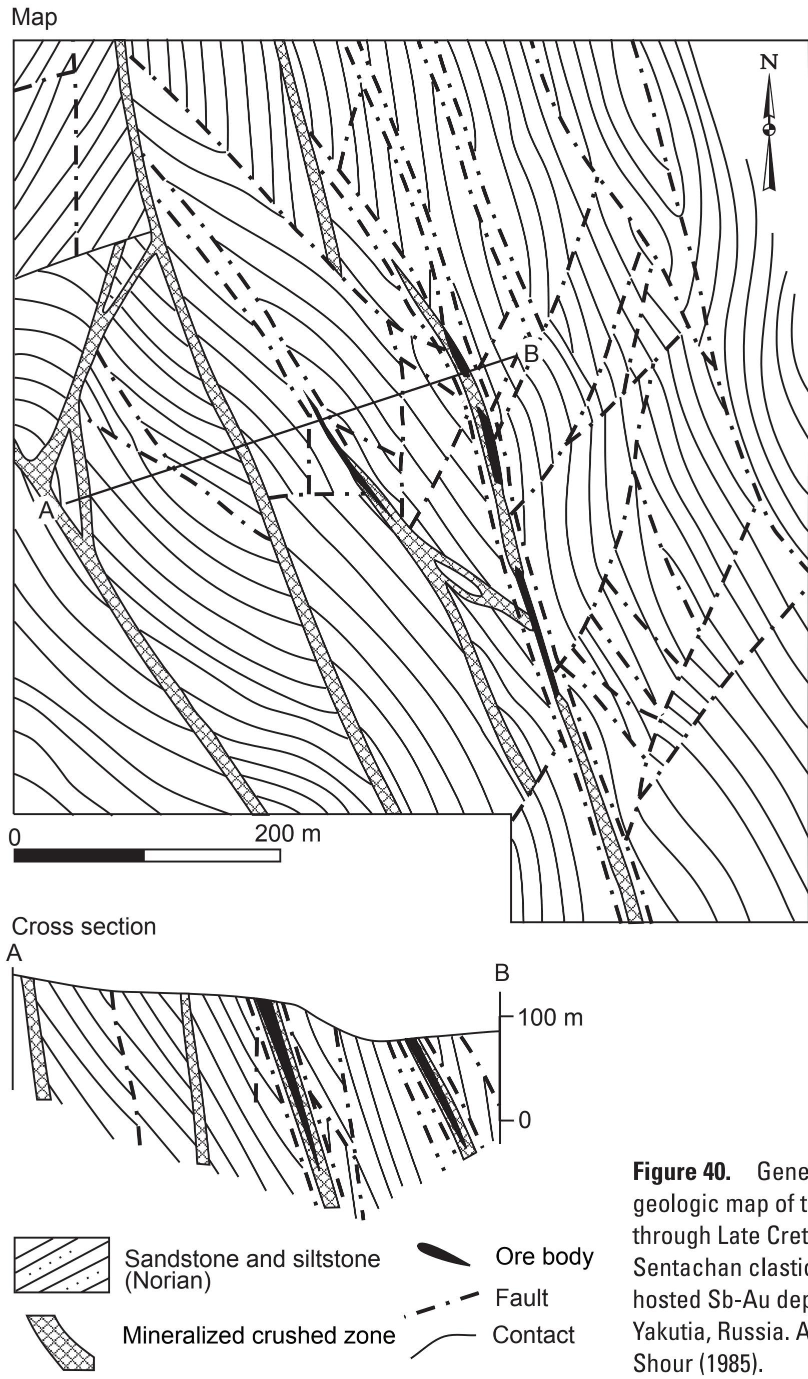


Figure 40. Generalized geologic map of the Aptian through Late Cretaceous Sentachan clastic-sediment-hosted Sb-Au deposit, Yakutia, Russia. Adapted from Shour (1985).

Cu-Ag Vein (Nokleberg and others, 1997)

Cu-Ag Vvein deposits consist mostly of Cu sulfides and accessory Ag minerals in quartz veins and stringers hosted in either weakly, regionally metamorphosed basalt, andesite-basalt, or clastic sedimentary rocks. The deposits may occur in structural slices of ultramafic rocks that occur along regional faults in clastic sedimentary rocks. The occurrences in lower grade, metamorphosed mafic volcanic rocks consist mainly of widespread zones of sulfide-bearing quartz veins; well-formed Cu sulfide quartz stringers and veins may also occur. Minerals are chalcopyrite, bornite, chalcocite, covellite, pyrite, pyrrhotite, malachite, and azurite, and rare native Cu; alteration minerals are epidote, chlorite, actinolite, albite, carbonates, and quartz. Special features are: (1) quartz veins and stringers that occur in extensive linear zones; (2) mineral occurrences in impregnations, stringers, layers, and rare breccia; and (3) locally high grades of Ag, Au, and Zn. In Northeast Asia, many occurrences are in Middle Riphean mafic volcanic rocks, Vendian through Lower Cambrian, and Ordovician through Silurian rocks. The depositional environment consisted of low-grade metamorphic belts containing mafic volcanic or clastic sedimentary rocks in continental margin arcs or collisional (anatectic) zones; veins are generally late-stage metamorphic. Examples of this mineral-deposit type are Goseong and Yanggudong, South Korea.

Piezoquartz (Arkhipov, 1979)

Piezoquartz deposits occur in Precambrian quartzite associated with high-alumina gneiss and mafic schist. The crystalline deposits generally occur at rupture intersections in flexures and periclines of folds, forming single veins (0.5 to 2 m thick and 20 to 30 m long) and vein zones (1 to 30 m thick, average of 5 to 15 m thick, and from a few tens of meters to 400 m long, average of 100 to 200 m). Most deposits occur in pipes, veins, and stockwork, a few tens of meters in diameter. Veins consist of crystalline or smoky quartz, clay filling voids, K-feldspar, and rare crystalline hematite, chlorite, sericite, tourmaline, albite, epidote, and adularia. Crystals occur on the walls of voids or in the lower parts of voids amidst clay; voids occur inside quartz veins, at the contacts of veins and host rocks, or in host rocks adjacent to veins. Host rocks are altered to sericite, chlorite, and epidote. Examples of this mineral-deposit type are Bugarykta and Perekatnoe, Russia.

Rhodusite Asbestos (Andreev, 1962; Romanovich and others, 1982)

Rhodusite asbestos deposits consist of rhodusite-asbestos and nonfibrous rhodusite in mottled layers with salt and gypsum. The mottled rocks consist of rhythmic layers of marl, argillite, siltstone, and sandstone; agillite predominates. The deposits are as much as tens of meters thick. Rhodusite-asbestos and nonfibrous rhodusite also occur in veinlets and disseminations. The depositional environment consisted of formation of epigenetic replacement of red-bed clastic rocks and mottled host rocks during initial metamorphism in intermontane depressions in arid areas with high-salinity water in sedimentary basins. An example of this mineral-deposit type is at Azkizskoye, Russia.

Talc (Magnesite) Replacement (Kim, 1972; Romanovich, 1973; Romanovich and others, 1982)

Talc (magnesite) teplacement deposits consist of metasomatic talc that replaces ultramafic and Mg-bearing sedimentary and magmatic rocks during regional or contact metamorphism.Two subtypes are defined: (1) metasomatic ferrous talc, talc-breunnerite, and talc-chlorite that occur in ultramafic rock, mainly dunite and harzburgite in veins, stocks, and lenses; and (2) low-ferrous talc minerals formed in dolomitic carbonaceous rocks. This second subtype consists of: (1) deposits associated with regional metamorphism with steatite, talc-schist, and talc-carbonates; and (2) deposits of talc, carbonate, and tremolite associated with contact metamorphism and related granitoid intrusions. Wallrocks are dolomite, interlayered dolomitic limestone and aluminosilicates (slate, amphibolite, quartzite). The deposits are bedded and generally large. Surficial processes may form a weathering crust with high-quality, powdery, low-ferrous talc. Associated minerals are magnesite, marshallite, and karst-bauxite. Major deposit control is ultramafic host rocks that are regionally metamorphosed to greenstone facies and intensely intruded by granitoids. The depositional environment consisted of dolomitic and ultramafic rocks in orogenic belts along continental margin arcs and collisional zones, and in pericratonal-platform subsidences. Examples of this mineral-deposit type are Alguiskoye, Savinskoe, Svetlyi Klyuch, and Togulenskoye, Russia, and Fanjiapuzi, Liaoning Province, China.

Metamorphic Graphite (Lee, 1960; Eremin, 1991)

Metamorphic graphite deposits consist of two subtypes: (1) deposits in regional high-grade metamorphosed rocks, including gneiss and schist with coarse-crystalline graphite; and (2) deposits formed during contact metamorphism of coal beds during Trapp intrusion, such as the Tungus graphite province in the North Asian craton, where the deposits formed with thermal metamorphism of coal layers during intrusion of thick Triassic diabase sills. The deposits are compositionally complex and consist of layers of amorphous graphite and numerous fragments and lenses of sedimentary rocks. Major mineral is fine-grained and flake graphite; associated minerals are pyrite, calcite, apatite, zircon, magnetite, rutile, and hydrosilicates. Examples of this mineral-deposit type are Noginskoye, Russia, Itgel Naidvar, Mongolia, and Liumao, Heilongjiang Province, China.

Metamorphic Sillimanite (Zhang, 1984; Jiang, 1994)

Metamorphic sillimanite deposits consist of multiple concordant layers containing 25 to 50 percent sillimanite in graphite-garnet-sillimanite schist, biotite-garnet-sillimanite schist, plagioclase-cordierite-sillimanite schist and gneiss, and lesser garnet schist, and phosphorus marble. Major mineral is sillimanite; accessory minerals are quartz, garnet, biotite, cordierite, K-feldspar, graphite, pyrite, pyrrhotite, tourmaline, and phlogopite. Protolith is high-Al argillaceous sedimentary rocks that formed in nearshore tidal flats and lagoons. Metamorphic grade ranges from amphibolite to granulite facies, with intense folding. The mineral-deposit type is commonly spatially associated with metamorphic graphite deposits. An example of this mineral-deposit type is at Sandaogou, Heilongjiang Province, China.

Phlogopite Skarn (Murzaev, 1974; Arkhipov, 1979)

Phlogopite skarn deposits consist of phlogopite in diopside and phlogopite-diopside schist, marble, and calc granofels that is metasomatized to coarse-grained phlogopite-diopside skarn. Some deposits are controlled by synforms and occur along fold hinges, on axial planes, and in the cores of superposed transverse folds. The deposits range from 0.7 to 2.5 km in length, and from 0.2 to 0.5 km in width; phlogopite skarn ranges from a few meters to several tens of meters in width from 10 to 20 m to several hundreds of meters in length. Minerals are phlogopite, diopside, hornblende, scapolite, apatite, and actinolite. Phlogopite occurs in nests that range from 0.5 to 1.5 to 6 m in width (average of 1 to 2 m); rare phlogopite occurs in thin veins. Phlogopite crystals are irregular, range from brown-green to brown, and vary from 8 to 15 cm across. Most deposits are associated with diopside-magnetite skarn. Local diopside- and diopside-scapolite-plagioclase skarn may contain molybdenite. The depositional environment consisted of the post-collisional stage of Precambrian orogenies. Examples of this mineral-deposit type are Fyodorovsko, Megyuskan, and Nadyozhnoe Russia.

Deposits Related to Surficial Processes

XI. Residual Deposits

Bauxite (Karst Type) (Patterson, 1986)

Bauxite (karst type) deposits consist of sedimentary bauxite that occurs mainly in depressions of karst surfaces in thick carbonate sequences. The deposits are confined to interformational breaks in carbonates. Deformation and metamorphism are typical. Main minerals are diaspore and boehmite; associated minerals are hematite, goethite, kaolinite, and minor quartz. The deposit structures include pisolitic, nodular, massive, and earthy. Examples of this mineral-deposit type are Novogodneye and Oktyabrskoye 4, Russia,

Laterite Ni (Singer, 1986b)

Laterite Ni deposits consist of Ni minerals and silicates in weathering crusts formed from ultramafic rocks, particularly peridotite, dunite, and serpentinized peridotite. Morphological types are areal, linear, and contact karst. The major minerals are complex Fe-Co-Ni silicates or oxides. Major minerals are garnierite, nepuite, and revdenskite; associated minerals are serpentine, nontronite, goethite, Mn oxide, and quartz. Goethite commonly contains abundant Ni. Silicate minerals occur in the lower part of residual weathering crusts and in infiltration deposits. Oxides consist of Ni-bearing Fe hydroxides and asbolan. Zonation from top to bottom is (1) an upper limonite zone with Ni in iron oxides and (2) a lower saprolite and boxwork zone with Ni in hydrous silicates. The depositional environment consisted of convergent margins with obducted ophiolite complexes; uplift was required to expose the ultramafic rocks to weathering. Examples of this mineral-deposit type are Alexandrovskoye 2 and Belininskoye, Russia.

Weathering Crust Mn (±Fe) (Kim and Kim, 1962; Varentsov and Rachmanov, 1978)

Weathering crust Mn (±Fe) deposits consist of extensive Mn-bearing weathering crusts formed as residual deposits on Mn-rich limestone and metamorphic rocks. Mn content results from leaching and removal of carbonates and silica. Mn crust consists of sand and clay masses that contain hypergene concentrations of Mn oxides. Main minerals are pyrolusite, psilomelane, manganite, vernadite, and local Fe hydroxides. Minerals occur in layers, lenses, branches, and sometimes karst cavities. The deposits range are as much as kilometers long and tens of meters thick; thicker deposits exhibit a clear zonation, with Mn minerals in the lower part overlapped by pure Mn bearing and Fe hydroxide minerals. The depositional environment consisted of subaerial exposures of Mn-bearing calcareous rocks in a humid climate. Examples of this mineral-deposit type are Karaulnaya Gorka and Seibinskoye 1, Russia.

Weathering Crust and Karst Phosphate (Rundqvist, 1986)

Weathering crust and karst phosphate deposits consist of phosphorite minerals in weathering crusts and karst in association with phosphatic rocks and phosphorite-bearing carbonates. The deposits formed in linear and karst structures in near-surface exposures. Secondary hypergene enrichment of phosphorite may occur. Dissolution and redeposition of phosphatic matter may form unconsolidated and stony phosphorite with granular and fragmental structures. The deposits occur in extensional regimes containing low-grade phosphates. An example of this mineral-deposit type is at Telekskoye, Russia.

Weathering Crust Carbonatite REE-Zr-Nb-Li (Lapin, 1996)

Weathering crust carbonatite REE-Zr-Nb-Li deposits consist of complex REE minerals in weathering crust formed on nepheline syenite and associated carbonatites. The more productive deposits areis weathering crusts developed on melanocratic feldspar-carbonates containing siderite, dolomite, calcite, pyroxene, amphibole, nepheline, apatite, monazite, fluorite, zircon, torianite, loparite, parisite, eudialyte, lepidomelane, and Cu, Zn, and Pb sulfides. Weathering crust consists of hydromica and ferrihalloysite types. Major REE minerals are bastnaesite, staffelite, rabdofanite, and melanterite, with associated pyrolusite and limonite. The deposits are compositionally complex and contain REE and Nb along with Li and Zr. Some deposits are large. Examples of this mineral-deposit type are Kiiskoye and Tomtor, Russia.

XII. Depositional Deposits

Placer and Paleoplacer Au (Hwang and Choi, 1961; Yeend, 1986)

Placer and paleoplacer Au deposits consist of gold in grains and rare nuggets in gravel, sand, silt, and clay, and their consolidated equivalents in alluvial, beach, eolian, and rarely, glacial deposits. Major minerals are gold, sometimes with attached quartz, magnetite, or ilmenite; rare PGE minerals may also occur. The depositional environment consisted of high-energy alluvial basins where gradients flatten and river velocities lessen, as on the inside of meanders, below rapids and falls, beneath boulders, and in shoreline areas where the winnowing action of surf concentrates gold in modern beaches or in uplifted or submerged beaches; numerous major placer districts occur in Russia, Mongolia, and China.

Placer Diamond (Orlov, 1973; Lampietti and Sutherland, 1978; Cox, 1986f)

Placer diamond deposits consist of diamonds in alluvial and beach sedimentary deposits and in sandstone and conglomerate. The conglomerate beds may contain paleoplacers. The deposits generally range from Tertiary and Quaternary in age, and the tectonic setting is generally stable cratons. An associated deposit type is diamond-bearing kimberlite. Main minerals are diamond (bort or carbonado) and ballas. Diamonds derived from ancient placers in sedimentary rocks commonly retain sand grains cemented to grooves, or to indentations in crystals. The depositional environment consisted of concentration in the low-energy parts of stream systems with other heavy minerals. The diamonds generally decrease in size and increase in quality with distance from the source. An example of this mineral-deposit type is at Huangsongdianzhi, Hunchun City, Jilin Province, China.

Placer PGE (Yeend and Page, 1986)

Placer PGE deposits consist of PGE minerals and alloys in grains in gravel, sand, silt, clay, and their consolidated equivalents in alluvial, beach, eolian, and, rarely, in glacial deposits. In some areas, placer and paleoplacer Au and placer PGE deposits occur together. Major minerals are PGE alloys, Os-Ir alloys, magnetite, chromite, and ilmenite. The depositional environment consisted of high-energy alluvial basins where gradients flatten and river velocities lessen, as on the inside of meanders, below rapids and falls, beneath boulders, and in shoreline areas where the winnowing action of surf concentrates PGE and gold in raised, present, or submerged beaches. An example of this deposit type is at Kondyor, Russia.

Placer Sn (Nokleberg and others, 1997)

Placer Sn deposits consist mainly of cassiterite and elemental gold in grains in gravel, sand, silt, clay, and their consolidated equivalents, mainly in alluvial deposits. The depositional environment was similar to that of placer and paleoplacer Au deposits. Examples of this mineral-deposit type are Verkhnegilyui, Russia, and Janchivlan, Khar Morit, Modot, and Zuuntarts, Mongolia.

Placer Ti-Zr (Yoon and others, 1959; Force, 1986b; Rosliakov and Sviridov, 1998)

Placer Ti-Zr deposits consist of zircon-ilmenite placers concentrated by marine beach processes and in continental surface environments. The host sediment is well-sorted, fine to medium sand with silt. The depositional environment consisted of stable coastal regions receiving sediment from deeply weathered terranes. The deposit morphology consists of lenses and elongate "shoestring" deposits that occur parallel to beaches, sometimes in multilayered packets. Major minerals are low-Fe ilmenite, zircon, leucoxene, anatase, rutile, staurolite, disthene, tourmaline, and monazite. Examples of this mineral-deposit type are Koppi-Nelman and Sash-Yular, Russia.

Exotic Deposits

Impact Diamond (Masaitis and others, 1975, 1998)

Impact diamond deposits occur in the Popigay, Russia, ring structure that is interpreted as an impact structure in a round surficial depression, several tens of kilometers in diameter. Occurring in the depression is a complex variety of impact rocks, volcanic in appearance, with varying amounts of (1) glass of andesite-dacite composition; (2) rocks and mineral fragments; (3) explosive allogenic breccias that were deposited after impact within or beyond the limits of the depression; and (4) authigenic breccia, formed from the bottom of the crater that underwent high-grade shock metamorphism, melting, and formation of pseudotachylite. Impactite also includes massive lavalike tagamite and glassy clastic suevite. Diamond occurs in graphite gneiss and tagamite that underwent shock metamorphism. Diamond crystals range in size from 0.05 to 20 mm in diameter; associated placer deposits contain diamonds as large as 8 to 10 mm in diameter. Most abundant diamonds are yellow; transparent, gray, or black crystals are rare. Diamonds from gneiss retain morphologic and structural features inherited from crystalline graphite. Common are tabular crystals with a characteristic striation of basal planes due to repeated twinning, parallel intergrowths, irregular intergrowths, and aggregates. For the origin of the Popigay ring structure, the prevaling interpretation is impact of a giant meteorite; supporting data consist of numerous indications of shock metamorphism with partial melting of the rocks derived from Early Precambrian crystalline bedrock. An example of this deposit type is at Popigay, Russia.

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Chapter 4

Archean through Mesoproterozoic Metallogenesis and Tectonics of Northeast Asia

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Introduction

This chapter presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia for the Archean through Mesoproterozoic. The major purposes are to provide a detailed summary of these features for readers who are unfamiliar with Northeast Asia. Several parts of this book on Northeast Asia provide background information. An overview of the regional geology, metallogenesis, and tectonics is provided in Chapter 1 along with other materials, such as employed geologic time scale and standard geologic definitions. The methodology for the metallogenic and tectonic analysis of this region is provided Chapter 2, and descriptions of mineral-deposit models are provided in Chapter 3. Additional information on project publications, descriptions of major geologic units, and summaries of metallogenic belts are provided in appendixes A-C.

Compilations Employed for Synthesis, Project Area, and Previous Study

The compilation of regional geology and metallogenesis in this introduction is based on publications of the major international collaborative studies of the metallogenesis and tectonics of Northeast Asia that were led by the U.S. Geological Survey (USGS). These studies have produced two broad types of publications. One type of study is a series of regional geologic, mineral deposit, and metallogenic-belt maps and companion descriptions for the region. Examples of major publications of this type are Obolenskiy and others (2003, 2004), Parfenov and others (2003, 2004a,b), Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006). The other type of study is a suite of metallogenic and tectonic analyses of these same regions. Examples of major publications of this type are Rodionov and others (2004), Nokleberg and others (2000, 2004, 2005), and Naumova and others (2006). Detailed descriptions of lode deposits are available in Ariunbileg and others (2003). For more detail than presented in this chapter, refer to the detailed descriptions of geologic units and metallogenic belts in these publications listed above.

The Northeast Asia project area consists of eastern Russia (most of Siberia and most of the Russian Far East), Mongolia, Northern China, South Korea, Japan, and adjacent offshore areas (fig. 1). This area is approximately bounded by 30 to 82° N. latitude and 75 to 144° E. longitude. The major participating agencies are the Russian Academy of Sciences, Academy of Sciences of the Sakha Republic (Yakutia), VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation, Mongolian Academy of Sciences, Mongolian University of Science and Technology, Mongolian National University, Jilin University, Changchun, China, the China Geological Survey, the Korea Institute of Geosciences and Mineral Resources, the Geological Survey of Japan/AIST, University of Texas, Arlington, and the USGS.

The Northeast Asia project extends and builds on data and interpretations from a previous project on the Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera (fig. 1) that was conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada. A summary of the major products of this previous project is included in appendix A and is online at http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.pdf.

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Major Geologic Units

The major Archean to Mesoproterozoic geologic and tectonic units of Northeast Asia are cratons, craton margins; cratonal terranes; and superterranes (fig. 2, table 1). Brief descriptions of map units are given in appendix B. Summary descriptions of the major units are provided in the following descriptions of metallogenic belts, and detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004), and Parfenov and others (2004b).

Major Cratons and Craton Margins

The Archean through Proterozoic backstop or core units for the region of Northeast Asia are the North Asian craton and overlying Phanerozoic units, various craton-margin units (Baikal-Patom, East Angara, South Taimyr, and Verkhoyansk terranes), various units in the Anabar and Aldan Stanovoy shields of the North Asian craton, and various terranes within the Sino-Korean and the South China cratons (fig. 2; appendix B).

The North Asian craton (NAC) consists of Archean and Proterozoic metamorphic basement and non deformed, flat-laying platform cover consisting of late Precambrian, Paleozoic, and Mesozoic sedimentary and volcanic rock. The cratonal units are exposed mainly in the Anabar shield to the North and the Aldan-Stanovoy shield to the south (fig. 2, table 1). Marginal to the North Asian craton are several related terranes. The Baikal-Patom cratonal margin (BP) consists of a fault-bounded basin containing Riphean carbonate and terrigenous sedimentary rock and younger Vendian and Cambrian sedimentary rock that discordantly overlie a

Figure 1. Regional summary geographic map for Northeast Asia showing major regions and countries.

fragment of the pre-Riphean basement of the North Asian craton. The East Angara cratonal margin (EA) consists of late Riphean terrigenous-carbonate sedimentary rocks (sandstone, siltstone, mudstone with interlayered dolomite and limestone) that overlie a fragment of the North Asia craton. The South Taimyr cratonal margin (ST) consists chiefly of a thick wedge of Ordovician through Jurassic craton margin deposits and deep basin deposits. The Verkhoyansk (North Asian) cratonal margin (VR) consists chiefly of a thick wedge of Mesoproterozoic, Neoproterozoic Devonian through Jurassic miogeoclinal deposits.

The Sino-Korean craton consists of several major Archean and Proterozoic metamorphic basement terranes (fig. 2, table 1) and younger Paleozoic through Cenozoic overlap units. The South China craton consists of two Proterozoic metamorphic basement terranes (fig. 2, table 1) and younger Paleozoic through Cenozoic overlap units.

Cratonal Terranes and Superterranes

Three cratonal terranes occur along the margins of the North Asian and Sino-Korean cratons and are interpreted as rifted and reaccreted fragments of the cratons. The cratonal terranes are as follows. (1) The Okhotsk terrane (OH) consists of Archean and Proterozoic gneiss and schist and early and middle Paleozoic miogeoclinal sedimentary rock. The terrane is interpreted as a fragment of the North Asian craton and Margin that was rifted in the Late Devonian or Early Carboniferous. (2) The Gyenggi-Yeongnam terrane (GY) consists of two major Archean and Proterozoic basement-rock terranes. The terrane is interpreted as a displaced fragment of the Sino-Korean craton, or possibly a fragment of the South China (Yangzi) craton. And (3) The Jiaonan cratonal terrane (JA) consists of a Paleoproterozoic major high-pressure terrane that is interpreted as a displaced fragment of the Sino-Korean craton.

Six superterranes occur along the margins of the North Asian and Sino-Korean cratons. Some of the superterranes are interpreted as rifted and reaccreted fragments of the cratons, whereas others are interpreted as having originally formed elsewhere.

The Proterozoic through Cambrian Argun-Idermeg superterrane (AR) consists of the Paleoproterozoic through late Paleozoic Argunsky and Idermeg, passive continental-margin terranes. The superterrane may be either exotic, with respect to the North Asian craton, or may be a rifted fragment of the craton.

The Late Riphean and older Tuva-Mongolia superterrane (TM) consists of a series of Archean and Paleoproterozoic cratonal terranes (Gargan and Baydrag), the Sangilen passive continental-margin terrane, and the Muya metamorphic terrane. These terranes are interpreted as accreting together to form the rear or back arc part of the Baikal-Mura island arc described below.

The Proterozoic through Permian Bureya-Jiamusi supterterrane (BJ) consists of a collage of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island arc terranes. The superterrane is interpreted as a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

The Proterozoic through Ordovician Kara superterrane (KR) consists of the Late Neoproterozoic through Ordovician Kara continental-margin turbidite terrane. The superterrane is interpreted as a rift fragment of the North Asian craton that was reaccreted in the Jurassic.

The Archean through Jurassic Kolyma-Omolon superterrane (KOM) consists of a tectonic collage of cratonal, passive continental-margin, island-arc, and ophiolite terranes. The cratonal and passive continental core of the superterrane was rifted from the North Asian craton and Margin in Late Devonian or Early Carboniferous. After subsequent building of overlying island arcs, the superterrane was reaccreted to the North Asian cratonal margin in the Late Jurassic with formation of the collisional granites of the Main and Northern granite belts.

Passive Continental-Margin Terranes of Unknown Affinity

Scattered around the margin of the North Asian craton and related units are four passive continental-margin terranes (along with one island-arc and one cratonal terrane) of unknown affinity. These units include (fig. 2, table 1) (1) the Late Riphean Central Angara passive continental margin terrane; (2) the Neoproterozoic and older Central Taimyr (composite) terrane composed of island-arc, cratonal, and passive continental-margin units; (3) the Late Neoproterozoic Kara passive continental-margin terrane; and (4) the Middle and Late Riphean West Angara continental-margin terrane.

Archean Metallogenic Belts and Host Units (>2,500 Ma)

From north to south, the major Archean (>2,500 Ma) metallogenic belts are the Jidong, Liaoji, Sharizhalgaiskiy, Sutam, West Aldan belts, and Wutai (fig. 3, appendix C). All four belts possess geologic units favorable for, and all contain, major stratiform banded iron formation (BIF) deposits that occur in the: (1) Sino-Korean terrane in northern China; and (2) granite-greenstone, orthogneiss, and gneiss terranes in southern Siberia that are interpreted as tectonic fragments derived from either the North Asian craton or possibly from other cratons. Some of the BIF deposits are interpreted as having formed in an Archean back-arc basin and (or) island arc. The isotopic ages of the stratiform deposits in the region range from about 3.5 to 2.5 Ga. Lesser Archean deposit types are stratiform volcanogenic massive sulfide, and Au in shear-zone

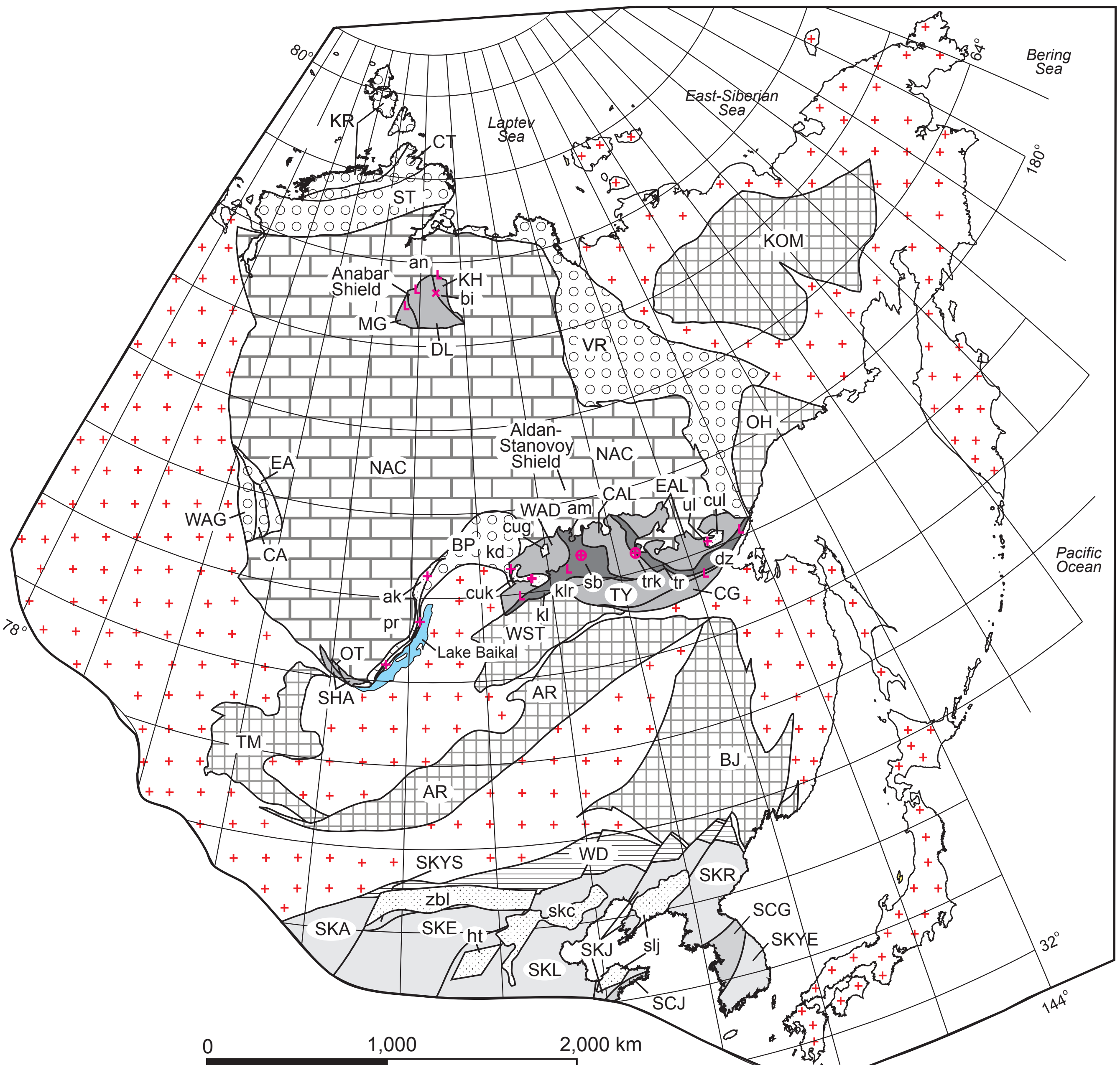

Figure 2. Generalized geodynamics map of Northeast Asia showing major Archean and Proterozoic cratons, cratonal margin, and passive continental-margin units. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004a,b); and (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003). Major Phanerozoic units omitted. Map.and Explanation. Refer to table 1 for unit descriptions.

and quartz vein that formed in later retrograde metamorphism, and talc (magnesite) deposits that formed during later replacements. The isotopic ages of the younger Au in shear-zone deposits range from 2.5 to 1.7 Ga to younger. The stratiform BIF and volcanogenic massive sulfide deposits formed early in the geologic history of the study area.

Jidong Metallogenic Belt of Banded Iron Formation (BIF, Algoma Fe) and Au in Shear-Zone and Quartz-Vein Deposits (Belt JD) (North China)

This Archean and Proterozoic metallogenic belt (fig. 3, appendix C) is hosted in a marine volcaniclastic sedimentary basin in the West Liaoning-Hebei-Shanxi terrane in the Sino-Korean craton in the East Hebei Province. Major deposits are a BIF deposit at Shuichang and a Au in shear-zone and quartz-vein deposit at Jinchangyu. The belt formed during two events: volcanism and sedimentation; and regional metamorphism, up to granulite facies, associated with folding and thrusting. A large number of BIF deposits, including those of Shuichang, Miyun, Shirengou, and Sijiaying, are associated with Au deposits. The metallogenic belt trends east-west and is about 300 km long, and 50 km wide. The BIF deposits at Shuichang, Miyun, Shirengou, and some Au deposits are hosted in granulite facies supracrustal rocks of the Qianxi Group whereas the Sijiaying BIF deposit is hosted in amphibolite facies supracrustal rocks of the Dantazi Group. The host rocks are derived from volcaniclastic and clastic sedimentary rock that formed in small volcaniclastic basins, or in aulacogens (Yan, 1985).

The main references on the geology and metallogenesis of the belt are Zhang and others (1986), Wu and others (1998), and Hart and others (2002).

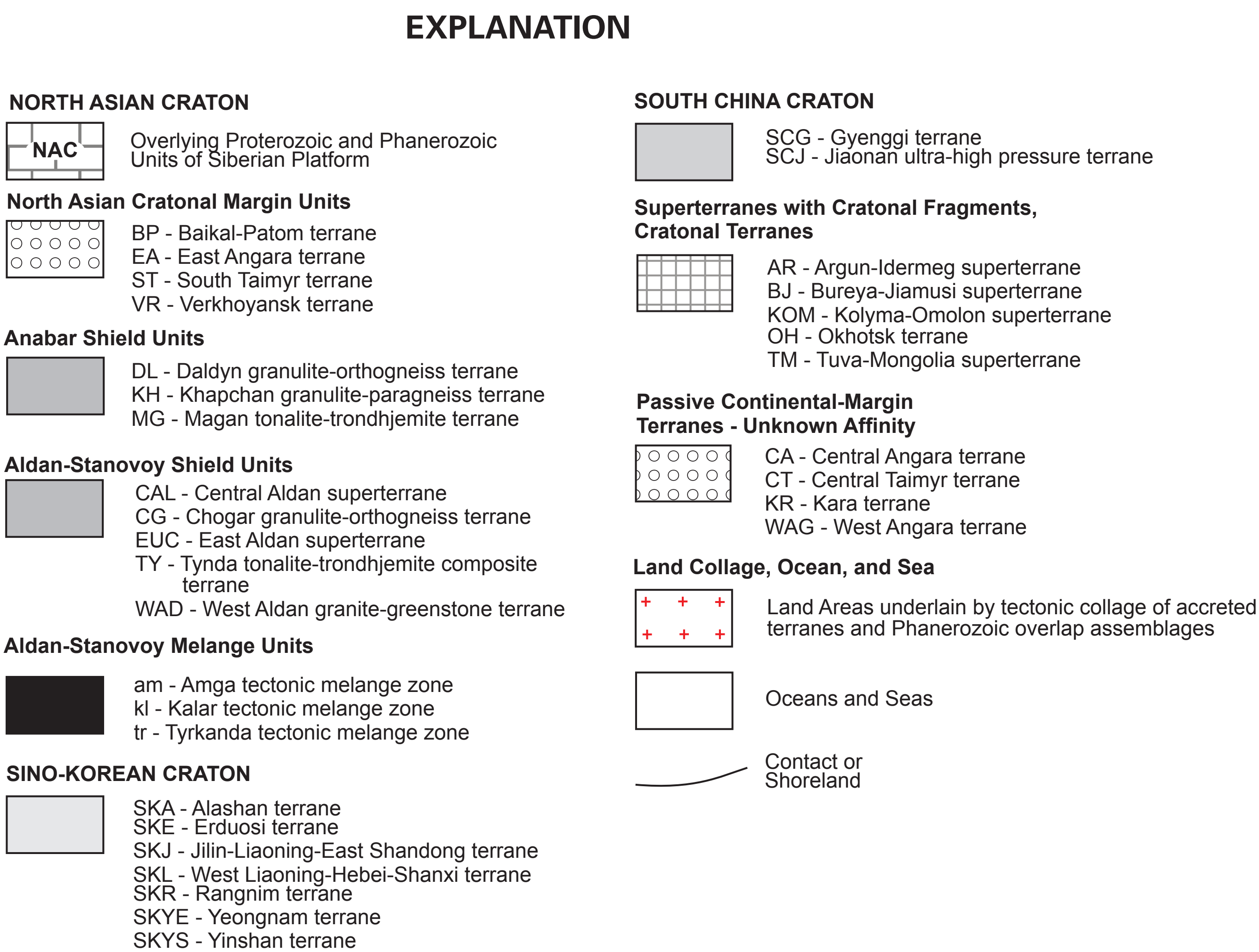

Figure 2.—Continued.

Table 1. Summary of major Archean and Proterozoic cratonal units, related mélange zones, and related passive continental margin units for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, and South Korea).

[Units arranged in alphabetical order of map symbol in each major section. Map units shown on figure 2]

Name and Type of Unit. Region. Map Unit	Major Archean and Proterozoic Cratonal Units	Age Range	Tectonic Environment	Peak Metamorphic Grade. Stitching Assemblages	Younger Overlying or Overlap Assemblages
NORTH ASIAN CRATON – OVERLYING PROTEROZOIC AND PHANEROZOIC UNITS					
North Asian craton – Siberian Platform. Eastern Siberia and Yakutia. NAC	Shallow-marine carbonate and non-marine and shallow-marine clastic, coal, mafic dikes, sills, and flows.	Riphean (Mesoproterozoic through Neoproterozoi).	Subdivision of North Asian craton	Non to greenschist facies. Local high-grade contact metamorphism adjacent to major plutons. Massive Permo-Triassic basalt flows of the Siberian trap and related mafic and ultramafic and granitic plutons.	Triassic through Middle Jurassic marine sandstone and shale, Late Jurassic and Early Cretaceous continental sandstone, siltstone, shale, and coal. Late Cretaceous continental sandstone, mudstone, coal, and conglomerate.
NORTH ASIAN CRATON MARGIN UNITS					
Baikal-Patom terrane. Transbaikalia. BP	Carbonate and terrigenous sedimentary rock.	Mesoproterozoic through Neoproterozoic	Craton margin	Kyanite-sillimanite to greenschist facies. Early Paleozoic granite batholiths and pegmatite veins with U-Pb zircon isotopic ages of 350 to 300 Ma	Vendian and Cambrian sedimentary rock
East Angara terrane. Eastern Siberia. EA	Sandstone, siltstone, mudstone, dolomite, limestone	Late Neoproterozoic	Craton margin	Non to greenschist facies.	Late Riphean through Cambrian dolomite and limestone
South Taimyr terrane. Northern Siberia. ST	Part of North Asian cratonal margin composed of clastic rock, shallow-marine terrigenous and carbonate rock.	Ordovician through Jurassic	Craton margin	Non to low-grade metamorphism. Early Triassic trap subalkaline and alkaline diabase dikes and sills.	Cretaceous and Tertiary marine and continental sedimentary rock.
Verkhoyansk terrane. Yakutia. VR	Shallow marine carbonate and clastic rock, and marine-littoral, deltaic, and shelf sedimentary rock.	Early Riphean (Mesoproterozoic) through Middle Jurassic	Craton margin.	Non to low-grade metamorphism. Cretaceous granite and granodiorite plutons with U-Pb zircon and Ar-Ar micas ages of 130 to 93 Ma.	Early Triassic and Early Jurassic alkalic basalt flows, and basalt dikes and sills. Cretaceous and Tertiary marine and continental rock
ANABAR SHIELD UNITS					
Daldyn granulite-orthogneiss terrane. Northern Yakutia. DL	Enderbites and mafic crystalline schists of Daldyn and Upper Anabar Groups	U/Pb concordia zircon age of 3.2 ± 0.32 Ga. Sm/Nd isochron age for mafic granulites of 3.1±0.8 Ga.	Subdivision of Anabar shield	Medium to high pressure granulite facies and anatexis occurred at 2.8 and 2.0 to 1.8 Ga.	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
Khapchan granulite-paragneiss terrane. Northern Yakutia. KH	Marble, calciphyres, calc-silicate rocks, garnet paragneiss, and lesser enderbite and schist.	Paleoproterozoic. Sm-Nd model age of garnet gneisses and metacarbonates are 2.4 to 2.3 Ga.	Subdivision of Anabar shield	Middle granulite facies. Sm-Nd mineral isochron dates indicate that granulite-facies metamorphism occurred at 1.9 Ga.	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
Magan tonalite-trondhjemite terrane. Northern Yakutia. MG	Late Anabar Group composed of biotite and biotite-amphibole orthogneiss and garnet-bearing and highly aluminous gneiss and carbonate rock.	Sm-Nd model age of 2.94 Ga.	Subdivision of Anabar shield	Granulite facies.	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.

Table 1. Summary of major Archean and Proterozoic cratonal units, related mélange zones, and related passive continental margin units for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, and South Korea).—Continued

[Units arranged in alphabetical order of map symbol in each major section. Map units shown on figure 2]

Name and Type of Unit. Region. Map Unit	Major Archean and Proterozoic Cratonal Units	Age Range	Tectonic Environment	Peak Metamorphic Grade. Stitching Assemblages	Younger Overlying or Overlap Assemblages
		ALDAN-STANOVOY SHIELD UNITS			
Central Aldan superterrane. Yakutia. CAL	Sutam granulite-paragneiss terrane composed of Seim Group that consists mainly of garnet-biotite gneiss and plagiogneiss, with lesser hypersthene-biotite, two-pyroxene, and diopside-amphibole plagiogneiss. CAST	Archean and Paleoproterozoi.c U/Pb concordia zircon age of charnocites is 3.1 ± 0.74 Ga. Sm/Nd age for paragnesses of 3.0 to 2.5 Ga.	Subdivision of Aldan-Stanovoy shield	Medium to high pressure granulite facies. U-Pb isochron zircon age (lower intercept) of 1.9 ± 0.35 Ga.	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
	Nimnyr granulite-orthogneiss terrane consisting of Kurumkan and Fedorov Groups. Kurumkan Group consists of quartzite and high-alumina gneiss. Fedorov Group consists of amphibole, diopside-amphibole, and two pyroxene-amphibole plagiogneiss. CANM	Paleoproterozoic. Orthogneiss with Nd model ages of ~2.5 to ~2.3 Ga that contains xenoliths of granite-gneiss with U/Pb zircon age of 3.35 Ga. Nd model ages of paragneiss are 3.06 to 2.1 Ga.	Subdivision of Aldan-Stanovoy shield	Low to middle pressure granulite facies	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
Chogar granulite-orthogneiss terrane. CG	High-grade diorite plagiogneiss, mafic and ultramafic schist.	Archean	Subdivision of Aldan-Stanovoy shield	Medium to high pressure granulite facies.	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
East Aldan superterrane. Yakutia. EAL	Uchur granulite-paragneiss terrane EUC	Paleoproterozoic. Nd model ages for paragneiss of 2.6 to 2.1 Ga.	Subdivision of Aldan-Stanovoy shield	High-pressure granulite facies with ages Pb-Pb zircon age for charnockites of 2.0 to 1.8 Ga.	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
	Batomga composite granite-greenstone terrane EBT	Late Archean through Paleoproterozoic. Nd model ages of 2.4 to 2.1 Ga.	Subdivision of Aldan-Stanovoy shield	High-pressure amphibolite facie to granulite facies. Granite dikes and veins and stocks with isotopic ages of 2,500 to 1,830 Ma, and in the Unakha greenstone belt are stocks of hornblende-biotite granite with an isotopic age of 1,830 Ma.	Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.

Table 1. Summary of major Archean and Proterozoic cratonal units, related mélange zones, and related passive continental margin units for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, and South Korea).—Continued

[Units arranged in alphabetical order of map symbol in each major section. Map units shown on figure 2]

ALDAN-STANOVOY SHIELD UNITS					
West Aldan granite-greenstone terrane. Southeastern Yakutia. WAD	Orthogneiss consisting of tonalite-trondhjemite of the Olekma complex. Kurulta granulite complex. Subgan greenstone complex. Tokko-Khani greenstone belt.	3.0 to 2.7 Ga.	Subdivision of Aldan-Stanovoy shield	Moderate pressure amphibolite to granulite facies. Granite plutons and pegmatite. Plutons of Charodakan granite complex dated at 2.6 Ga.	Paleoproterozoic medasedimentary rocks of the Udokan and Uguy series in the Kodar-Udokan, Early Khani, Oldongso, and Uguy graben-like basins. A U-Pb age of volcanogenic zircons from metagraywacke and tuffaceous sandstone of the Udokan series in the Kodar-Udokan basin is 2.18±0.05 Ga.
MAJOR MELANGE UNITS IN ALDAN-STANOVOY SHIELD					
Amga tectonic melange zone. Yakutia. am	Rock assemblages of variable composition, age, and metamorphic grade. Most widespread are orthogneiss and subordinate tonalite-trondhjemite gneiss.	Isotopic ages for granitic gneiss of 2.4 to 2.5 Ga and pegmatoid gneissic granite of 2.2 Ga.	Subdivision of Aldan-Stanovoy shield	Granulite facies with local faulted greenstone belts. Granite and pegmatite with isotopic ages of 2.0 to 1.9 Ga.	Tectonic melange zones of the Aldan-Stanovoy shield were welded at about 2.1 to 1.8 Ga into a single continental block. Overlain by Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
Kalar tectonic melange zone. Yakutia. kl	Rock assemblages of variable composition, age, and metamorphic grade. Most widespread are tonalite-trondhjemite orthogneiss, greenstone belts, anorthosite, and granite.	Isotopic ages of 3.15 to 2.4 to 2.2 Ga.	Subdivision of Aldan-Stanovoy shield	Granulite facies with local faulted greenstone belts. Pegmatite and a layered gabbro-anorthosite pluton with an isotopic age of 1.9 to 1.8 Ga.	Tectonic melange zones of the Aldan-Stanovoy shield were welded at about 2.1 to 1.8 Ga into a single continental block. Overlain by Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.
Tyrkanda tectonic melange zone. Yakutia. tr	Rock assemblages of variable composition, age, and metamorphic grade. Most widespread are paragneiss and anorthosite, and granite..	Isotopic ages of 3.15 to 1.9 Ga.	Subdivision of Aldan-Stanovoy shield	Granulite facies. Charnockite with magmatic zircon age of 1.9 Ga.	Tectonic melange zones of the Aldan-Stanovoy shield were welded at about 2.1 to 1.8 Ga into a single continental block. Overlain by Late Riphean and Vendian and younger Paleozoic marine units of the North Asian craton.

Table 1. Summary of major Archean and Proterozoic cratonal units, related mélange zones, and related passive continental margin units for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, and South Korea).—Continued

[Units arranged in alphabetical order of map symbol in each major section. Map units shown on figure 2]

Name and Type of Unit. Region. Map Unit	Major Archean and Proterozoic Cratonal Units	Age Range	Tectonic Environment	Peak Metamorphic Grade. Stitching Assemblages	Younger Overlying or Overlap Assemblages
		SINO-KOREAN CRATON			
Alashan terrane. Northwestern China SKA	Granulite paragneiss, greenstone, amphibolite, metasedimentary rock.	Rb-Sr whole rock isochron metamorphic age of 1,927 Ma.	Subdivision of Sino-Korean craton	Middle to low pressure greenschist and ampibolite facies. Low metamorphic-grade	Mesoproterozoic terrigenous and carbonate rock.
Erduosi terrane. North-central China. SKE	Granulite orthogneiss and paragneiss composed of metasdeimentary rock, tonalite, trondhjemite, and khodalite.	Archean through Paleoproterozoic. U-Pb isochron ages of 2,600 to 1,800 Ma.	Subdivision of Sino-Korean craton	Granulite facies.	Metamorphosed Paleoproterozoic and Mesoproterozoic sedimentary rock and breccia.
Jilin-Liaoning-East Shandong terrane. Northeastern China. SKJ	Tonalite-trondhjemite-gneiss, granitoid mylonite derived from trondhjemite, and granitoid gneiss.	U-Pb zircon ages of 3,800 to 2,500 Ma.	Subdivision of Sino-Korean craton	Granulite to amphibolite facies. Granitic gneiss with UK-Pb zircon isotopic age of 2.6 to 2.5 Ga.	Metamorphosed Paleoproterozoic and Mesoproterozoic carbonate and sedimentary rock and breccia.
West Liaoning-Hebei-Shanxi terrane. Northern China. SKL	Granulite-orthogneiss, felsic orthogneiss, metasedimentary schist, mafic to ultramafic granulite schist, granite-greenstone belts composed of tonalite-trondhjemite-granodiorite, and monzonite,	U-Pb zircon age for chrome-mica quartzite is 3,722 to 3,630 Ma.	Subdivision of Sino-Korean craton	Granulite facies. Granite with isotopic ages of 2,800 to 2,500 Ma.	Paleoproterozoic cataclastic rock and carbonate rock of the Hutuo Group.
Rangnim terrane. Korea. SKR	Granulite-paragneiss composed of gneiss, migmatite, and metamorphic granite of the Nangnim Supergroup.	Archean	Subdivision of Sino-Korean craton	Granulite to amphibolite facies.	Unconformably overthrust are Neoproterozoic Sangwon Supergroup of slightly metamorphosed sedimentary rock and marine sedimentary rock of the Early Paleozoic Chonsun Supergroup, and the late Paleozoic and early Mesozoic Pyeongang Group.
Yeongnam terrane. Korea. SKYE	Granulite-paragneiss composed of Sabaegsan Complex with metapelitic rocks, para- and orthgneiss; Sanch'ong Complex with metamorphosed gabbro, diorite, syenite, anorthosite, and gneiss; and Honam Complex with granitic gneiss, paragneiss, and metasedimentary rock.	Late Archean through Paleoproterozoic)	Subdivision of Sino-Korean craton	Amphibolite facies.	Unconformably overlain by nonmetamorphosed marine sedimentary rock of the early Paleozoic Chosun Supergroup, and late Paleozoic Pyeonngang Group

Table 1. Summary of major Archean and Proterozoic cratonal units, related mélange zones, and related passive continental margin units for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, and South Korea).—Continued

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Name and Type of Unit. Region. Map Unit	Major Archean and Proterozoic Cratonal Units	Age Range	Tectonic Environment	Peak Metamorphic Grade. Stitching Assemblages	Younger Overlying or Overlap Assemblages
		SINO-KOREAN CRATON			
Yinshan terrane. North-central China SKYS	Granite-greenstone composed of amphibolite, and hornblende schist, albite-biotite schist, hornblende-albite schist metamorphosed volcanic, and terrigenous rock, and tonalite and granite.	U-Pb zircon isotopic age for tonalite is 2,450 to 2,470 Ma.	Subdivision of Sino-Korean craton	Lower amphibolite facies.	Metamorphosed Paleoprotero-zoic and Mesoproterozoic sedimentary rock and breccia.
		SOUTH CHINA CRATON			
Gyenggi terrane. Korea. SCG	Granulite-paragneiss. Geongggi complex and Seosan group with high-grade metasedi-mentary rock; Mesoprotero-zoic Yeoncheon Group with low-grade metasedimentary rock; and Neoproterozoic Taean Group with ow-grade metasedimentary rock.	Mesoproterozoic and Neopro-terozoic and older	Subdivision of South-China craton	Low-grade to amphibolite facies.	Cretaceous terrigenous rock of Sindong and Hayang Groups and the volcanic rock of the Yucheon Group.
Jurassic Daebu granite Jiaonan ultra-high pressure terrane. Northeastern China) SCJ	Paleoproterozoic Jiaonian Group with high- and ultra-high grade metasedimentary rock.	Paleoproterozoic	Subdivision of South-China craton	Lower amphibolite facies with local eclogite facies. Diorite with a U-Pb zircon isotopic age of 1,855 Ma	Intruded by Permian Jihei plu-tonic belt and overlain by Me-sozoic and Tertiary continental rock including Cretaceous units of Laiyang volcanic and sedimentary basin.
		SUPERTERRANES AND TERRANES WITH CRATONAL UNITS			
Argun-Idermeg superterrane. Transbailalia, northern Mon-golia. AR	Gneiss, granite, amphibolie, schist.	Paleoproterozoic. U-Pb isotopic age of 740 ±± 20 Ma.	Cratonal basement to passive continental-margin terranes. may be exotic to North Asian craton or may be a rifted frag-ment of the craton.	Amphibolite facies.	Riphean through Vendian through late Paleozoic sedi-mentary rock.
Bureya-Jiamusi superterrane. Russian Southeast. BJ	Early Paleozoic metamorphic core complex composed of gneiss, schist, marble, quartz-ite, and amphibolite.	Neoproterozoic through Triassic	Metamorphic (cratonal). Pos-sible a fragment of Gondwana that was accreted to the Sino-Korean craton.	Amphibolite facies. Early Paleozoic granitic plutons.	Cretaceous Umelkan-Ogodzhin volcanic-plutonic belt.
Kolyma-Omolon superterrane. Yakutia. KOM	Gneiss and schist.	Archean through Paleoprotero-zoic	Rifted fragment of North Asian craton.	Granulite to amphibolite facies. Late Jurassic collisional granite.	Proterozoic and early Paleozoic continental-margin sedimen-tary rock.
Okhotsk terrane. Yakutia. OH	Gneiss and schist.	Archean through Paleoproterozo-ic. U-Pb zircon age of 3.7 Ga	Rifted fragment of North Asian craton.	Granulite to amphibolite facies.	Middle Devonian limestone, sandstone, shale, and conglomerate amd younger marine units..

Table 1. Summary of major Archean and Proterozoic cratonal units, related mélange zones, and related passive continental margin units for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, and South Korea).—Continued

[Units arranged in alphabetical order of map symbol in each major section. Map units shown on figure 2]

Name and Type of Unit. Region. Map Unit	Major Archean and Proterozoic Cratonal Units	Age Range	Tectonic Environment	Peak Metamorphic Grade. Stitching Assemblages	Younger Overlying or Overlap Assemblages
SUPERTERRANES AND TERRANES WITH CRATONAL UNITS					
Tuva-Mongolia superterrane. Altayu-Sayan. TM	Gargan and Baydrag cratonal terranes. Sangilen passive continental margin terrane Muya metamorphic terrane.	Archean and Paleoproterozoic. Paleoproterozoic or Neoproterozoic. Paleoproterozoic?	Cratonal.	Non to low-grade metamorphism. Granite bodies with Nd-Sm isotopoic model ages of 789 and 784 Ma.	Vendian-Cambrian terrigenous-carbonate sedimentary rocks.
PASSIVE CONTINENTAL-MARGIN TERRANES OF UNKNOWN AFFINITY					
Central Angara terrane. Eastern Siberia. CA	Terrigenous sedimentary rock, flysch, limestone, and dolomite.	Late Riphean (Neoproterozoic).	Passive continental margin.	Greenschist to rare amphibolite facies. Granitoids with age of 760 Ma.	Vendian-Cambrian terrigenous-carbonate units.
Central Taimyr terrane. Taimyr Peninsula. CT	Chelyuskin terrane. Faddey terrane. Kolosovsky terrane.	Neoproterozoic and older	Island arc (Chelyuskin), cratonal (Faddey), & passive continental margin (Kolosovsky).	Non-metamorphosed to greenschist to amphibolite facies Granitoid bodies with isotopic ages of 740 to 850 Ma.	
Kara terrane. Taimyr Peninsula. KR	Sandstone, siltstone, and pelite.	Late Neoproterozoic	Passive continental margin.	Greenschist to amphibolite facies. granite and migmatite with Rb-Sr and K-Ar isotopic ages of 277 to 270 Ma.	
West Angara terrane. Yakutia. WAG	Terrigenous sandstone, siltstone, limestone, and dolomite. and carbonate sedimentary rock	Middle and Late Riphean	Passive continental margin.	Lower greenschist to amphibolite facies. Granite and migmatite of Teya comple with U-Pb zircon isotopic age of 866 to 760 Ma.	Late Riphean and Early Cambrian marine sedimentary rock.

Shuichang Banded Iron Formation (BIF, Algoma Fe) Deposit

This deposit (Zhang Yixia and others, 1986) (fig. 4) occurs in the Qian'an iron mine that is part of a western belt and an eastern belt of BIF deposits. The western belt is 15 km long, 2 km wide, trends north-northeast, and contains the large Shuichang deposit. The eastern belt is relatively small. The two belts occur in different parts of a complicated fold. The Shuichang deposit consists of multiple layers of stratiform and lensoid deposits. The average thickness of a single deposit is 10 m and locally ranges up to 170 to 300 m. The ores are mainly banded with minor laminations. Locally, paragneiss structures occur. The main minerals are coarse-grained magnetite

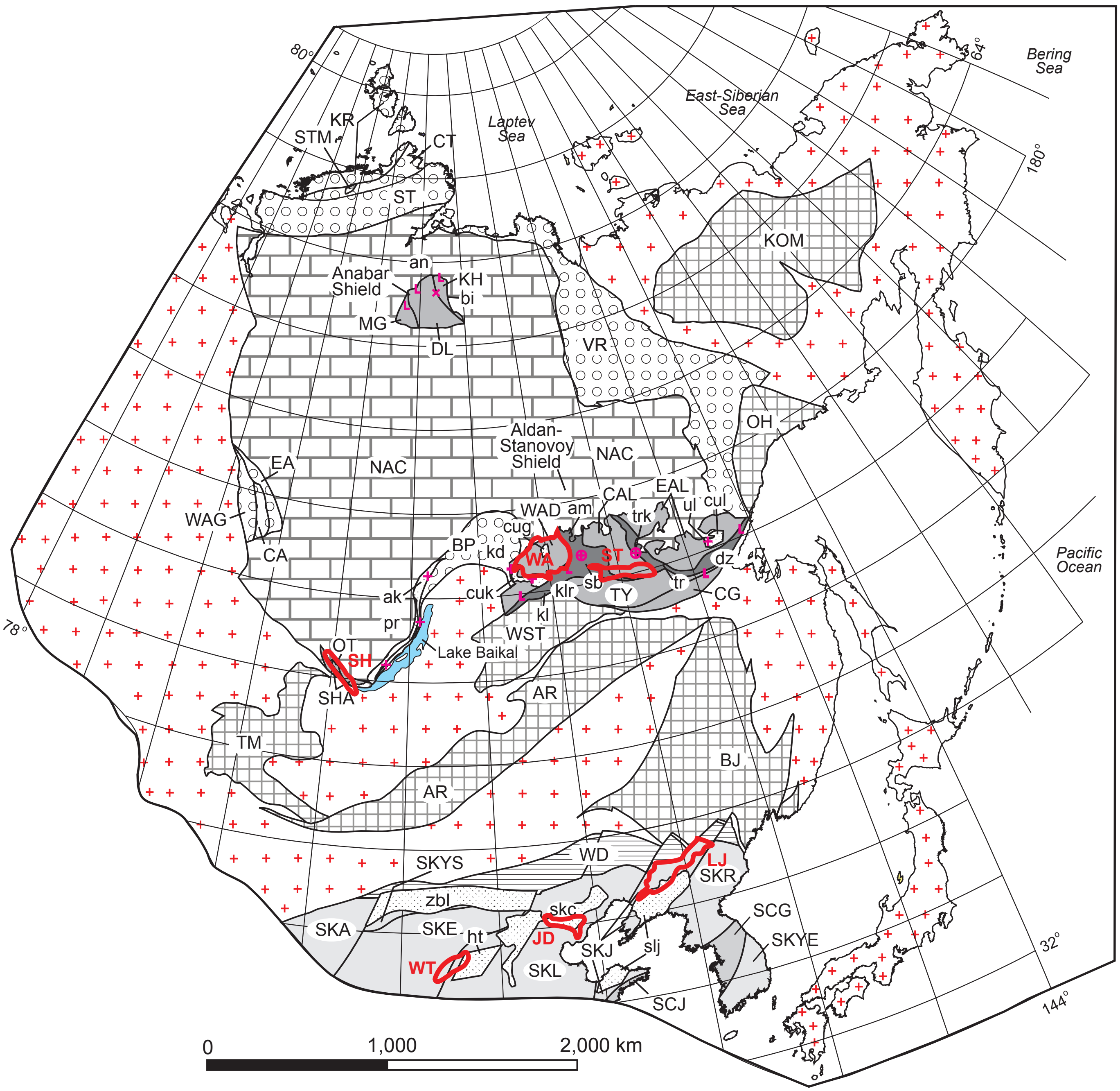


Figure 3. Generalized map of major Archean metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 and table 1 for explanation of geologic units. Metallogenic belt outlines are adapted from Obolenskiy and others (2003, 2004), Rodionov and others (2004), and Parfenov and others (2003, 2004a). Metallogenic belts for area east of 144º E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2005).

and quartz, and minor pyroxene and garnet. Host rocks are granulite facies biotite microgneiss, sillimanite gneiss derived from mafic volcanic rock, intermediate volcanic graywacke, felsic volcanic graywacke, and muddy siltstone that formed in a moderately deep Archean volcanic and sedimentary basin. Rb-Sr isotopic age of the sequence is more than 3,500 Ma. The deposit is large and contains reserves of greater than 100 million tonnes, ranging from 20 to 35 percent Fe.

Sijiaying Banded Iron Formation (BIF, Algoma Fe) Deposit

This deposit (Zhang and others, 1986; Wu, 1993; Wu and others, 1998) consists of multiple stratiform deposits in host rocks of biotite microgneiss, K-feldspar microgneiss, and minor intercalated amphibolite, quartzite, and marble. The deposit occurs in a gently-dipping anticline and syncline. Fe minerals are mainly laminated, minorly banded and massive, and are composed of fine-grained magnetite and quartz. Some parts of the deposit are composed of hematite, with minor actinolite, tremolite, amphibole, and sulphides. The host strata are Archean amphibolite facies metamorphically derived from mafic volcanic lava, felsic volcanic graywacke, felsic volcanic greywacke, and carbonates that formed in a deep marine basin. The BIF belt is 25 km long and trends north-south. The deposit is large and contains reserves of 2,200 million tonnes grading 30 percent Fe, and locally up to 50 percent Fe.

Jinchangyu Au in Shear0Zone and Quartz-Vein Deposit

This deposit (Zhang and others, 1986; Xu and others, 1994; Wu and others, 1998) consists of fine and dense Au-bearing quartz-veinlets that occur parallel to schistosity in mylonite, and in veinlets and disseminations in mylonite. The ore minerals are mainly composed of pyrite and minor chalcopyrite, chalcocite, gold, and calaverite. Gangue minerals are albite, quartz, sericite, and minor chlorite and calcite. Host rock alterations are albite, silica, sericite, chlorite, pyrite, and carbonate alteration. The deposit occurs in a tonalite, trondhjemite, and granodiorite terrane in the North China Platform. Host rocks are derived from mafic volcanic rock, volcanic graywacke, and BIF that were metamorphosed into granulite, pyroxene gneiss, and amphibolite. The isotopic age of the metamorphic rock is 3.5 Ga. The metamorphosed supracrustal rocks are interpreted by some workers as a greenstone belt. The shearing and retrograde metamorphism at greenschist facies occurred probably at 2.5 to 2.6 Ga, 1.7 to 1.8 Ga., or later. Widely overprinted Jurassic and Cretaceous magmatism modified the deposits, and some workers interpreted these deposits as related to Mesozoic magmatism. Hart and others (2002) show that three ages for white mica from the Jinchangyu deposit exhibit argon loss and a decrease in apparent age from approximately 204 to 180 Ma, thereby indicating an early Early Jurassic or older age for mineralization.

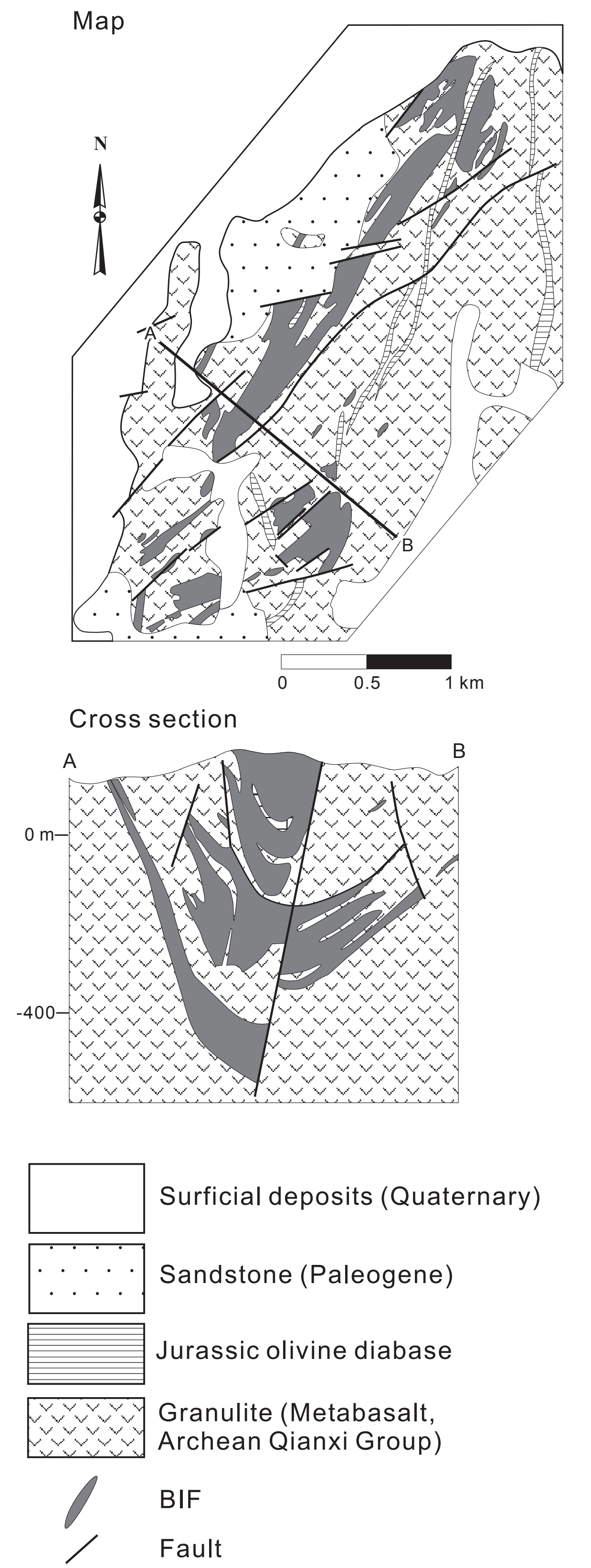


Figure 4. Shuichang iron deposit (BIF, Algoma type), Jidong metallogenic belt, west Hebei, North China. Schematic geological map and cross section. Adapted from Ma Guogun (1993).

The deposit is large and has reserves of 19 tonnes and an average grade of 7.53 g/t Au.

Origin and Tectonic Controls for Jidong Metallogenic Belt

The BIF deposits are interpreted as having formed in a volcanic and sedimentary basin that formed along an unstable protocontinental margin, or in a fragment of Archean craton (Zhang Yixia and others, 1986). The Au deposits are interpreted as having formed during retrograde metamorphism to greenschist facies. Archean BIF deposits have a Rb-Sr isotopic age greater than 3,500 Ma. Proterozoic or younger ages for Au deposits are based on isotopic ages of 2.5 to 2.6 Ga., 1.7 to 1.8 Ga., or younger values. The host Archean Liaoning-Hebei-Shanxi terrane contains the following major units (1) tonalite-trondhjemite and granodiorite, (2) gneiss and amphibolite, and (3) enderberite gneiss. The oldest U-Pb age of zircon of chrome mica in quartzite is 3,720 to 3,600 Ma (Wu and others, 1998). Highly-metamorphosed supracrustal rocks comprise a minor part of the terrane and are interpreted as having formed an active continental margin (Lu Liangzhao and others, 1996).

Liaoji Metallogenic Belt of Banded Iron Formation (BIF, Algoma Fe), Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types), and Au in Shear-Zone and Quartz-Vein Deposits (Belt LJ) (Northeastern China)

This composite Late Archean metallogenic belt (fig. 3, appendix C) is hosted in marine volcaniclastic and sedimentary basins and greenstone belts of the Jilin-Liaoning-East Shandong terrane in the Sino-Korean craton. The belt contains numerous BIF deposits in the Anshan-Benxi area, some volcanogenic Cu-Zn massive sulphides, and Au shear-zone and BIF deposits in the Liaobei and Jiapigou areas. The belt extends northeast from the eastern Liaoning Province into the northeastern Jilin Province and is about 1,000 km long and 100 km wide. The deposits in the belt are hosted in the supracrustal rocks of the Anshan, Qingyuan, and Longgang Groups that are metamorphosed at amphibolite facies. These groups are derived from a sequence of mafic, intermediate, and siliceous volcanic rock and clastic sedimentary rock formed in small volcanic and sedimentary basins along an ancient continental margin. Because of the ancient geologic units and lack of detailed data, several mineral deposit types are combined into a composite belt. Large BIF deposits in Anshan-Benxi area have been the main source of ore for the Anshan Steel Company. The significant Fe deposit is at Gongchangling. The volcanogenic Cyprus Cu-Zn massive sulfide deposit at Hongtoushan is a well-known deposit. Au deposits in the Jiapigou area are related to ductile shear zones. The main references on the geology and metallogenesis of the belt are Cheng (1986), Wu and others (1998), and Hart and others (2002).

Gongchangling Banded Iron Formation Deposit (BIF, Algoma Fe)

This deposit (Cheng and others, 1994) (fig. 5) consists of several layers in host metamorphic rock of the Archean Anshan Group that occurs in an anticlinorium that was intruded and reworked during two periods of granite plutonism at about 2,100 to 2,300 Ma, and 1,700 to 1,900 Ma. The host metamorphic rocks are biotite microgneiss, amphibolite, mica schist, biotite gneiss, and garnet-chlorite schist that are derived from volcanic and sedimentary units. There are one to eight deposit beds, and individual deposit beds range from several meters to several tens of meters thick and from several hundred meters to 1 km long. Textures in the deposit layers are banded, paragneissic, and massive, and the ore minerals are coarse-grained magnetite, quartz and minor amphibole. Moderate amount of rich ores, with more than 50 percent Fe consist mainly of magnetite, maghemitite, graphite, quartz, garnet, cummingtonite, pyrite, and pyrrhopyrite with mainly massive textures and local porous textures. There are two different interpretations for the origin of the Fe-rich ores: formation during hydrothermal reworking of lean ore, or enrichment of primary siderite (BIF) beds during regional metamorphism. The metamorphic age of the Anshan Group that hosts the Gongchangling Fe deposit 2,500 to 2,650 Ma. The age of the source rocks is probably older than 2,800 Ma (Cheng, 1986). The deposit is large and has reserves of 760 million tonnes and an average grade of 32.8 percent Fe.

Hongtoushan Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type) Deposit

This deposit (Zhang and others, 1984; Ge and others, 1989) consists of chimney, vein, and stratiform deposits hosted in the lower and middle parts of the Hongtoushan Formation of Archean Anshan Group. The Hongtoushan Formation consists of biotite-plagioclase-gneiss and amphibole-plagioclase gneiss, with intercalations of felsic gneiss and magnetite quartzite. Ore mainly consists of pyrite (50 percent), pyrrhotite (20 to 30 percent), chalcopyrite (1 to 10 percent), sphalerite (1 to15 percent), as well as small amount of galena, cubanite, and chalcocite. The ores are massive, brecciform, banded, and disseminated. Limited proximal wall rock alterations were developed, including silica alteration, sericite alteration, chlorite alteration, tremolitization and cordieritization. The deposit occurs at the southern margin of Tieling-Qingyuan uplift, north side of the Hunhe fracture zone. The deposit is medium-size and has reserves of 471,500 tonnes grading 1.72 percent Cu and reserves of 688,400 tonnes grading 3.04 percent Zn.

Jiapigou Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Xu and others, 1994) consists of sulphide-poor Au veins that occur in a northwest-trending belt that is concordant to a northwest-trending hosting shear zone. More than ten Au deposits occur in the northwest-trending shear zone that is 40 km long and ranges from 5 to 10 km wide. Ore minerals are pyrite, minor chalcopyrite, galena, sphalerite, scheelite, wolframite, pyrrhotite, siderite, and scarce sulfosalt minerals. Alterations consists of formation of quartz, sericite, carbonate, pyrite, and chlorite. Au/Ag ratio of the ores is high, and the Au fineness is 820. The deposit is hosted along the northern boundary of the Jilin-Liaoning-Shangdong tonalite, trondhjemite, granodiorite terrane of the North China Platform. The supracrustal rocks are mafic and intermediate volcanic rock and sedimentary rock metamorphosed to amphibole and local granulite facies. The oldest isotopic age is 3.0 Ga. Younger heating events occurred at mainly 2.5 to 2.6 Ga, and 1.9 to 1.6 Ga. Many workers suggest that the supracrustals in the area comprise a greenstone belt (Cheng Yancheng and others, 1996). The origin of the deposit is debated with some geologists interpreting the deposits as related to magmatism during the Hercynian and (or) Yanshan Orogeny. Hart and others (2002) show that the gold deposits in the Jiapigou district are about 220 Ma according to SHRIMP U-Pb zircon dating on syn-gold mineralization felsic dikes and ^{40}Ar-^{39}Ar dating on gold-related sericite (Y. Qiu, unpub. data, 2004).The deposit is

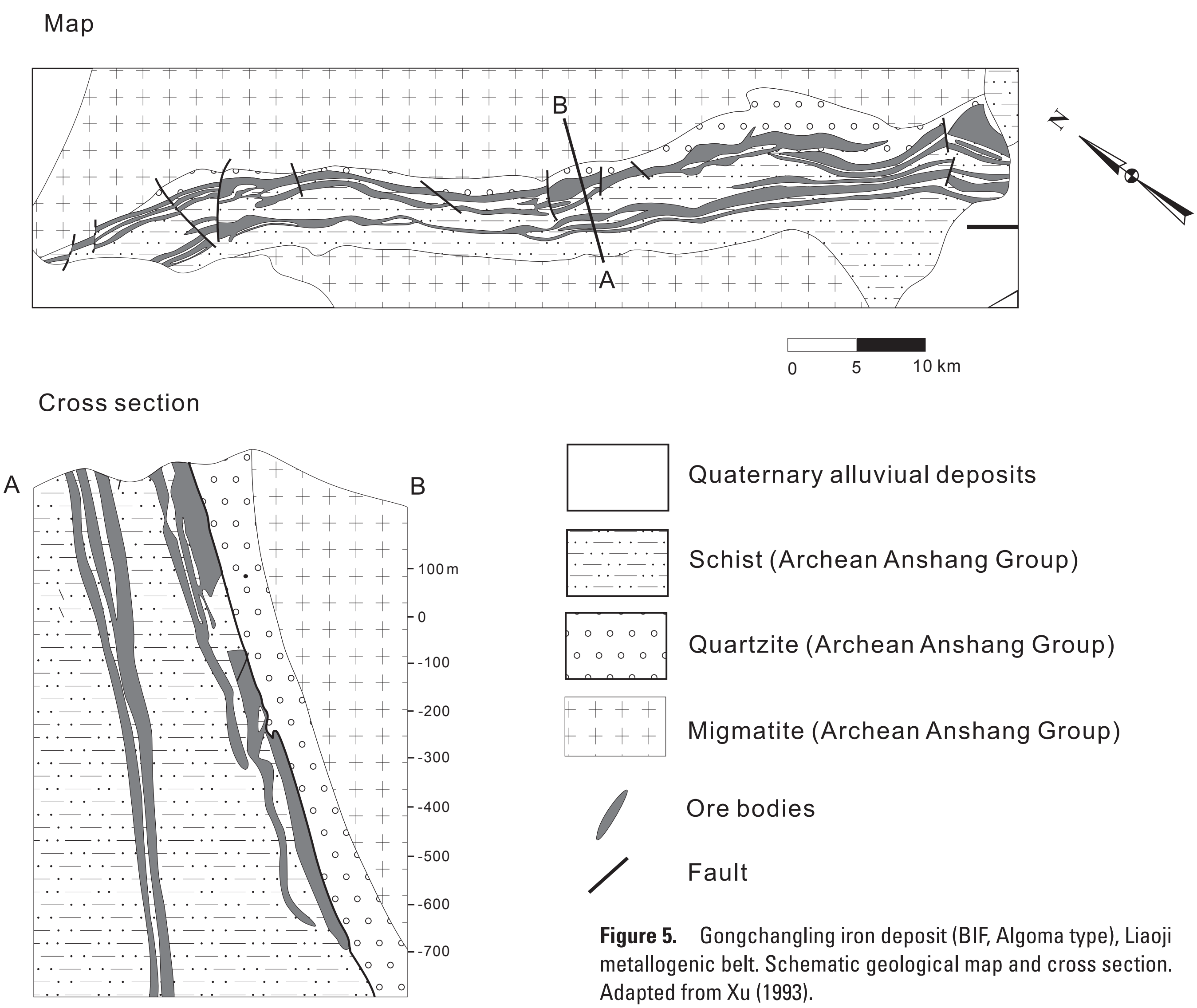


Figure 5. Gongchangling iron deposit (BIF, Algoma type), Liaoji metallogenic belt. Schematic geological map and cross section. Adapted from Xu (1993).

large and has reserves of 17 tonnes gold and an average grade of 5 to 10 g/t Au.

Origin and Tectonic Controls for Laioji Archean Metallogenic Belt

The BIF and massive sulfide deposits in the belt are interpreted as having formed during volcanism and sedimentation in an island arc. The Au shear-zone deposits are interpreted as having formed during retrograde metamorphism to greenschist facies. Shen Baofeng and others (1994) interpret that the greenstone belts in Northern Liaoning (Hunbei) area formed in a tectonic setting similar to that of a modern active continental margin, while the greenstone belts in Anshan-Benxi and Jiapigou areas formed along a rift along a continental margin that was contemporaneous with regional metamorphsim, folding, and thrusting.

The Archean Jilin-Liaoning-East Shandong terrane that hosts the metallogenic belt consists mainly of the following units (1) tonalite, trondhjemite, granodiortie; and (2) gneiss and amphibolite. The major disticts in Anshan-Benxi area in the northern Liaoning and Jiapigou areas are hosted in the northern Liaoning and Jiapigou greenstone belts respectively. The U-Pb age of zircon in the trondhjemite (mylonite) is 3,804 Ma (Wu and others, 1998). Hu Guiming and others (1998) interpret the Jilin-Liaoning-East Shandong terrane as the Liaoji amalgamation terrane (block) that contains several small terranes. Some of these small terranes are interpreted as fragments of continental nucleim whereas others are interpreted as greenstone belts derived form oceanic crust.

Sharizhalgaiskiy Metallogenic Belt of Banded Iron Formation and Talc (magnesite) Replacement Deposits (Belt Shz) (Russia, East Sayan)

This Archean metallogenic belt (fig. 3, appendix C) occurs in both the Sharyzhalgay granulite-orthogneiss and Onot granite-greenstone terranes of the North Asian craton that are partly overlapped by the Riphean and Paleozoic sedimentary rocks. The belt occurs in the southeastern part of East Sayan Mountains in the Sharyzhalgay uplift, extends for more than 150 km, and is 50 km wide. The belt is controlled by the major Sayan and branches of the Tochersky faults.

The host Sharyzhalgay terrane consists of biotite and biotite-hornblende gneiss, schist, amphibolite, and biotite-hypersthene and biotite-two pyroxene gneiss, granulite, ferruginous quartzite, and coarse-grained marble. The sedimentary rocks of the terrane are metamorphosed to granulite and amphibolite facies. The Sharyzhalgay series in the Sharyzhalgay terrane has U-Pb, Rb-Sr, and Sm-Nd isotopic ages ranging from 3.3 to 1.85 Ga.

The host Onot granite-greenstone terrane is a fragment of a greenstone-belt composed calc-alkaline bimodal metavolcanic rock overlapped by metamorphosed sedimentary rocks that are metamorphosed to biotite and garnet-biotite gneiss, sillimanite schist, ferruginous quartzite, and dolomite with interbedded amphibolite, magnesite rock and talc rock. Sedimentary rock in the Onot terrane are dated as Archean. The deeply metamorphosed sequences in the Sharyzhalgay uplift host numerous ferruginous quartzite deposits in the East Sayan Fe district. The major deposits are the Kitoy group of occurrences, the Onot group of deposits, and deposits at Sosnovy Baits, Baikalskoye, and Savinskoye.

The main references on the geology and metallogenesis of the belt are Baranov and others (1971), Mikhailov (1983), Poletaev (1973) Romanovich and others (1982), Urasina and others (1993), Uchitel (1967), Uchitel and Korabelnikova (1966), Shafeev and others (1977), Scherbakov and others (1977), Bibikova and others (1981) and Poller and others (2005).

Savinskoe Talc (magnesite) Replacement Deposit

This deposit (Baranov and others, 1971; Poletaev, 1973; Scherbakov and Poletaev, 1977; Romanovich and others, 1982; Urasina and others, 1993) occurs on the western side of the Onot granite-greenstone terrane containing Archean volcaniclastic and carbonate sedimentary rock. Commercial magnesite deposits are hosted in a suite of biotite-amphibole schist, magnesian limestone, dolomite, and amphibolite. The deposits occur along a major fault that extends more than 25 km. The deposit is large and has reserves of about 300 million tones and resources of 2.5 billion tonnes. Magnesite is coarse crystalline.

Origin and Tectonic Control for Sharizhalgaiskiy Metallogenic Belt

Some deposits (Kitoy group and Baikalskoye deposit) in the Sharizhalgaiskiy belt occur in Archean sequences, whereas others (Onot group-Sosnovy Baits deposits) occur in Proterozoic sequences (Mikhailov, 1983). The bedded form of ferruginous quartzite and spatial location in the beds of two-pyroxene schist are interpreted as the results of metamorphism of ferruginous volcanic and sedimentary sequences (Uchitel, 1967; Shafeev and others, 1977).

Sutam Metallogenic Belt of Banded Iron Formation (BIF) Deposits (Belt ST) (Russia, Aldan-Stanovoy Shield)

This Archean metallogenic belt (fig. 3, appendix C) occurs in the southern part of the Central Aldan granulite-orthogneiss superterrane (unit CAL, fig. 3) in the Sutam high-temperature and high-pressure granulite-paragneiss terrane (too small to depict on figure 3). The age of the belt is interpreted as Archean (>2500 Ma). Gneiss in the Sutam terrane is dated from 2.5 to 3.0 Ga. The main BIF deposit is at Olimpiyskoe. Most of the terrane (60 percent) consists of paragneiss in the Seim Group, and the rest (40 percent) is granite-and enderbite-gneiss. The Seim Group consists mainly (80 percent) of garnet-biotite gneiss and plagiogneiss, sometimes with sillimanite and cordierite, and lesser hypersthene-biotite, two-pyroxene, and diopside-amphibole plagiogneiss. Also occurring in the Seim Group are quartzite, calc-silicate rock, and coarse-grained marble. The rest of the group (20 percent) consists of two-pyroxene, two-pyroxene-amphibole, and, rarely, olivine-two-pyroxene schist, and magnetite quartzite. Sm-Nd isotopic ages for paragneiss parental rock range from 2.5 to 2.9 Ga whereas ages for orthogneiss range up to 3.1 Ga. Coeval metamorphism occurred after 2.5 Ga. The upper age limit of the early granulite metamorphism of the Seim Group rocks is constrained by the time of formation of garnet-biotite roddingite gneiss along the Seim thrust with Rb-Sr isotopic ages of 2.28 ± 0.06 Ga (Gorokhov and others, 1981) or a U-Pb isochron zircon age (lower intercept) of 1.9 ± 0.35 Ga from orthogneiss The belt contains BIF composed of magnetite quartzite related to mafic and ultramafic rock. Most extensively studied is the Olimpiyskoe deposit (Kadensky, 1960; Nikitin, 1990).

The major references on the geology and metallogenesis of the belt are Kadensky (1960), Dook and others (1986), Gorokhov and others (1981), Khil'tova and others (1988), Nikitin (1990), and Parfenov and others (1999, 2001, 2003).

Olimpiyskoe Banded Iron Formation (BIF, Superior Fe) Deposit

This deposit (Nikitin, 1990, Parfenov and others, 2001) (fig. 6) consists of 11 lenticular deposits of medium- and coarse-grained banded hypersthene-magnetite quartzite. The deposits occur in an area that is 11 km long and ranges from 3 to 4 km wide and contains two rock groups. The first and main group consists of magnetite-hypersthene and magnetite-two mica gneiss interbedded with amphibole-two mica and magnetite-two mica-plagioclase schist in the core of an aniform. The Fe-ore horizon with magnetite and hypersthene-magnetite quartzite occurs in the outer part of the antiform. The second-group occurs in the core of a synform and consists of feldspar quartzite interlayered with garnet- and sillimanite quartzite. Beds of diopside-bearing rocks and coarse-grained marble also occur. Occurring in the second-group rocks is a Fe-ore horizon of magnetite hypersthene and spessartine-magnetite hypersthene. The deposits vary from 0.5 to 4 km thick and 20 to 200 m long. The deposit is large with resources of 500 million tonnes of Fe to a depth of 300 m, and 900 million tonnes to a depth of 500 m.

Origin and Tectonic Controls for Sutam Metallogenic Belt

Two rock groups containing BIF occur in the Sutam belt. The first is magnetite-hypersthene and magnetite-two pyroxene gneiss interbedded with amphibole-two pyroxene and magnetite-two pyroxene-plagioclase schist. The Fe deposit horizon consisting of magnetite and hypersthene-magnetite quartzite occurs in the outer part of the antiform. The second rock group consists of feldspar quartzite interlayered with garnet-and sillimanite-bearing varieties. Beds of diopside-bearing rocks and coarse-grained marble also occur. Related to the second rock group is another Fe ore horizon containing magnetite hypersthene and garnet-magnetite hypersthene. Two rock groups together form a highly metamorphosed greenstone sequence.

West Aldan Metallogenic Belt of Banded Iron Formation (BIF), and Au in Shear-Zone and Quartz-Vein Deposits (Belt WA) (Russia, Southern Yakutia)

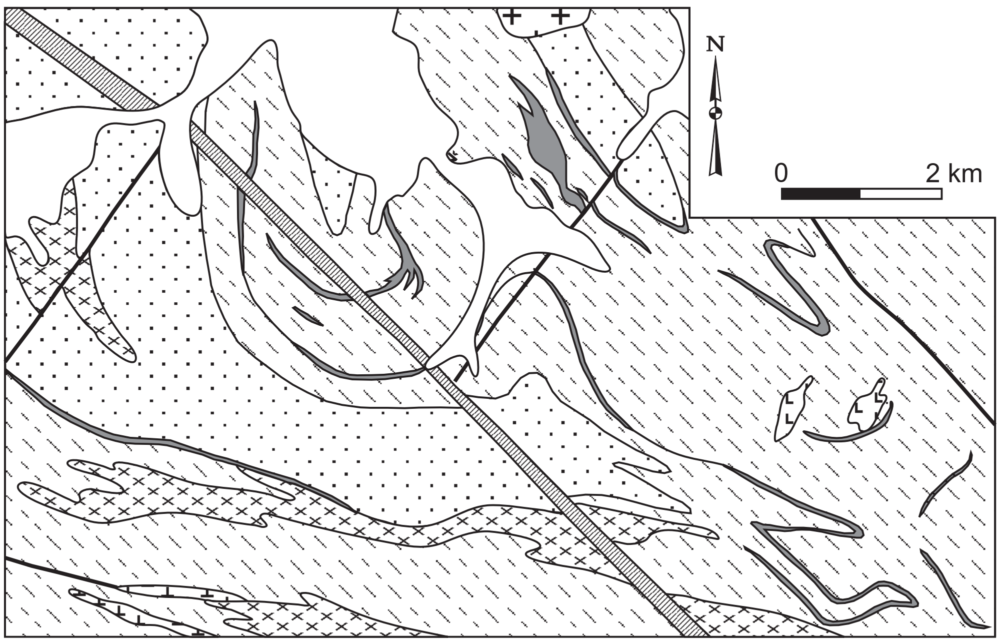
This Archean through Paleoproterozoic metallogenic belt is hosted in the West Aldan granite-greenstone composite terrane (unit WAD, fig. 2). The West Aldan belt contains large BIF deposits (banded magnetite quartzite), Au and Pt occurrences in greenstone belts, apatite-magnetite, magnetite-skarn, and zircon-ilmenite deposits. The age isotopic age of the BIF deposits is 3.0 to 2.7 Ga. The age of the Au occurrences is Late Archean and Paleoproterozoic. The main deposits are at Tarynnakh, Nelyuki, and Dagda (BIF), and at Lemochi and Olondo (Au in shear-zone and quartz-vein).

The host West Aldan granite-greenstone composite terrane consists of linear greenstone belts composed of Archean metavolcanic and metasedimentary rock dated from 3.2 to 2.7 Ga, that are intruded and surrounded by tonalite, trondhjemite gneiss, granite, and amphibolite. Units are metamorphosed under a wide range of temperatures and pressures, including granulite facies. Orthogneiss is composed mainly of tonalite and trondhjemite and occurs in the Olekma complex that contains several large linear blocks separated by four longitudinal belts. The complex is about 300 km long and 30 km wide. The complex also contain greenstone slabs in the Subgan complex and the Kurulta granulite complex. Blastomylonite bounds the greenstone belts. These various complexes and slabs form separate terranes, therefore, the West Aldan terrane is a composite terrane.

The main references on the geology and metallogenesis of the belt are Arkhipov (1979), Bilanenko and others (1986), Gorelov and others (1984), Popov and others, (1997), and Parfenov and others (2003), Smelov (1989).

Tarynnakh Banded Iron Formation (BIF) Deposit

This deposit (Akhmetov, 1983; Gorelov and others, 1984; Bilanenko and others, 1986) (fig. 7) consists of three deposits separated by gneissose granite, gneiss, and schist of varying composition. The deposits are dominated by fine-grained hornblende-actinolite-magnetite ferruginous quartzite. Cummingtonite-magnetite, chlorite-magnetite, and magnetite varieties also occur. Fe quartzite is interlayered with biotite-quartz and muscovite-sericite-quartz schist (sometimes with garnet, staurolite, kyanite, sillimanite, and andalusite) and quartzite in units as much as 1.4 to 3.3 km thick. Amphibole-plagioclase schist and amphibolite that is 0.5 to 7 m wide and granitoid as thick as 0.2 to 8 m also occur. Units are metamorphosed to epidote-amphibolite facies at moderate pressures. The deposits extend for 22.5 km and have a thickness of 330 m. The deposits dip predominantly west at high angles (60 to 90°). The structure of the bodies is mainly controlled by sublongitudinal



Quaternary sediments

Paleopoterozoic granite

Neoarchean (2.5 to 2.8 Ga) feldspar quartzite with interlayered garnet and sillimanite layers

Neoarchean magnetite-hypersthene, biotite-hypersthene and magnetite-two-pyroxene gneisse with interlayered two-pyroxene schist

Neoarchean magnetite quartzite and magnetite hypersthenite

Neoarchean metagabbro

Neoarchean metahyperbasite

Mesoarchean (~ 3.0 Ga) granitoids

Fault

Diaphthoresis zone

Figure 6. Olimpiyskoye iron deposit, Sutam metallogenic belt. Schematic geologic map. Adapted from V.M. Nikitin (written commun., 2003).

faults. The deposit is large with estimated reserves of about 2 billion tonnes averaging 28.1 percent total Fe.

Charskoye Group of Banded Iron Formation (BIF, Superior Fe) Deposits

This group of deposits (Petrov, 1976; Myznikov, 1995; M.N. Devi and others, written commun., 1977) occurs in the northern Chita Oblast on the left bank of the Chara River in the Kodar Ridge in the western Aldan Fe distict and comprises part of the western flank of Chara-Tokko Fe district. The group extends along a submeridional trend for 185 km and is 50 km wide. The main ferruginous quartzite deposits occur at Nizhne Sakukan, Oleng-Turritakhskoye, Sakukannyrskoye, Severnoye, Sulumatskoye, and Yuzhnoye. The isotopic age of the deposits is 2.6 to 2.5 Ga (Arkhangelskaya, 1998). The deposits form a cluster near a fault basin filled with metamorphosed Archean volcanogenic and clastic rocks (Myznikov, 1995). Ferruginous quartzite and other ferruginous-siliceous rocks in the Chara group occur along three submeridional-striking bands. The deposits consist of steeply dipping layers of magnetite. There are 10 types of Fe deposits, the most characteristic of which are banded magnetite quartzite, biotite-hornblende-magnetite quartzite, massive magnetite, and hypersthene-magnetite schist. The deposit is large with an average grade of 28 percent Fe.

Olondo Au in Shear-Zone and Quartz-Vein Occurrence

This deposit (Popov and others, 1990; Popov and others, 1997; Zhizhin and others, 2000; Smelov and Nikitin, 1999; Shaporina and Popov, 2000) consists of quartz veins and massive carbonate-amphibole-quartz-sulfide in the metasomatite and blastomylonite zones cutting metabasalt and meta-ultramafic rock of the Olondo greenstone belt. Au content of the metavolcanic host rocks increases with intensity of metasomatism to a maximum grade of 0.2 to 5.0 g/t. The deposits vary from a few centimeters to 10 to 15 m wide and dip steeply. The average grade for single bodies is 3 to 5 g/t Au, up to 2.5 g/t Pt.

Origin and Tectonic Controls for West Aldan Metallogenic Belt

The belt is hosted in the West Aldan granite-greenstone composite terrane composed of linear greenstone belts composed of metavolcanogenic and sedimentary rock with isotopic age of about 3.22 Ga. These units are surrounded by tonalite-trondhjemite gneiss, granite, and highly metamorphosed (up to the granulite facies) gneiss. The BIF deposits (magnetite quartzite) occur in stratiform layers and lenses in metabasalt and amphibolite, and less frequently in siliceous metavolcanic rock, and schist. The BIF deposits are interpreted as having formed in a back-arc basin and (or) island arc. The Au occurrences are mainly in shear zones that cut metabasalt, amphibolite, and ultramafic rock, and are interpreted as having formed

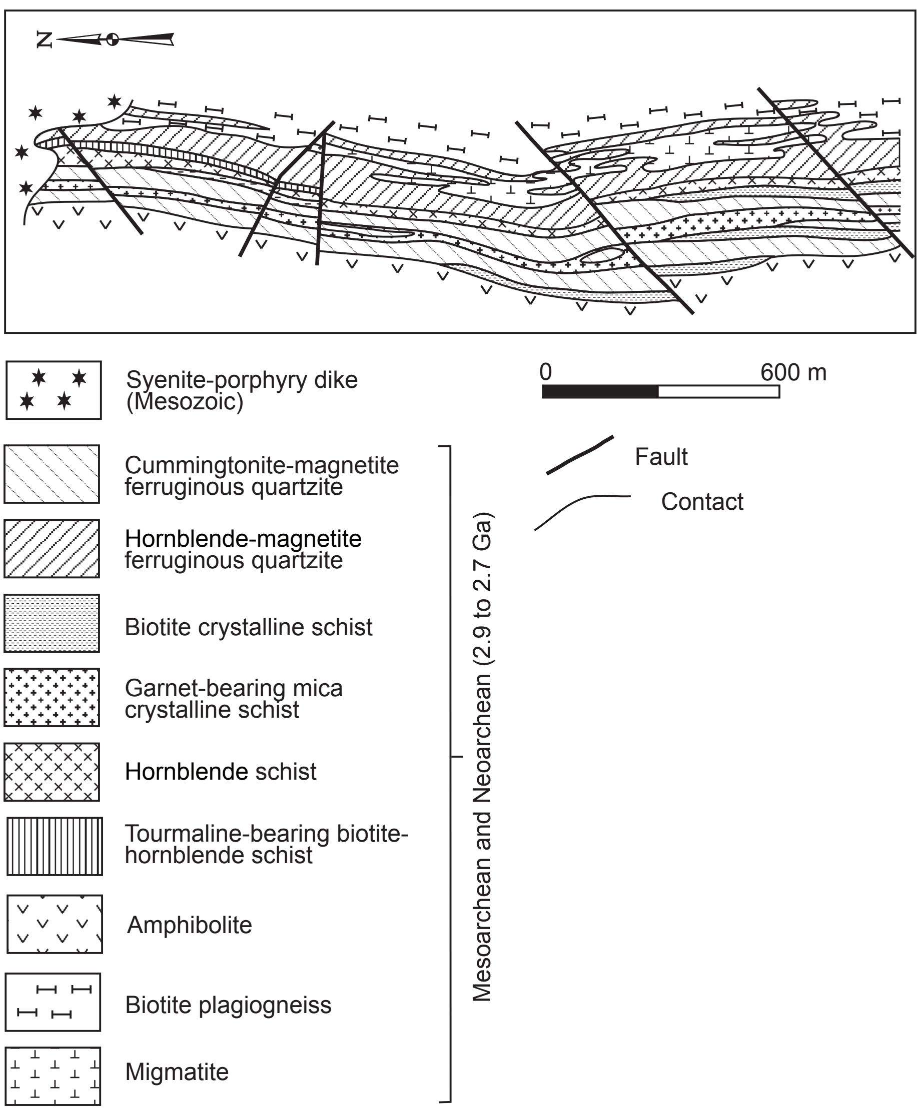


Figure 7. Tarynnakh banded iron formation deposit, West Aldan metallogenic belt. Schematic geologic map. Adapted from Gorelov and others (1984).

during amalgamation of terranes at about 2.6 to 2.5 Ga or during later Paleoproterozoic tectonic events.

Wutai Metallogenic Belt of Banded Iron Formation (BIF, Algoma Fe) Deposits (Belt WT) (North China)

This Archean metallogenic belt (fig. 3, appendix C) is hosted in the marine volcaniclastic and sedimentary basins and greenstone belts of West Liaoning-Hebei-Shanxi terrane in the Sino-Korean craton. The significant BIF deposits are at Baizhiyuan and Jinganku. This metallogenic belt occurs in the Wutaishan area in western Shanxi Province. The belt is 200 km long and up to 20 km wide. BIF deposits occur in the Baizhiyuan Formation and Jinganku Formation of the Wutai Group and have isotopic ages of >2,500 Ma). The host units are mafic and felsic volcanic rock, and sedimentary rock. The significant deposit is at Baizhiyuan. The main reference on the geology and metallogenesis of the belt is Shen and others (1994).

Baizhiyan Banded Iron Formation (BIF, Algoma Fe) Deposit

This deposit (Shen and others, 1994) consists of several stratiform layers that are concordant to the host amphibolite, mica schist, and gneiss. Individual Fe layers are 30 to 50 m thick and range up to 3 to 5 km long. The ores are mainly banded and are composed of an oxide facies (magnetite and quartz), a silicate facies (magnetite, quartz, and grunerite), and a carbonate facies (siderite, ferrodolomite, and other minerals). The host units are part of the Late Archean Wutai Group that is derived from mafic and felsic volcanic rock, sedimentary rock, and canbyite formation in a greenstone belt regionally metamorphosed to greenschist facies. In the area of the deposit is a group of similar, moderate to large Fe deposits that occur in a northeast-trending belt. The deposit is large and has reserves of 179.7 million tonnes with average grades of 33.31 percent Fe, 0.26 percent S, and 0.06 percent P.

Origin and Tectonic Controls for Wutai Metallogenic Belt

The Wutai greenstone belt that hosts the BIF deposits is interpreted as having formed in an immature to mature island arc. The southwestern Archean Liaoning-Hebei-Shanxi terrane (Wutaishan area) that hosts the Wutai metallogenic belt of BIF deposits consists of the following major units (1) greenstone belts consisting of fine-grained biotite gneiss, plagioclase amphibolite, metamorphosed ultramafic rock; chlorite schist, chlorite-albite schist, plagioclase quartzite, quartzite, and phylllite (Wutai Group), and (2) tonalite, trondhjemite, and granodiorite. The Wutai greenstone belt is interpreted as having formed in a rift along a continental margin (Shen and others, 1994); however, another interpretation is that the Wutai greenstone belt and related BIF deposits formed in an immature to mature island arc.

Origin of Metallogenic Belts in North China

In Northern China, the BIF in the Jidong (JD), Liaoxi (LX) and Wutai (WT) metallogenic belt, is interpreted as initially forming in an island arc environment (Zhai and others, 2000). However, Zhang and others (1986) suggest that the BIF in the Jidong (JD) was formed in a volcanic and sedimentation basin along an unstable continental margin . The BIF in the Liaoji (LJ) metallogenic belt is interpreted as initially forming in a small oceanic basin (Zhai and others, 2000), or in the oceanic rifts along a continental margin (Shen Baofeng and others, 1986). The volcanogenic Zn-Pb-Cu massive sulfide in the Liaoji (LJ) metallogenic belt interpreted as initially forming in an island arc environment (Zhai Mingguo and others, 2000). All BIF and volcanogenic Zn-Pb-Cu massive sulfide deposits in all metallogenic belts have undergone metamorphism and deformation related to amalgamation of the superterranes and terranes to form supercontinent (Sino-Korea craton) at about 2,500 Ma (Zhai and others, 2000).

The Au in the shear-zone and quartz-vein deposits in the Jidong (JD), the Liaoxi (LX), and the Liaoji (LJ) metallogenic belts is interpreted as having formed during retrograde metamorphism to greenschist facies. Recent investigations of large gold deposits along the northern margin of the North China craton include Au in the shear-zone and quartz-vein deposits in the Jidong (JD), Liaoxi (LX) and Liaoji (LJ) metallogenic belts; however, these gold deposits are now interpreted as the products of multiple Late Paleozoic-Mesozoic mineralizing events. Up to six mineralizing events may have occurred throughout the northern margin of the North China craton from about 352 to 129 Ma, based on the the Ar-Ar alteration ages of gangue minerals, in combination with unpublished SHRIMP and other U-Pb ages.

Paleoproterozoic Metallogenic Belts and Host Units (2,500 to 1,600 Ma)

The major Paleoproterozoic (2500 to 1600 Ma) metallogenic belts are the Baydrag, Dyos-Leglier, Jiliaojiao, Kalar-Stanovoy, Luliangshan, Nimnyr, Qinglong, Tyrkanda-Stanovoy, and Uguy-Udokanskiy belts (fig. 8, appendix C).

Three of these belts possess geologic units favorable for major stratiform sediment-hosted deposits, including the the Baydrag, Luliangshan, Jiliaojiao, Qinglong, and Uguy-Udokanskiy belts. The deposits types are BIF, sedimentary-metamorphic borate, sedimentary-metamorphic magnesite, sediment-hosted Cu, clastic-sediment-hosted Sb-Au, and Korean Pb-Zn massive sulfide. The deposits are mainly hosted in sedimentary basins in the Tuva-Mongolia superterrane, Sino-Korean craton, and cratonal terranes that are either derived from the North Asian craton, or possibly from other cratons. The isotopic ages of the stratiform deposits range from about 2.23 to 2.8 Ga. The favorable geologic environments for the belts were sedimentary basins on craton margins or on cratons and, locally, in rift basins.

Two of these belts contain geologic units favorable for major deposits hosted in alkaline igneous rock and carbonatite, including the Nimnyr and Uguy-Udokanskiy belts. The deposit types are apatite carbonatite, Ta-Nb-REE alkaline metasomatite, and zoned mafic-ultramafic Cr-PGE deposits that are interpreted as having formed during rifting of craton or cratonal terranes. The isotopic ages of the

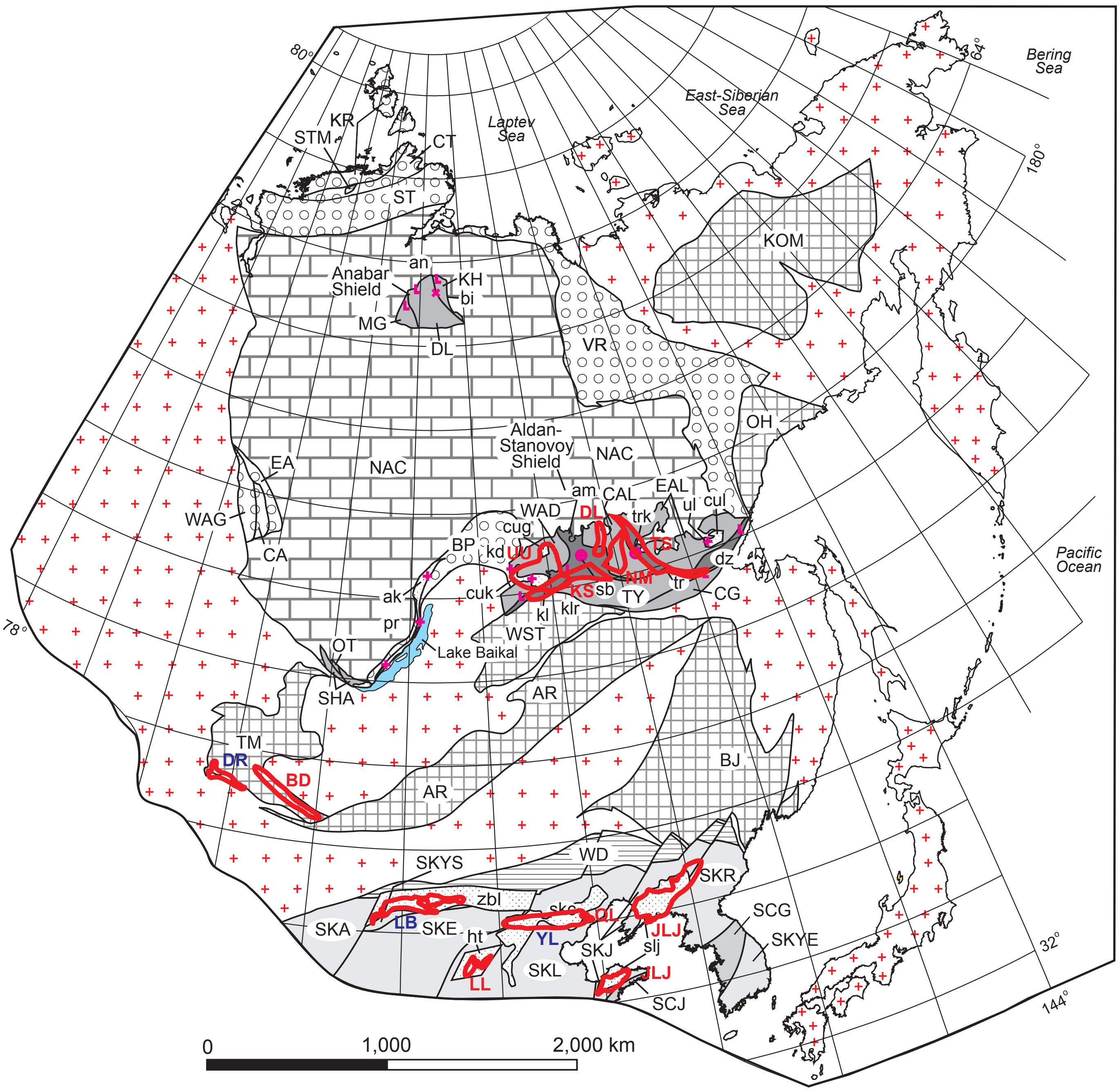


Figure 8. Generalized map of major Paleoproterozoic belts (in red), Mesoproterozoic metallogenic belts (in purple), and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004), Rodionov and others (2004), and Parfenov and others (2003, 2004a). Metallogenic belts for area to east of 144° E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

intrusive-related deposits and Au in shear-zone deposits (described below) range from about 2.0 to 1.6 Ga. The host igneous rocks overlie or intrude cratonal terranes that are interpreted as having been derived from the North Asian crato, or possibly from other cratons.

Four belts contain geologic units favorable for major Au in shear-zone and quartz-vein deposits, including the Jiliaojiao, Kalar-Stanovoy, Luliangshan, and Tyrkanda-Stanovoy belts. The veins hosting the deposits intrude the North Asian and Sino-Korean cratons. These deposits are related to low-grade metamorphism and deformation that is interpreted as having occurred during terrane collision.

Baydrag Metallogenic Belt of Banded Iron Formation (BIF) Deposits (Belt BD) (Central Mongolia)

This metallogenic belt (fig. 8, appendix C) occurs in the Paleoproterozoic Baydrag cratonal terrane and contains major BIF deposits in the Baidrag group. The northwest-striking metallogenic belt extends 400 km and ranges from 30 km to 50 km wide. BIF occurrences are hosted in Paleoproterozoic gneiss, amphibolite, schist, marble, and quartzite in the Baydrag metamorphic complex. U-Pb isochron and Pb-Pb thermoisochron zircon ages for tonalite gneiss of the Baydrag metamorphic complex range from 2,650 ± 30 Ma to 2,800 Ma and are 2,400 Ma for charnockite of the Bombogor intrusive complex (Zaitsev and others, 1990).

The main references on the geology and metallogenesis of the belt are Andreas and others (1970), Filippova and Bydrin (1977), Bahteev, and Chijova (1990), Zaitsev, Mitrofanov, and others (1990), and Tomurtogoo (1999).

Baydragiin Gol III BIF Occurrence

This occurrence (Andreas and others, 1970) consists of layered silica-magnetite bodies hosted in a Paleoproterozoic unit of gneiss and quartzite. The bodies trend northwest and are concordant with host gneiss. The silica-magnetite bodies are approximately 4,500 m long and 10 to 100 thick. The main ore mineral is magnetite and the average grade is 25.7% Fe.

Origin and Tectonic Controls for Baydrag Metallogenic Belt

The BIF deposits are hosted in Paleoproterozoic gneiss, amphibolite, crystalline schist, marble, and quartzite derived from a volcanic and clastic sedimentary rock basin. Host rocks are intruded by the Bombogor intrusive complex that is interpreted as having formed in a continental margin arc.

Dyos-Leglier Metallogenic Belt of Fe Skarn Deposits (Belt DL) (Russia, Aldan-Stanovoy Shield)

This Paleoproterozoic metallogenic belt (fig. 8, appendix C) is related to the Nimnyr granulite-orthogneiss terrane that is part of the Central Aldan superterrane. The isotopic age of the belt is interpreted as 1.9 to 2.3 Ga. The major Fe skarn deposits are at Tayozhnoe, Dyosovskoe, and Emeldzhak. The metallogenic belt trends 400 km southwest-northeast across the Nimnyr terrane. The major deposits are Tayozhnoe and Dyosovskoe districts in the South Aldan. These Fe districts occur in the central part of the Aldan-Stanovoy shield, about 80 to 130 km north of the Berkakit railway station, and contain the Leglier, Dyos, and Sivagli groups of deposits that comprise 32 Fe skarn deposits and occurrences. The largest deposits are at Tayozhnoe and Dyosovskoe. The Emeldzhak district occurs in the northeastern part of the Dyos-Leglier metallogenic belt, extends across a 100 by 25 km^2 area, and contains several phlogopite-magnetite deposits and occurrences in Paleoproterozoic amphibole-diopside gneiss, coarse-grained marble, and biotite gneiss; these deposits are genetically related to magnesian skarn.

The main references on the geology and metallogenesis of the belt are Arkhipov (1979), Bilanenko and others (1986), Kovach and others (1995a,b), and Parfenov and others (1999, 2001, 2003).

Dyosovskoe Fe Skarn Deposit

This deposit (fig. 9) consists of Fe skarn that extend sublatitudinally for 20 km and range from 1 to 3 km wide. The Fe-ore horizon occurs in three parallel synforms overturned to the north that dip at 30 to 70° and are complicated by larger folds and zones of longitudinal thrust and strike-slip faults. Deformation causes sharp variations in thickness of ore horizon both along strike and downdip. Thickness of Fe-ore bodies varies from 1 to 40 m. Diopside-magnetite and serpentine-magnetite are predominate. The deposit is metamorphosed to amphibolite facies. Deposit and host rock contain irregularly distributed pyrite, pyrrhotite, and chalcopyrite in disseminations. The deposit is large with resources of 700 million tonnes ore, with concentrate grading 66.7 percent Fe and Mn, and 0.43 percent Cu and Co. Impurities are 1.11 percent S, 0.12 percent P, and 0.02 percent Zn.

Tayozhnoe Fe Skarn Deposit

This deposit (Bilanenko and others, 1986) (fig. 10) is 200 m thick and consists of magnetite skarn, magnesian skarn, amphibole-diopside rock, coarse-grained marble, and biotite gneiss of Paleoproterozoic age with an isotopic age of 2.3 to 2.1 Ga. Subjacent rocks are amphibole gneiss and schist.

Metamorphic rocks are intruded by metamorphosed ultramafic rock, gabbro, and diorite. Host rocks are metamorphosed to granulite facies. In plan the deposit is horseshoe shaped, curved to the northwest, and, in section, forms a recumbent synform that dips steeply southwest. Concordant and en-echelon deposits are 2 km long and range from 10 to 100 km thick. The major sulfides are pyrite, pyrrhotite, and chalcopyrite. Some layers contain ludwigite and ascharite. Gangue minerals are diopside, olivine, chinohumite, salite, hornblende, and phlogopite in various combinations. The deposit is large with resources of 1.2 billion tonnes grading 20 to 60 percent Fe with an average grade of 39.8 percent Fe, 2.12 percent S, and 0.1 percent P_2O_5.

Origin and Tectonic Controls for Dyos-Leglier Metallogenic Belt

The belt is interpreted as having formed during a late-stage or postcollisional tectonic event. Deposits consist of magnetite skarn, magnesian skarn, amphibole-diopside rock, calciphyre, and biotite gneiss that are metamorphosed from amphibolite to granulite facies. Host rocks are amphibole gneiss and schist and high-alumina gneiss and quartzite-gneiss that are intruded by metamorphosed ultramafic rock, gabbro, and diorite that are metamorphosed to granulite facies. Deposits range from concordant to en-echelon.

Jiliaojiao Metallogenic Belt of Sedimentary Metamorphic Borate, Sedimentary Metamorphic Magnesite and Talc Replacement, Banded Iron Formation (BIF, Superior Fe), Korean Pb-Zn Massive Sulfide Metamorphic Graphite, and Au in Shear-Zone and Quartz-Vein Deposits (Belt JLJ) (Northeastern China)

This Late Paleoproterozoic metallogenic belt (fig. 8, appendix C) contains numerous large to super-large deposits. The belt extends from the Eastern Jilin Province to the Liaodong Peninsula, and farther south to Shandong Peninsula. The belt is 800 km long and 50 to 100 km wide, and it is hosted in the Paleoproterozoic East Shandong-East Liaoning-East Jilin rift basin that overlaps the Archean Jilin-Liaoning-East Shandong terrane of the Sino-Korea craton. The varied deposits in the belt are closely related to an extensive, thick sequence of volcanic rock, clastic rock, and carbonate (Ji'an, Laoling, Laohe, Jingshan and Fenzishan Groups). The metallogenic belt is a composite that includes several mineral deposit types. The most significant deposits are at Wengquangou, Xiafangshen, Fanjiapuzi, Dalizi, Qinchengzi, Zhangjiagou, Baiyunshna, Nancha, and Nanshu.

The main references on the geology and metallogenesis of the belt are Zhang and others (1984), Peng and others (1993), and Fang (1994).

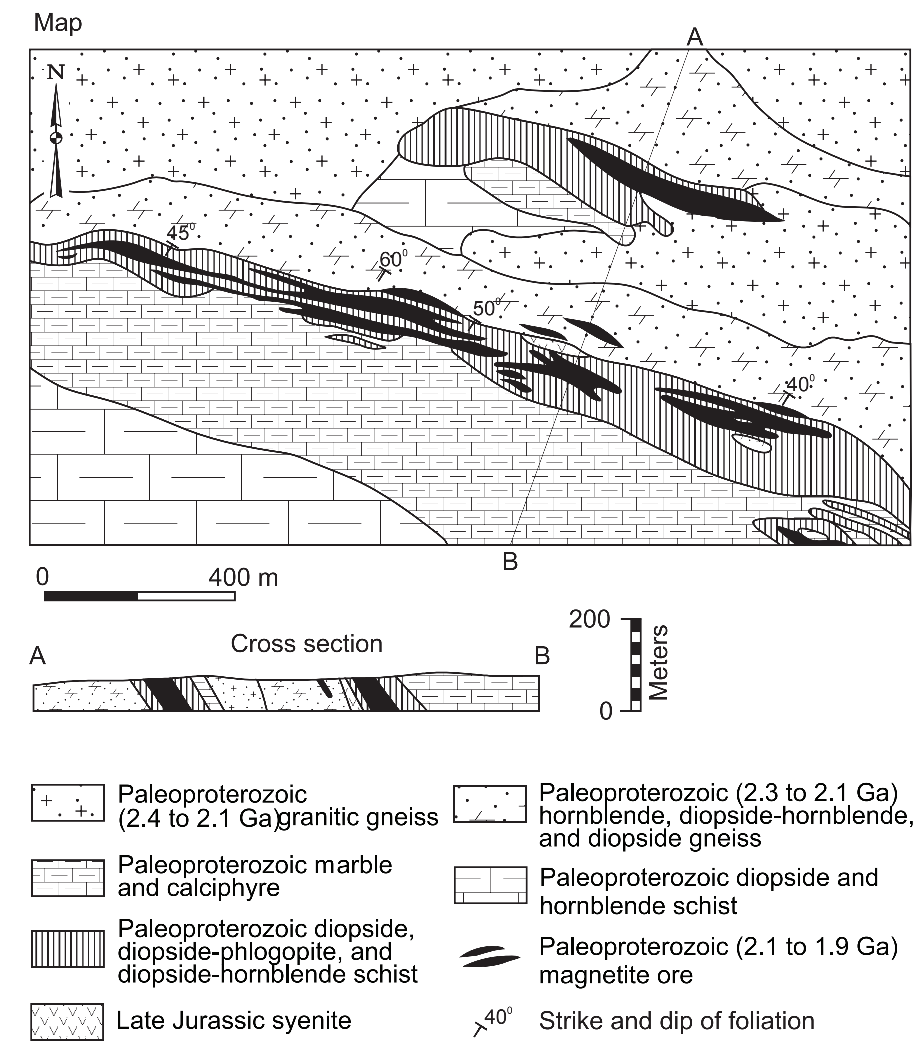


Figure 9. Dyosovskoe Fe-skarn deposit, Dyos-Leglier metallogenic belt. Schematic geologic map and cross section. Adapted from Serdyuchenko and others (1960).

Wengquangou Sedimentary Metamorphic Borate Deposit

This deposit (Peng and others, 1993; Editorial Committee of the Discovery History of Mineral Deposits of China, 1996) (fig. 11) is hosted in an unusual Paleoproterozoic volcanic and sedimentary sequence, including tourmaline-bearing rock and albite- and microcline-bearing rocks. Ludwigite also occurs. The deposit is hosted in Mg magnesian carbonates and Mg silicate rock metamorphosed to amphibolite facies and intensely deformed at about 1.9 Ga. Nine stratiform deposits occur in metamorphosed rock units in a syncline that trends east-west for about 4.5 km. The largest no.1 lode extends 2,800 m east-west and 1,500 m wide north-south, and averages 45 m thick. Deposit types are metasedimentary (type A) and hydrothermal (type B). Type A is conformably hosted in stratiform magnesian carbonates (mainly magnesite). Suanite [$Mg_2(B_2O_5)$] is the main ore mineral, and, it suggests derivation from B-and Mg-carbonate originally deposited in evaporite-related sedimentary rock. Type B deposit occurs in stratiform Mg silicates in breccia or deformed bands and are the most important deposits in the area. Breccia fragments consist of laminated, fine-grained farsterite and diopside in a matrix of suanite and magnesite. Breccia contains fractured Mg silicates with irregular shape fragments in the matrix. The deposit averages about 30.65 percent Fe and to 7.23 percent B_2O_3. Many interpretations exist for the the origin of mineral deposit, including metasomatism, migmatization hydrothermal activity, metamorphosed hydrothermal-sedimentary deposit, and others. A recent study suggests formation during metamorphism of an evaporite sequence in a Paleoproterozoic rift (Peng and others, 1993). The deposit is superlarge and has reserves of 21.9 million tonnes B_2O_3.

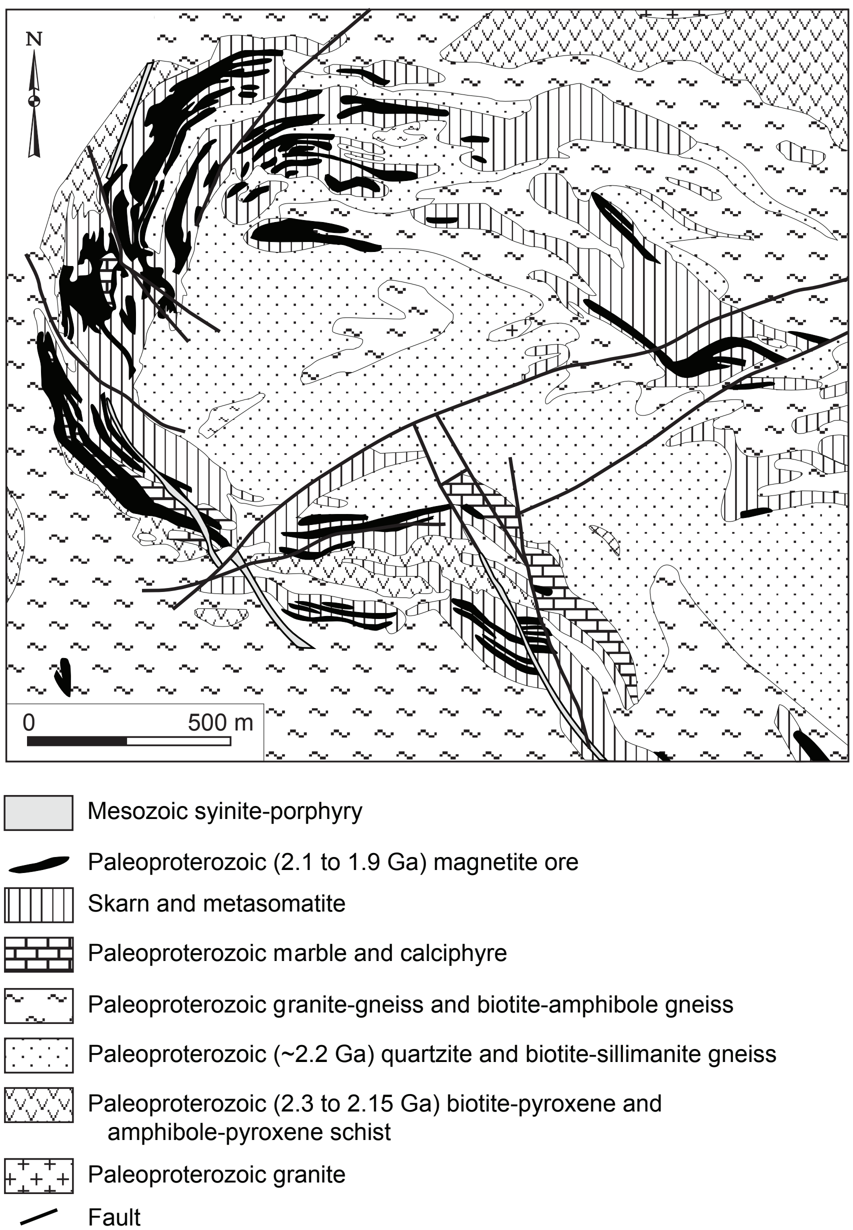


Figure 10. Tayozhnoe Fe skarn deposit, Dyos-Leglier metallogenic belt. Schematic geologic map. Adapted from Serdyuchenko and others (1960) and Parfenov and others (2001).

Xiafangshen Sedimentary Metamorphic Magnesite Deposit

This deposit (Li and others, 1994) (fig. 12) occurs in the Proterozoic Eastern Liaoning rift zone in the Paleoproterozoic Dashiqiao Formation. The host rocks are mainly two-mica quartz schist, sillimanite-kyanite-straurolite two-mica schist, magnesite marble, and dolomitic marble, and have a total thickness of 3,516 m. Deposit layers occur in a north-northeast-striking monocline that extends 3,250 m. Deposits are multiply layered and stratiform. The lowest deposit is dominant, extends 3,626 m along strike, and averages 205 m thick. Deposit minerals are mainly massive with secondary banded deposits consisting of magnesite and minor talc, tremolite, dolomite, and clinochlorite. Magnesite is dominantly medium- and coarse-grained and contains 47.30 percent MgO. The deposit is superlarge and has reserves of 258 million tonnes.

Fanjiapuzi Talc (Magnesite) Replacement Deposit

This deposit (Li and others, 1994) occurs in the eastern Liaoning Proterozoic rift zone and is closely associated with Mg host rocks in the upper part of the Paleoproterozoic Dashiqiao Formation. The deposit occurs on the northern limb of a north-northeast-trending synclinorium in the huge Yingkou-Dashiqiao-Fanjiapuzi magnesite belt. Deposits are stratiform and lenticular and are comfortable with wallrocks. Coarse-grained magnesite often occurs in talc ores. Where talc content is more than 70 percent, hand sorting produces high quality, rose or white ores that contains 30 to 32 percent MgO, 59 to 62 percent SiO_2, <19 percent CaO, and <0.5 percent Fe_2O_3. Where ore whiteness is more than 85 and talc content is between 50 and 90 percent, flotation process produces a high quality talc powder. The deposit is superlarge and has reserves of 36 million tonnes.

Dalizi Banded Iron Formation (BIF, Superior Fe) Deposit

This deposit (Zhang and others, 1984) consists of various bedded, stratiform and lens-shaped deposits that occur in a 10-km-long area. A single deposit ranges from 10 to 30 m thick. Deposits are concordant to the deposit-hosting strata. Three types of deposits are recognized according to major ore minerals, siderite, hematite, and magnetite. Siderite deposits are mostly bedded, are concentrated in carbonate rocks, are rich in Pb and Zn, and have potential for stratiform Pb-Zn deposits. Hematite deposits, that are closely associated with magnetite deposits, are massive and banded. The host strata are metamorphosed to greenschist facies and consists of silty mudstone and carbonate rocks of the Paleoproterozoic Laoling Group that are intensely folded. Deposit swarms are clustered in axes of transverse folds. The primary sedimentary environment is interpreted as a secondary shallow basin that formed in a Paleoproterozoic rift. Siderite is concentrated in carbonate sedimentary facies. The deposit is of medium size.

Qingchengzi Korean Pb-Zn massive Sulfide Deposit

This deposit (Tu and others, 1989; Zhang and others, 1984) consists of stratiform, feather, and vein masses of mainly galena, sphalerite, pyrite, and pyrrhotite, with minor arsenophyrite, chalcopyrite, bornite, and tetrahedrite that are hosted in marble of the Proterozoic Liaohe group. Ore minerals are medium- to coarse-grained and vary from euhedral or subhedral. Ore structural types aredissemination, band, veinlet, network, breccia, and crushed grain. The deposit occurs at the intersection of Yingkou-Kuandian uplift and Qianshan Mountain Range. The deposit is large and has reserves of 728,900 tonnes Pb, 349,300 tonnes Zn. Average grade is 2.64 percent Pb, 1.90 percent Zn.

Baiyunshan Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Xu and others, 1994) consists of lensoid, lenticular, nested, and irregular masses of pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, and sphalerite, and gangue

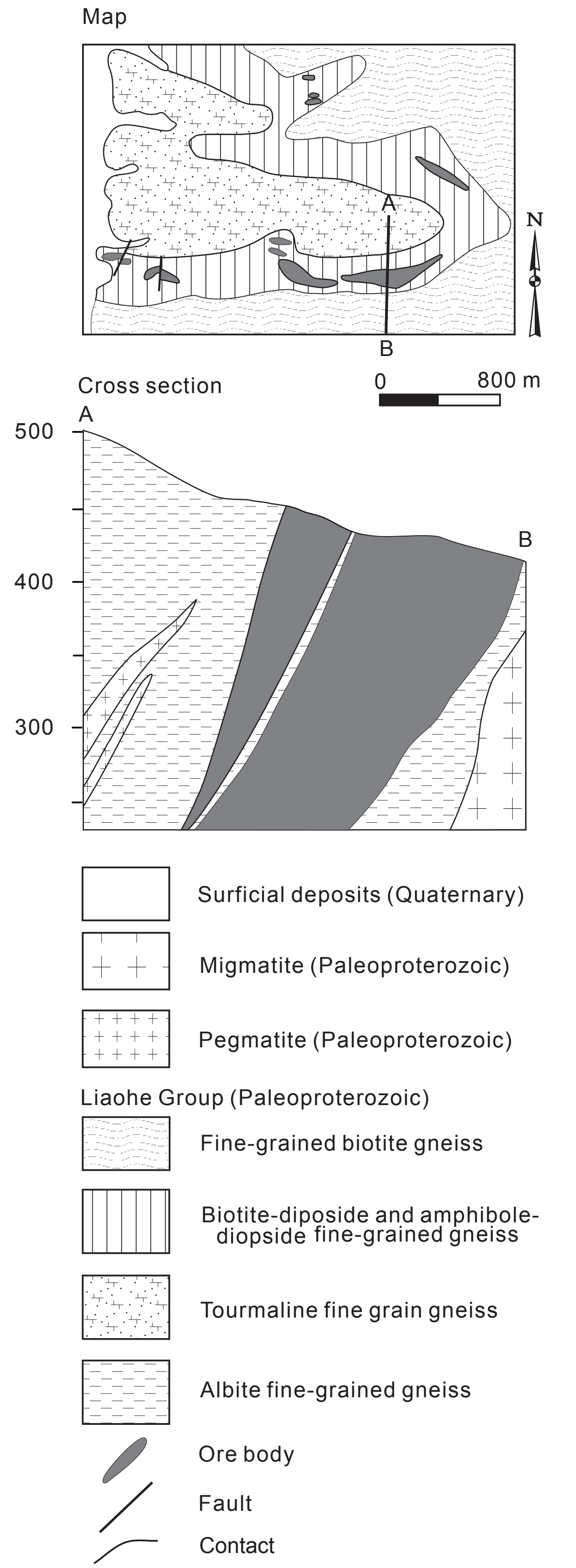


Figure 11. Wengquangou sedimentary-metamorphic borate deposit, Jiliaojiao metallogenic belt. Geologic sketch map and cross section. Adapted from Jiang and others (1994).

minerals, including quartz, sericite, K feldspar, calcite, and dolomite. Ore minerals occur along interformational folds in phyllite, mica schist, and dolomite. Ore minerals vary from massive to disseminated. Host rocks are altered to quartz, sericite, and pyrite. Gold varies from fine-grained to microscopic and grades into electrum. Host rocks are slightly metamorphosed Paleoproterozoic carbonaceous, volcanic, clastic, and carbonate rocks of the Liaohe Group that is part of the Sino-Korean craton. The deposit is of medium size.

Nancha Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Wang, 1989) consists of gold, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, and minor galena, sphalerite, bornite, chalcocite, and magnetite. Ore minerals vary from disseminated, fine veined, brecciated, and banded. Textures are idiomorphic, hypidiomorphic-xenomorphic, and metasomatic replacement. The Nancha deposit is more than 3000 m long, strikes northwest, and is several hundred meters wide. From the southwest to northeast, three mineralized sectors are recognized. The main deposits in the first sector occur in a structurally altered zone between basal schist, quartzite, and marble of the Huashan Formation and an upper, thick dolomite marble of the Zhenzhumeng Formation. The deposits in the second and third sectors occur in a structurally altered zone in thick dolomitic marble of the Zhenzhumen Formation. The sectors vary from stratiform or lenticular, and a single sector ranges from several tens to a hundred meters long. Wide-spread carbonate and silica alteration is associated with the deposit. Other important alterations are formation of arsenopyrite and pyrite. The deposit origin is controversial. The deposit is medium size.

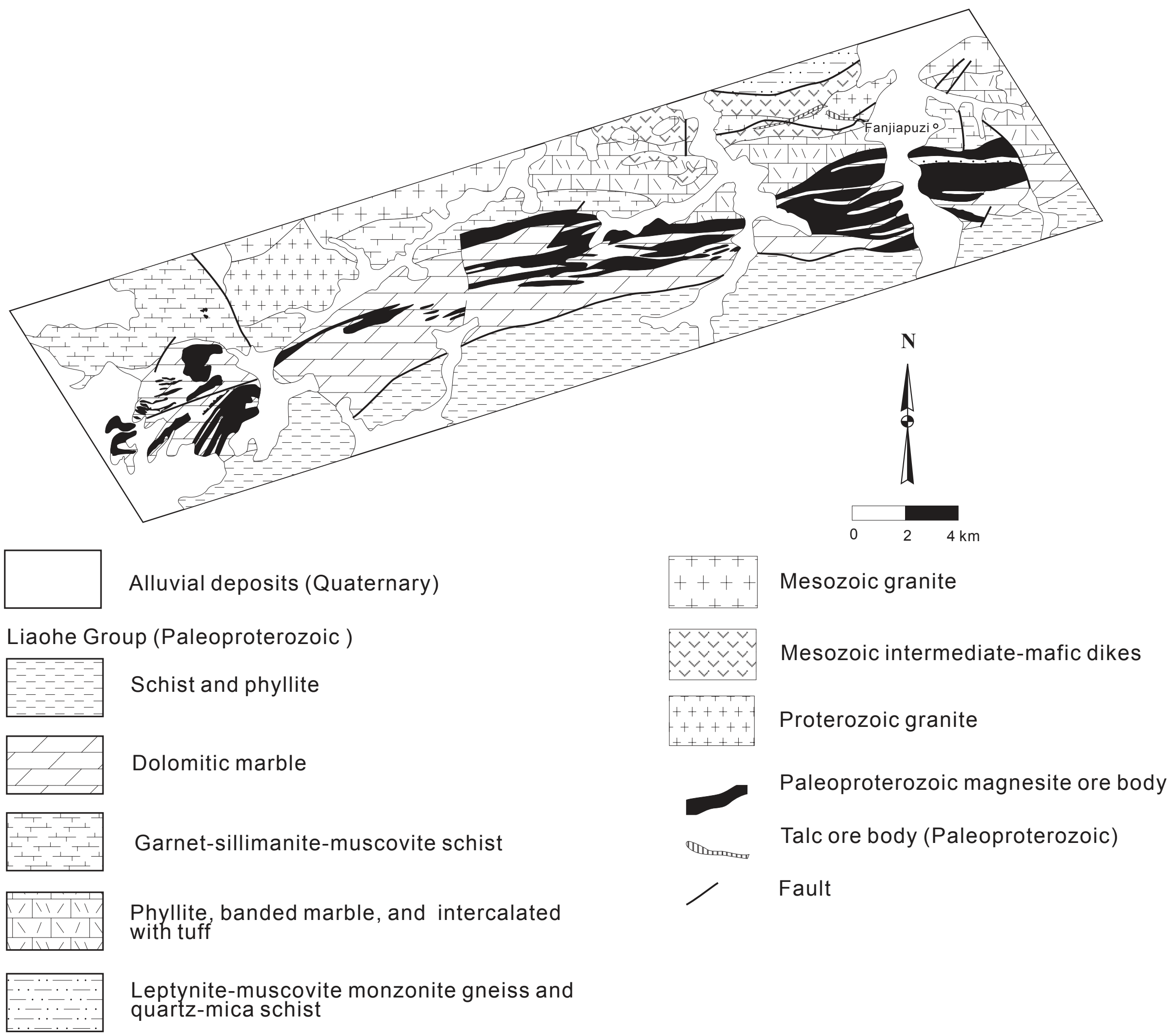


Figure 12. Xiafanshen metamorphic-sedimentary magnesite deposit and Fanjiapuzi talc replacement deposit, Jiliaojiao metallogenic belt. Regional schematic geological map. Adapted from Zhang (1984).

Nanshu Metamorphic Graphite Deposit

This deposit (Zhang and others, 1984) consists of a graphite-bearing horizon that is hosted in the Paleoproterozoic Jingshan Group in three sequences (1) marble and amphibole-plagioclase gneiss intercalated with graphite gneiss, (2) amphibole-plagioclase intercalated with marble and graphite gneiss, and (3) marble and amphibole-plagioclase gneiss. The first and second sequences contain major graphite layers. Graphite occurs in crystalline and amorphous forms. Amorphous graphite masses are soft and massive, occur along bedding and cleavage, and are intercalated in lenses with host rocks. Crystalline graphite masses are apparently bedded, multiply layered, lenticular, and concordant to host gneiss and marble. The deposits vary from 50 to 1,000 m long and extend 50 to 400 m downdip. Grade and thickness are relatively constant. The main ore mineral is graphite, and the gangue minerals are biotite, tremolite, quartz, microcline, plagioclase, muscovite, hypersthene, clinozoisite, garnet, apatite, and sphene. Other recoverable sulphide-minerals include pyrite, pyrrhotite, chalcopyrite, bornite, and sphalerite. The deposit exhibits gneissic, banded, and granoblastic structures. Ore-mineral texture is mainly lepidoblastic. The deposit is interpreted as having formed from metamorphism of organic carbon in clastic sedimentary rock that was deposited in a shallow marine environment. The deposit is large.

Origin and Tectonic Controls for Jiliaojiao Metallogenic Belt

The belt is interpreted as having formed in a passive continental margin, possibly as part of the Paleoproterozoic East Shandong-East Liaoning-East Jilin rift. The parental rocks include intermediate and siliceous volcanic rock, clastic rocks, and very thick carbonates. During metamorphism to amphibolite and greenschist facies the host rocks were transformed into (1) fine grained biotite, hornblende or diopside-bearing gneiss, leucocratic gneiss intercalated with graphite biotite gneiss, Al-rich gneiss, schist, amphibolite, marble and Ca-Mg silicate granofels, and (2) phyllite, muscovite-biotite schist, fine-grained leucocratic gneiss, and dolomitic marble. The environment of formation and deposit controls are debated (Zhang and others, 1984, Fang, 1994, Peng and others, 1993).

Kalar-Stanovoy Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt KS) (Russia, Aldan-Stanovoy Shield)

This latitudinal Paleoproterozoic metallogenic belt (fig. 8, appendix C) extends for 300 km along the Kalar tectonic melange zone and measures up to 100 km wide. The isotopic age of the belt is about 2,000 Ma. The Kalar tectonic melange zone separates the West Aldan granite-greenstone terrane from the Tynda tonalite, trondhjemite, gneiss terrane to the south. The zone consists of extensive major thrust and strike-slip faults and companion folds, and it contains a large number of tectonic slabs that differ in composition, age, and metamorphic grade. Examples of tectonic slabs are granulites in the Khani-Kurul'ta, Zverev, and Iengra blocks, orthogneiss (tonalite and trondhjemite), anorthosite, granite, and Archean and Paleoproterozoic greenstone belts. The metallogenic belt contains numerous Au occurrences, as at Pravokabaktanskoe and Namarskoe, and deposits, as at Ledyanoe and Skalistoe, which are related to diaphthorite formed in Archean and Paleoproterozoic rocks. Also occurring are Ti-magnetite and apatite occurrences and deposits in mafic and ultramafic rock.

The main references on the geology and metallogenesis of the belt are Fedorovskiy (1972), Beryozkin (1977), Koshelev and Chechyotkin (1996), Moiseenko and Eirish (1996), Bushmin and others (1983), Dook and others (1986), Rudnik (1989), Jahn and others (1990), Kovach and others (1995b), and Parfenov and others (1999, 2003).

Kavakta Apatite-Ti-Fe Occurrence in Zoned Mafic and Ultramafic Pluton

This occurrence is located about 30 km east of the Nagornyi settlement in the Kalar tectonic melange zone and is hosted in the large Kavakta mafic and ultramafic pluton with dimensions of 5 by 10 km^2 (fig. 13). The central part of the pluton consists of dunite, peridotite, troctolite, and anorthose, and the marginal part of the pluton consists of norite, magnetite-bearing gabbro-norite and gabbro. The ultramafic rock part of the pluton contains pyrite, chalcopyrite, pyrrhotine, minor pentlandite, and rare mackinawite, cubanite, valleriite, violarite, and bornite. The host rocks of the pluton are biotite and amphibole-biotite gneiss with bands and lenses of amphibolite metamorphosed to the amphibolite facies.

The pluton contains two orebodies. An apatite-Ti-magnetite body occurs in the northeast part of the pluton and is 4.5 km long and about 1.5 km wide. The other orebody occurs in the western and southwestern side of the pluton and is 0.5-10 km wide and about 5.25 km long. The apatite-Ti-magnetite ores averages 15 percent Fe, 3.6 percent TiO_2, 2.3 percent P_2O_5 and 0.06 percent V_2O_5. Apatite concentrates containing 37 to 57 percent P_2O_5 were prepared with the extraction of 88 percent. The reserves of apatite-Ti-magnetite ores are about 5 billion tonnes (Stogniy and others, 1998).

Ledyanoe Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Koshelev and Chechyotkin, 1996; Moiseenko and Eirish, 1996) (fig. 14) occurs in shear-zone and quartz-vein and mineralized zones in blastomylonite that cut retrograded Paleoproterozoic gabbro and anorthosite, leucocratic anorthosite and rare melanocratic anorthosite, charnockite, and pegmatoid granitoid. The veins vary from 0.2 to 0.5 to 4 m thick and are 2 km long. The deposit occurs in a 6 by 3 km^2 area. The veins are concordant with blastomylonite, and dip both steeply south and north. Wallrock blastomylonite is cut by quartz and carbonate veinlets that comprise 15 to 30 percent rock volume. The veins consist of white saccharoidal cavernous quartz and sulfides (pyrite, and rare chalcopyrite, galena, sphalerite, and pyrrhotite) that comprise 5 percent rock volume. Grade ranges from 11.7 to 30 g/t Au.

Origin and Tectonic Controls for Kalar-Stanovoy Metallogenic Belt

The Kalar-Stanovoy belt is interpreted as having formed during the collision between Tynda and West Aldan terranes in Aldan-Stanovoy region and during subsequent collapse of orogenic belt. The cause of collision was amalgamation of terranes during the formation of the North Asia craton. Au deposits occur in shear zones that cut metamorphosed mafic and ultramafic and plutonic rock.

Luliangshan Metallogenic Belt of Banded Iron Formation (BIF, Superior Fe) and Au in Shear-Zone and Quartz-Vein Deposits (Belt LL) (North China)

This metallogenic belt (fig. 8, appendix C) is hosted in the Hutuo rift basin and occurs in the Luliangshan Mountains in the Northeast Shanxi Province. The belt is more than 200 km long, varies from 40 to 60 km wide, and is hosted in the Hutuo Group overlap assemblage in the Archean Liaoning-Hebei-Shanxi terrane. BIF deposits are related to metamorphic clastic rocks and marble, whereas shear-zone Au deposits are hosted in metamorphosed clastic rocks of the Hutuo Group. The metallogenic belt is a composite that includes several mineral-deposit types. The significant deposits are at Yuanjiachun (BIF) and Hulishan (shear-zone Au).

The main references on the geology and metallogenesis of the belt are Zhang Qiusheng and others (1984), and Zhai and others (2000).

Yuanjiachun Banded Iron Formation (BIF, Superior Fe) Deposit

This deposit (Zhang and others, 1984) consists of bedded and stratiform Fe deposits that are concordant to host rocks that consist of clastic rock, mudstone, carbonate rocks and minor volcanic rock that are metamorphosed to greenschist facies. The Fe beds strike north-south for several kilometers to more than ten kilometers and are 300 m thick. Ore minerals are mainly oxides and consist of specularite, hematite, magnetite, quartz, cummingtonite, and stilpnomelane. The deposit minerals occur in silicate and carbonate rocks with laminated and stripped structures. Host rocks are part of the Paleoproterozoic Luliang Group. The original sedimentary environment is interpreted as a second-order basin in a rift zone along a craton margin. The deposit is similar to Superior Lake Fe deposits. The deposit is large and has reserves of 895 million tonnes grading 32.37 percent Fe.

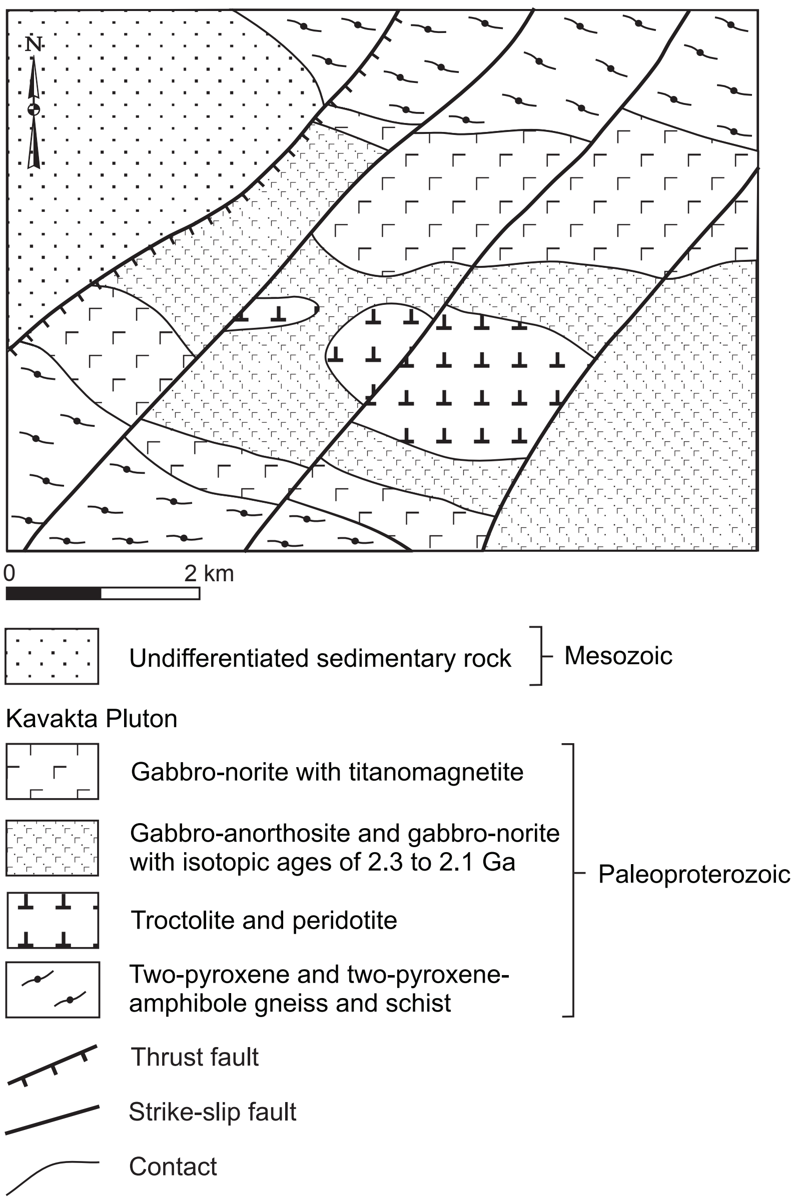


Figure 13. Kavakta mafic-ultramafic related Ti-Fe (V) deposit, Kavakta metallogenic belt. Adapted from Stogniy and others (1996).

Hulishan Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Chang and Tian, 1998) occurs in an intensely deformed zone that consists of isoclinial folds developed in metamorphosed volcanic and sedimentary rock of the Wutai Group and metamorphosed conglomerate of the Hutuo Group. The deposit occurs in bands, veinlets, disseminations and stockworks. Bands consist of quartz, sericite, limonite, and sulphide minerals. Au occurs along schistosity as disseminations and streaks. Disseminations, veinlets, and stockworks contain mainly pyrite, chalcopyrite, and pyrrhotite. Ore minerals are Au, pyrite, chalcopyrite, pyrrhotite, magnetite, and native lead, and minor galena and bornite. Gangue minerals are quartz, sericite, chlorite, calcite, siderite, and Fe-dolomite, and minor apatite, tourmaline, corundum, amphibole, and fluorite. Au mostly occurs in quartz and limonite, or between the two minerals. Au fineness is high (Au+Ag greater than 98 percent). Proximal alteration consists of silica, sericite, chlorite, carbonate, and pyrite alterations. The deposit is interpreted as having formed during shearing and deformation in the late stage of evolution of an Archean greenstone belt that has a Pb-Pb isotopic age of 2,230 ± 130 Ma. The deposit is of medium size.

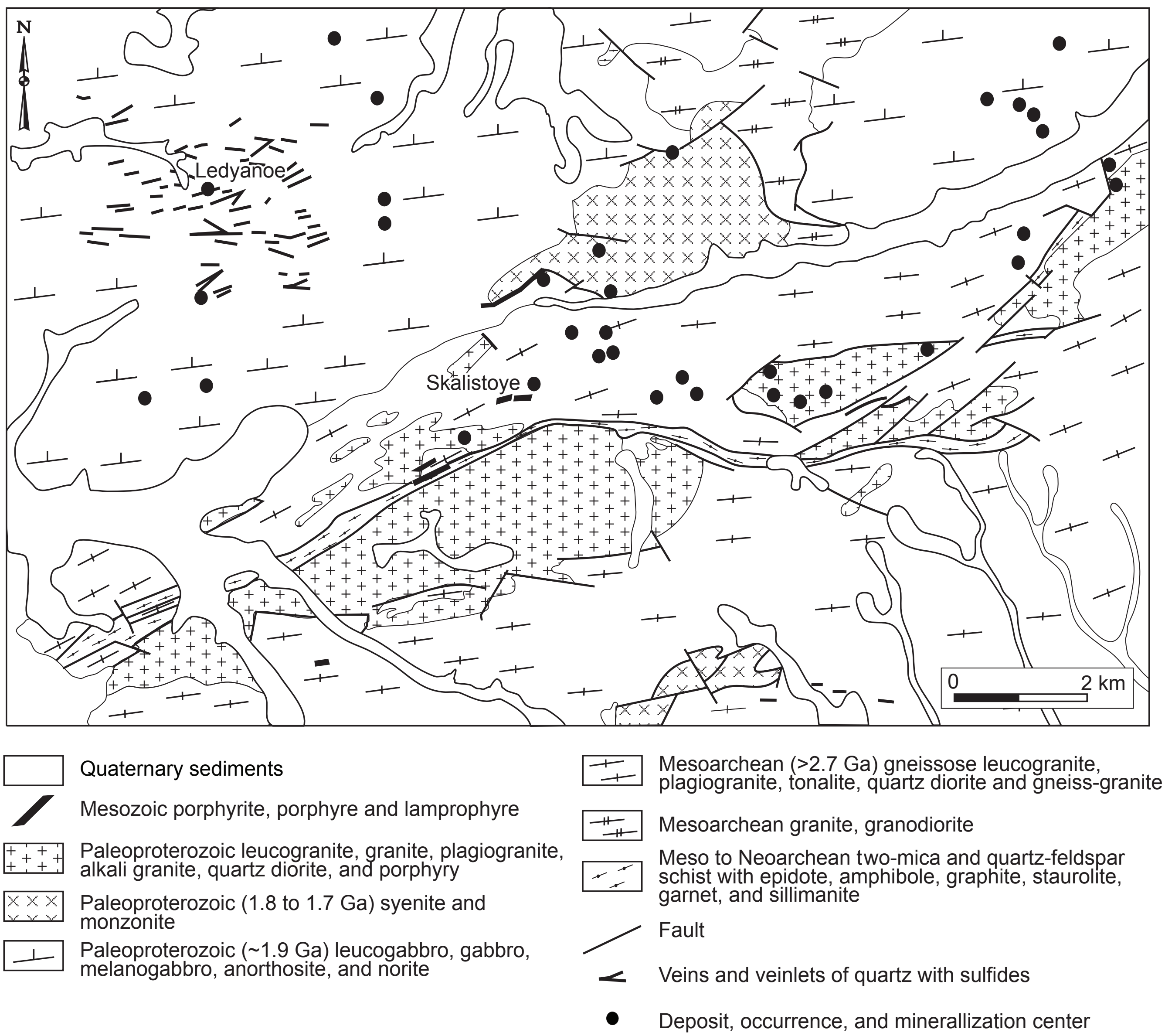
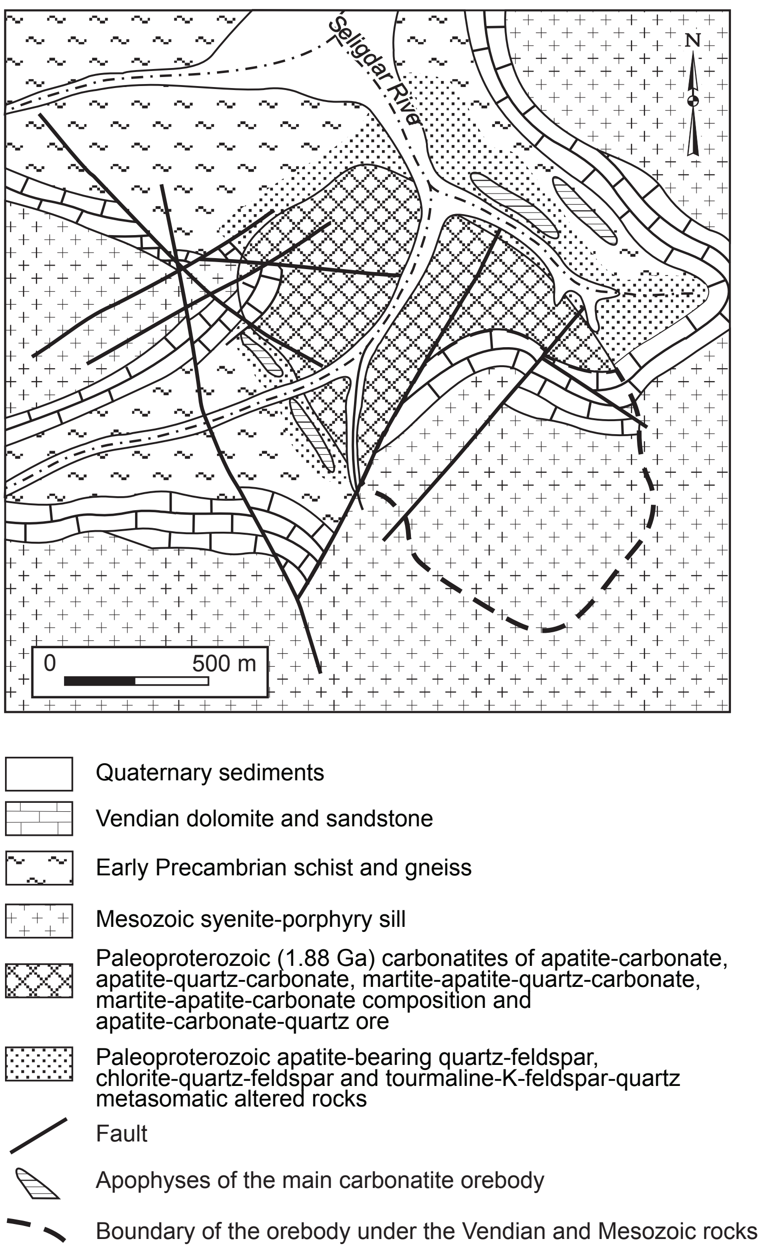


Figure 14. Ledyanoe Au in shear-zone and quartz-vein deposit, Kalar-Stanovoy metallogenic belt. Schematic geologic map. Adapted from Moiseenko and Eirish (1996) and Parfenov and others (2001).

Origin and Tectonic Controls for Luliangshan Metallogenic Belt

The BIF iron and shear-zone Au deposits are interpreted as having formed in the Paleoproterozoic Hutuo rift or foreland basin (Zhai and others, 2000) that was superposed on the Archean Sino-Korean craton. The Paleoproterozoic overlap assemblage of the Archean Liaoning-Hebei-Shanxi terrane consists of the following geological units (from the bottom to top): (1) metaconglomerate, quartzite, feldspar quartzite, phyllite, and dolomite; (2) phyllite, dolomite, sandy slate and quartzite intercalated with metabasalt; and (3) metaconglomerate, phyllite, plagioclase quartzite, and quartzite. A U-Pb zircon isotopic age for metabasalt is 2,366 Ma. Both the strata and the deposits are regionally metamorphosed, folded, and sheared to greenschist facies (Zhang others, 1984).



Nimnyr Metallogenic Belt of Apatite Carbonatite Deposits (Belt NM) (Russia, Aldan-Stanovoy Shield)

This metallogenic belt (fig. 8, appendix C) is related to carbonatite plutons and veins in the Nimnyr granulite-orthogneiss terrane in the Central Aldan superterrane. The age of the belt is interpreted as being late Paleoproterozoic, and it has an isotopic age of 1,800 to 1,900 Ma. The main deposit is the Seligdar apatite carbonatite mineral deposit. The metallogenic belt extends longitudinally for 300 to 400 km in the northern Aldan-Stanovoy shield and is 40 km wide in the central part. The belt contains eleven deposits and occurrences related to carbonatite plutons.

The main references on the geology and metallogenesis of the belt are Smirnov (1978), Entin and others (1991), and Parfenov and others (1999, 2003).

Seligdar Apatite Carbonatite Deposit

This deposit (Smirnov, 1978; Entin and others, 1991) (fig. 15) consists of apatite in an asymmetric carbonatite stock with dimensions of 2 by 1.02 km. At a depth of 1.6 km, the stock narrows to a few hundred square meters. The stock contains carbonatite composed of apatite and carbonate; apatite, quartz, and carbonate; martite, apatite, quartz, and carbonate; martite, apatite, and carbonate; and quartz. Occurring in the periphery are apatite-quartz-feldspar metasomatite and tourmaline-K-feldspar-quartz metasomatite. Both early- and late-stage carbonatite occur. The early carbonatite occurs in veins, vein zones, and stockworks in a mafic complex and in crystalline basement of the Aldan-Stanovoy shield. Thickness of the veins varies from a few centimeters to 30 to 40 m, and the length varies from a few meters to 500 m and rarely up to 1.5 km. The early carbonatite is mainly calcite rich with lesser feldspar, magnetite, serpentine, phlogopite, and apatite. The late carbonatite occur in dikes and stocks that intrude the early carbonatite, and it consists of dolomite, anhydrite, apatite, quartz, chlorite, and lesser barite. Martite also occurs along with rare tourmaline, fluorite, sulfates, and apatite. A typical lithology consists of apatite-silicified rock with hematite that resembles jaspilite. The deposit is large, and has reserves of 1,616 million tonnes averaging 6.72 percent P_2O_5.

Figure 15. Seligdar apatite carbonatite deposit, Nimnyr metallogenic belt. Schematic geologic map. Adapted from Vasilenko and others (1982).

Origin and Tectonic Controls for Nimnyr Metallogenic Belt

The Nimnyr metallogenic belt is related to carbonatite that is interpreted as having formed during interplate rifting. The deposits consist of apatite-carbonate, apatite-quartz-carbonate, martite-apatite-quartz-carbonate, and martite-apatite-carbonate, and apatite-carbonate-quartz that is related to and hosted in asymmetrical carbonatite stocks.

Qinglong Metallogenic Belt of Banded Iron Formation (BIF, Algoma Fe) and Clastic-Sediment-Hosted Sb-Au Deposits (Belt QL) (North China)

This metallogenic belt (fig. 8, appendix C) is hosted in marine volcaniclastic and sedimentary basins of West Liaoning-Hebei-Shanxi terrane in the Sino-Korean craton in the Jidong area (Eastern Hebei Province). The major Fe deposit is at Zhalanzhangzi, and the major Au deposits is at Qinglonghe. This metallogenic belt is 80 km long and measures as much as 30 km wide. BIF deposits are related to the Paleoproterozoic Zhuzhangzi Group and clastic-sediment-hosted Sb-Au deposits are related to the Paleoproterozoic Zhangjiagou Formation in the Qinglonghe Group. The main reference on the geology and metallogenesis of the belt is Zhang and others (1986).

Zhalanzhangzhi Iron (BIF, Algoma Fe) Deposit

This deposit (Zhang and others, 1986) consists of bedded and stratiform deposits. The main deposit bed is more than 2,000 m long and 10 to 30 m thick, and it is hosted in tourmaline microgneiss, garnet-mica schist in an asymmetric fold. The deposit occurs in the core and at limbs of the fold. The deposits dip between 60 to 70 degrees. The deposits are mainly banded, and consist of magnetite, quartz, actinolite, tremolite, and cummingtonite, with minor calcite, garnet, biotite, and pyrite. Grain size is about 0.05 mm. The total Fegrade of of the ores is low and some ores contain high sulphur. The host rocks (Zhuzhangzhi Group) is interpreted as having formed in an aulacogen filled mainly with clastic sedimentary rock, carbonates, and intercalated lesser mafic and more abundant felsic volcanic rock. Host rocks are metamorphosed to amphibolite facies. The deposit is large, and has reserves of 200 million tonnes Fe.

Qinglonghe Clastic-Sediment-hosted Au-Sb Deposit

This deposit (Wu and Hu 1992) occurs in the metamorphosed clastic rocks of the Paleoproterozoic Zhangjiagou Formation. The deposits are veined, stratiform, and lenticular. The deposit controls are distribution of the strata and faults. Most deposits show concordant relation to their hosts, and only a few veins cut bedding of host rocks. The two main deposits types are disseminated-veinlet and Au-bearing quartz-vein. Main ore minerals are pyrite, arsenopyrite, and gold, and subordinate minerals are pyrrhotite and chalcopyrite. Gangue minerals are plagioclase, quartz, muscovite, biotite, chlorite, calcite, and barite. The deposit minerals display idiomorphic-hypidiomorphic granular textures, and massive and disseminated structures. The sequence of formation of ore minerals is: arsenopyrite, Au-pyrite, and Au-pyrrhotite with chalcopyrite and fine-grained pyrite. Five deposits stages are recognized (1) Au-bearing silica alteration, (2) milky white quartz vein, (3) pyrite, (4) carbonate, and (5) muscovite-potassic feldspar-quartz vein. The Proterozoic strata are interpreted as providing initial Au and during remobilization and concentration in later geological events. The deposit is medium size.

Origin and Tectonic Controls for Qinglong Metallogenic Belt

BIF is hosted in marine volcaniclastic and clastic sedimentary rocks with minor conglomerate that are metamorphosed to amphibolite and greenschist facies. The belt is interpreted as having formed in a passive continental margin or aulacogen that was subsequently regionally metamorphosed and thrusted (Zhang and others, 1986).

Tyrkanda-Stanovoy Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt TS) (Russia, Aldan-Stanovoy Shield)

This metallogenic belt (fig. 8, appendix C) is hosted in the Tyrkanda tectonic-melange zone between the East Aldan superterrane and Central Aldan superterrane and between the East Aldan superterrane and Tynda terrane. The zone consists of tectonic slabs of paragneiss and anorthosite that are bounded by narrow blastomylonite zones with local abundant granite bodies. The age of the belt is interpreted as 1.9 Ga. The belt extends for 700 km and varies from 20 to 150 km wide. The main deposit is the Au in the shear-zone Kolchedannyi Utyos deposit, and the belt contains several Au occurrences.

The main references on the geology and metallogenesis of the belt are Karsakov and Romanovsky (1976), Moiseenko and Eirish (1996), and Parfenov and others (1999, 2003).

Kolchedannyi Utyos Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Karsakov and Romanovsky, 1976; Moiseenko and Eirish, 1996) consists of a northwestern-trending linear system that contains close-spaced quartz-pyrite veins with irregular, indistinct contacts (fig. 16). The veins are hosted in pyroxene, biotite-pyroxene, and

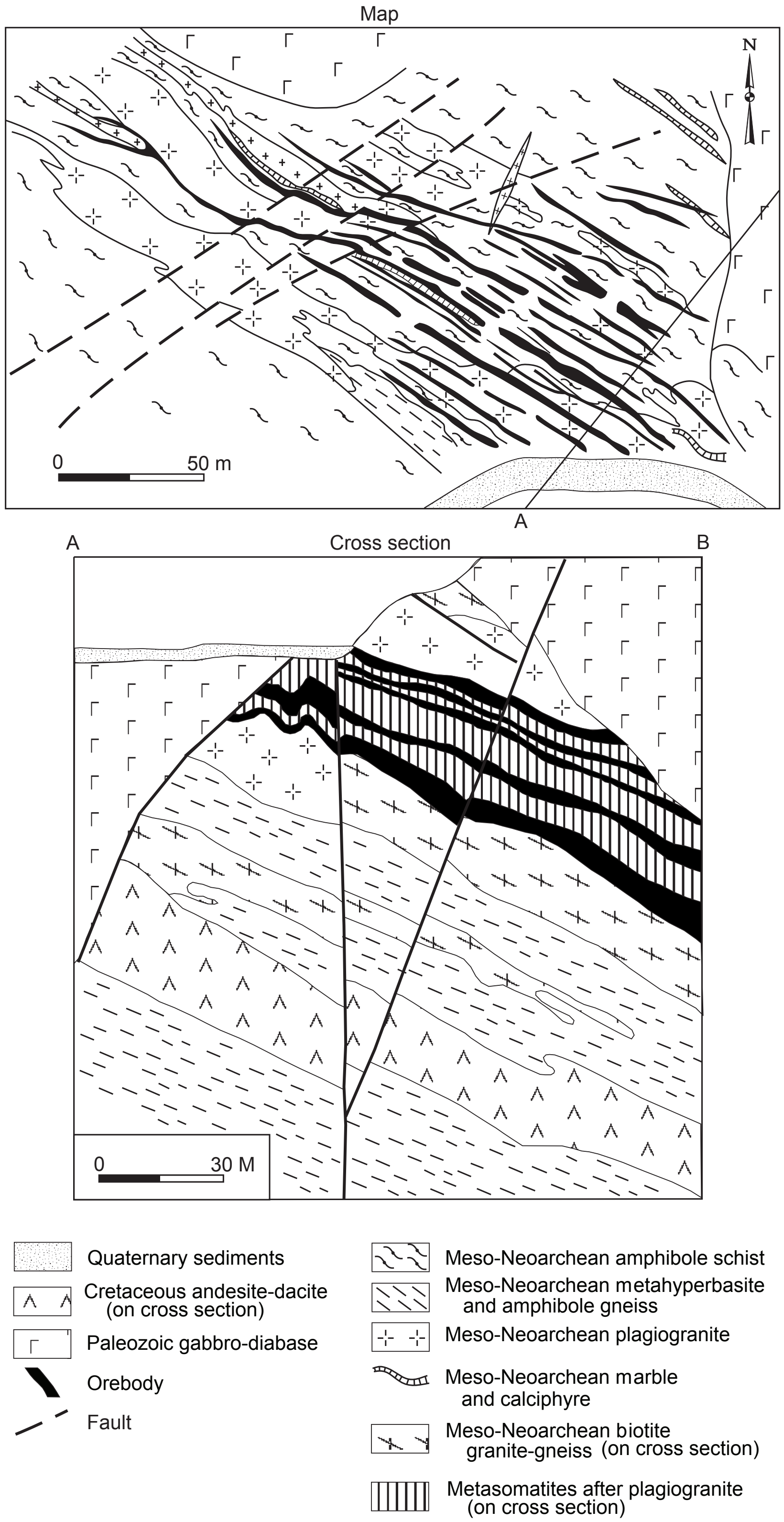


Figure 16. Kolchedannyi Utyos Au in shear-zone and quartz-vein deposit, Tyrkanda-Stanovoy metallogenic belt. Schematic geologic map and cross section. Adapted from Moisenko and Eirish (1996) and Parfenov and others (2001).

hornblende-pyroxene gneiss and schist interlayered with amphibolite, marble, and garnet- and graphite-bearing rocks. The ore minerals occur in disseminations, masses, and local breccia, and are mainly pyrite (20 to 90 percent), with lesser chalcopyrite (5 to 15 percent), and magnetite, sphalerite, and pyrrhotine. Quartz (from 30 to 70 percent) occurs in honeycombed frameworks, veinlets and nests, and sometimes crystal druses. The deposits are separated by silicified barren gneiss and pegmatoid microcline-plagioclase metasomatite. At the surface, deposits are oxidized to limonite, lazurute, malachite, and jarosite. The average grade ranges from 1 to 2 to 120 g/t, Au, 6-20 g/t Ag, and, locally, up to 64.1 g/t Ag.

Origin and Tectonic Controls for Tyrkanda-Stanovoy Metallogenic Belt

The belt is interpreted as having formed during collision between the Tynda composite terrane and Central Aldan and East Aldan superterranes. The reason for collision is unclear. Au shear-zone deposits cut metamorphosed mafic and ultramafic bodies and plutonic rocks.

Uduy-Udokanskiy Metallogenic Belt of Sediment-Hosted Cu, Zoned Mafic-Ultramafic Cu-PGE (± Cr, Ni, Au, Co, Ti, or Fe), and Ta-Nb-REE Alkaline Metasomatite Deposits (Belt UU) (Russia, Aldan-Stanovoy Shield)

This metallogenic belt (fig. 8, appendix C) is hosted in the West Aldan granite-greenstone terrane and the Udokan and Uguy Basin overlap assemblages. The belt extends for 250 km and ranges from 25 to 225 km. The Paleoproterozoic Udokan basin is composed of a 9 to 12-km-thick sequence of carbonate and clastic units in the Paleoproterozoic Udokan complex, and intrusive granitoids and gabbros. The Udokan complex consists of (1) carbonaceous sandstone and shale flysch (Kodar series), (2) variegated carbonate and siltstone and sandstone molasse (Chiney suite), and (3) variegated siltstone and sandstone molasse (Kemensky series). Sedimentary rocks are regionally and contact metamorphosed during variable-age magmatic events, including migmatitic granite of Kuandinsky complex, Kodar complex granitoids, and dikes; gabbro, anorthosite, and norite of the Chiney complex; alkaline metasomatite of the Katuginsky complex (all Proterozoic). The major sediment-hosted Cu deposits, which occur in the southwestern part of the Uguy-Udokanskiy metallogenic belt are at Burpalinskoye, Krasnoye, Udokanskoye, Pravo-Ingamakit, Sakinskoye, Sulbanskoye, and Unkurskoye. The major zoned mafic-ultramafic Cr-PGE (± Cu, Ni, Co, Ti, or Fe) deposit is at Chineyskoe, and the major This Nb-REE alkaline metasomatite deposit is at Katuginskoye that is related to the Paleoproterozoic Kuandinsky migmatite and granite complex, and REE deposits related to the Paleoproterozoic Kadar granitoid complex. The belt is fairly promising for Cu, Ti, Ni, V, Pt, Au, Ni, Ta, and REE deposits.

The main references on the geology and metallogenesis of the belt are Bogdanov and Apol'sky (1988), Chechetkin and others (1995), Arkhangelskaya (1998), Parfenov and others (1999, 2003), and Ptitsyn and others (2003).

Udokanskoye Sediment-Hosted Cu Deposit

This deposit (Chechetkin, and others, 1985, 1995; Volodin and others, 1994) (fig. 17) occurs in the Kodar-Udokan Basin and has an isotopic age of 2.2 to 1.8 Ga (Arkhangelskaya, 1998; Ptiksyn and others, 2003). The sedimentary rock of the Udokan basin contains the Cu-bearing Naminginsky stratigraphic unit. The Cu layers at Chitkandinsky, Alexandrovsky, Sakukansky, and Ikabiisky consist of quartz sandstone with lenses and beds of calcareous sandstone, siltstone, and argillite. These layers are concordant with host rocks and extend from several hundred meters to a few kilometers and approaches 21.4 km at the Udokan deposit. The deposits occur in beds, parting, lenses, and nests. Ore minerals occur as disseminations, veinlets, nests, semi-massive, and massive. The main ore minerals are chalcocite, covellite, bornite, chalcopyrite, pyrite, and pyrrhotite. Also occurring are Pb, Zn sulfides, and native gold and silver (Chechetkin and others, 1995). The deposit size is unknown and has an average grade of 1.86 to 2.43 percent Cu, 13.6 ppm Ag, 0.51 ppm Au, and 0.0004 percent Ti.

Usuu Sediment-Hosted Cu Occurrence

This deposit (Davydov and Chiryaev, 1986) consists of Cu occurrences in the Goruoda Formation that extends for 25 km along the eastern flank of the Uguy basin. The formation exhibits lagoonal and bar facies. Three thick horizons of Cu deposits occur. The lower horizon contains carbonate rock and sandstone. The deposit consists of rare Cu-sulfides in disseminations. The middle horizon contains quartz-bearing sandstone, and more abundant Cu-sulfides in disseminations. Thickness of the horizon ranges locally up to 60 m with Cu grades of up to 1 percent. The upper horizon contains disseminated Cu-sulfides in brecciated sandy dolomite and cross-bedded sandstone with a carbonate matrix. The upper horizon is 84 m thick, and the Cu grade is 0.11 to 1 percent. Ore minerals are chalcopyrite, bornite, chalcocine, and pyrite, with subordinate magnetite and hematite, and rare fahlore, covellite, galena, and native copper. Hypergeneic malachite, azurite, and chrysocolla also occur. The deposit is small.

Chineyskoye Zoned Mafic-Ultramafic Cu-PGE (± Cu, Ni, Co, Ti, or Fe) Deposit

This deposit (Gongalsky and others, 1995; Popov and others, 2009) occurs in the Chiney stratified gabbro and anorthosite pluton in the Chiney complex bearing that contains Cu, Ti-Fe-V, and PGE deposits (Gongalsky and others, 1995). The Chiney pluton occurs at an intersection of sublatitudinal system of faults along the southern margin of the Udokan basin. Cu sulfides occur in (1) thin laminated Ti magnetite, (2) highly alkaline rocks in the endocontact of the pluton, (3) leucogabbro, (4) sandstone, (5) skarn, and (6) tectonic zones. Chalcopyrite is predominant (90 percent). Occurring are endocontact disseminations (pyrrhotite-chalcopyrite, pyrite-chalcopyrite), and exocontact disseminations and masses (pyrrhotite-chalcopyrite, bornite-chalcopyrite and chalcopyrite). Ores minerals are pentlandite, sphalerite, minerals of linnaeite, arsenides, and sulfoarsenides. Disseminated Cu sulfides (1 to 3 percent) occur in all varieties units of the Chineisky massif. The deposit is large with an average grade of 0.40 to 16.75 percent Cu, 0.1 to 72.0 ppm Pt; 1 to 255 ppm Pd; 0.15-9.60 ppm Au, 0.027 to 0.260 percent Ni; 0.005 to 0.01 percent Co.

Katuginskoye Ta-Nb-REE Alkaline Metasomatite Deposit

This deposit (Sobachenko, 1998) contains Zr and cryolite and has an isotopic age of 2,066±6 Ma (Arkhangelskaya, 1998). The deposit is related to the Katuginsky alkaline metasomatite complex that occurs along Kolar mélange zone at the junction of the West Stanovoy and West Aldan terranes. The structural zone contains major faults and numerous ruptures, intrusive and extrusive rock of various compositions and a wide range of metamorphic facies (greenschist to granulite), and granitoids.

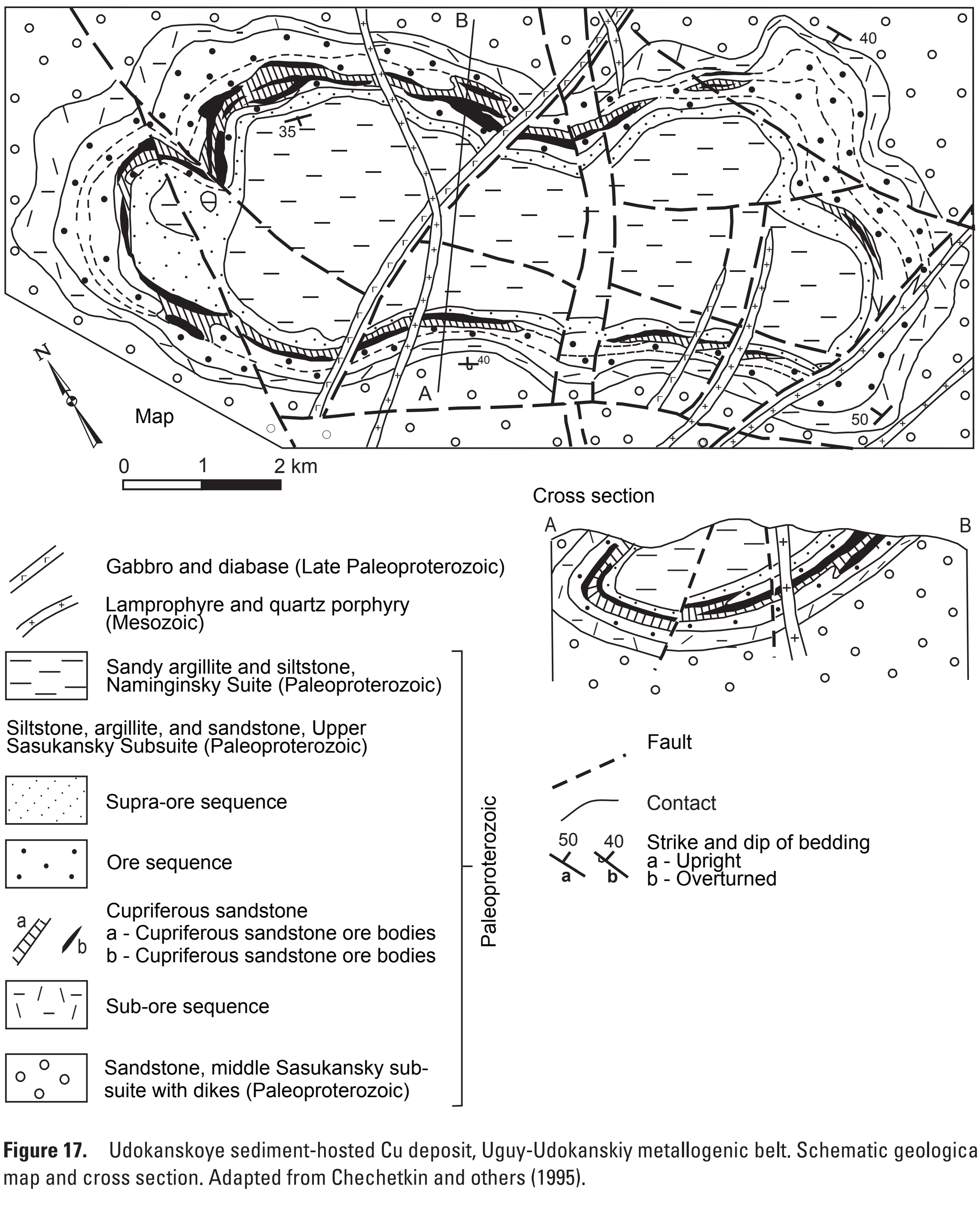


Figure 17. Udokanskoye sediment-hosted Cu deposit, Uguy-Udokanskiy metallogenic belt. Schematic geological map and cross section. Adapted from Chechetkin and others (1995).

The alkaline-granite REE metasomatite deposits formed during the latter event (Arkhangelskaya, 1974). The deposit consists of microcline-albite-quartz metasomatite with finely impregnated REE minerals. The deposit is divided into two blocks (Western and Eastern) by a northeast-striking fault. The eastern block is uplifted 400 m relative to the western block. In plan view, the ore body is triangular with outcrops of rocks elongated in western and southeastern directions. The internal structure of metasomatite bodies is conformable with structure of enclosing gneiss and schist. The thickness of metasomatites in Eastern body is 600 m, and Western body is over 900 m. Dark mineral assemblages are biotite, biotite-riebeckite, riebeckite-arfvedsonite, arfvedsonite-aegirine varieties of microcline-albite-quartz metasomatite. The main ore minerals are pyrochlore, zircon, rare-earth fluorite, gagarinite, and cryolite. The content of pyrochlore increases 10-fold from biotite through arfvedsonite to arfvedsonite-aegirine metasomatites (from 700 to 63,100 ppm). Chemical composition and REE concentrations (Ta, Nb, TR, Zr) indicate a deep, possibly mantle origin of solution forming alkaline metasomatites and associated economic REE deposit. The deposit is large.

Origin and Tectonic Controls for Uguy-Udokanskiy Metallogenic Belt

The Udokan Basin that hosts this metallogenic belt contains thick (up to 10,000 m) clastic and minor carbonate rocks that are intrude by zoned mafic-ultramafic plutons and granite with isotopic ages of about 2.2 to 1.8 Ga. The rocks are deformed, folded, and zonally metamorphosed up to amphibolite facies. The Cu and PGE deposits that occur in zoned mafic-ultramafic plutons and Cu deposits that occur in clastic sedimentary rocks are interpreted as having formed along a passive continental-margin rift. The younger Ta-Nb-REE alkaline metasomatite deposits are interpreted as having formed during later collision and intrusion of granite.

Mesoproterozoic Metallogenic Belts and Host Units (1,600 to 1,000 Ma)

The major Mesoproterozoic (1,600 to 1,000 Ma) metallogenic belts are the Darvi, Langshan-Bayan Obo, and Yanliao belts (fig. 8). All three belts possess geologic units favorable for major stratiform sediment-hosted deposits. Where known, the isotopic ages of deposits in the belts range from 1,400 to 1,100 Ma. The favorable geologic environments for the belts with sediment-hosted deposits were sedimentary basins in passive continental-margin units deposited on the Sino-Korean craton, or on the cratonal units of the Tuva-Mongolia superterrane that may be derived from the North Asian craton or possibly from another craton(s). The sedimentary exhalative Pb-Zn (SEDEX) and polygenic REE-Fe-Nb deposits in the the Langshan-Bayan Obo belt (containing the famous Bayan Obo REE-Fe-Nb mine) are interpreted as having formed during extrusion of carbonatite magma, associated hydrothermal activity, and deposition of overlap sedimentary assemblages that formed in a rift along the passive continental margin of the Sino-Korean craton.

Darvi Metallogenic Belt of Sedimentary Bauxite and Sedimentary Fe-V Occurrences (Belt DR) (Mongolia)

This Mesoproterozoic metallogenic belt (fig 8, appendix C) is related to sedimentary layers in the Baydrag cratonal terrane in the Govi-Altai region. The main sedimentary bauxite deposit is at Alag uul. The Alaguul diaspore deposit is hosted in Riphean sedimentary rocks in the Darvi fragment of the Baydrag terrane.

The main references on the geology and metallogenesis of the belt are Pinus and others (1984), Zaitsev and others (1984), and Tomurtogoo (1999).

Alag Uul Sedimentary Bauxite Deposit

This deposit (Pinus and others, 1984) is hosted in intercalated chloritite, amphibolite, graphite-bearing metaclastic rock and is closely spatially related to sedimentary Fe deposits (Zaitsev and others, 1984). The Riphean diaspore bauxite occurs in a zone up to 10 km long and 5 km wide. The belt is interpreted as having formed during bauxite sedimentation in a Riphean sedimentary basin that overlapped the Baydrag cratonal terrane and subsequent regional metamorphism of sedimentary bauxite. The average grades are 49 percent Al_2O_3, 36 percent of Fe_2O_3, 2 percent SiO_2, 4 percent TiO_2. Probable reserves are 100,000 tonnes bauxite.

Origin and Tectonic Controls for Darvi Metallogenic Belt

The belt is interpreted as having formed during bauxite sedimentation in Lower to Middle Riphean sedimentary basin along a passive continental margin.

Langshan-Bayan Obo Metallogenic Belt of Sedimentary Exhalative Pb-Zn (SEDEX) and Polygenetic REE-Fe-Nb Deposits (Belt LB) (Northwestern and North-Central China)

This metallogenic belt (fig. 8, appendix C) occurs in the central part of Inner Mongolia, along the Yinshan Mountains. The belt is 600 km long and 50 km wide, strikes northeast in the western part and changes to east-west strike in the eastern part. The belt is hosted in the Early Mesoproterozoic Zhangbei-Bayan Obo-Langshan rift-related metasedimentary and metavolcanic rocks deposit onthe Sino-Korean craton. The sedimentary exhalative Pb-Zn (SEDEX) and Pb-Zn-Cu deposits in the belt are large to superlarge, and the Bayan Obo Fe-Nb-REE deposit is world class. The stratigraphic horizons hosting SEDEX deposits are in the Mesoproterozoic Zhartaishan and Agulugou Formations though the horizon varies for different SEDEX deposits (Xu Guizhong and others, 1998). The Bayan Obo Fe-Nb-REE deposit is hosted in the 8th of 9 members in the Mesoproterozoic Bayan Obo Group. The significant deposits in are at Bayan Obo and Hugeqi.

The main references on the geology and metallogenesis of the belt are Chao and others (1992), Shi and others (1994), Tu (1998), and Xu and others (1998).

Bayan Obo Polygenic REE-Fe-Nb Deposit

This deposit (Lin and others, 1994; Xiufu and others 1997; Tu, 1998; Qiao and others, 1997) (fig. 18) occurs in am east-west trending Mesoproterozoic rift zone along the northern margin of Sino-Korean craton. The mining district containing the deposit contains several ore bodies that occur in a zone that is about 18 km long along an east-west trend and 5 km wide. Host strata are quartzite, slate, limestone, and dolomite that is main host rock. The bodies are stratiform and lenticular, with masses, bands, layers, and veins, and disseminations. Based on mineralogy, nine types of ores are identified that include sixty

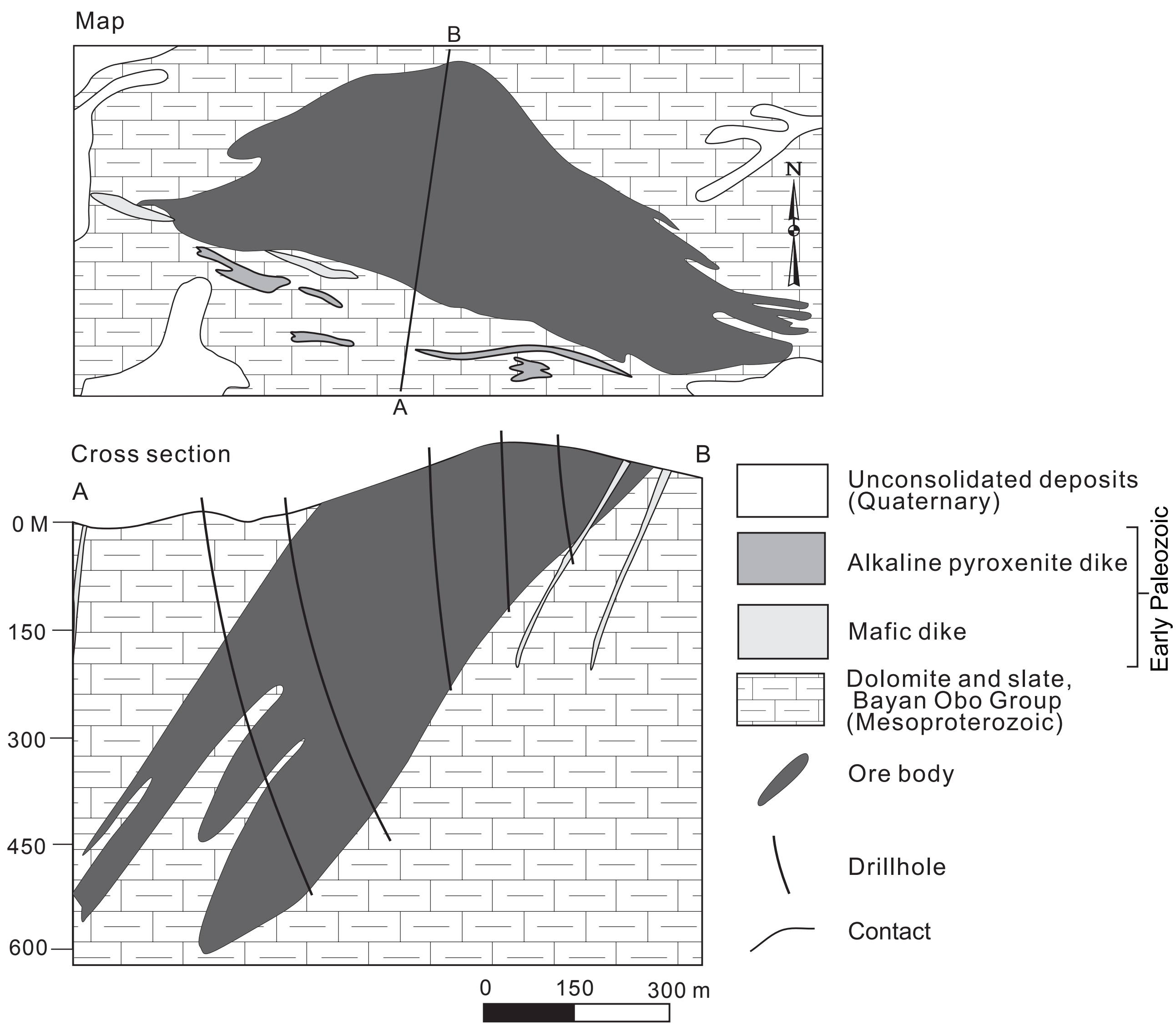


Figure 18. Bayan Obo polygenic REE-Fe-Nb deposit (Bayan-Obo type), Langshan-Bayan Obo metallogenic belt. Adapted from Li (1993).

Nb, REE, Ti, Zr, Nb, and Fe minerals and 19 new minerals such as Huanghoite and others. Besides clear features of hot water sedimentation, the deposit also exhibits Mg, Fe, Na and F metasomatism. Sm-Nd monazite isochron age for bastnaesite and riebeckite is 1200 to 1300 Ma, whereas Th-Pb and Sm-Nd age of Ba-REE-F carbonates and aeschynite is 474 to 402 Ma. In recent years Qiao and others (1997) suggest that some host strata are early Paleozoic. The deposit is superlarge and has reserves of 40.1 million tonnes and an average grade of 3 to 5.4 percent REE; Reserves of more than 1 million tonnes Nb_2O_5 have an average grade of 0.1 to 0.14 percent Nb_2O_5.

Huogeqi Sedimentary Exhalative Pb-Zn (SEDEX) Deposit

This stratiform deposit (Ge and others, 1994) occurs in the Langshan Mountains and consists of stratiform bodies hosted in phyllite, schist, and quartzite of the Proterzoic Langshan group that has a Rb-Sr isotopic age of 1100 Ma. Ore minerals are mainly chalcopyrite, pyrite, pyrrhotite, magnetite, galena, and sphalerite, with small amounts of arsenopyrite and hematite. Wall rocks are altered to silica, diopsie-grunerite, biotite, sericite, and chlorite. The deposit is large and has reserves of 0.973 tonnes Pb, 0.782 tonnes Zn, and 0.711 million tonnes Cu. Average grades of Pb, Zn, and Cu are 1.44 percent, 1.46 percent, 1.35 percent, respectively.

Origin and Tectonic Controls for Langshan-Bayan Obo Metallogenic Belt

The Bayan Obo deposit is interpreted as a SEDEX deposit related to a carbonatite magma and associated hydrothermal activity. The belt hosted in a Mesoproterozoic overlap sedimentary assemblage deposit, formed in the Zhangbei-Bayan Obo-Langshan rift along the passive continental margin of the Sino-Korean craton. The Early Mesoproterozoic overlap assemblage hosting the belt in the Yinshan Archean terrane consists of (1) metasedimentary schist, biotite gneiss, quartzite, marble, (2) metaconglomerate, quartzite, stromatolite-bearing crystalline limestone, phyllite, slate, mica schist, actinolite schist, and minor metamorphosed intermediate and siliceous volcanic rock of the Zhartai Group with an age of 1,500 to 1,600 Ma, and (3) phyllite, slate, quartzite, meta-sandstone, and dolomite of the Bayan Obo Group with an age of 1,350 to 1,650 Ma. Some authors interpret the assemblage as the Mesoproterozoic Langshan-Zhartaishan Basin that formed along the northwestern margin of North China Plate (Xu Guizhong and others, 1998). The world class Bayan Obo Fe-Nb-REE deposit is a non-conventional super-large of deposit (Tu Guangzhi, 1998) is unique in the world. The origin is still debated (Chao and others, 1992, Tu 1998). Tu (1998) suggested that Bayan Obo deposit is a SEDEX deposit related to the carbonatite magma and associated hydrothermal activity. Various studies on the Bayan Obo deposit focus on the syngenetic nature of igneous carbonatite and the epigenetic replacement of the sedimentary dolomite. These two types of processes are not strictly exclusive and both may be part of a SEDEX deposit model.

Yanliao Metallogenic Belt of Chemical-Sedimentary Fe-Mn and Sedimentary-Exhalative Pb-Zn (SEDEX) Deposits (Belt YL-2) (Northern and Northeastern China)

This metallogenic belt (fig. 8) is hosted in the Jixian Group in platform sedimentary cover rocks on the Sino-Korea craton. The belt occurs in the eastern Yanshan Mountain in the West Liaoning and Northeast Hebei Provinces, is 200 to 300 km long, more than 50 km wide, and strikes east-west. The belt is the continuation of the Yanliao Mesoproterozoic metallogenic belt. The deposits are mainly hosted in the Neoproterozoic Jixian Group with isotopic ages of 1400 to 1100 Ma. The host rocks for the deposits are variably-colored siltstone and silty shale and intercalated with limestone. The significant deposits are at Wafangzi and Gaobanhe. The main reference on the geology and metallogenesis of the belt is Wang (1985).

Wafangzi Chemical-Sedimentary Fe-Mn Deposit

This deposit (Ye and others, 1994) consists of stratiform and lensoid masses. The thickness of a single layer is only 10 to 30 cm. The deposit comprises three layers that are 1 to 2 m thick on average. These three layers are hosted in pelitic rock the middle part of the Mesoproterozoic Tieling Formation of the Jixian Group in a northeast-striking anticlinorium. The deposit occurs on the southeastern limb of the anticlinorium. The ores are divided into three types (1) sedimentary manganite and rhodochrosite with para-oolitic, banded, massive, and psephitic textures, (2) contact metamorphic ores consisting of bixbite, braunite, manganoferrite, coarse-grained rhodochrosite, Ca-rhodochrosite, Mn-olivine, Mn-garnet, diopside, and sulphides, and (3) oxidized ores consisting of massive, banded, and radiating psilomelane, pyrolusite, calcite, dolomite, and quartz. The sedimentary environment is interpreted as shallow marine or nearshore. To the west of the deposit is a group of smaller sedimentary Mn deposits. The deposit is large and has reserves of 37.69 million tonnes grading 18 to 24 percent Mn.

Gaobanhe Sedimentary Exhalative Pb-Zn (SEDEX) Deposit

This deposit (Tu and others 1989) consists of nine stratiform deposits that occur in an east-west-trending belt that is 6 km long and 3 km wide. The host rocks are Mn shale and dolomite of late Proterozoic Gaoyuzhuang Formation. Ore minerals are mainly sphalerite, galena, and pyrite, and the ore varies from massive to banded. Framboidal, colloform, and pelletoidal pyrite are common. The deposit occurs in the east-west-trending Yanliao Basin on the Sino-Korea craton. The deposit is medium size with an average grade of about 2 percent Zn and a lower concentration of Pb.

Origin and Tectonic Controls for Yanliao 2 Metallogenic Belt

The belt is interpreted as having formed in a shallow marine basin on the Sino-Korea craton and is hosted in the Middle and Neoproterozoic Hebei-Liaoning sedimentary basin. The Mesoproterozoic part of the basin consists of (1) sandy-muddy dolomite, (2) dolomite, (3) shale; (4) quartz sandstone, dolomite, and limestone, dolomitic limestone, (5) sandstone and siltstone, (6) muddy limestone. The Yanliao oceanic basin changed from a shallow sea in the Jixianan period to an epicontinental sea in the Qinbaikou period (Wang, 1985). The Mn deposits of the Wafangzi type are interpreted as having formed in a shallow oceanic basin.

Archean through Mesoproterozoic Metallogenic and Tectonic Model—General Comments

A metallogenic and tectonic model for the North Asian and the Sino-Korean cratons is developed for the Proterozoic (2.5 to 1.6 Ga), and Mesoproterozoic (1.6 to 1.0 Ga) (figs. 19-23). The model is based on the boundaries of the cratons and their relative positions at 850 Ma (Wang and others, 1991; Nokleberg and others, 2000; Kravchinsky and others, 2001) and new modeling work by C.R. Scotese presented herein. The model employs isotopic age data obtained for the Tynda and Chogar terranes of the Stanovoy region (Larin and others, 2002a,b; Karsakov, 1983), the Okhotsk terrane and the Omolon superterrane (Khil'tova and others, 1988), indicating that these terranes were part of the Sino-Korean craton. The part of the model for Sino-Korean craton is also based on the data from the Geodynamic Map of Northeast Asia (Parfenov and others, 2003).

The model is based on the assumption that during the Proterozoic, the North Asian craton was a single unit consisting of various Archean and Paleoproterozoic terranes of the Aldan-Stanovoy and Anabar shields, terranes of the buried basement of the Siberian platform, the Okhotsk terrane, and the Kolyma-Omolon superterrane, as well as various metamorphic Mesoproterozoic terranes. The relative positions of the crystalline basement blocks in the Proterozoic cratons significantly differed from their present positions.

In addition, the model employs data on the composition and age of buried terranes that are overlain by the sedimentary cover of the Siberian platform and the Verhoyansk margin of the North Asian craton (Smelov and Timofeev, 2007). These units are not depicted on the summary geodynamics map (fig. 2), but are depicted on figures 19 to 23.

Terranes Overlain by the Siberian Platform

Information about the nature of the Tunguska, Tyung, Tyryn, and Berekta terranes are buried beneath the cover rocks of the Siberian Platform is derived from petrological and isotopic-geochemical studies of basement xenoliths in various types of volcanic rocks and from intrusive rocks sampled in deep boreholes. The boundaries of the terranes are delineated from aeromagnetic studies because the tectonic mélange zones and the terrane-bounding faults generally form positive linear anomalies. The terranes themselves are characterized either by arcuate anomalies or by homogenous magnetic fields.

Tunguska Tonalite-Trondhjemite Gneiss Terrane (TGS)

This terrane occurs in the western part of the North Asian craton where aeromagnetic data provide a more detailed delineation of the terrane boundaries. However, petrographic information from drillholes is scarce and only available for the Baikit anticline and the Malo-Botuobiya kimberlite field. The rocks in these latter two areas are biotite and amphibole plagiogneiss that consists of tonalitic to trondhjemite, granite gneiss, and granodiorite gneiss with Nd model ages ranging from ~3.3 to ~2.6 Ga. The terrane is interpreted as an extension of the Near-Sayan Uplift (Sharizhalgay and Onot terranes) in the western part of the Anabar shield (Magan Terrane) and likely represents marginal parts of the Tunguska Archean craton which was reworked during a Paleoproterozoic continental collision as a part of the orogenic belts.

Tyung Terrane (TNG)

This terrane occurs along the southeastern margin of the North Asian craton and generally is interpreted as a fragment of an Archean craton (Rosen and others, 1994). However, metamorphic rock xenoliths in the kimberlite pipes in this area include two granulite facies rock units. The first unit is garnet-amphibole-clinopyroxene and amphibole schist with TNd (DM) ages ranging from ~3.3 to ~2.9 Ga, and the second unit is amphibole-two-pyroxene schist with a Nd model age of ~2.1 Ga. The latter unit is fairly close to the TNd (DM) ages of ~2.5 Ga obtained from eclogite xenoliths in the same kimberlitic pipe. Petrographic and geochemical studies reveal no differences in the metamorphic grade and degree of secondary alteration between the two rock units and suggest that the continental crust of the Tyung terrane formed in two stages, one in the Archean (~3.3 to ~2.9 Ga), and the other in the Paleoproterozoic (~2.5 to ~2.1 Ga). The closing of Sm-Nd isotopic systems in minerals of garnet-clinopyroxene amphibolite of both age groups occurred at ~1.9 to ~1.7 Ga, suggesting a long cooling period of the lower crust following granulite-grade metamorphism.

Tyryn Terrane (TRN)

This terrane is defined by geophysical data and may represent the northern part of the Batomga terrane (EBT) that is buried beneath the sedimentary cover of the Siberian Platform and the Verkhoyansk margin of the North Asian craton.

Berekta Terrane (BRK)

This terrane occurs in the northeastern part of the North Asian craton is defined from geophysical data and from basement rocks that are exposed in the arch of the Olenek Uplift, within the Sololi inlier. The terrane is overlain by flat-lying Riphean deposits of the Siberian Platform. The basement rocks of the terrane are the Aekit Series (see discussion of the Olenek Uplift above) and are coeval with the Udokan Series of the West Aldan composite terrane. Both series are interpreted as Archean gneiss complexes that are supported by the occurrence of xenoliths of amphibole leucocratic plagiogneisses with Nd model ages of ~3.3 Ga in the Obnazhonnaya kimberlitic pipe. However, samples from these units contain large $^{147}Sm/^{144}Nd$ ratios (0.1883) that are close to chondritic and depleted mantle values, and the determination of model ages is impossible.

Basement of the Verkhoyanskoy Margin of North Asian craton

The eastern margin of the North Asian craton (Yana-Indigirka superterrane) is overlain by sedimentary rock. The composition and age of the basement is determined from studies of crystalline basement rock sampled in deep drillholes and xenoliths in various granitoid plutons that intrude Phanerozoic sedimentary rocks of the Verkhoyansk terranet. The Ivanovskaya borehole penetrated crystalline rocks, including biotite and biotite-muscovite micro-paragneiss, metasandstone, quartzite schist, and garnet-amphibole schist, at depths of 3,386 to 3,518 m below the base of overlying Permian sedimentary sequence. The crystalline rocks are metamorphosed to greenschist and lower amphibolite facies, and TNd (DM) ages of the microparagneiss fall into two groups: ~2.5 to ~2.3 Ga and ~1.5 to ~1.0 Ga. The Nd data indicate that both Paleo- and Mesoproterozoic rocks were the source of detritus for these rocks. The xenoliths of biotite-two-feldspar banded gneiss and biotite schist in granitoid rocks were metamorphosed to amphibolite facies and may reflect contact metamorphism by the surrounding granitoid pluton. They are characterized by $^{147}Sm/^{144}Nd$ ratios of 0.1080 to 0.1206 and TNd (DM) ages of about1.5 to 1.3 Ga, suggesting a Mesoproterozoic age for the source rocks from which the metasedimentary cover rocks were derived.

The occurrence of Mesoproterozoic metamorphic complexes in the basement of the Verkhoyansk terrane is also supported by U-Pb (SHRIMP) ages of ~1.5 to ~1.05 Ga from detrital zircons in the middle and upper Riphean sedimentary rocks. The Lower Carboniferous conglomerate in the northern basement of the Verkhoyanskoy terrane contains granite clasts and two-mica schist boulders with K-Ar ages of ~1.4 to ~0.9 Ga. The conglomerate is composed of granite clasts and is metamorphosed sandstone and quartzites and is interpreted to have been formed in a littoral zone that was adjacent to a basement uplift at the front of the foldbelt.

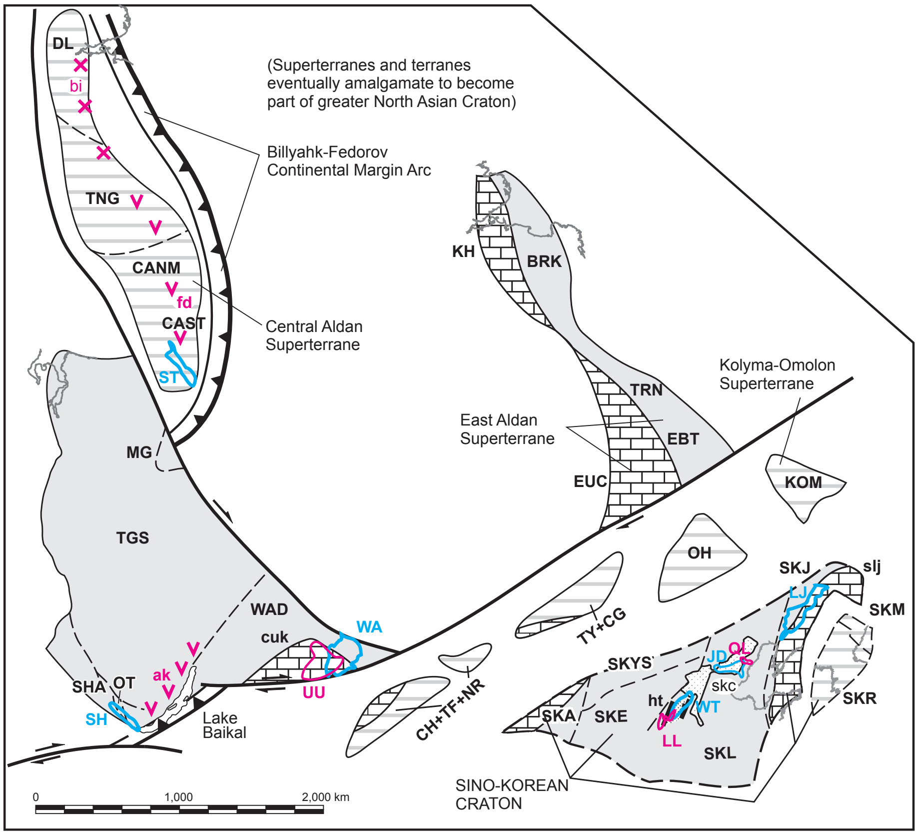
Archean and Proterozoic Metallogenic and Tectonic Model

Tectonics

At the end of Archean (≥2,500 Ma) (fig. 19), the North Asian craton was not a single structure. Various terranes, now amalgamated to form the craton, formed at several different times. The oldest terranes are the Okhotsk (OH) cratonal and the Chogar (CG) granulite-orthognesiss terranes that started to form in the Paleoarchean (3.7 to 3.5 Ga). The protoliths of the oldest rocks of the Central Aldan granulite-gneiss superterrane and the Daldyn Granulite-orthogneiss terranes formed from about 3.35 to 3.0 Ga, while protoliths of the protoliths of the West Aldan (WAD) granite-greenstone and Onod (OT) terranes formed at about 3.2 to 2.7 Ga. Protoliths of the Tynda (TY) tonalite-trondhjemite-gneiss, Chuya (CH) (granite gneiss), Tonod (TF), and Nercha (NR) terranes formed from about 2.9 to 2.5 Ga. Most of these protoliths formed in an island arc or back-arc basin environment. These terranes and superterranes were likely amalmated into the cratons or microcontinents in the late Archean. The West Aldan terrane accretion occurred at about 2.6 Ga and was accompanied by granite formation and granulite metamorphism. In all other terranes, these processes are poorly defined or highly modified by later events. Also at this time-stage, the West Aldan and probably Batomga granite-greenstone terranes were overlapped by platform cover, and parts of the Daldyn and Central Aldan granulite-gneiss terranes were forming.

In between the units that would form the North Asian craton (described above, fig. 19) and the Sino-Korean craton (described below, fig. 2) were the Chogar granulite-orthogneiss, Chuya, Kolyma-Omolon, Okhotsk, Nechera, Omolon, Tonod, and Tynda terranes (Larin and others, 2002a,b) (fig. 19). Interestingly, the ages of protoliths of the Nercha, Tonod, Chuya, Tynda, Chogar and Okhotsk terranes, that comprise part of the North Asian craton are similar to the terranes that comprise the Sino-Korean craton. At this time, no major overlap assemblages were forming or have since been eroded.

In contrast to the North Asian craton and margin terranes, the eastern Sino-Korean craton is interpreted as a single unit that contained the Yinshan, Erduosi, Jilin-Liaoning-East Shandong and, West Liaoning-Hebei-Shanxi terranes.The major Archean tectonic events in the Sino-Korean craton were (1) crustal growth of the Sino-Korean Block during the Paleoarchean through Mesoarchean (3,600 to 2,800 Ma), (2) the beginning of the Archean plate tectonic mechanism in the Early Neoarchean (2,800 to 2,700 Ma) that consisted of amalgamation of the West Liaoning-Hebei-Shanxi, the Jilin-Liaoning-Eastern Shandong, Rangnim, and Yeongnam terranes that constituted island arcs and back-arc basins, (3) the formation of tonalite-trondhjemite-gneiss belts, (4) the amalgamation of the Alashan (SKA), West



GEOLOGIC UNITS

ak - Akitkan volcanic-plutonic belt
cuk - Chara-Uchur rift system (Paleoproterozoic) - Udokan basin
bi - Billyahk plutonic belt (Paleoproterozoic)
fk - Fedorov volcanic-plutonic belt
skc - Hebei-Liaoning sedimentary basin
ht - Hutuo rift basin (Paleoproterozoic)
slj - East Shandong-East Liaoning-East Jilin rift basin (Paleoproterozoic)

North Asian Craton

BRK - Berekta Terrane (Granite-greenstone) (Late Archean)
CANM - Nimnyr terrane (Granulite-orthogneiss) (Paleoproterozoic)
CAST - Sutam terrane (Granulite-paragneiss) (Late Archean)
CG - Chogar Granulite-orthogneiss terrane (Archean)
CH - Chuja terrane (Paragneiss) (Late Archean through Neoproterozoic)
DL - Daldyn terrane (Granulite-orthogneiss) (Middle Archean)
EBT - Batomga composite terrane (Granite-greenstone) (Late Archean)
EUC - Uchur terrane (Granulite-paragneiss) (Paleoproterozoic)
KH - Khapchan terrane (Granulite-paragneiss) (Paleoproterozoic)
KOM - Kolyma-Omolon superterrane (Archean to Jurassic)
MG - Magan terrane (Tonalite-trondhjemite-gneiss) (Paleoproterozoic)
NR - Nechera terrane (Granulite-paragneiss) (Archean? and Proterozoic)
OH - Okhotsk terrane (Cratonal) (Archean through Jurassic)
SHA - Sharizhalgay terrane (Granulite-orthogneisse) (Archean through Paleoproterozoic)
TF - Tonod terrane (Greenschist) (Paleoproterozoic)
TGS - Tunguska terrane (Tonalite-trondhjemite) (Archean)
TNG - Tyung terrane (Granulite-orthogneiss) (Archean to Paleoproterozoic)
TRN - Tyryn Terrane (Granite-greenstone) (Late Archean)
TY - Tynda terrane (Tonalite-trondhjemite-gneiss) (Archean and Paleoproterozoic)
WAD - West Aldan terrane (Granite-greenstone) (Archean)

Sino-Korean Craton

SKA - Alashan terrane (Granulite-paragneiss) (Paleoproterozoic)
SKE - Erduosi terrane (Granulite-paragneiss) (Archean)
SKJ - Jilin-Liaoning-East Shandong terrane (Tonalite-trondhjemite-gneiss) (Archean)
SKL - West Liaoning-Hebei-Shanxi terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKM - Machollyong terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKR - Rangnim terrane (Granulite-paragneiss) (Archean)
SKYS - Yinshan terrane (Granite-greenstone belt) (Archean)

METALLOGENIC BELTS

Paleoproterozoic
LL - Luliangshan
QL - Qinglong
UU - Uguy-Udokanskiy

Archean
JD - Jidong
LJ - Liaoji
SH - Sharizhalgaiskiy
ST - Sutam
WA - West Aldan
WT - Wutai

Figure 19. Early Paleoproterozoic (2,500 to 2,000 Ma) time stage of metallogenic and tectonic model (with additional Archean metallogenic belts). Figure adapted from Parfenov and others (chapter 9, this volume).

EXPLANATION

Craton

Passive continental margin on subsided craton

Microcontinent

Continental slope

Intracontinental sedimentary basin

Collage of accreted terranes and overlap assemblages

Ocean or sea underlain by oceanic crust; includes continental margin and slope units

Sea underlain by continental crust

SUBDUCTION-RELATED ISLAND-ARC AND CONTINENTAL-MARGIN ARCS

Mainly volcanic and lesser plutonic units

Mainly plutonic and lesser volcanic units

TRANSFORM-PLATE BOUNDARY, INTRA-PLATE (PLUME) MAGMATIC UNITS

Subalkaline and alkaline volcanic and plutonic belts

Plateau basalt, trap

Rift-related bimodal volcanic and plutonic rocks

Intra-plate granitoids

COLLISIONAL GRANITOIDS

CONTACTS, FAULTS, AND SYMBOLS

Subduction zone and its accretionary wedge

Thrust

Strike-slip fault

Normal fault

Fold- and thrust-belt formed on the subsided craton margin

Stratigraphic contact

OH Metallogenic belt with abbreviation

Figure 19.—Continued.

Liaoning-Hebei-Shanxi (SKL), Jilin-Liaoning-Eastern Shandong (SKJ), and Rangnim (SKR) terranes to form the crystalline basement of SKC during the Late Neoarchean (2,600 to 2,500 Ma), and (5) the amalgamation of the main Archean terranes to form the crystalline basement of Yinshan (SKYS), Erdos (SKE), Western Liaoning-Hebei-Shanxi (SKL) and Jilin-Liaoning-Eastern Shandong (SKJ) terranes during the latest Neoarchean (2,500 to 2,450 Ma).

Metallogenesis

The major Archean metallogenic belts formed in a variety of tectonic environments (fig. 19, appendix C).

In the Jidong belt (JD, figs. 3, 19) the BIF deposits are interpreted as having formed in a volcanic and sedimentation basin along an unstable proto-continental margin, or in a fragment of Archean part of the Sino-Korean craton. The Au deposits are interpreted as having formed during retrograde metamorphism to greenschist facies.

In the Liaoji belt (LJ, figs. 3, 19), the host greenstone belt in the Northern Liaoning (Hunbei) area is interpreted as having formed in an active continental margin, whereas the greenstone belts in the Anshan-Benxi and Jiapigou areas are interpreted as having formed in oceanic rifts along a continental margin. The Au deposits are interpreted as having formed during retrograde metamorphism to greenschist facies. Because of the ancient ages of geologic units and the lack of detailed data, several mineral-deposit types are combined into a composite belt.

In the Sharizhalgaiskiy belt (SH, figs. 3, 19), some deposits (Kitoy group and Baikalskoye deposit) are hosted in Archean units. Other deposits (for example, the Onot group, Sosnovy Baits deposit) are hosted in Proterozoic units. Layering in ferruginous quartzite and in two-pyroxene schists is interpreted as having been derived from ferruginous volcanic and sedimentary rock sequences.

In the Sutam belt (ST, figs. 3, 19), two rock groups with BIF occur (1) magnetite-hypersthene and magnetite-pyroxene gneiss is interbedded with amphibole-pyroxene and magnetite-pyroxene-plagioclase schist, and BIF consisting of magnetite and hypersthene-magnetite quartzite occur in outer part of an antiform, and (2) feldspar quartzite interlayered with garnet- and sillimanite-bearing schist with diopside calciphyre. Also occurring are magnetite-hypersthene and garnet-magnetite hypersthene layers.

The West Aldan metallogenic belt (WA, figs. 3, 19) is interpreted as having formed in a back-arc basin and (or) in an island arc. Au occurrences are mainly in the shear zones cutting metabasalt, amphibilite, and ultramafic rock. Shear zones formed during amalgamation of terranes, or during later tectonic events. BIF (magnetite quartzite) deposits in the belt forms in stratiform layers and lenses in metabasalt and amphibolite and local siliceous metavolcanic rock and schist.

In the Wutai belt (WT, figs. 3, 19), the host Wutai greenstone belt and BIF deposits are interpreted as having formed in a nonmature to mature island arc.

Paleoproterozoic Metallogenic and Tectonic Model

Early Paleoproterozoic Tectonics

In the Early Paleoproterozoic (2,500to 2,000 Ma) (fig. 19), large granite-greenstone terranes (fragments of which were subsequently amalgamated to become craton) of the North Asian craton began converging along strike-slip faults. The major tectonic events were as follows. (1) Passive continental margins and microcontinents, such as the Daldyn and Tyung (TNG) terranes, and the Central Aldan superterrane, formed a single amalgamated block, which formed along one edge of the Billyahk-Fedorov continental nargin arc. (2) The Tunguska, Sharizhalgay, and West Aldan terranes were amalgamated and were juxtaposed against the previous block. (3) Overlying the West Aldan terrane was the Chara-Uachur rift system that formed the Udokan Basin. (4) The Khapchan terrane and the East Aldan superterrane were amalgamated and migrated towards the above terranes.

Between the above components of the North Asian craton and the below components of the Sino-Korean terrane (fig. 19), an extensive suite of terranes was starting to amgamate and subsequently to form marginal parts of the North Asian craton. These terranes included the Chuja, Okhotsk, Tonod, and Tynda terranes, and the Central Aldan and Kolyma-Omolon superterranes. The convergence of the Sino-Korean and North Asian cratons along the strike-slip fault was accompanied by initiation of the Hutuo rift basin (ht). Within the Tynda terrane, a rifting process was associated with formation of greenstone belt structures (Korsakov, 2000). In addition, various parts of the core and margins of the Sino-Korean craton were forming, including the Alashan, Erduosi, Jilin-Liaoning-East Shandong, West Liaaoning-Hebei-Shanxi, Machollyong, and Rangnim terranes.

Metallogenesis

The Uguy-Udokan sediment-hosted Cu metallogenic belt (UU) (Russia, Aldan-Stanovoy shield) is hosted by the Udokan and Uguy basins (cuk) of the Chara-Uchur rift system. The age of the belt is interpreted as Early Proterozoic. The belt includes sediment-hosted Cu deposits such as the Usuu deposit. The belt occures in the western part of the Aldan-Stanovoy shield and overlaps the West Aldan terrane and Kalar tectonic melange zone. The large Udokan Cu sandstone deposit is to the southwest of the belt, within the rift-related Udokan trough filled in with thick (up to 10 000 m) clastics and minor carbonate rocks dated at 2,200 to 1,800 Ma. The rocks corresponding to the upper part of the trough section also fill in relatively small graben-like Uguy, Oldongso, and Lower Khani basins, unconformably overlying various crystalline rocks of the West Aldan granite-greenstone composite terrane (Parfenov and others, 1999; Bogdanov and Apol'sky, 1988; Davydov and Chiryaev, 1986)

In the Luliangshan belt (LL, figs. 8, 19), the banded iron formation (BIF, Superior Fe) deposits are interpreted as having formed in a Paleoproterozoic Hutuo Basin that was superposed on the Archean Northern China craton. The Au in shear-zone and quartz-vein deposits are interpreted as having formed during later collision and regional metamorphism.

In the Qinglong belt (QL) banded iron formation (BIF) (Zhalanzhangzhi) and clastic-sediment-hosted Sb-Au (Qinglonghe) BIF are hosted in marine volcaniclastic and clastic sedimentary rocks with minor conglomerate that are metamorphosed to amphibolite and greenschist facies. The belt is interpreted as having formed in a passive continental margin or aulacogen that was subsequently regionally metamorphosed and thrusted (Zhang Yixia and others, 1986).

Middle Paleoproterozoic Tectonics

In the Middle Paleoproterozoic (2,000 to 1,900 Ma), major accretions occurred to form the North Asian craton (compare figs. 19 and 20). The left part of the craton consisted of the amalgamated TGS, SHA, and WAD terranes. The central part of the craton consisted of the DL, TNG, and Central Aldan superterrane (CAL), and the right part of the craton consisted of the KH, EUC, and EBT terranes. Along the bottom of the craton were the accreted CH, TF, NR, TY, OH, and KOM terranes. These accretions resulted in formation of the Daldyn-Aldan and Khapchan-Uchur, Sharizhalgay-Nechera and Stanovoy orogenic belts and formation of the major Kalar, Amga, and Turkanda tectonic mélange zones (figs. 2, 20).

Also in the Middle Paleoproterozoic (2,000 to 1,900 Ma), major overlap and stitch assemblages formed on the North Asia craton (not shown on figures 2 and 20) (1) Udokan and Uguy basins with ages 2,200 to 1,900 Ma, (2) the Akitkan volcano-plutonic belt, (3) the Anabar, Dzugdzur and Kalar anorthositic belts, (4) Billyahk and Ulkan plutonic belts, and (5) Kodar and Tyrkanda granitic belts.

Also at this time, amalgamation of the Sino-Korean craton to the North Asian craton (lower part of fig. 20), produced the Sharizhalgay-Nechera and Stanovoy orogenic belts. This event was accompanied by granulite facies metamorphism in some of the terranes (Nutman and others, 1992).

The major terranes forming in the Sino-Korean craton were the Machollyong, Rangnim and Yeongnam granulite-paragneiss terranes. The major overlap and stitch assemblages forming on the Sino-Korean craton were (not shown on figures 2 and 20) was the Hutuo rift. The major terrane forming in the South China craton was the Jiaonan Ultra-High Pressure terrane.

Late Paleoproterozoic Tectonics

In the first part of the Late Paleoproterozoic, (1,900 to 1,800 Ma) (fig. 21), the North Asian craton was fully formed as described in the previous section. Also at this time, displacement of the Sino-Korean craton and the southern terranes of the North Asian craton occurred relative to its northern terranes along a left-lateral strike-slip fault. The collision was probably related to the on-going formation of the supercontinent Pangea, and it resulted in the intrusion of collisional granites at about 1.85 Ga.

In the second part of the Late Paleoproterozoic (1,800 to 1,600 Ma) (fig. 21), major rift basins were initiated parallel to the zone of collision between the North Asian and Sino-Korean cratons. In addition, new major rift basins formed at this time, including the ak, cuk, and cul basins (fig. 21). Some of the rifting was accompanied by subalkaline and alkaline magmatism. In the Central Aldan and West Aldan terranes, ultrabasite and carbonatite bodies were emplaced. The major overlap and stitch assemblages forming on the Sino-Korean craton were (units ht, slj) (1) the Hutuo rift, (2) the Shandong-East Liaoning-East Jilin rift, (3) the Zhangbei-Bayan Obo-Langshan rift, and (4) the Hebei-Liaoning sedimentary basin.

Paleoproterozoic Metallogenesis

The major Paleoproterozoic metallogenic belts formed in a variety of tectonic environments (formed in a variety of tectonic environments (figs. 8, 20-21, appendix C).

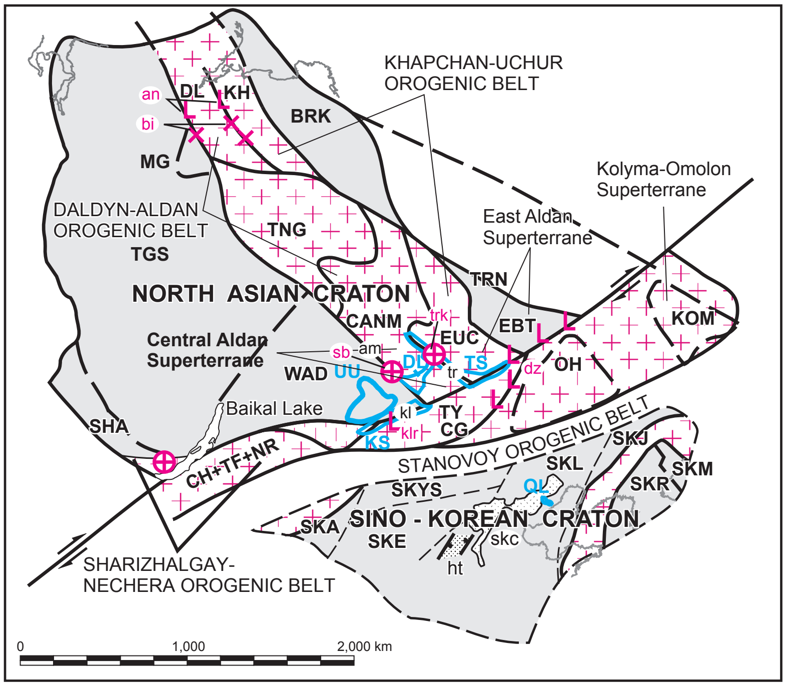
In the Baydrag belt (BD, fig. 8) the BIF deposits are interpreted as having formed in volcanic and clastic sedimentary rock basin. During the Paleoproterozoic, the host Tuva-Mongolia superterrane was far removed from the North Asian craton and is not depicted in figures 21 or 22.

In the Dyos-Legier belt (DL, figs. 8, 20) the Fe skarn deposits are interpretd as having formed from 2.0 to 1.9 Ga, during intrusion of Paleoproterozoic, late-collisional granitoids into the Aldan-Stanovoy shield that is a core part of the North Asian craton.

The Jiliaojiao belt (JLJ, figs. 8, 21) is a composite metallogenic belt that includes several mineral-deposit types, including sedimentary-metamorphic borate, sedimentary-metamorphic magnesite, talc (magnesite) replacement, banded iron formation (BIF, Superior Fe), Korean Pb-Zn massive sulfide, metamorphic graphite, and Au in shear-zone and quartz-vein deposits. The environment of formation and deposit controls are debated. The sediment-hosted deposits are herein interpreted as having formed in the East Shandong-East Liaoning-East Jilin rift. The Au in shear-zone and quartz-vein deposits are herein interpreted as having formed during metamorphism and intense deformation at about 1.9 Ga.

The Kalar-Stanovoy (KS) belt (KS, figs. 8, 20) formed from 2.0 to 1.9 Ga and contains Au in shear-zone and quartz-vein deposits that are interpreted as having formed during the collision between Tynda and West Aldan terranes in Aldan-Stanovoy region (North Asia craton) and during subsequent collapse of the orogenic belt. The cause of collision was amalgamation of terranes during the formation of the North Asia craton.

The apatite carbonatite deposits in the Nimnyr belt (NM, figs. 8, 21) formed from 1.9 to 1.6 Ga and are interpreted as



GEOLOGIC UNITS
ak - Akitkan volcanic-plutonic belt
an - Anabar anorthositic belt (Archean)
bi - Billyahk plutonic belt (Paleoproterozoic)
cuk - Chara-Uchur rift system (Paleoproterozoic) - Udokan basin
dz - Dzugdzur anorthositic belt (Paleoproterozoic)
klr - Kalar anorthosite belt (Paleoproterozoic)
ht - Hutuo rift basin (Paleoproterozoic)
sb - Subgan granite belt (Paleoproterozoic)
skc - Hebei-Liaoning sedimentary basin
tkn - Tyrkanda granite belt (Paleoproterozoic or older)

North Asian Craton

BRK - Berekta Terrane (Granite-greenstone) (Late Archean)
CANM - Nimnyr terrane (Granulite-orthogneiss) (Paleoproterozoic)
CG - Chogar Granulite-orthogneiss terrane (Archean)
CH - Chuja terrane (Paragneiss) (Late Archean through Neoproterozoic)
DL - Daldyn terrane (Granulite-orthogneiss) (Middle Archean)
EBT - Batomga composite terrane (Granite-greenstone) (Late Archean)
EUC - Uchur terrane (Granulite-paragneiss) (Paleoproterozoic)
KH - Khapchan terrane (Granulite-paragneiss) (Paleoproterozoic)
KOM - Kolyma-Omolon superterrane (Archean to Jurassic)
MG - Magan terrane (Tonalite-trondhjemite-gneiss) (Paleoproterozoic)
NR - Nechera terrane (Granulite-paragneiss) (Archean? and Proterozoic)
OH - Okhotsk terrane (Cratonal) (Archean through Jurassic)
SHA - Sharizhalgay terrane (Granulite-orthogneisse) (Archean through Paleoproterozoic)
TF - Tonod terrane (Greenschist) (Paleoproterozoic)
TGS - Tunguska terrane (Tonalite-trondhjemite) (Archean)
TNG - Tyung terrane (Granulite-orthogneiss) (Archean to Paleoproterozoic)
TRN - Tyryn Terrane (Granite-greenstone) (Late Archean)
TY - Tynda terrane (Tonalite-trondhjemite-gneiss) (Archean and Paleoproterozoic)
WAD - West Aldan terrane (Granite-greenstone) (Archean)

am - Amga tectonic melange zone
kl - Kalar tectonic melange zone
tr - Tyrkanda tectonic melange zone

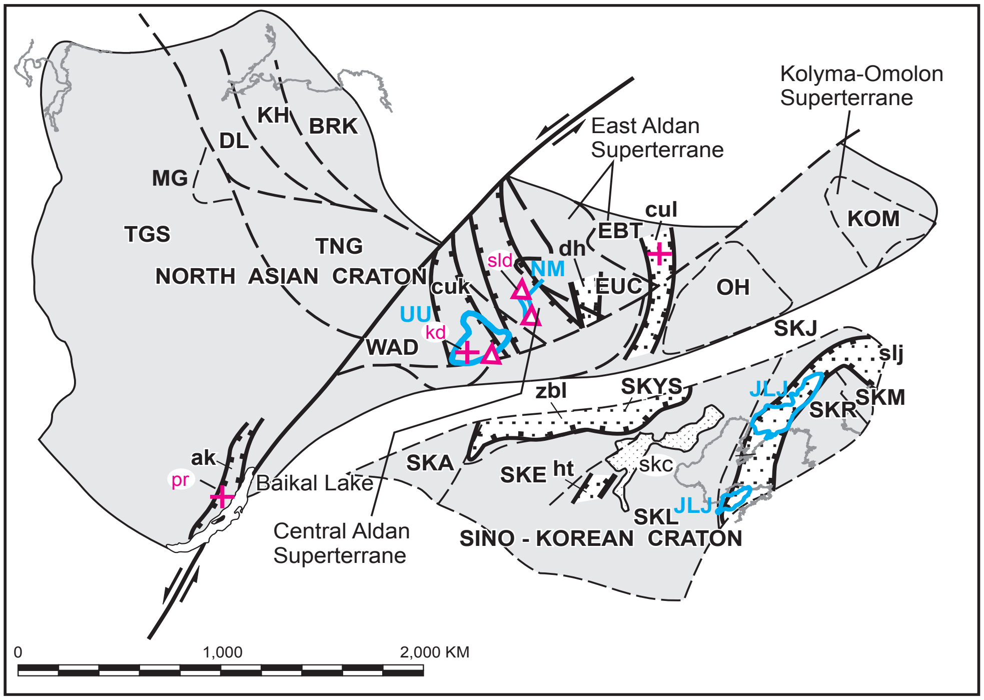
Sino-Korean Craton

SKA - Alashan terrane (Granulite-paragneiss) (Paleoproterozoic)
SKE - Erduosi terrane (Granulite-paragneiss) (Archean)
SKJ - Jilin-Liaoning-East Shandong terrane (Tonalite-trondhjemite-gneiss) (Archean)
SKL - West Liaoning-Hebei-Shanxi terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKM - Machollyong terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKR - Rangnim terrane (Granulite-paragneiss) (Archean)
SKYS - Yinshan terrane (Granite-greenstone belt) (Archean)

METALLOGENIC BELTS

DL - Dyos-Leglier
KS - Kalar-Stanovoy
NM - Nimnyr
QL - Qinglong
TS - Tyrkanda-Stanovoy
UU - Uguy-Udokanskiy

Figure 20. Middle Paleoproterozoic (2,000 to 1,900 Ma) time stage of metallogenic and tectonic Model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).



GEOLOGIC UNITS

ak - Akitkan volcanic-plutonic belt
cuk - Chara-Uchur rift system (Paleoproterozoic)
cul - Ulkan rift basin (Paleoproterozoic)
dh - Davangra-Khugda rift basin (Paleoproterozoic)
kd - Kodar granitic belt (Paleoproterozoic)
ht - Hutuo rift basin (Paleoproterozoic)
pr - Primorsky plutonic complex (Paleoproterozoic)
skc - Hebei-Liaoning sedimentary basin
sld - Seligdar plutonic belt
slj - East Shandong-East Liaoning-East Jilin rift basin (Paleoproterozoic)
zbl - Zhangbei-Bayan Obo-Langshan rift basin (Paleoproterozoic)

North Asian Craton

BRK - Berekta Terrane (Granite-greenstone) (Late Archean)
CANM - Nimnyr terrane (Granulite-orthogneiss) (Paleoproterozoic)
CAST - Sutam terrane (Granulite-paragneiss) (Late Archean)
DL - Daldyn terrane (Granulite-orthogneiss) (Middle Archean)
EBT - Batomga composite terrane (Granite-greenstone) (Late Archean)
EUC - Uchur terrane (Granulite-paragneiss) (Paleoproterozoic)
KH - Khapchan terrane (Granulite-paragneiss) (Paleoproterozoic)
KOM - Kolyma-Omolon superterrane (Archean to Jurassic)
MG - Magan terrane (Tonalite-trondhjemite-gneiss) (Paleoproterozoic)
OH - Okhotsk terrane (Cratonal) (Archean through Jurassic)
TGS - Tunguska terrane (Tonalite-trondhjemite) (Archean)
TNG - Tyung terrane (Granulite-orthogneiss) (Archean to Paleoproterozoic)
TRN - Tyryn Terrane (Granite-greenstone) (Late Archean)
WAD - West Aldan terrane (Granite-greenstone) (Archean)

Sino-Korean Craton

SKA - Alashan terrane (Granulite-paragneiss) (Paleoproterozoic)
SKE - Erduosi terrane (Granulite-paragneiss) (Archean)
SKJ - Jilin-Liaoning-East Shandong terrane (Tonalite-trondhjemite-gneiss) (Archean)
SKL - West Liaoning-Hebei-Shanxi terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKM - Machollyong terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKR - Rangnim terrane (Granulite-paragneiss) (Archean)
SKYS - Yinshan terrane (Granite-greenstone belt) (Archean)

METALLOGENIC BELTS

NM - Nimnyr
UU - Uguy-Udokanskiy
JLJ - Jiliaojiao

Figure 21. Late Paleoproterozoic (1,900 to 1,600 Ma) time stage of metallogenic and tectonic model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

having formed during interplate rifting in the Central Aldan superterrane that was amalgamated to the North Asian craton.

In the Qinglong belt (QL, figs. 8, 20), the banded iron formation (BIF, Algoma Fe) and clastic-sediment-hosted Sb-Au deposits are as interpreted as having formed in a passive continental margin or aulacogen that was subsequently regionally metamorphosed and thrusted. The belt is hosted in the West Liaoning-Hebei-Shanxi terrane of the Sino-Korean craton.

The Au in shear-zone and quartz-vein deposits of the Tyrkanda-Stanovoy belt (TS, figs. 8, 20, 21) formed from 2.0 to 1.9 Ga and are interpreted as having formed during collision between the Tynda composite terrane and Central Aldan and East Aldan superterranes during amalgamation of these units to the margin of the North Asian craton.

The Uguy-Udokanskiy belt (UU, figs. 8, 20, 21) formed from 2.2 to 1.8 Ga and is a composite metallogenic belt that includes several mineral deposit types, including zoned mafic-ultramafic Cu-PGE, sediment-hosted Cu, and Ta-Nb-REE alkaline metasomatite deposits that are hosted in the West Aldan terrane. The Cr and PGE deposits occur in zoned mafic-ultramafic plutons and the sediment-hosted Cu deposits are interpreted as having formed in the continental-margin rift (unit cuk). The Ta-Nb-REE alkaline metasomatite deposits are interpreted as having formed during later collision and formation of anatectic granite.

Mesoproterozoic Tectonics

In the Mesoproterozoic (1,600 to 1,000 Ma), the following major terranes were forming or continued to form (1) Gyenggi granulite-paragneiss terrane (SCG) in the South China craton, and the West Stanovoy (WST) and Mamont (CTM) metamorphic terranes, Wundurmiao WD accretionary wedge terranes. The paleogeographic position of last three terranes in the Mezoproterozoic is unknown, and the paleogeographic position of the South China craton was far removed from the region of the North Asian and Sino-Korean cratons.

In the North Asian craton, the Early Mesoproteozoic (1,600 to 1,300 Ma) (fig. 22) was marked by the initiation and development of major sedimentary basins, including the East Angarsk, Near-Kolyma, Patom, and Uchur-Maya Basins that formed along the passive continental margins along the present-day boundaries of the craton. In addition, the Nyurba rift basin formed in the inner part of the craton

In the Sino-Korean craton, the Early Mesoproteozoic (1,600 to 1,300 Ma) (fig. 22) was marked by the developomehnt of major rift basins, including the Zhangbei-Bayan Obo-Langshan rift, and the Hebei-Liaoning sedimentary basins that formed along the present-day northern boundary of the craton. The rifting and formation of passive continental margins along both cratons were the result of the onset of the breakup of the Paleoproterozoic continent Pangea.

In the North Asian craton, the Late Mesoproteozoic (1,300 to 1,000 Ma) (fig. 23 was marked by a collision between the North Asian craton and a Mesoproterozoic continent (Yana-Indigirka superterrane), which was accompanied by greenschist to amphibolite facies metamorphiasm, emplacement of collisional granites, and formation of accretionary complexes (Lena-Aldan Orogenic Belt or Near-Kolyma block) (Beus and others, 1962). The collision was synchronous with the formation of the supercontinent Rodinia, of which the North Asian craton was a part until 850 Ma. The breakup of Rodinia was marked by the initiation of rifts and formation of the passive continental margin along the northern boundary of the North Asian craton (Parfenov and others, 2003).

Mesoproterozoic Metallogenesis

The major Mesoproterozoic metallogenic belts formed in a variety of tectonic environments (figs. 8, 22-23, appendix C).

The Darvi belt (DR, fig. 8), contains sedimentary bauxite (Alag Uul) and edimentary Fe-V deposits that forming during bauxite sedimentation in Lower to Middle Riphean sedimentary basin that overlapped the Baydrag cratonal terrane and subsequent regional metamorphism of sedimentary bauxite. During this time, the Tuva-Mongolia superterrane was far removed from the North Asian craton and is not depicted in figures 22 or 23.

The Langshan-Bayan Obo belt (LB, figs. 8, 22, 23) contains sedimentary exhalative Pb-Zn (SEDEX) deposits and a large polygenic REE-Fe-Nb deposit at Bayan Obo. The Bayan Obo deposit is interpreted as a SEDEX deposit related to a carbonatite magma and associated hydrothermal activity. The belt is hosted in the Paleoproterozoic and Mesoproterozoic Zhangbei-Bayan Obo-Langshan rift basin and related metasedimentary and metavolcanic units that formed along the passive continental margin of the Sino-Korean craton.

The Yanliao belt (YL, figs. 8, 22, 23) contains chemical-sedimentary Mn (Wafangzi) and sedimentary exhalative Pb-Zn (SEDEX) deposits in the Jixian Group that are interpreted as having formed in a shallow marine basin on the Sino-Korean craton.

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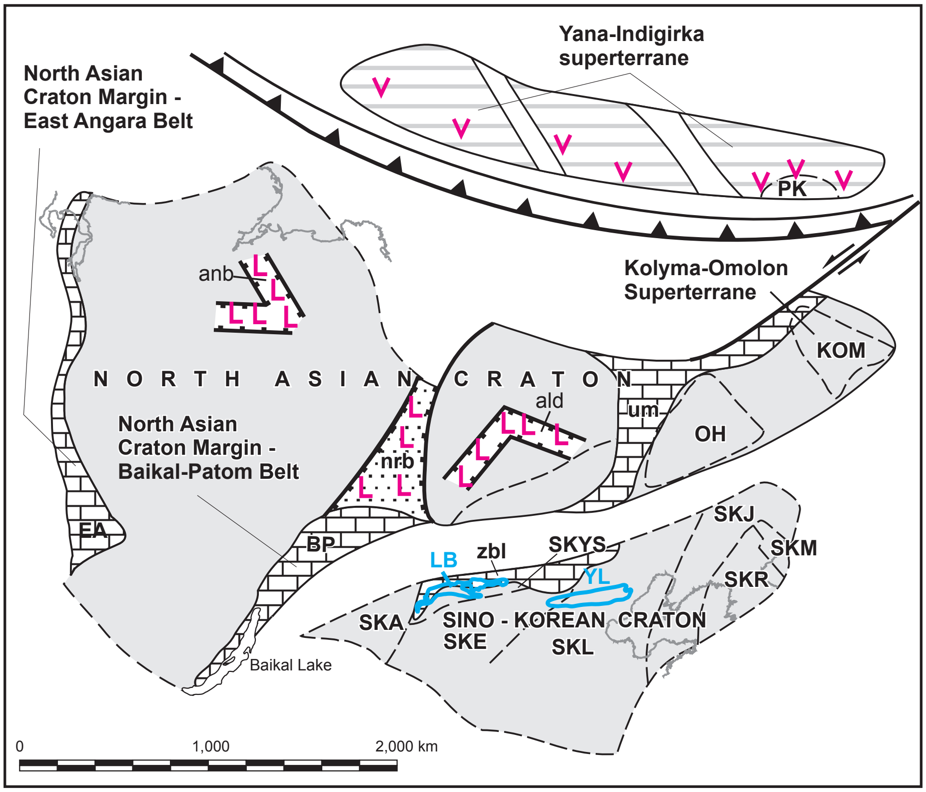


GEOLOGIC UNITS

anb - Anabar dike belt
ald - Aldan dike belt
nrb - Nyurba rift basin (Mesoproterozoic)
um - Uchur-Maya basin
zbl - Zhangbei-Bayan Obo-Langshan metasedimentary and metavolcanic rocks (Mesoproterozoic)

BP - Baikal-Patom terrane
EA - East Angara terrane
PK - Near - Kolyma terrane

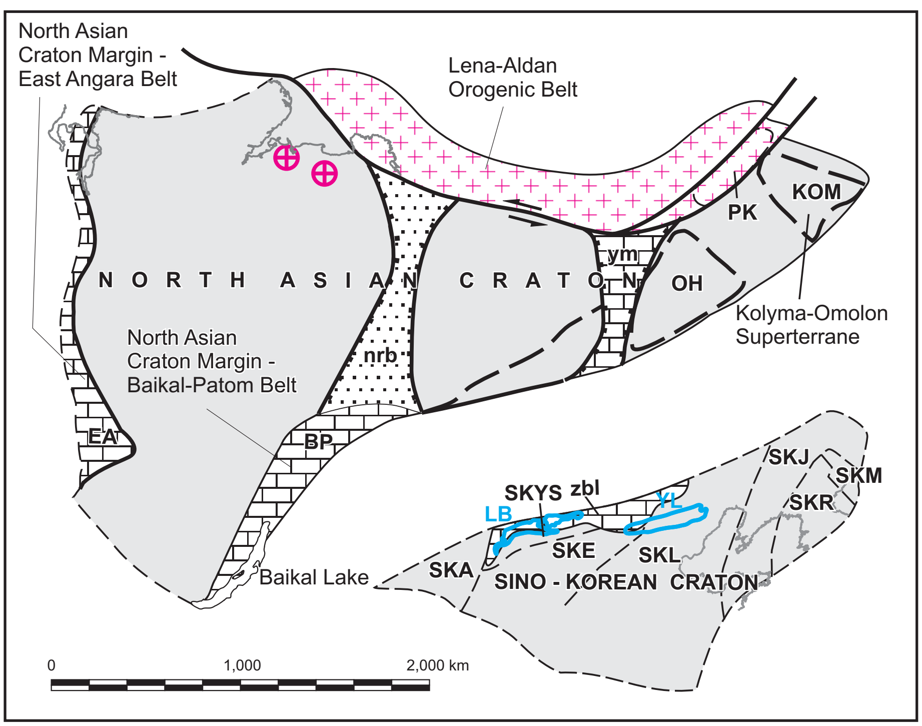
KOM - Kolyma-Omolon superterrane
OH - Okhotsk terrane

Sino-Korean Craton
SKA - Alashan terrane
SKE - Erduosi terrane
SKJ - Jilin-Liaoning-East Shandong terrane
SKL - West Liaoning-Hebei-Shanxi terrane
SKM - Machollyong terrane
SKR - Rangnim terrane
SKYS - Yinshan terrane

METALLOGENIC BELTS

LB - Langshan-Bayan Obo
YL - Yanliao

Figure 22. Early Mesoproterozoic (1,600 to 1,300 Ma) time stage of metallogenic and tectonic model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).



GEOLOGIC UNITS

nrb - Nyurba rift basin (Mesoproterozoic)
ym - Yudoma-Maya basin
zbl - Zhangbei-Bayan Obo-Langshan metasedimentary and metavolcanic rocks (Mesoproterozoic)

BP - Baikal-Patom terrane
EA - East Angara terrane

KOM - Kolyma-Omolon superterrane
OH - Okhotsk terrane
PK - Near-Kolyma terrane

Sino-Korean Craton
SKA - Alashan terrane
SKE - Erduosi terrane
SKJ - Jilin-Liaoning-East Shandong terrane
SKL - West Liaoning-Hebei-Shanxi terrane
SKM - Machollyong terrane
SKR - Rangnim terrane
SKYS - Yinshan terrane

METALLOGENIC BELTS

LB - Langshan-Bayan Obo
YL - Yanliao

Figure 23. Late Mesoproterozoic (1,300 to 1,000 Ma) time stage of metallogenic and tectonic model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

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Chapter 5

Neoproterozoic through Silurian Metallogenesis and Tectonics of Northeast Asia

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Introduction

This article presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia for the Neoproterozoic through Silurian. The major purposes are to provide a detailed summary of these features for readers who are unfamiliar with Northeast Asia. Several parts of this book on Northeast Asia provide background information. An overview of the regional geology, metallogenesis, tectonics, of the region, and other materials, such as employed geologic time scale and standard geologic definitions, are provided in chapter 1. The methodology for the metallogenic and tectonic analysis of this region is provided in Chapter 2. Descriptions of mineral deposit models are provided in Chapter 3. Additional information on project publications, descriptions of major geologic units, and summaries of metallogenic belts are provided in appendixes A-C.

Compilations Employed for Synthesis, Project Area, and Previous Study

The compilation of regional geology and metallogenesis in this introduction is based on publications of the major international collaborative studies of the metallogenesis and tectonics of Northeast Asia that were led by the U.S. Geological Survey (USGS). These studies have produced two broad types of publications. One type is a series of regional geologic, mineral-deposit, and metallogenic-belt maps and companion descriptions for the regions. Examples of major publications of this type are Obolenskiy and others (2003, 2004), Parfenov and others (2003, 2004a,b), Nokleberg and others (2004, 2005), Rodionov and others (2004), and Naumova and others (2006). The other type is a suite of metallogenic and tectonic analyses of these same regions. Examples of major publications of this type are Rodionov and others (2004), Nokleberg and others (2000, 2004), and Naumova and others (2006). Detailed descriptions of lode deposits are available in Ariunbileg and others (2003). For more detail than presented in this chapter, refer to the detailed descriptions of geologic units and metallogenic belts in the above publications.

The Northeast Asia project area consists of eastern Russia (most of Siberia and most of the Russian Far East), Mongolia, Northern China, South Korea, Japan, and adjacent offshore areas (fig. 1). This area is approximately bounded by 30 to 82° N. latitude and 75 to 144° E. longitude. The major participating agencies are the Russian Academy of Sciences; Academy of Sciences of the Sakha Republic (Yakutia); VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation; Mongolian Academy of Sciences; Mongolian University of Science and Technology; Mongolian National University; Jilin University; Changchun; China; the China Geological Survey; the Korea Institute of Geosciences and Mineral Resources; the Geological Survey of Japan/AIST; University of Texas Arlington; and the USGS.

The Northeast Asia project extends and is built on data and interpretations from a previous project on the Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera that was conducted by the U S G S, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada. A summary of the major products of this project is contained online at: http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.pdf and in appendix A.

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Major Geologic Units

The major Neoproterozoic (Late Riphean through Vendian) through Silurian geologic and tectonic units of Northeast Asia are cratonal margin units, sedimentary basins formed on craton and cratonal margins and accreted terranes and superterranes (fig. 2, table 1). Short descriptions of map units are given in appendix B. Summary descriptions of the major units are provided in descriptions of metallogenic belts (below), and detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004), and Parfenov and others (2004b).

Major Craton Margins and Craton-Margin Terranes

The Archean through Proterozoic backstop or core units for the region of Northeast Asia are the North Asian craton and overlying Phanerozoic units, various cratonal margin units [Baikal-Patom, East Angara, South Taimyr, and Verkhoyansk terranes (fold- and thrust-belts)],and the Sino-Korean craton (fig. 2, appendix C).

The Baikal-Patom cratonal margin (BP) consists of a fault-bounded basin containing Riphean carbonate and terrigenous sedimentary rock, and younger Vendian and Cambrian

Figure 1. Regional summary geographic map for Northeast Asia showing major regions and countries.

sedimentary rock that discordantly overlie a fragment of the pre-Riphean basement of the North Asian craton. The East Angara cratonal margin (EA) consists of late Riphean terrigenous-carbonate sedimentary rock (sandstone, siltstone, mudstone with interlayered dolomite and limestone) that overlie a fragment of the North Asian craton. The South Taimyr cratonal margin (ST) consists chiefly of a thick wedge of Ordovician through Jurassic cratonal margin deposits and deep basin deposits. The Verkhoyansk cratonal margin (VR) consists chiefly of a thick wedge of Mesoproterozoic, Neoproterozoic, and Cambrian through Jurassic miogeoclinal deposits.

The Sino-Korean craton consists of several major Archean and Proterozoic metamorphic-basement terranes (fig. 2, table 1), and younger Paleozoic through Cenozoic overlap units. The South China craton consists of two Proterozoic metamorphic-basement terranes (fig. 2, table 1), and younger Paleozoic through Cenozoic overlap units.

Passive Continental Margin Terranes of Unknown Affinity

Scattered around the margin of the North Asian craton and related units are four passive continental-margin terranes (and one island-arc and one cratonal terrane) of unknown affinity. These units include (fig. 2, table 1) (1) the Late Riphean Central Angara passive continental-margin terrane; (2) the Neoproterozoic and older Central Taimyr (composite) terrane composed of island arc, cratonal, and passive continental-margin units; (3) the Late Neoproterozoic Kara passive continental-margin terrane; and (4) the Middle and Late Riphean West Angara continental-margin terrane.

Superterranes

Five superterranes occur along the margins of the North Asian and Sino-Korean cratons. Some of the superterranes are interpreted as rifted and reaccreted fragments of the cratons, whereas others are interpreted as having originally formed elsewhere.

The Proterozoic through Cambrian Argun-Idermeg superterrane (AR) consists of the Paleoproterozoic through late Paleozoic Argunsky, and Idermeg, passive continental-margin terranes. The superterrane may be either exotic, with respect to the North Asian craton, or may be a rifted fragment of this craton. The superterrane is interpreted as accreting in the Ordovician through Silurian.

The Proterozoic through Permian Bureya-Jiamusi suptertterrane (BJ) consists of a collage of early Paleozoic metamorphic, continental-margin arc, subduction-zone, passive continental-margin and island-arc terranes. The superterrane is interpreted as a fragment of Gondwana that was accreted to the Sino-Korean craton during the Late Permian and accreted to the North Asian craton during the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

The Proterozoic through Ordovician Kara superterrane (KR) consists of the Late Neoproterozoic through Ordovician Kara continental-margin turbidite terrane. The superterrane is interpreted as a rift fragment of the North Asian craton that was reaccreted during the Jurassic.

The Archean through Jurassic Kolyma-Omolon superterrane (KOM) consists of a tectonic collage of cratonal, passive-continental-margin, island-arc, and ophiolite terranes. The cratonal and passive-continental core of the superterrane was rifted from the North Asian craton and margin during the Late Devonian or Early Carboniferous. After subsequent building of overlying island arcs, the superterrane was reaccreted to the North Asian cratonal margin during the Late Jurassic with formation of the collisional granites of the Main and Northern granite belts.

The Late Riphean and older Tuva-Mongolia superterrane (TM) consists of a series of Archean and Paleoproterozoic cratonal terranes (Gargan and Baydrag), the Sangilen passive continental-margin terrane, and the Muya metamorphic terrane. These terranes are interpreted as having accreted together to form the rear (back arc) part of the Baikal-Mura island arc described below. The superterrane is interpreted as having accreted during the Late Neoproterozoic.

Tectonic Collages Between the North Asian and Sino-Korean Cratons

Between the North Asian and Sino-Korean cratons are a series of accreted Neoproterozoic through Silurian tectonic collages composed primarily of Proterozoic craton-margin units, and Paleozoic island arcs and tectonically linked subduction zones. These tectonic collages were accreted successively from north to south during closures of the Paleo-Asian and Solon Oceans. Most of the tectonic collages contain one ore more island arcs and tectonically linked subduction-zones. Because of successive accretions from north to south, the ages of collages are generally young from north to south. However, this pattern is locally interrupted because some collages, or parts of collages, were interspersed because of subsequent strike-slip faulting.

The tectonic collages between the North Asian and Sino-Korean cratons are as follows.

(1) The Altay collage (AL) (Vendian through Ordovician age, accreted during the Late Silurian) consists of the Vendian through Early Ordovician Salair island-arc and various fragments of arc-related turbidite terranes, subduction-zone terranes, metamorphic terranes derived from arc-related units, thick Cambrian and Ordovician overlap turbidite units that formed on a continental slope and rise, and fragments of originally adjacent oceanic terranes. The collage is interpreted as an island-arc system that was active near the southwestern margin (present-day coordinates) of the North Asian craton and previously accreted terranes.

(2) The Atasbogd collage (AB) (Ordovician through Permian age, accreted during the Late Carboniferous or

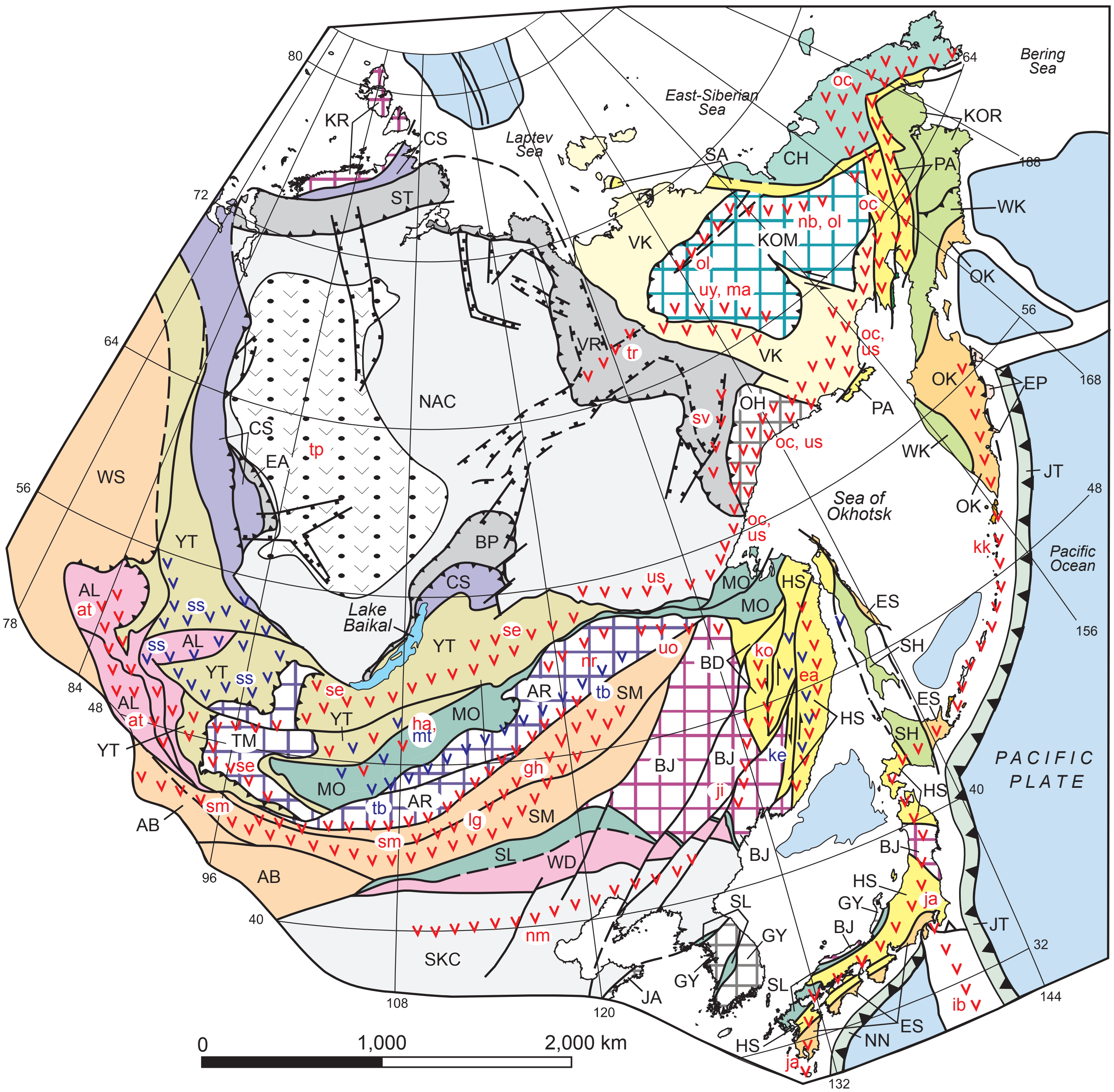


Figure 2. Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North Pacific tectono-stratigraphic terrane map at 10 million scale (Nokleberg and others, 1997). Map shows locations major geologic and tectonic units including cratons, cratonal margins; cratonal terranes and superterranes; tectonic collages; overlap and transform continental-margin arcs; island arcs, and sea and ocean units. Map and Explanation. Refer to table 1 and text for unit descriptions.

EXPLANATION

Cratons and Cratonal Margins

Cratons: NAC - North Asian (Archean and Proterozoic); SKC - Sino-Korean (Archean and Proterozoic)

Cratonal Margin: BP - Baikal-Patom (Riphean through Cambrian and older basement; EA - East Angara (Riphean and older basement; ST - South Taimyr (Ordovician through Jurassic); VR - Verkhoyansk (Devonian through Jurassic).

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

AL - Altay (Vendian to Ordovician)
WD - Wundurmiao (Riphean through Ordovician)

AB - Atasbogd (Ordovician through Permian); SM - South Mongolia-Khingan (Ordovician through Carboniferous); WS - West Siberian (Ordovician through Carboniferous)

MO - Mongol-Okhotsk (Devonian through Late Jurassic); SL - Solon (Carboniferous and Permian)

Tectonic Collages Along the Northern and Eastern Margins of North Asian and Sino-Korean Cratons

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

BD - Badzhal (Triassic through Early Cretaceous); PA - Penzhina-Anadyr (Late Jurassic and Cretaceous); HS - Honshu-Sikhote-Alin (Jurassic and Early Cretaceous); SA - South Anyui (Permian through Jurassic);

KOR - Koryak (Late Jurassic through Paleocene; SH - Sakhalin-Hokkaido (Cretaceous); WK - West Kamchatka (Mid-Cretaceous through Early Tertiary)

ES - East Sakhalin (Late Cretaceous and Early Tertiary); OK - Olyutorka-Kamchatka (Late Cretaceous to Paleocene)

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

JT- Japan Trench (including Kuril-Kamchatka trench) (Miocene through Holocene;
NN - Nankai (Miocene through Holocene)

Cratonal Terranes and Superterranes

Cratonal terranes (Archean and Proterozoic): GY - Gyeonggi-Yeongnam; JA - Jiaonan; OH - Okhotsk

Late Proterozoic and Cambrian superterranes: AR - Argun-Idermeg; TM - Tuva-Mongolia

Archean through Permian superterranes: BJ - Bureya-Jiamusi; KR - Kara

Jurassic Superterrane:
KOM - Kolyma-Omolon (Archean through Jurassic)

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

at - Altay arc (Devonian and early Carboniferous, 381 to 290 Ma)
ea - East Sikhote-Alin arc (Late Cretaceous through early Tertiary, 96-65 Ma)
gh - Gobi-Khankaisk-Daxing'anling arc (Permian, 295 to 250 Ma)
ha - Hangay arc (Late Carboniferous and Early Permian, 320 to 272 Ma)
ji - Jihei arc (Permian, 295 to 250 Ma)
ko - Khingan arc (Early and mid-Cretaceous)
lg - Lugyngol arc (Permian and Triassic, 295 to 250 Ma)
ma - Main granite belt (Late Jurassic, 144 to 134 Ma)
nb - Northern granite belt (Early Cretaceous, 138 to 120 Ma)
nm - North Margin (Late Carboniferous and Permian, 320 to 272 Ma)
nr - Norovlin arc (Devonian and Early Carboniferous, 410 to 255 Ma)
oc - Okhotsk-Chukotka arc (Late Cretaceous and early Tertiary, 96 to 53 Ma)
ol - Oloy arc (Late Jurassic, 154 to135 Ma)
se - Selenga arc (Permian through Jurassic, 295 to135 Ma)
sm - South Mongolian arc (Carboniferous through Triassic, 320 to 203 Ma)
ss - South Siberian arc (Devonian)
sv - South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157 to 93 Ma)
tr - Transverse granite belt (Early Cretaceous, 134 to 124 Ma)
uo - Umlekan-Ogodzhin arc (Cretaceous, 135 to 65 Ma)
us - Uda-Murgal and Stanovoy arc (Jurassic and Early Cretaceous, 203 to 96 Ma)
uy - Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154 to 120 Ma)

Plume-Related Igneous Province

tp - Tungus Plateau igneous province - (Late Permian and Early Triassic, 245 Ma)

Active Arcs

ib - Izu-Bonin (late Cenozoic, 20 to 0 Ma)
ja - Japan (late Cenozoic, 23 to 0 Ma)
kk - Kuril-Kamchatka (late Cenozoic, 11 to 0 Ma)

Transpressional Arcs

ke - Kema (Mid-Cretaceous)
mt - Mongol-Transbaikal (Late Triassic through Early Cretaceous, 230 to 96 Ma)
ss - South Siberian (Early Devonian, 415 to 400 Ma)
tb - Transbaikalian-Daxinganling (Middle Jurassic through Early Cretaceous,175 to 96 Ma)

Symbols, Faults, and Contacts

Overlap-continental-margin arc
Transform-continental-margin arc
Active subduction zone
Thrust
Strike-slip fault
Fault
Contact
Riphean aulacogen
Devonian aulacogen
Modern rift system (Gakkel Ridge)
OS Metallogenic belt

Figure 2.—Continued.

Table 1. Summary of major Neoproterozoic through Silurian geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit. Map Symbol	Type of Unit (Craton, Terrane, Overlap Asseblage)	Age range	Tectonic Environment	Tectonic Linkage
NORTH ASIAN AND SINO-KOREAN CRATONS AND OVERLYING PROTEROZOIC AND PHANEROZOIC UNITS				
North Asian. NAC Sino Korean. SKC	Craton	Archean through Mesozoic	Cratonal and passive continental margin	
NORTH ASIAN CRATON MARGIN UNITS				
Baikal-Patom. BP East Angara. EA South Taimyr. ST Verkhoyansk. VR	Overlap assemblages	Neoproterozoic through Mesozoic	Passive continental margin with pericratonal subsidences	Original overlap assemblages on North Asian Craton that were subsequently transformed into fold- and thrust-belts and terranes.
SUPERTERRANES				
Argun-Idermeg. AR	Superterrane	Paleoproterozoic through late Paleozoic	Passive continental-margin	May be either exotic with respect to the North Asian Craton or may be a rifted fragment of the craton. Accreted in Ordovician through Silurian.
Bureya-Jiamusi. BJ	Superterrane	Proterozoic through Permian	Composite	Consists of early Paleozoic metamorphic , continental-margin arc, subduction-zone, passive continental-margin and island-arc terranes. Interpreted as a fragment of Gondwana. Accreted to the Sino-Korean Craton in the Late Permian and accreted to the North Asian Craton in the Late Jurassic.
Kara. KR	Superterrane	Proterozoic through Ordovician	Passive continental-margin	Consists of Late Neoproterozoic through Ordovician Kara continental-margin turbidite terrane. Interpreted as a rift fragment of the North Asian Craton that was reaccreted in the Jurassic.
Kolyma-Omolon. KOM	Superterrane	Archean through Jurassic	Composite	Consists of of cratonal, passive continental-margin, island-arc, ophiolite terranes. The cratonal and passive continental core of the superterrane was rifted from the North Asian Craton and Margin in Late Devonian or Early Carboniferous. Reaccreted to the North Asian cratonal margin in the Late Jurassic.
Tuva-Mongolia. TM	Superterrane	Late Riphean and older	Composite	Consists of Gargan and Baydrag cratonal terranes, Sangilen passive continental-margin terrane. Accreted in the Late Neoproterozoic.

Table 1. Summary of major Neoproterozoic through Silurian geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).—Continued

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit. Map Symbol	Type of Unit (Craton, Terrane, Overlap Asseblage)	Age range	Tectonic Environment	Tectonic Linkage
		TECTONIC COLLAGES		
Altai. AL	Collage	Vendian through Ordovician	Mainly Island arc and subduction zone	Consists of the Vendian through Early Ordovician Salair island-arc and various fragments of arc-related turbidite terranes, subduction-zone terranes, metamorphic terranes derived from arc-related units, thick Cambrian and Ordovician overlap turbidite units that formed on a continental slope and rise, and fragments of originally adjacent oceanic terranes. Collage interpreted as an island-arc system that was active near the southwest margin (present-day coordinates) of the North Asian Craton and Margin and previously accreted terranes. Accreted in Late Silurian.
Atasbogd. AB	Collage	Ordovician through Permian	Composite	Consists of: the Ordovician through Permian Waizunger-Baaran terrane, Devonian through Carboniferous Beitianshan-Atasbogd terrane, and (3) Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. Collage is interpreted as a southwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian Craton and Margin and previously accreted terrane. Accreted in Late Carboniferous or Early Permian.
Circum-Siberia. CS	Collage	Neoproterozoic	Composite	Consists of Baikal-Muya island arc, the Near Yenisey Ridge island arc, and the Zavhan continental-margin arc, all of Neoproterozoic age, and small fragments of cratonal and metamorphic terranes of Archean and Proterozoic age. The three separate Neoproterozoic island-arc systems formed south (present-day coordinates) of the North Asian Craton and Margin. Accreted in Neoproterozoic
South Mongolia-Khingan. SM	Collage	Ordovician through Carboniferous	Island arc and subduction zone	Consists of the South Mongolia-Khingan arc and tectonically linked subduction-zone terranes. The collage is interpreted as a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian Craton and Margin and previously accreted terranes. Collage was separated from the North Asian Craton by a large back-arc basin. accreted in Late Carboniferous or Early Permian.

Table 1. Summary of major Neoproterozoic through Silurian geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).—Continued

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit. Map Symbol	Type of Unit (Craton, Terrane, Overlap Asseblage)	Age range	Tectonic Environment	Tectonic Linkage
		TECTONIC COLLAGES		
Wundurmiao. WD	Collage	Mesoproterozoic through Silurian	Island arc and subduction zone	Consists of Late Ordovician through Silurian Laoling island-arc terrane, Mesoproterozoic through Middle Ordovician Wundurmiao subduction-zone terrane, and Neoproterozoic Seluohe subduction-zone terrane. The collage is interpreted as the Laoling island-arc system that formed near Sino-Korean Craton. Both the island-arc system and craton were widely separated from North Asian Craton in the early Paleozoic. Accreted in Late Silurian.
West Siberian. WS	Collage	Ordovician through Carboniferous	Island arc and subduction zone	Consists of the Late Silurian through Early Carboniferous Rudny Altai island-arc, and the tectonically linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. Collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage. Accreted in Late Carboniferous or Early Permian.
Yenisey-Transbaikal. YT	Collage	Vendian through Devonian	Mainly Island arc and subduction zone	Consists of the Vendian through Middle Cambrian Kuznetsk-Tannuola, Dzhida-Lake island-arc terranes, tectonically linked back-arc basins, and now tectonically eroded subduction-zone terranes. The collage is interpreted as a linear array of island-arc systems that formed south (present-day coordinates) of the North Asian Craton and Margin and previously accreted terranes. The eastern part of the collage also includes the West Stanovoy metamorphosed terrane that may be a displaced fragment of the North Asian Craton or of another craton. Accreted in Vendian through Early Ordovician.

Early Permian) consists of (1) the Ordovician through Permian Waizunger-Baaran island-arc terrane, (2) the Devonian through Carboniferous Beitianshan-Atasbogd island-arc terrane, and (3) the Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. The collage is interpreted as a southwestern continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and previously accreted terranes. The collage was initially separated from North Asian craton by a large back-arc basin.

(3) The Circum-Siberia collage (CS) (Paleoproterozoic and Mesoproterozoic age, accreted during the Neoproterozoic) consists of the Baikal-Muya island arc, the Near Yenisey Ridge island arc, and the Zavhan continental-margin arc, all of Neoproterozoic age, and small fragments of cratonal and metamorphic terranes of Archean and Proterozoic age. The three separate Neoproterozoic island-arc systems formed south (present-day coordinates) of the North Asian craton and cratonal margin.

(4) The South Mongolia-Khingan collage (SM) (Ordovician through Carboniferous age, accreted during the Late Carboniferous or Early Permian) consists of the South Mongolia-Khingan arc and tectonically linked subduction-zone terranes. The collage is interpreted as a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian craton and previously accreted terranes. The collage was separated from the North Asian craton by a large back-arc basin.

(5) The Wundurmiao collage (WD) (Mesoproterozoic through Silurian age, accreted during the Late Silurian) consists of the Late Ordovician through Silurian Laoling island-arc terrane, the Mesoproterozoic through Middle Ordovician Wundurmiao subduction-zone terrane, and the Neoproterozoic Seluohe subduction-zone terrane. The collage is interpreted as the Laoling island-arc system that formed near the Sino-Korean craton. Both the island-arc system and craton were widely separated from North Asian craton in the early Paleozoic.

(6) The West Siberian collage (WS) (Ordovician through Carboniferous age, accreted during the Late Carboniferous or Early Permian) consists of the Late Silurian through Early Carboniferous Rudny Altai island arc, and the tectonically linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. The collage is a northwestern continuation (present-day coordinates) of the South Mongolia-Khingan collage.

(7) The Yenisey-Transbaikal collage (YT) (Vendian through Devonian age, accreted during the Vendian through Early Ordovician) consists of the Vendian through Middle Cambrian Kuznetsk-Tannuola, Dzhida-Lake island-arc terranes, tectonically linked back-arc basins, and now tectonically eroded subduction-zone terranes. The collage is interpreted as a linear array of island-arc systems that formed south (present-day coordinates) of the North Asian craton and previously accreted terranes. The eastern part of the collage also includes the West Stanovoy metamorphosed terrane that may be a displaced fragment of the North Asian craton or of another craton.

Summary of Neoproterozoic (1,000 to 540 Ma) Metallogenesis

Metallogenic Belts Related to Sedimentary Basins formed on Craton Margins

Several metallogenic belts possess geologic units favorable for major stratiform sediment-hosted deposits, including the Angara-Pit belt (with sedimentary hematite Fe and volcanogenic-sedimentary Fe deposits), Bodaibinskiy and Central-Yenisei belt (with Au in black shale deposits), Jixi belt (with banded iron formation (BIF), Algoma Fe deposits), Kyllakh and Pribaikalskiy belts (with carbonate-hosted Pb-Zn deposits), and Vorogovsko-Angarsk belt (with sedimentary exhalative Pb-Zn (SEDEX), and carbonate-hosted Pb-Zn (Mississippi valley type) deposits). Where known, the fossil or isotopic ages of host rocks or deposits range from Riphean through Vendian. These deposits are hosted either in sedimentary units on the North Asian cratonal margin (Angara Pit, Bodaibinskiy, and Kyllakh belts), or in sedimentary basins deposited on passive continental-margin terranes that were possibly derived from the cratonal margin (Central Yenisei Vorogovsko-Angarsk belts). These favorable geologic units and deposits are interpreted as having formed during sedimentation on continental shelves, or during rifting of a continental shelf.

Metallogenic Belts Related to Island Arcs

Several metallogenic belts possess geologic units favorable for major volcanic-hosted and/or granite-hosted deposits, including the Baikalo-Muiskiy belt (with volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn deposits) and the Lake belt (with volcanogenic Cu-Zn massive sulfide (Urals type), volcanogenic-sedimentary Fe, Cu skarn, Fe skarn, granitoid-related Au vein, mafic-ultramafic related Cu-Ni-PGE, podiform Cr, mafic-ultramafic related Ti-Fe deposits). These favorable geologic environments were in island-arcs or on sea floors underlying the arcs in the Baikal-Muya island-arc terrane (part of the Circum-Siberia collage), the Lake island-arc terrane (part of the Yenisey-Transbaikal collage), and island-arc terranes in the Tuva-Mongolia superterrane.

Metallogenic Belts Related to Terrane Accretion

Several metallogenic belts possess geologic units favorable for Au in shear-zone and quartz-vein deposits, including the Bokson-Kitoiskiy (with sedimentary bauxite deposits) and Central-Yenisei belts that are hosted in either the western

North Asian craton or the Yenisey-Transbaikal and Circum-Siberia collages. These favorable geologic environments consisted of regional metamorphism and hydrothermal alteration that were associated with accretion of terranes to the North Asian cratonal margin. The Bokson-Kitoiskiy metallogenic belt also contains serpentine-hosted asbestos deposits that are interpreted as having formed in the same tectonic environment. The Prisayanskiy belt is hosted in terranes derived from the North Asian craton and contains REE carbonatite, and mafic-ultramafic related Ti-Fe deposits that are interpreted as having formed in Neoproterozoic magmatic events. The Jixi metallogenic belt contains minor Homestake Au deposits for which the tectonic origin is unclear.

Major Neoproterozoic (1,000 to 540 Ma) Metallogenic Belts and Host Units

The major Neoproterozoic metallogenic belts are the Angara-Pit, Baikalo-Muiskiy, Bodaibinskiy, Bokson-Kitoiskiy, Central-Yenisei, Hovsgol, Jixi, Kyllakh, Lake, Pribaikalskiy, Prisayanskiy, and Vorogovsko-Angarsk belts (fig. 3, appendix C).

Angara-Pit Metallogenic Belt of Sedimentary Hematite and Volcanogenic-Sedimentary Fe Deposits (Belt AP) (Yenisei Ridge, North-Asian Craton Margin, Russia)

This Upper Riphean metallogenic belt is hosted in the North Asian cratonal margin (East Angara fold- and thrust-belt) and occurs in the southeastern part of the Yenisei Ridge. The belt forms a band along the east wing of the Central anticlinorium from the Angara River to the north to the Gorbilok River to the south, and is up to 100 km long. The belt contains three large chlorite-hematite deposits at Nizhne-Angarskoye, Ishimbinskoye, and Udorongovskoye, and numerous smaller occurrences. The deposits occur in clastic sedimentary rock of the late Riphean Nizhneangarsk. Each deposit consists of several (about 7 to 36) ore layers that vary from 2 to 16 m thick (ranging up to 30 m), have a total thickness of as much as 50 m, and are 0.3 to 14 km long. All deposits exhibit similar geological structure, mineral composition, and quality of ore minerals. Ore layers and lenses are hosted in clastic and clastic-chemogenous sedimentary rocks, mainly hematite gritstone and conglomerate, hematite sandstone, and sandy hematite-chlorite siltstone. Host rocks and deposits are metamorphosed to phyllite (Matrosov and Shaposhnikov, 1988). The major deposit is at Nizhne-Angarskoye.

The main references on the geology and metallogenesis of the belt are Yudin (1968), Brovkov and others (1985), and Matrosov and Shaposhnikov (1988).

Nizhne-Angarskoye Sedimentary Hematite Fe Deposit

This deposit (Yudin, 1968; Brovkov and others, 1985) consists of layered hematite hosted in late Riphean argillite, siltsone, and sandstone. The Fe horizon is 45 to 180 m thick and occurs in 36 separate deposits that range up to 29 m thick, extend up to 15 km along strike, and range to 650 m depth. Fe layers are intercalated with sedimentary rocks that range from to 2 to 15 m thick. Ore layers consist of hematite, sandy-hematite, argillaceous chlorite hematite gritstone, hematite-siderite. Main ore minerals are hydrogoethite, hematite, and goethite with lesser siderite, magnetite, and pyrite. Gangue minerals are quartz, leptochlorite, clays, and sericite. The deposit contains 0.03 percent S and 0.08 percent P. The deposit is large with reserves of 1,200 million tonnes grading 40.4 percent Fe.

Origin and Tectonic Controls for Angara-Pit Metallogenic Belt

The belt is interpreted as having formed during a preorogenic stage of the Yenisei pericratonal subsidence in a back-arc (interland) sedimentary basin. Lithological-facial control of distribution of sedimentary hematite ores occurred. The paleodelta setting of formation of Fe ores is indicated by structural, mineralogical, and geochemical features of host rocks (Yudin, 1968). A possible source of clastic ore minerals was residual Fe-rich weathering crust (Brovkov and others, 1985).

Baikalo-Muiskiy Metallogenic Belt of Volcanogenic-Hydrothermal-Sedimentary Massive Sulfide Pb-Zn (±Cu), Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite, and Serpentine-Hosted Asbestos Deposits (Belt BM) (Russia, Northern Transbaikalia)

This Neoproterozoic metallogenic belt occurs in the Baikal-Muya island-arc terrane, the Muya metamorphic terrane, and part of the Olokit-Delunur craton-margin rift terrane. The major deposits are at Kholodninskoye, Lugovoye, and Molodezhnoye. The belt occurs along the northern periphery of the Vitim highland (northeastern coast of Lake Baikal) and extends from Lake Baikal to Vitim River. The belt is 500 km long and 120 km wide.

The lower part of the Baikal-Muya island-arc terrane consist of tectonic slabs of ophiolite of various ages with hemipelagic sedimentary rock (Lower Kelyansky suite); and a middle Riphean island-arc complex basalt, andesite, and plagiorhyolite (Verkhne Kelyansky suite), and gabbro and plagiogranite intrusions. The island-arc rocks are metamorphosed to greenschist facies (Bulgatov and Gordienko, 1999; Bozhko and others, 1999).

The Muya terrane consists of the metamorphic Kindikansky, Ileirsky, and Lunkutsky suites.

The Olokit-Delunuran craton-margin rift terrane consists of Riphean volcaniclastic and sedimentary rocks of the Olokit series with abundant interbedded tholeiitic basalt and rhyolite, volcanogenic siliceous sedimentary rock and tuff, and late Riphean carbonaceous, clastic, carbonate sedimentary rock of the Dovyren series. All units are metamorphosed to amphibolite facies and folded. The top displays subhorizontally lying postaccretionary sedimentary rock of intermontane basins (basalt, rhyodacite and molasse of the Padrinsky series late Riphean).

The suture complexes are collisional late Paleozoic granitoids of the Barguzin-Vitim belt.

The belt contains a group of deposits and large ore occurrences: Kholodninskoe

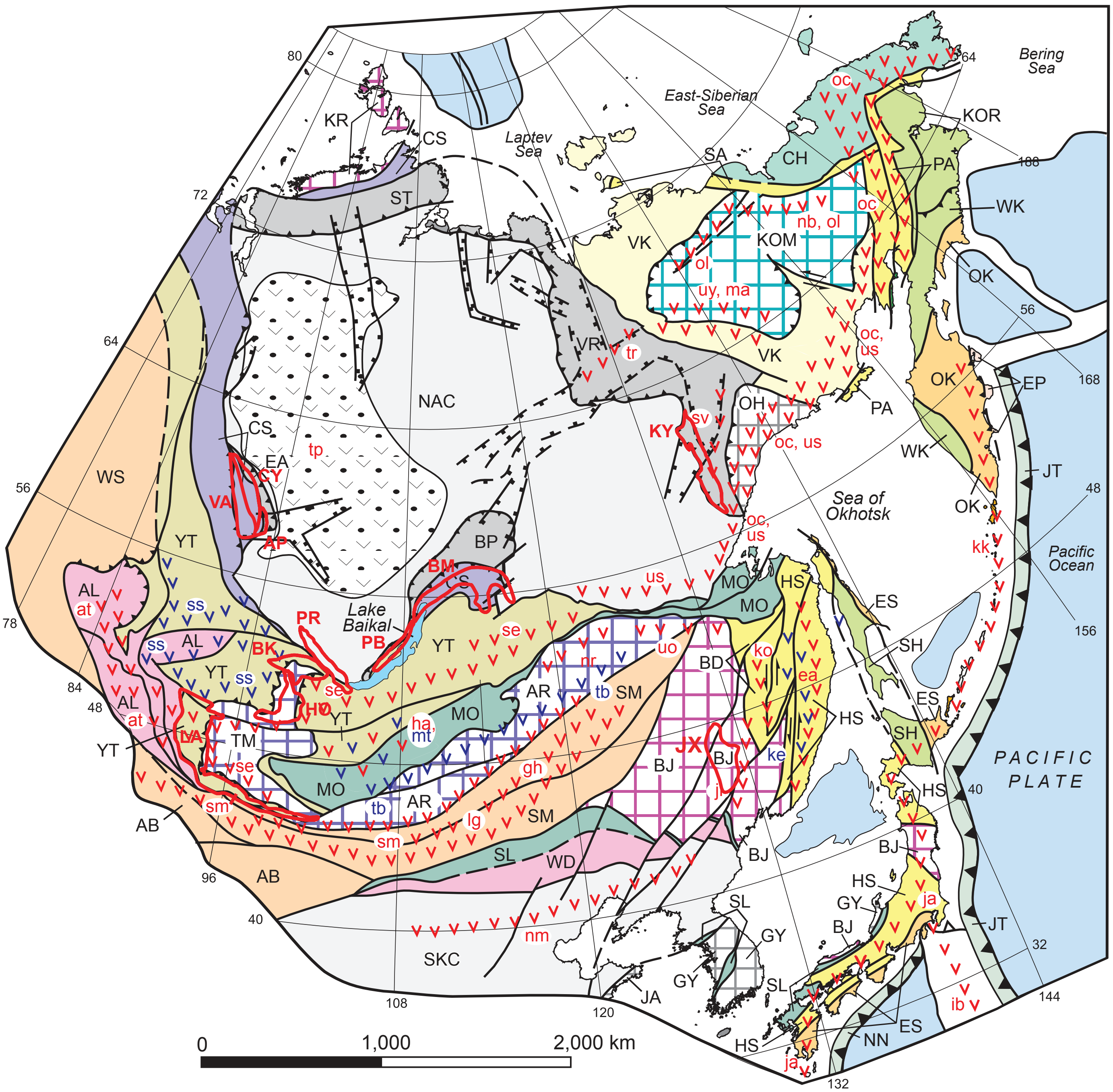


Figure 3. Generalized map of major Neoproterozoic metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 and table 1 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area east of 144º E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

(volcanogenic-hydrothermal-sedimentary massive Pb-Zn sulfide (±Cu) (fig. 4), Lugovoye-polymetallic (Pb-Zn-Cu, Ba, Ag, Au) carbonate-hosted metasomatic. These deposits occur along the northern margin of the Baikal-Muya island arc in sedimentary rocks of the Olokit-Delunuran accretionary-wedge terrane. There are deposits of Ni (Chaisky, Baikalsky), Mo and Fe (Tyisky, Abchadsky-ferruginous quartzite), Ti, Mn and REE. In the Baikal-Muya belt some basins (Distanov and others, 1982) contain local synclines filled with volcanogenic and siliceous-clastic rocks. As a result of metamorphism of amphibolite facies they turned to be garnet-quartz-plagioclase-micaceous schist, quartzite and marble. They host stratified pyrite-pyrrhotite-sphalerite-galena-chalcopyrite ores of banded texture (Kholodninsky deposit, occurrences Kholoysky and Kosmonavtov). The deposits are enclosed in horizons of rhythmically alternating carbonaceous aleuropelitic rock of diverse composition (Distanov and Kovalev, 1995). The deposits are multistaged, and associated younger shear zones exhibit streaky-stockwork aggregates of quartz, carbonate, sphalerite, pyrite, and galena.

The central part of the basin hosts the band of foliated Ni-bearing intrusions of olivinite-peridotite-troctolite composition of the Dovyren complex (Chaisky, Ioko-Dovyren, Baikalsky, Nurundukan plutons). The ultramafic varieties of the complex contain streaky-stockwork deposits of pyrrhotite, pentlandite, chalcopyrite and magnetite (Chaisky deposit of mafic-ultramafic related Cu-Ni-PGE). Ores often show increased content of cobalt, chromium, and platinoids.

The late Riphean and Cambrian overlap complex of the Upper Angara sedimentary basin hosts deposits of polymetallic (Pb-Zn-Ag) metasomatic-hosted model type (Lugovoye deposit) occurring in silicified horizons of limestone. The deposits consist of lensoid-shaped aggregates of sphalerite, galena, pyrite, and fluorite.

Bedded bodies of metasomatically altered dunite and harzburgite include commercial chrysotile-asbestos deposits with top quality commodity (Molodezhnoye, Ust-Kelyansky) that belongs to serpentine-hosted asbestos model type. The nephrite deposits (Paramskoye, Buronskoye) occur in the margins of ultramafic bodies and zones of apocarbonate metasomatism. Enclosing rocks have small occurrences of graphite (Muyskoye). The volcanic complexes of paleoophiolite composition encompass minor Au-sulfide-pyrite deposits confined to large zones of mylonitization of interblock origination (Kamennoye, Samokutskoye, Ust-Karalonskoye). Bedded lensoid sulfide ores contain pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, and sulfosalts of Ag with Pt and Pd.

The main references on the geology and metallogenesis of the belt are Distanov and others (1982), Bulgatov (1983), Distanov and Kovalev (1995), Bozhko and others (1999), and Bulgatov and Gordienko (1999).

Origin and Tectonic Controls for Baikalo-Muyskiy Metallogenic Belt

Various deposits in the belt are interpreted as having formed in Baikal-Muya island arc or during Riphean accretion of terrane with Muya metamorphic terrane and Olokit-Delunuran craton-margin rift terrane.

Bodaibinskiy Metallogenic Belt of Au in Black Shale Deposits (Belt Bod) (Russia, Northern Transbaikalia)

This Neoproterozoic through Early Carboniferous metallogenic belt occurs in the Patom fold- and thrust-belt in the North Asian cratonal margin. The major deposits are at Sukhoy Log, Vysochaishi, and Dogaldynskoye. The belt extends for 150 km east-west and 160 km north-south. The belt occurs in the Mesoproterozoic through early Paleozoic overlap complex of the Patom sedimentary basin that formed in a deep-water shelf along the southeastern passive continental margin of the North Asian craton. The basin is filled with thick (8 to 10 km) carbonate and clastic sedimentary rock of the Teptorginsky, Balaganakh, Dalnetaiginsky and Bodaibo series (Ivanov and others, 1995). The black shale sequences comprise an important part of the basin. The rocks are metamorphosed to kyanite-sillimanite grade and collisional granitoids of the late Riphean Yazovsky complex are coeval with metamorphism. The deposit-controlling structure is the Bodaibo synclinorium that contains the Bodaibo and Kropotkino basins (Sher, 1961). Narrow axial parts of anticlines with shear zones, intense foliation and hydrothermal-metasomatic deposits control some districts, as at Alexander-Dogaldynsky, Sukhoy Log, Verninsky, and Kamensky. Loci of warping of major fold folds and crosscutting, diagonal ruptures are favorable for Au-quartz-vein and Au-sulfide-quartz veinlet deposits (Buryak, 1982), herein termed Au in black shale. Major deposits occur at Sukhoy Log, Vysochaishy, Verninsky, and Nevsky. The largest district at Sukhoy Log extends more than 2.5 km and has deposits as much as 200 m thick.

The main references on the geology and metallogenesis of the belt are Buryak (1982), Konovalov (1985), Neumark and others (1990), Rundquist and others (1992) and Ivanov and others (1995).

Sukhoy Log Au in Black Shale Deposit

This deposit (Konovalov, 1985) (fig. 5) consists of two types (1) quartz and sulfide veinlets and disseminations of (75 percent reserves); and (2) low-sulfide quartz veins (25 percent reserves). The first type consists of layered linear stockwork consisting of veinlets and disseminations with pyrite and quartz. Sulfides range from 2 to 5 percent, pyrite is abundant (95 percent). Rare minerals are galena, sphalerite, arsenopyrite, pyrrhotite, chalcopyrite, pentlandite, millerite, and cubanite. Au is very fine-grained (0.1-0.14 mm) and fineness is 780 to 820. Gold occurs in cracks in pyrite and rarely in arsenopyrite. The second type consists of 22 quartz veins with complicated morphology and occurs on the western edge of the deposit. This type consists of coarse-crystalline quartz (90 to 95 percent), pyrite (1 to 3 percent), carbonates (siderite,

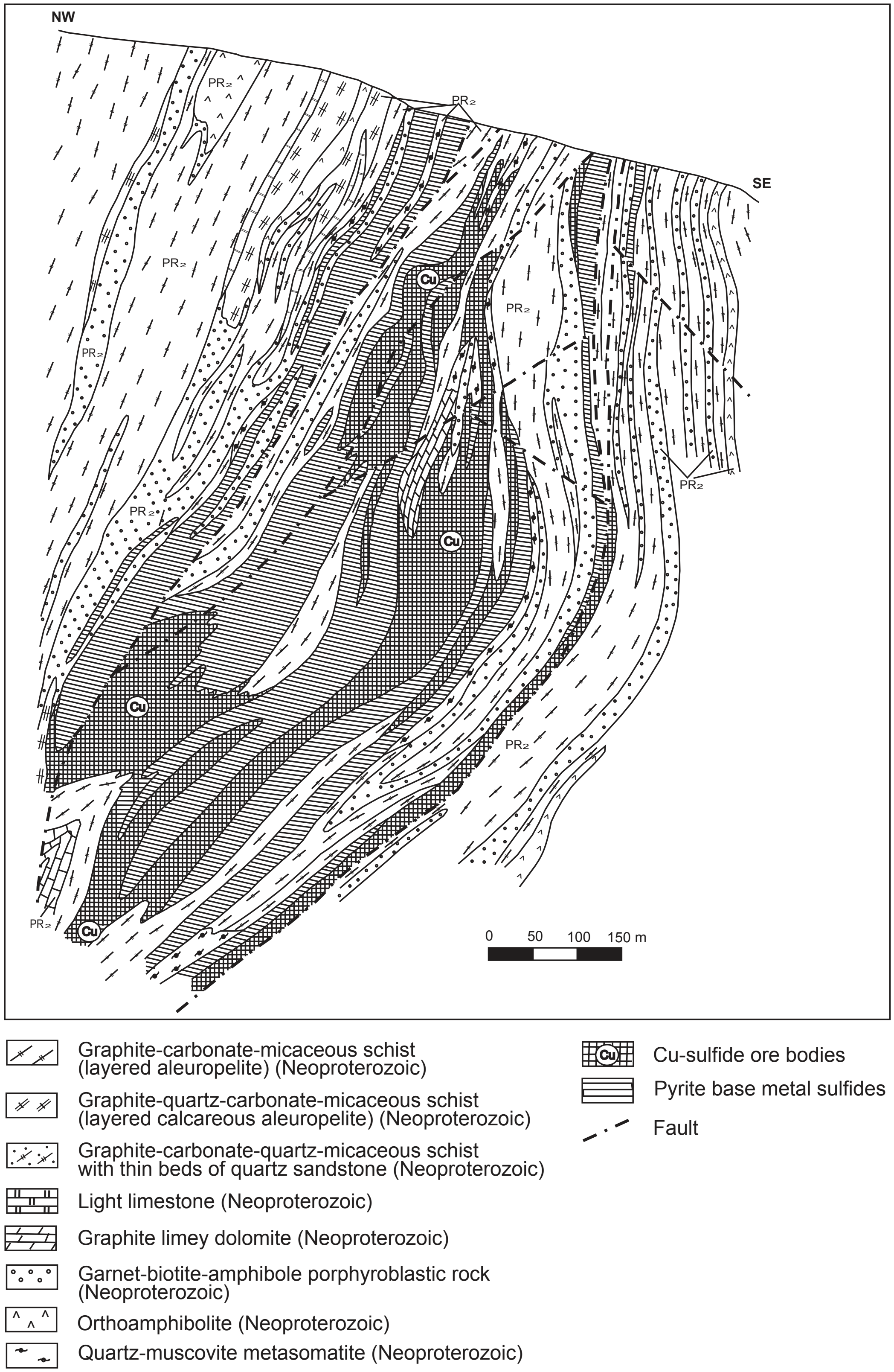


Figure 4. Schematic cross section of Kholodninskoe (volcanogenic-hydrothermal-sedimentary massive Pb-Zn sulfide deposit, Baikalo-Muiskiy metallogenic belt. Adapted from Distanov and others (1982).

ankerite, dolomite, calcite), and pseudomorphs of limonite after pyrite. Also occurring are rare muscovite, chlorite, galena, sphalerite, chalcopyrite, arsenopyrite, and pyrrhotite. Gold is intergrown with pyrrhotite, chalcopyrite, and galena. Pt grade increases with sulfide content. The Sukhoy Log deposit occurs in the central part of a 3rd order anticline with sublatitudinal strike. The anticline core contains Neoproterozoic black shale alternating with limestone and quartz sandstone that are metamorphosed to greenschist facies. The deposit is large and has an average Au grade of 2.8 to 3.6 ppm and a similar Pt grade.

Origin and Tectonic Controls for Bodaibinskiy Metallogenic Belt

The major deposits in the belt are interpreted as having formed in two stages. (1) In the Riphean and early Paleozoic, Au accumulated during sedimentation with later metamorphism and hydrothermal activity (Buryak, 1982). These events formed scattered Au-sulfide deposits. (2) In the middle to late Paleozoic, postcollisional intrusion of granite and leucogranite along with hydrothermal activity formed commercial Au-quartz-sulfide deposits (Konovalov, 1985). The age of Au from deposit Sukhoy Log is about 320 Ma. A subsequent magmatic and hydrothermal event was intrusion of the middle and late Paleozoic Kadali-Butuinsky dike complex (Rundquist and others, 1992). This event formed Au-Ag-sulfosalt deposits. The belt is promising for discovery of large Au deposits.

Bokson-Kitoiskiy Metallogenic Belt of Sedimentary Bauxite, Magmatic Nepheline, Serpentine-hosted Asbestos, and Au in Shear-Zone and Quartz-Vein Deposits (Belt B-K) (Russia, East Sayan)

This Neoproterozoic through Silurian metallogenic belt is related to veins in plutons intruding in the Belaya-Kitoy

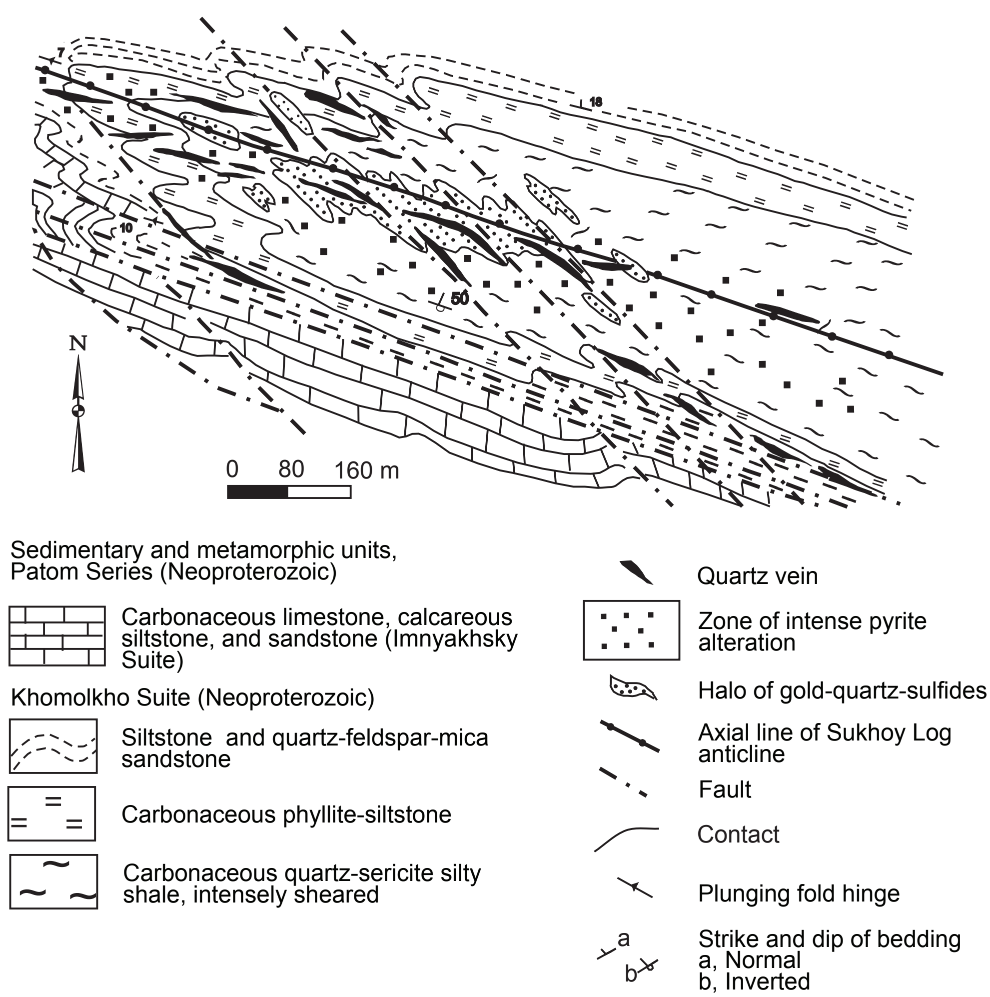


Figure 5. Generalized geologic map of Sukhoy Log Au in black shale deposit, Bodaibinskiy metallogenic belt. Adapted from Konovalov (1985).

metamorphic terrane, Hug accretionary wedge, and Tunka tonalite-trondhjemite-gneiss terranes, the Tannuola plutonic belt, and the Huvsgol-Bokson sedimentary overlap assemblage. The belt occurs in the central part of East Sayan Mountains in the upper parts of Irkut, Urik, and Kitoy Rivers, extends along a nearly sublatitudinal trend for 315 km, and is 150 km wide. The metallogenic belt is a composite that includes several mineral deposit types.

The Gargansky terrane consists of Archean plagiogranite-gneiss overlapped by a Riphean carbonates. The Ilchir terrane consists of a Riphean ophiolite, the Dibinsky suite of rhythmically bedded sedimentary volcanic rock, the Sarkhoy suite of calc-alkaline and tholeiitic volcanic rock, and the middle Riphean Khugeinsky suite of clastic and volcanic rock metamorphosed at high-pressure. The Huvsgol-Bokson overlap assemblage consists of carbonate and clastic sedimentary rocks of the Vendian and Cambrian Bokson series.

Igneous suture complexes are the subduction-related tonalite Sumsunur complex with U-Pb and Rb-Sr ages of 790 Ma, and Devonian and Carboniferous granitoids of the Kholbinsky, Ognitsky, and Botogol complexes.

The major deposits are the Boksonskoye sedimentary bauxite, Botogolskoye magmatic nepheline, Ilchirskoye serpentinite-hosted asbestos, Bourun-Kholba Au in shear-zone and quartz-vein, Zun-Kholba Au in shear-zone and quartz-vein, and the Pionerskoye Au in shear-zone and quartz-vein deposits.

The main references on the geology and metallogenesis of the belt are Krutsko (1962, 1964), Levitsky and others (1984), Dobretsov and Ignatovich (1989), Feofilaktov (1992), and Mironov and others (1995).

Zun-Kholba Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Dobretsov and Ignatovich, 1989, Feofilaktov, 1992; Zhmodik and others, 1994) (fig. 6) consists of a steeply dipping zone (8000 by 200 to 600 m) that strikes northwest and contains more than 30 bodies of which 12 are economic. The bodies are divided into (1) steeply dipping quartz-polysulfide; (2) banded chalcopyrite-pyrite bodies; and (3) quartz veins. The first type, which is economically important and is hosted in talc-chlorite and carbonaceous-siliceous shales, consists of a combination of veins and disseminations with 20 to 50 percent sulfides. Major ore minerals are pyrite (as much as 30-45 percent), pyrrhotite (as much as 5 to 30 percent), chalcopyrite (as much as 10 percent), galena (as much as 5 to 8 percent), sphalerite (up to 5 percent), rare bornite, chalcocite, bismuthine, native silver, and Au and Ag tellurides. Gangue minerals are quartz, calcite, and talc, and rare albite, chlorite, muscovite, sericite, and graphite. The wall rocks contain zones of beresite, talc, graphitie, and listvinite alterations. Sulfide-body dimensions are 150 to300 by 0.2 by 0.4 m and occur in limestone. Sulfide grade ranges up to 50-80 percent and sulfides are mainly pyrite, sphalerite, galena, chalcopyrite, and pyrrhotite. Small quartz-sulfide veins contain 1-2 percent and rarely 5 percent sulfides, and has an average grade of 9.8 ppm Au and 13 ppm Ag. The deposit occurs in the central part of the Samarta-Kholba shear zone along the northern boundary of the Gargansky terrane. The deposit is medium size and has an average grade of 26 ppm Au, 24 to 37 ppm Ag, and 1.7 ppm Pt.

Boksonskoye Sedimentary Bauxite Deposit

This deposit (Il'ina, 1958; Orlova, 1958) consists of bauxite layers that occur over different dolomites (spotty, reef-generating, algae, banded, pink and red) in part of the thick Bokson suite in Archean and Proterozoic metamorphic and mafic igneous rock. Thickness of the bauxite beds average 5 m, locally up to 30 m. Bauxite occurs in masses, layers, breccia, and locally in sandstone. The deposit contains 35 minerals and the primary minerals are bemite, kaolinite, dickite, leptochlorite, and gallauzite, and rare montmorillonite, pyrophyllite, Fe oxides, and hydroxide. Secondary minerals are sericite, muscovite, talc, serpentine, zeolite, hydrargillite, diaspore, chlorite, crysotile, quartz, calcite, and gypsum. The ore minerals are hematite, goethite, pyrite, and magnetite. Terrigenous minerals are tourmaline, olivine, feldspar, quartz, rutile, leucoxene, and alunite. Varieties of mineral assemblages are red-brown diaspore-hematite, gray-green diaspore chlorite, and intermediate diaspore-chlorite-hematite. The bauxite formed from coastal marine and lagoon sediments. The age of the deposit is 600 to 540 Ma. This is the oldest bauxite deposit in Russia. The deposit is large and has an average grade of 40 percent Al_20_3.

Botogolskoye Magmatic Nepheline Deposit

This deposit (Solonenko, 1950) occurs in the Botogol alkaline nepheline syenite massif that forms an elongated oval that is 6 by 2 km and intrudes Proterozoic schist and carbonate rock. The massif formed in three stages (1) normal pyroxene and quartz syenite; (2) alkaline pyroxene and nepheline syenite; and (3) leucocratic nepheline syenite. Two deposit bodies occur, the 0.6 km^2 Severny body and the 0.2 km^2Yuzhny body. The bodies are separated by a kilometer-wide zone of a low-grade deposit. The Severny body is mainly leucocratic nepheline syenite with local biotite and pyroxene. The Yuzhny body is mainly pyroxene nepheline syenite. The deposit is interpreted as having formed in a back-arc rift. The deposit is medium size and has an average grade of 21 percent Al_20_3.

Ilchirskoye Serpentinite-Hosted Asbestos Deposit

This deposit (Shamansky, 1945; Krutsko, 1964) occurs in the Ilchir lens-shaped massif (2.5 by 1 km) composed of Vendian peridotite and serpentinite. The deposit is an irregular lens with dimensions of 1700 by 100-380 by 150-550 m. The deposit has a concentric structure: a central part of asbestos-bearing serpentinite with a core of unaltered harzburgite; outward, serpentinite devoid of asbestos; and serpentinite-talc-carbonate

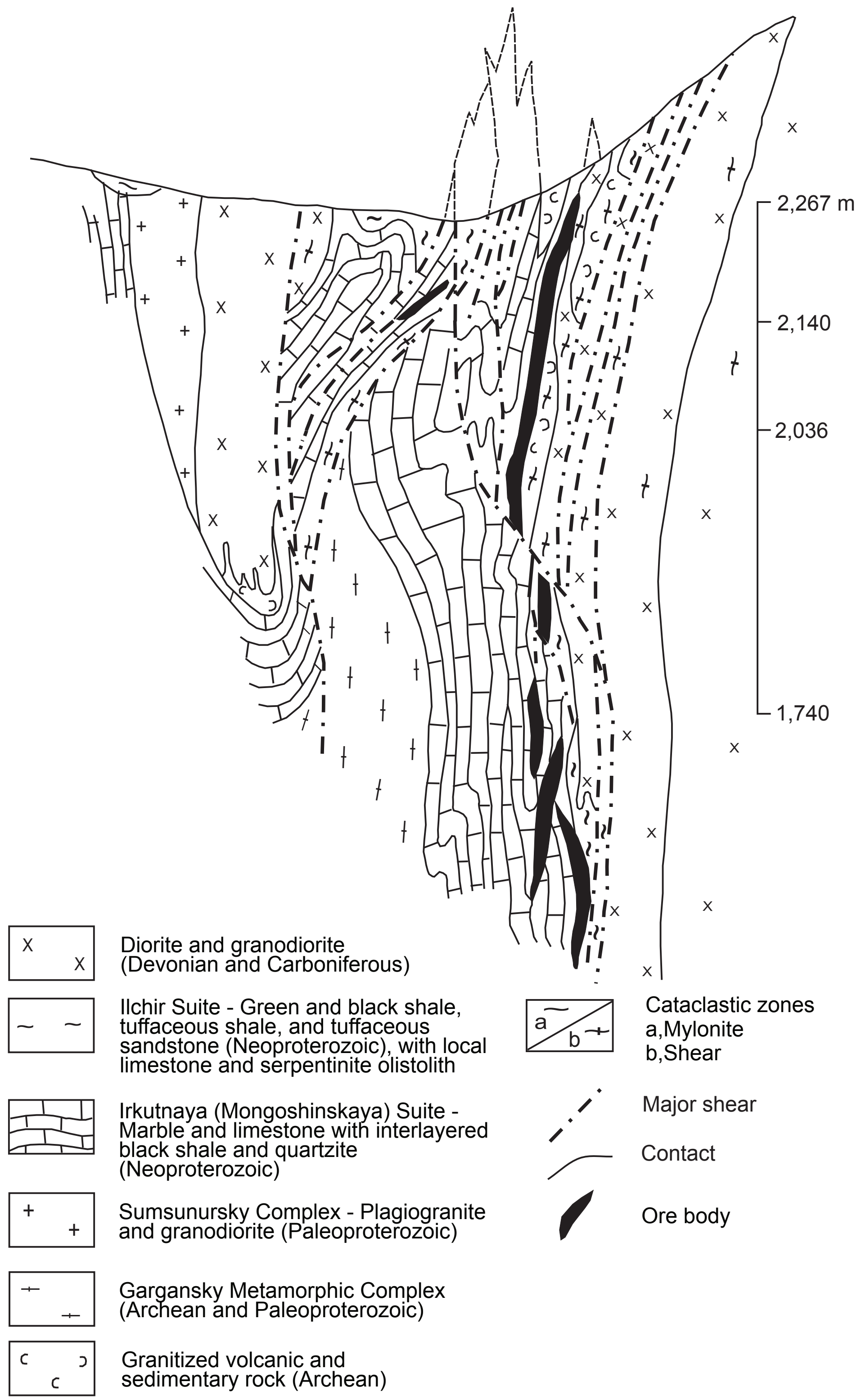


Figure 6. Schematic cross section of Zun-Kholba Au in shear-zone and quartz-vein deposit, Bokson-Kitoiskiy metallogenic belt. Adapted from Mironov and others (1995).6. Schematic cross section of Zun-Kholba Au in shear-zone and quartz-vein deposit, Bokson-Kitoiskiy metallogenic belt. Adapted from Mironov and others (1995).

rock. High-grade asbestos occurs in two tectonic zones that cut the massif and vary from 100 to 400 m thick. Asbestos is a large network type with veinlets ranging from 20-30 mm thick (locally up to 70 mm), cutting in various directions, and occurring about 1 to 2 m apart. The ore minerals are chrysotile-asbestos, bastite, serpentine, ophite, magnetite, talc, chromite, brucite, antigorite, carbonates, pyroxene, and olivine. Asbestos is silky, durable, and is useful for technological purposes. The deposit is small and has an average grade of 2.5 percent asbestos fibre and 0.08 to 0.25 percent textile grade asbestos.

Origin and Tectonic Controls for Bokson-Kitoiskiy Metallogenic Belt

This belt is hosted in metamorphic, oceanic, accretionary wedge, and tonalite-trondhjemite-gneiss terranes that underwent Cambrian through Silurian metamorphism, hydrothermal alteration, and plutonic intrusion. A younger suture complex is the subduction-related Sumsunur complex tonalite with a U-Pb and Rb-Sr isotopic age of 790 Ma. The deposits in the belt are interpreted as having formed in multiple events.

Central Yenisei Metallogenic Belt of Au in Black Shale, Au in Shear-Zone and Quartz-Vein, and Clastic-Sediment-Hosted Sb-Au Deposits (Belt CY) (Yenisei Ridge, North-Asian Craton Margin, Russia)

This Late Neoproterozoic metallogenic belt is hosted in the passive continental margin of the West Angara terrane and is related to regional metamorphism and granitoid magmatism. The belt extends north-northwest along the axial zone of the Yenisei Ridge for 450 km and is 40 to 80 km wide in the central anticlinorium formed from Proterozoic rocks metamorphosed to amphibolite and epidote-amphibolite facies (Paleoproterozoic Teisk series), and to greenschist facies (Mesoproterozoic Sukhopit series). The metallogenic belt is bounded by the Tatarsk fault zone to the west and by the Ishimbinsk fault zone to the east. The central anticlinorium is cut by a northeast-striking transform fault that controls the regional structure, the occurrence of synorogenic and postorogenic granitoid intrusions, and the location of major districts. Au and Au-Sb deposits are predominant in the belt and occur mainly in three districts (from north to south) (1) Severo-Yenisei (Sovetskoye, Eldorado, Ajakhta, and others); (2) Verkhne-Enashiminsk (Olimpiada, Enashiminskoye); and (3) Partizansk (Udereiskoye, Razdolninskoye). Host rocks are mainly carbonate and clastic rock and black shale in the middle and lower parts of the middle Riphean Sukhopit series. Collisional batholithic granitoid S-type plutons of the Tataro-Ayakhtinsk complex (with an isotopic age of 850 Ma) are widespread (Kornev and others, 1996). The three main types of deposits are (1) Au-quartz-vein (Sovetskoye and others); (2) Au in black shale (Olimpiada and others); and (3) clastic-sediment-hosted Sb-Au (Udereiskoye, Razdolninskoye). Most deposits are polygenetic and formed during the middle to late Riphean and Vendian.

The main references on the geology and metallogenesis of the belt are Distanov and others (1975), Li and others (1984), Brovkov and others (1985), Kornev and others (1996), and Obolenskiy and others (1999).

Sovetskoye Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Petrovskaya, 1967; Petrov, 1974; Smirnov, 1978; Serdyuk, 1997; Simkin, 1997) consists of quartz-Au veins cutting Neoproterozoic phyllite that is intruded by small gabbro and diabase bodies, and Paleozoic syenite porphyry. The deposit occurs in a thick, conformable shear zone that is complicated by small-scale folds. The district containing the deposit extends up to 8 km along strike, ranges up to 650 m wide, and extends to 390 m depth. The deposit consists of subparallel, branching veins, veinlets, and lenses. Separate veinlets and veins vary from less than a cm to 10 to 20 cm thick. Veins contain mainly coarse-grained quartz and fragments of low-grade altered host rock. Gangue minerals are carbonate, sericite, albite, and chlorite. Ore minerals constitute about 5 percent and are pyrite, arsenopyrite, lesser chalcopyrite, galena, sphalerite, pyrrhotite, and marcasite. Gold is fine-grained. Fineness of Au averages 940. The deposits consist mainly of quartz, quartz-pyrite, quartz-arsenopyrite, and quartz-sulfide types. Quartz-sulfide type contains the most Au. Contact zones of deposits are more productive. Two types of hydrothermal wall-rock alterations are (1) combination of tourmaline, albite, sericite, and chlorite alteration; and (2) silica, sericite, chlorite, and sulfide alteration. Magmatic intrusive rocks occur 2 to 5 km to the northeast and consist of diabase and gabbro, and dikes of mica lamprophyre, syenite porphyry, and a slightly eroded granitoid pluton. A major magmatic chamber beneath the deposit is interpreted as the source of deposit-forming solutions (Brovkov and others, 1985). The deposit is medium size and has an average grade of 2.2 g/t Au.

Olympiada Au in Black Shale Deposit

This deposit (Li and others, 1990) (fig. 7) occurs in the central part of the Central-Yenisei metallogenic belt in the Verkhne-Enashiminsk district and consists of layered and saddle-shaped bodies of disseminated Au-sulfide in metasomatite hosted in regionally metamorphosed Neoproterozoic carboniferous and clastic rock. The deposit occurs in a roof pendant above the large Neoproterozoic Chirimbinsk granitoid pluton. Host rocks are quartz-carbonate and micaceous schist with intercalated dolomite and carboniferous and quartz-muscovite schist. Host rocks are hydrothermally altered to quartz-carbonate and mica, mica-carbonate and zoisite-quartz-mica metasomatite. Skarn locally occurs with metasomatite. The ore minerals are pyrrhotite, arsenopyrite, stibnite, berthierite, pyrite, and native Au, and rare galena, sphalerite, chalcopyrite, scheelite, fahl, and Bi-minerals. The ore minerals constitute 4 to 5 percent total amount of deposit. Free gold is fine-grained and disseminated and varies from 0.001 to 0.1 mm wide. Gold occurs with arsenopyrite, pyrrhotite, and granoblastic quartz. Two generations of native gold occur, an early generation with a fineness of 910 to 997, and a later generation with a fineness of 647 to 757 that is associated with carbonate-hosted Sb occurrences. Weathering crust is wide-spead and contains higher-grade Au. Mining of Au-bearing crust is continuing. Weathering crust ranges to 390 m depth. The deposit is large and has reserves of 700 tonnes Au grading 3 to 4 g/t Au.

Udereiskoye Clastic Sediment-Hosted Sb-Au Deposit

This deposit (Distanov and others, 1975; Berger, 1981; Brovkov and others, 1985) consists of quartz veins and veinlets with Au and Sb minerals hosted in Mesoproterozoic quartz-chlorite-sericite, quartz-sericite, and chlorite-sericite schist. The deposit is mainly in a steeply dipping shear zone that is conformable with host-rock structure. Saddle-shaped reefs also occur. The deposit consists of about 12 to 15 veins that total up to 10 to 80 m thick. Commercial deposits are outlined by sampling and contain both ore veins and

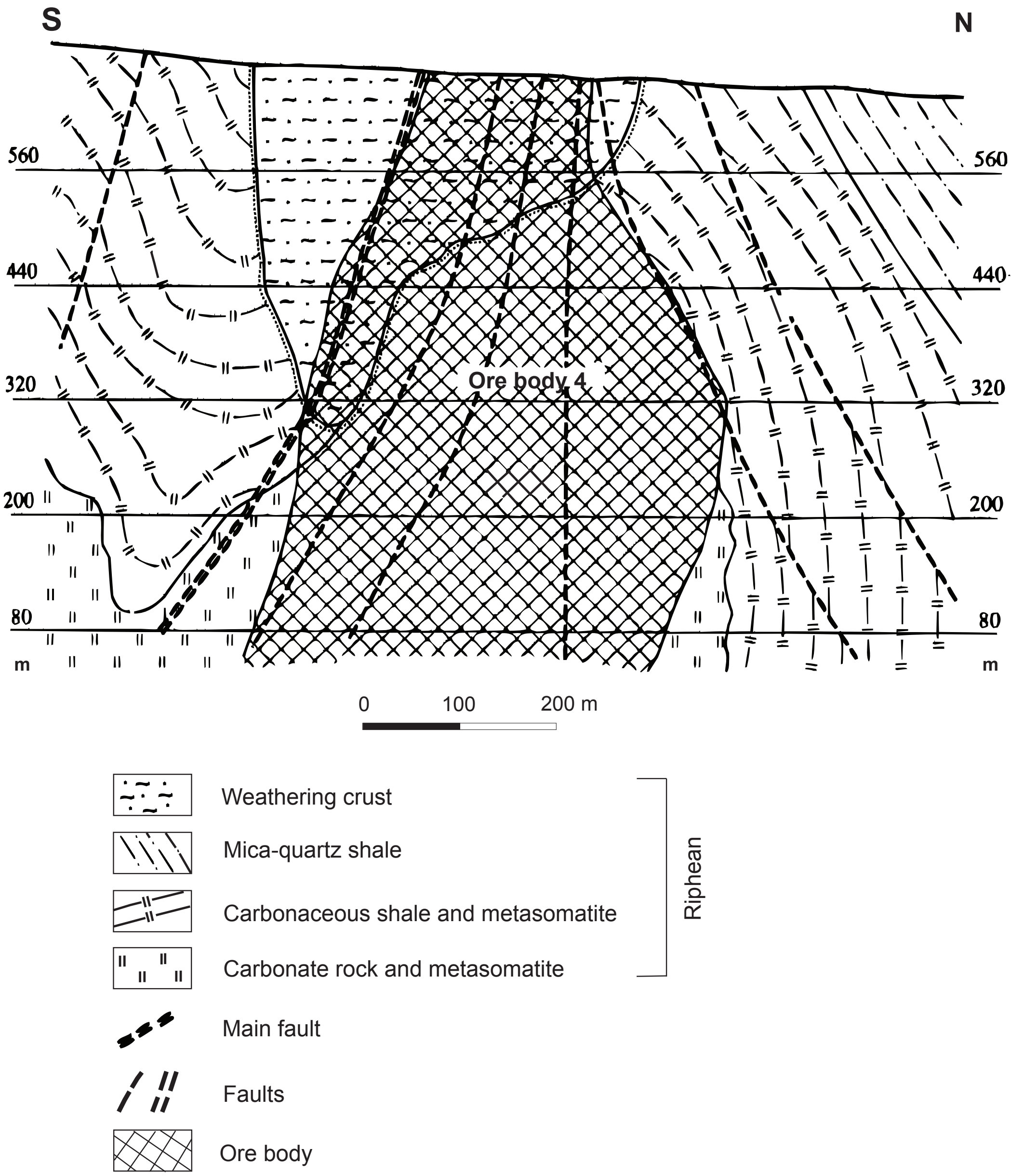


Figure 7. Schematic cross section of Olympiada Au in black shale deposit, Central-Yenisei metallogenic belt. Adapted from Genkin and others (1994).

mineralized host rocks. Host rocks are slighly hydrothermally altered with formation of sericite, chlorite, silica, sulfides, carbonate, and tourmaline. The main ore minerals are quartz, stibnite, berthierite, arsenopyrite, pyrite, carbonate, sericite, native gold, sphalerite, galena, chalcopyrite, argentite, and fluorite. Distribution of Au in deposits is irregular. Higher Au concentrations occur in arsenopyrite. The deposit is interpreted as having formed in a complicated multistage process. Two younger mineral assemblages are quartz, arsenopyrite, and pyrite with Au, and quartz, berthierite, and stibnite with sparse Au. The deposit is medium size and has an average grade of 0.28 to 4.2 g/t Au.

Origin and Tectonic Controls for Central-Yenisei Metallogenic Belt

The gold deposits of the belt are interpreted as having formed during collisional development of the late Riphean continental margin of the North Asian craton. Au initially occurring in black shale was subsequently concentrated and remobilized during collision-related metamorphism, granitoid intrusion, and hydrothermal activity (Obolenskiy and others, 1999). The belt occurs in the Sukhopit series that consists of sandstone and argillite formed in a marginal sea-shelf facies. Host rocks have anomalous Au, Sb, and W and are interpreted as possibl sources of ore (Berger, 1981). Au-quartz-vein deposits are associated with granitoid intrusions that form batholithic granitoids with deposits. Disseminated Au deposits in black shale (Olimpiada and others) are related to metasomatite hosted in carbonate and clastic rocks in a roof pendant of a large granitoid pluton (Li and others, 1984). Sb-Au clastic-sediment-hosted, hydrothermal vein deposits occur in the Partizansk ore district in the southern part of the belt and are hosted in middle Riphean carbonaceous schist of the Uderei series (Distanov and others, 1975). K-Ar hydromica metasomatite isotopic ages for the youngest stage of deposits are 605 ± 30 Ma (Distanov and others, 1975) and 664 ± 36 Ma (Ovchinnikov and Voronovskiy, 1974). These ages are coeval with the Rb-Sr age of 601 ± 9 Ma for the Tatarsk granitoid pluton (Sobachenko and others, 1986). Recent interpretations for the origin of the belt consist of multistage polygenetic sedimentary, metamorphic, and hydrothermal origin of Au and Sb-Au deposits with primary accumulation of gold in black shale and subsequent concentration and remobilization during metamorphism and granitoid-related hydrothermal activity (Li, 1974a,b; Berger, 1981; Nekludov, 1995).

Damiao Metallogenic Belt of Mafic-Ultramafic Related Ti-Fe (V) and Zoned Mafic-Ultramafic Cr-PGE Deposits (Belt DM) (North China)

This Neoproterozoic metallogenic belt is hosted in mafic-ultramafic plutons intruding the West Liaoning-Hebei-Shanxi granulite-orthogneiss terrane in the Sino-Korean craton. The belt occurs in Mount Yanshan in the Damiao area of the eastern Hebei Province. The belt trends east-west, is about 130 km long, and 50 km wide. The significant deposit is at Damiao.

The main reference on the geology and metallogenesis of the belt is Cheng Yuqi and others (1994).

Damiao Mafic-Ultramafic Related Ti-Fe (V) Deposit

This deposit (Cheng Yuqi and others, 1994) (fig. 8) consists of a number of lenses and veins. The larger deposits extend along strike up to 300 to 500 m, extend downdip to 500 m and range from several tens to a hundred meters thick. The deposits occur at the contact zone between anorthosite and gabbro, or in the dikes of anorthosite and gabbro. The ores are mainly massive Ti-magnetite, minor ilmenite, and sparse pyrite and chalcopyrite. Gangue minerals are chlorite, amphibole, plagioclase, and minor apatite. P_2O_5 content is 0.07 percent. Also occurring is stockwork mainly in the gabbro adjacent to the contacts with anorthosite. The ore minerals are disseminated and are mainly Ti magnetite, ilmenite, plagioclase, augite, hypersthene, actinolite, chlorite, apatite, rutile, and sulphides. P_2O_5 content is 0.59 to 0.93 percent, and Fe content is less than 20 percent. The host mafic intrusion intrudes Early Precambrian units along the northern margin of the Sino-Korea craton, and is controlled by east-west-trending regional faults. K-Ar isotopic ages for the anorthosite range from 992 to 604 Ma. The deposit is large with reserves of 130 thousand tonnes V_2O_5, grading 0.16 to 0.39 percent V_2O_5, reserves of 58 thousand tonnes TiO_2, grading 7.17 percent TiO_2, and 32 to 34 percent Fe.

Gaositai Zoned Mafic-Ultramafic Related Cr-PGE Deposit

This deposit (Cheng, Yunchung and others, 1996) consists of a number of chromite bodies hosted in serpentinizied dunite and diopside pyroxenite that form part of an untramafic intrusion that is 9 km long and 1 km wide. The intrusion intrudes Early Precambrian metamorphic rock. The chromite bodies occur in veinlets and disseminations, and rare masses. The ore minerals grade into host rocks. The deposit occurs in the northern margin of the North China Platform in the Yanshan Mountains. Nearby are a number of similar small chromite deposits that occur along an east-west trend. The deposit is small and has reserves of 170,000 tonnes grading 14.12 percent Cr_2O_3 and locally up to 40 percent Cr_2O_3.

Origin and Tectonic Controls for Damiao Metallogenic Belt

The belt is hosted in Neoproterozoic mafic-ultramafic plutons that intrude Archean crystalline rocks of West Liaoning-Hebei-Shanxi terrane. The plutons occur along northwest-trending major faults along the northern margin of the Sino-Korean craton. The mafic and ultramafic intrusions have isotopic ages of 992 to 604 Ma. The plutons and deposits are interpreted as having formed during interplate magmatism related to a Neoproterozoic active continental margin along the north margin of the Sino-Korean craton**.**

Hovsgol Metallogenic Belt of Sedimentary Phosphate, Sedimentary Mn, and Sedimentary Fe-V Deposits (Belt HO) (Northern Mongolia)

This Vendian through Early Cambrian metallogenic belt occurs in the Huvsgol-Bokson sedimentary overlap assemblage. Sedimentary phosphate deposits and occurrences are mostly in the Vendian through Early Cambrian lower siliceous dolomite member of the Doodnuur or Kheseen Formations. Sedimentary Fe, sedimentary Mn, and sedimentary Fe-V occurrences are mainly above of the productive phosphate deposition in the Kheseen Formation, and also in clastic horizons of the Early Cambrian Khordil Formation (Ilyn, 1973). The metallogenic belt was first defined as a zone and as the Chubsugul phosphate basin by Ilyn (1973). Dejidmaa and others (1996) defined the belt as a complex metallogenic belt with sedimentary phosphorite, sedimentary Mn, Fe, Fe-Mn, and Fe-V deposits. The basin comprises approximately 30,000 km^2, trends generally north-south, is approximately 300 km long, and ranges from a few tens to 120 km wide (Ilyn, 1973). The major deposits are the Urandosh, Uhaagol, Janhai, Ongilog nuur, Manhan

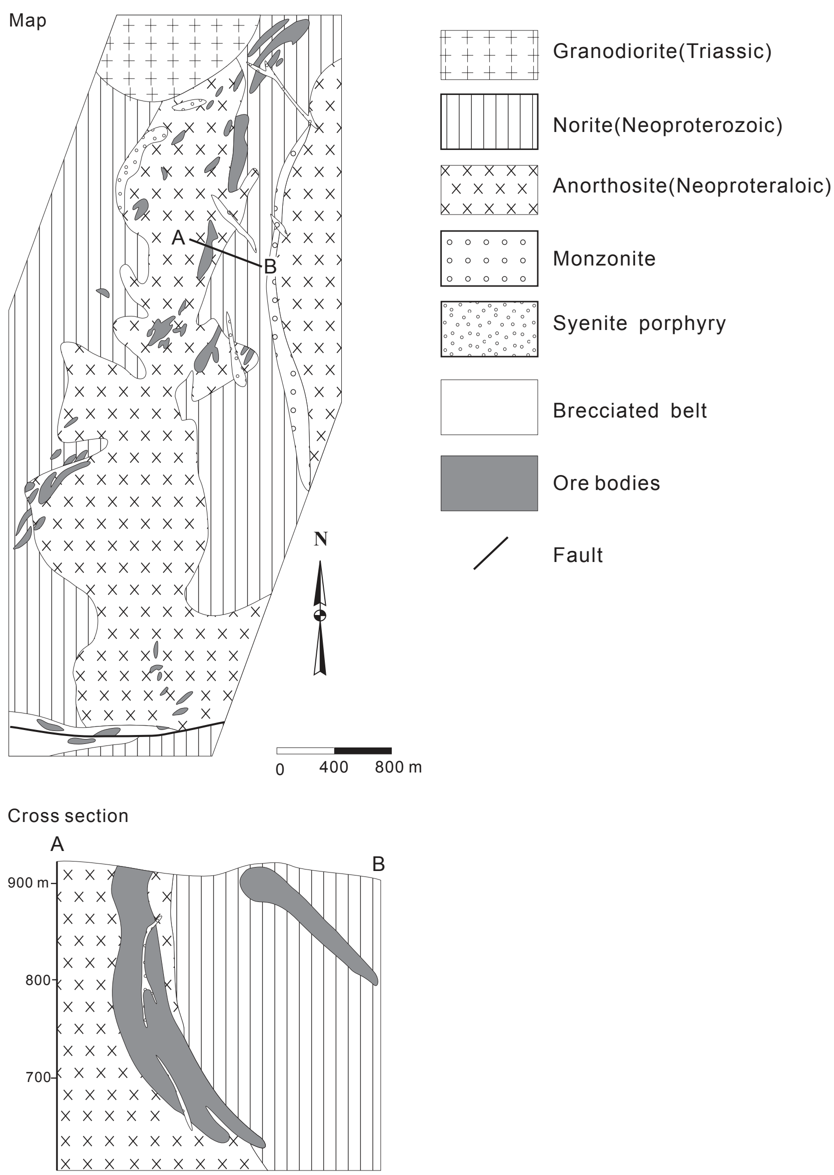


Figure 8. Generalized geologic map and cross section of Damiao mafic-ultramafic related Ti-Fe (V) deposit, Damiao metallogenic belt. Adapted from Dong (1993).

uul, and Burenhaan phosphorite deposits; the Ikh-Baga Tsagaangol and other Mn occurrences; and the Hatigiin gol, Tsahir uul, and other Fe-V occurrences.

The main references on the geology and metallogenesis of the belt are Dejidmaa and others (1966), Ilyn (1973), and Tomurtogoo and others (1999).

Hubsugul Sedimentary Phosphate Deposit

This deposit (Muzalevskii, 1970; Il'in, 1973; Byamba, 1996) consists of up to five phosphorite beds that alternate with dolomite, limestone, chert, aleurolite, and argillite in a phosphorite-bearing zone. The phosphorite beds range from 5 to 50 m thick, generally occur with carbonate rock, and form mainly aphanite and granular types. The deposit occurs in the Hubsugul Basin on the western coast of Lake Hubsugul. The basin extends 25 km stretching from south to north. The deposit occurs on both edges of the Hesen syncline in the lower part of the Vendian and Middle Cambrian Hubsugul series that consists of terrigenous and carbonate rock deformed in the late Riphean. The phosphorite deposit overlies Vendian sedimentary rock and is overlain by Late Cambrian limestone with archaeocyathids. The deposit is large and has an average grade of 20 to 40 percent P_2O_5. The deposit has produced 632.9 million tonnes.

Hitagiin gol Sedimentary Fe-V Deposit

The deposit (S. Tseveennamjil and others, written commun., 1983) occurs in Early Cambrian carbonate and terrigenous units in the Horidol Formation of the Hovsgol Group. Three horizons with V minerals occur, two hosted in siliceous carbonaceous slate, and one in chert. The host rocks are intercalated carbonaceous slate, siltstone, chert , and limestone, and quartzite. The deposit ranges from 600 to 2,700 m long and from 20 to 110 m thick. The resources are 11,039 million tonnes V_2O_5. Grades range from 0.05 to 0.235 percent V, up to 0.05 percent Mo, 0.002-0.034 percent Cu, and up 1.0 percent Pb, and 0.2 to 1.0 percent Ba.

Saihangol Sedimentary Mn Deposit

The deposit (C.A. Kiselov and others, written commun., 1959) consists of pyrolusite and minor hematite in siliceous layers in carbonate of the Early Cambrian Khoridol Formation. Main ore mineral is pyrolusite with minor hematite. The host rock containing the pyrolusite siliceous beds ranges from 10-20 m thick. The pyrolusite beds are 300 m long and 1.5 to 2.0 m thick. The beds dip steeply to north. The deposit is large and has an average grade of 4.0 to 36.72 percent MnO, 3.2 to 21.88 percent Fe_2O_3. Resources are 293 million tonnes ore containing 65 million tonnes Mn, and 43 million tonnes Fe.

Origin and Tectonic Controls for Hovsgol Metallogenic Belt

The belt is interpreted as having formed during shallow-water, carbonate-dominated sedimentation in the Minusa-Tuva back-arc basin.

Igarsk Metallogenic Belt of Sediment-Hosted Cu Deposits (Belt IG) (Western margin of North Asian Craton, Russia)

This Vendian through Early Cambrian metallogenic belt occurs in the northwestern North Asian cratonal margin and consists of lenses of red-bed sedimentary rocks that occur in a Vendian submontane basin in the Riphean Igarsk uplift (Dyuzhikov and others, 1988). The belt occurs in a sublongitudinal, narrow band up to 100 km long. The host late Riphean and Early Cambrian sedimentary rocks occur in three structural levels (1) intensely deformed clastic and carbonate rock of the Ludovsk and Gubinsk series (early and middle Riphean); (2) clastic and carbonate deposits of the Chernorechensk series, and red-bed clastic rocks of the Izluchinsk Series (late Riphean); and (3) carbonate rock with rare sandstone and siltstone of the Vendian and Early Cambrian Sukharinsk Series. There are two persistent horizons of Cu deposits. The lower horizon occurs in a transitional zone between the Izluchinsk red-bed suite and the underlying grey sedimentary rock of the Chernorechensk suite. This horizon is about 5 m thick (rarely up to 15 m) and consists of fine-grained disseminated digenite, bornite, and chalcopyrite. The upper horizon occurs at the base of marine grey deposits of the Sukharinsk suite and overlying red-beds of the Izluchinsk suite. The horizon is 10 to 30 m thick. Cu-rich areas often occur in the upper ore horizon (Graviiskoye and Sukharinskoye deposits). Two types of deposits are distinguished, deposits directly connected with host strata and crosscutting high-grade deposits in fracture zones. The major deposit is at Graviiskoye.

The main references on the geology and metallogenesis of the belt are Malich and Tuganova (1980), Malich and others (1987), Djuzhikov and others (1988), and Lurie (1988)

Graviiskoye Sediment-Hosted Cu Deposit

This deposit (Rzhevskiy and others, 1980; Gablina and others, 1986; Djuzhikov and others, 1988; Lurie, 1988) (fig. 9) is hosted in late Riphean red and grey sedimentary rock consisting of alternating argillite, clay limestone, and marl. Southern, Northern, Central, and Eastern deposits are recognized. The Southern and Northern deposits occur in basal layers of lagoon sedimentary rock. The Southern deposit is 3.3 km long, and the Northern deposit is 1 km, and both vary from a few meters to 60 m thick. Sulfide minerals occur in streaks. Main ore minerals are diagenite, bornite, chalcopyrite, and pyrite. Slight silica alteration of wall rocks occurs. The Central deposit occurs above a paleouplift between two reefs. The deposit is 900 m long and up to 70 m thick. Main ore minerals are djurleite and bornite that occur in lenses and streaks. Sparse chalcopyrite and galena occur at the deposit periphery. Wall-rock alteration consists mainly of intense silica alteration with widespread antraxolite. The Eastern deposit consists of numerous lenses and ore-bunches of Cu minerals in conglomerate and breccias in the reef shelf. Main ore minerals are digenite and bornite with rare chalcopyrite, galena, and pyrite. Wall-rock alteration consists of carbonate minerals, and sparse antraxolite. The deposit is small.

Origin and Tectonic Controls for Igarsk Metallogenic Belt

The belt forms the northern large segment of the Pribaikal-Yeniseisk Cu belt in the Igarsk uplift (Malich and others, 1987). The Cu-bearing rocks coincide with the late Riphean Norilsk-Turukhansk aulacogen. Cu deposits are related to the zones of lateral pinching of red-bed molasse sedimentary rock that formed in the final stage of development of orogen basin (Malich and Tuganova, 1980). Cu minerals were deposited in a katagenesis environment during migration of ground water. Metals precipitated along the hydrosulfuric geochemical barriers. The deposits are interpreted as having formed along flexures, anticline uplifts, and fracture zones that were favorable to migration of Cu-bearing grond waters (Lurie, 1988).

Jixi Metallogenic Belt of Banded Iron Formation (BIF, Algoma Fe), Homestake Au, Metamorphic Graphite, and Metamorphic Sillimanite Deposits (Belt JX) (Northeastern China)

This Neoproterozoic through Cambrian metallogenic belt occurs in the eastern Heilongjiang Province and is hosted in the Jiamusi metamorphic terrane and the Paleozoic Zhangguangcailing continental-margin arc superterrane. The belt trends north-south, is about 400 km long, and about 100 km wide. Most of the BIF, graphite, and sillimanite deposits are related to the Al-rich clastic rock and carbonate of the Mashan and Xingdong Groups that are regionally metamorphosed to granulite or amphibolite facies. Some deposits, such as the Dongfengshan BIF and Homestake Au-vein deposits, are related to volcaniclastic rock and carbonate in the Dongfengshan Group that is regionally metamorphosed to lower greenschist or amphibolite facies. The Mashan Group was interpreted as Late Archean or Paleoproterozoic, but recent isotopic ages suggest a Neoproterozoic age. The main deposits are at Shuangyashan, Liumao, and Dongfengshan.

The main reference on the geology and metallogenesis of the belt is Lu and others (1996).

Shuangyashan Banded Iron Formation (BIF, Algoma Fe) Iron Deposit

This deposit (Deng, 1980; Cao, 1993b) consists of bedded and stratiform BIF deposits that occur concordant to the

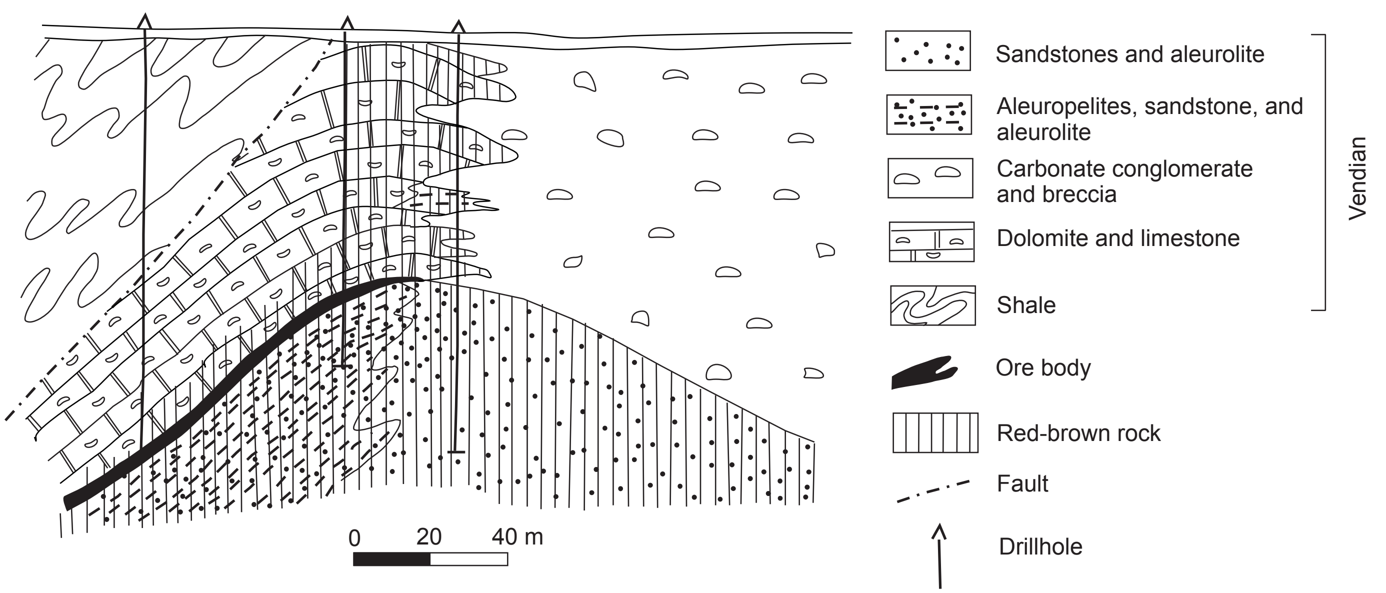


Figure 9. Schematic cross section of Graviiskoye sediment-hosted Cu deposit, Igarsk metallogenic belt. Adapted from Dyuzhikov and others (1988).

host rocks. The main deposit is 2,169 m long, 8 m thick, and extends 520 m down dip. The host rocks are sillimanite schist and gneiss, and marble of the Xingdong Group. The ores vary from banded to massive and consist of magnetite, hematite, scheelite, pyrite, quartz, augite, and diopside. The deposit is large and has an average grade of 30 percent Fe.

Liumao Metamorphic Graphite Deposit

This deposit (Xiao and others, 1994) (fig. 10) consists of bedded, stratiform and lensoid graphite in Al-rich gneiss, and is hosted in sillimanite gneiss, graphite schist and gneiss, and marble in the Jiamusi terrane. The deposit consists of graphite schist (13 to 16 percent C) and graphite gneiss (3 to 8 percent C). The main minerals are feldspar, quartz, mica, calcite, dolomite and varied metamorphic minerals, including more than 30 associated minerals. Single deposit layers range from 15 to 17 m thick and extend from several hundred to a thousand meters. Graphite schist, the main part of the deposit, comprises up to 80 percent ore. The host rocks are interpreted as having formed in a near shore and lagoon volcanic and sedimentary basin. A group of large graphite deposits occur in adjacent areas. The deposit is superlarge and has reserves of 28.25 million tonnes graphite.

Dongfengshan Homestake Au Deposit

This deposit (Xu and others, 1994) consists of stratiform Au deposits in BIF in the Proterozoic Dongfengshan Group. The BIF deposit occurs at the core of a anticline, varies from 40 m to 120 m thick, and contains 0.01 to 100.41 g/t Au. Four mineral facies occur in the BIF (1) a sulfide layer (5 m thick);

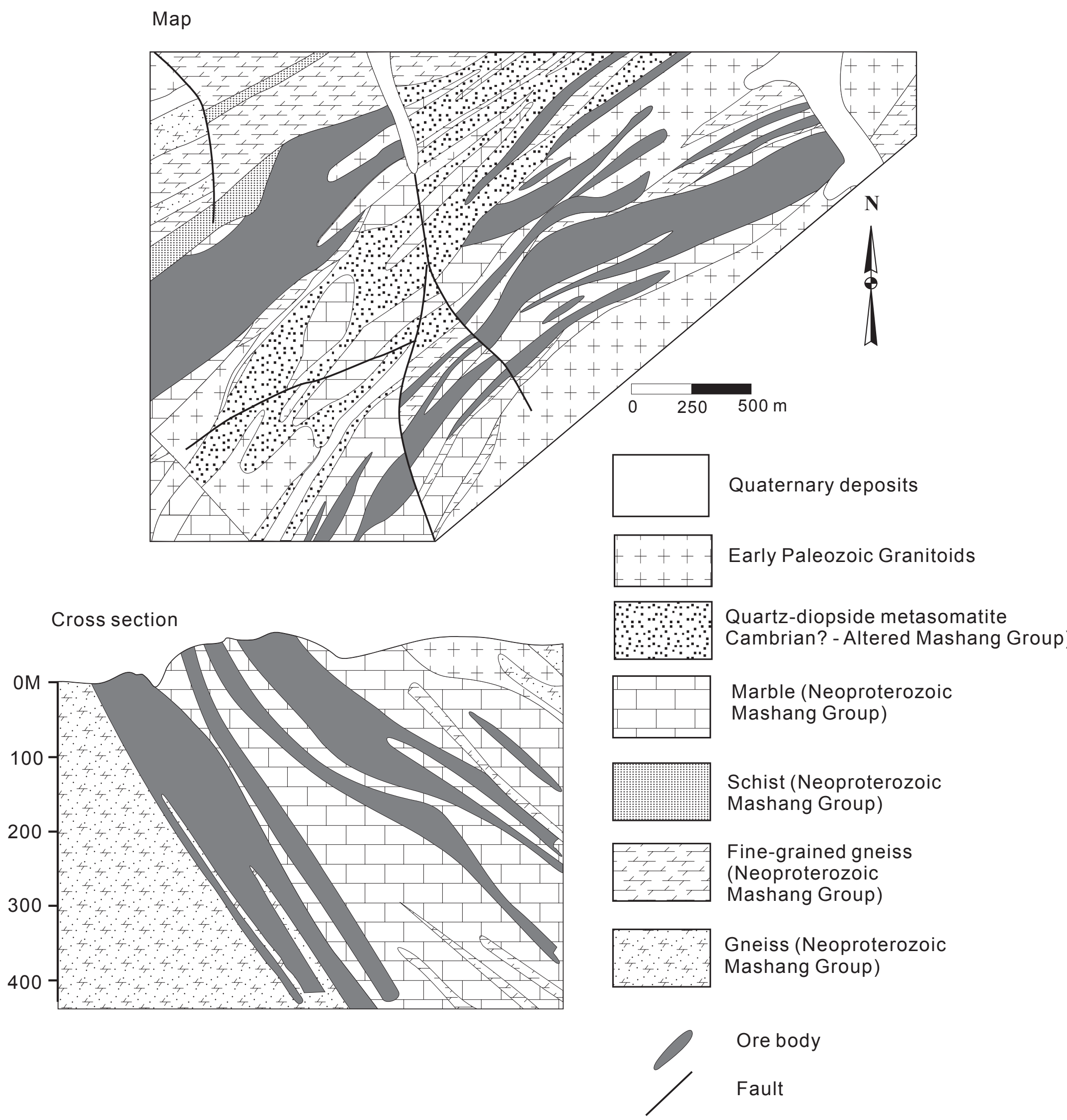


Figure 10. Generalized geologic map and cross section of Liumao metamorphic graphite deposit, Jixi metallogenic belt. Adapted afrom Zhang (1984).

(2) a carbonate layer (5 m thick); (3) a silicate layer (about 20 m thick); and (4) an oxide layer (about 10 m thick). Stratiform Au occurs mainly in sulfide layers and has complicated mineral assemblage including spessartine, dannemorite, eulite, biotite, quartz, tourmaline, flouroapatite, rutile, pyrrhotite, arsenopyrite, danaite, cobaltite, gersdorffite, chalcopyrite, sphalerite, magnetite, rutile, ilmenite, native Au, electrum, and graphite. Averaged fineness is 933. The deposit occurs at the intersection of the Jilin-Heilongjiang Variscian orogenic belt and the Jiamusi fault zone. The deposit is small and has an average grade of 19 g/t Au.

Origin and Tectonic Controls for Jixi Neoproterozoic Metallogenic Belt

The belt is hosted in a khondalite that is interpreted as derived from Al-rich mudstone and carbonate deposited in isolated oceanic basin and lagoon in a shallow sea (Lu and others, 1996). Part of the belt is hosted in the Jiamusi metamorphic terrane that consists of (1) sillimanite schist, quartz schist, felsic gneiss, graphitic schist, and marble of the Mashan Group; and (2) migmatite, gneiss, quartz schist, graphite schist, banded iron formation, and marble of the Xindong Group. Part of the metallogenic belt is also hosted in the Zhangguangcailing continental-margin terrane that consists of slate, schist, quartzite, marble, and metasandstone. The sedimentation probably occurred in the Neoproterozoic. The isotopic age of metamorphism is 500 Ma. The region including the Jixi Neoproterozoic-Cambrian metallogenic belt, is interpreted as part of the Gobi-Amur microcontinent that was derived from the Gondwanaland passive continental margin.

Kyllakh Metallogenic Belt of Carbonate-Hosted Pb-Zn (Mississippi Valley type) Deposits (Belt KY) (Russia, Southern Verkhoyansk terrane (fold- and thrust-belt))

This Vendian metallogenic belt is hosted in carbonate sedimentary rock. The belt extends longitudinally for 400 km along the North Asian craton boundary in the southern Verkhoyansk terrane (fold- and thrust-belt). The belt is hosted primarily in thick Riphean through Cambrian carbonate and clastic rock. Several stratigraphic horizons of stratiform Pb-Zn and Cu deposits are recognized. The main deposits (from bottom to top) are in the (1) middle Riphean Bik and Muskel Formations (Cu, Pb-Zn); (2) late Riphean Lakhanda Formation (Pb-Zn); (3) late Riphean Uy Formation (Cu, Pb-Zn); (4) Vendian Sardana formation (Pb-Zn); (5) Early Cambrian Pestrotsvetnaya Formation (Cu); and (6) Middle Cambrian Ust'-Maya Formation (Cu). The major horizon is the Vendian Sardana Formation that contains about 40 Pb-Zn deposits and occurrences that occur in a transition zone from the western, near-platform facies to the eastern, basin facies area. The Sardana Formation is subdivided into a lower barren sandstone, mudstone, and carbonate unit, and an upper productive limestone and dolomite unit. Commercial deposits occur in the area of facial thinning out of saccharoidal dolomite. The major deposits are at Sardana, Urui, and Pereval'noe.

The main references on the geology and metallogenesis of the belt are Arkhipov (1979), Davydov and others (1990), Davydov (1992), and Parfenov and others (1999).

Sardana Carbonate-Hosted Pb-Zn (Mississippi Valley type) Deposit

This deposit (Ruchkin and others, 1977; Kutyrev and others, 1988; Davydov and others, 1990) consists of disseminated, banded, massive, brecciated, and stringers of ore minerals in and adjacent to a dolomite bioherm that ranges from 30 to 80 m thick and is hosted in the Neoproterozoic (late Vendian) Yudom Formation. Lensoid deposits are concordant with dolomite in the Upper Sardana subformation that contains three members (from bottom to top) (1) light-grey fine-grained dolosparite (17 to 30 m thick); (2) dark-grey bituminous limestone and dolosparite (5 to 29 m thick); and (3) layered limestone and massive saccharoidal dolosparite (31 to 87 m thick). Several ore horizons occur, and the central area on the western limb of the Kurung anticline is the most productive. In this area, three Pb-Zn sulfides deposits extend for 150 to 1300 m and range from 9 to 70 m thick. The largest part of the deposit occurs in the third member and ranges up to 50 m thick. Galena and sphalerite are predominant and occur in masses, veinlets, and disseminations. Main ore minerals are sphalerite, galena, and pyrite, with subordinate chalcopyrite, marcasite, and arsenopyrite. Oxidized ore minerals are smithsonite, cerussite, anglesite, goethite, hydrogoethite, and aragonite. The deposit is the largest deposit in the Sardana Formation and occurs in the Selenda syncline that is complicated by the Kurung anticline and longitudinal thrusts. Low-grade disseminations occur in Neoproterozoic (upper Vendian) dolomite for many kilometers in both limbs and in the axis of a north-south-trending syncline that is 3 km wide and more than 10 km long. The deposit is intruded by sparce diabase and dolerite dikes. Average combined Pb+Zn grade is 6 percent, with a maximum of 50 percent. The deposit is large and has reserves of more than 1.0 million tonnes combined Pb+Zn. Drilling indicates additional sulfide bodies occur at a depth of 200 to 300 m.

Origin and Tectonic Controls for Kyllakh Metallogenic Belt

The belt is interpreted as having formed in a residual terrigenous marginal basin spatially related to the North Asian cratonal margin.

Lake Metallogenic Belt of Volcanogenic Cu-Zn Massive Sulfide (Urals type, Volcanogenic-sedimentary Fe, Podiform Cr, Mafic-Ultramafic Related Ti-Fe, Cu (± Au, Ag, Fe) Skarn, Fe Skarn, Granitoid-related Au Vein, Cyprus Cu-Zn Massive Sulfide, and Mafic-Ultramafic Related Cu-Ni-PGE Deposits (Belt LA) (Western Mongolia)

This Late Neoproterozoic (Vendian) to Late Cambrian metallogenic belt is hosted in the Lake island-arc terrane (Tomurtogoo and others, 1999). The metallogenic belt was defined by Dejidmaa and others (1996) as a complex metallogenic belt with different type deposits and occurrences. The northern part of the belt trends north-south and the southern part trends southeast to east. The belt is approximately 30 to 100 km in the southern part, varies from 200 to 250 km wide in northern part, and is approximately 1000 km long. A large part of the belt is covered by Cenozoic surficial deposits and large lakes. Cu sulfide deposits and volcanogenic-sedimentary Fe deposits and occurrences are related to the Vendian through Early Cambrian Khantaishir ophiolite complex in basalt, andesite, dacite, and rhyolite volcanic rock in the Early Cambrian Tsol uul, Icheet, Daagandel, Ulaanshand, and Khanhohii Formations. The mafic-ultramafic related podiform Cr and zoned mafic-ultramafic related Fe-Te occurrences occur in ultramafic rock in the Vendian through Early Cambrian Khataishir ophiolite complex, and in ultramafic intrusions in the Khanhohii area. Cu skarn, Fe skarn, and granitoid-related vein, stockwork, and replacement Au deposits are related to the Middle and Late Cambrian throughgtohiin shil igneous complex that consists of gabbro, tonalite, and granite. Gabbroic Ni-Cu occurrences are related to the Middle Cambrian Khyargas nuur igneous complex that consists of layered pyroxenite, gabbro, norite, and troctolite (Izokh and others, 1990).

The major deposits in the belt are (1) major disseminated Cu sulfide deposits at Borts uul, Mendeeheindavaa, Narandavaa, and Suvraagiin; (2) Au massive sulfide deposits at Gozgor, Khurendosh uul and Suvraa; (3) volcanogenic-sedimentary type Fe occurrence at Bayanhudag; (3) mafic-ultramafic related podiform Cr occurrences at Nogoontolgoi and Bideriingol; (4) mafic-ultramafic related Fe-Ti occurrences at Turgengol and Dumberel uul; (5) Cu skarn occurrences at Togloin khudag, Alag uul, and Jargalant nuruu; (6) Fe skarn occurrence at Arvangurav; (7) granitoid-related stockwork and replacement type Au occurrence at Khyargas; and (8) alayered gabbroic type Ni-Cu(± PGE) occurrences at Bust khairhan and Altan khudag.

The main references on the geology and metallogenesis of the belt are Izokh and others (1990), Dejidmaa and others (1996), and Tomurtogoo and others (1999).

Bideriingol Podiform Chromite Deposit

This deposit (A. Rauzer and others, written commun., 1987) consists of lenses of massive chromite and pockets of disseminated chromite in ultramafics of the Khantaishir ophiolite Complex of Vendian through Early Cambrian age. Lenses are 0.2 m by 3.0 m. Disseminated chromite mineralization forms pockets 5.0 m by 3.0 m in melanged serpentenite. Chromite constitutes from 20-30 percent to 50 to 70 percent the pockets. Grab samples from weakly disseminated ore contained 0.3-0.5 percent Cr, 0.2 to 0.5 percent Ni, 0.02 percent Co, and 0.01 percent. Cu

Borts Uul Volcanogenic Cu-Zn Massive Sulfide (Urals type) Deposit

This deposit (D. Baatar and others, written commun., 1979) consists of sulfide rich lenses and tabular bodies in volcanic rock at the intersection of the Khangai and Zavkhan major faults. The deposit contains three parts. The Northern part hosts faulted horizons and lenses of andesite, dacite, basalt tuff and volcanic breccia. The three main bodies are tabular and conformable with host volcanic rocks. Sulfide bodies and host rocks are folded together. Sulfide bodies ranges from 1 to 17 m thick and extend up to 1.4 km long. Ore minerals occur in irregular masses, disseminations, stringers, and nests. A gradational contact occurs between host rock and sulfides. Grade varies widely up to 4.0 percent Cu and the average grade sulfide bodies is 0.5 to 0.6 percent Cu, up to 60.0 g/t Ag and up to 0.4 g/t Au. Ore minerals are chalcopyrite, chalcocite, bornite, cuprite, covellite, and copper oxides. Host rock is altered and white. Chlorite and epidote alteration is widely developed. The Central part consists of sheets and lenses of andesite, basalt, dacite tuff, tuff, and tuff-breccia, strikes northwest, and extends for 0.5 km. Two main zones range from 2.0 to 15.0 m thick and contain sulfide lenses or tabular bodies that range from 0.2 to 2.0 m thick and dip steeply. Other features are similar to the Northern part. Average grades are 1.3 percent Cu and 5.0 g/t Ag. The third or Pyrite part occurs 1.5 km east of the Central part and is hosted in dacite porphyry and tuff. Finely disseminated pyrite occurs in a zone 100 by 250 m. Pyrite is intensively oxidized and limonite is well developed. Cu minerals are rare. Grades are up to 0.1 percent Cu, up to 0.4 g/t Au, and up to 5.9 g/t Ag. The deposit is large and has an average grade of 0.6 to 1.3 percent Cu with a cutoff grade of 0.1 percent Cu. Resource in the Northern part is 28,200 tonnes Cu with average grade of 1.0 to 1.5 percent Cu to a depth of 100 m.

Khyargas Granitoid-Related Au Vein Deposit

This deposit (B.A. Samozvantsev and others, written commun.,1982) consists of a sublatitudinal-trending listwanite zone in serpentinite. The zone ranges from 50.0 m to 100.0 m wide, is up to 500.0 m long, and occurs in a melange zone. The ore minerals are pyrite and chalcopyrite, malachite, and Fe oxides. Abundant ore minerals occur in the northwest part in an area up to 16.0 m thick, and in the northwest part in an area up to 8.0 m thick. Channel samples grade up to 1.6 percent Cu, up to 3.0 g/t Au (in 1 sample 6.0 g/t), up to 20.0 g/t Ag, up to 0.3 percent Ni, and up to 0.6 percent As. To the southwest, the zone is surrounded by small outcrops of amphibole-garnet skarn with hematite and malachite. The skarn contains 0.01 to 0.09 percent Zn and Cu, 0.2 g/t Au and 1.0 g/t Ag. For the deposit, the average grade is 0.01 to 0.09 percent Zn+Cu, 0.2 g/t Au, and 1.0 g/t Ag.

Naran Davaa Cyprus Cu-Zn Massive Sulfide Deposit

This deposit (A.A. Rauzer, and others, written commun., 1987) consists of a northwest-trending zone with chlorite, epidotie, quartz-sulfide stringers, and disseminated pyrite, chalcopyrite, hematite. The zone occurs in an area 0.7 km wide and 2.5 km long in Vendian mafic-ultramafic bodies and Vendian through Lower Cambrian chlorite and chlorite-sericite schist that are overlain by Middle Devonian carbonate rock. The zone is as much as 10.0 m thick and up to a few hundred meters long. Rock chip and grab samples contain 0.01 percent to 1.0-2.0 percent Cu, 0.001 to 0.2 percent Ni, 0.001 to 0.01 percent Co, up to 0.2 percent Cr, up to 15.0 g/t Ag, 0.001 percent Mo, and up to 0.01 g/t Au. Abundant sulfides (chalcopyrite, malachite, and azurite) occur in areas of disseminated sulfides. The average grade in abundant sulfide bodies ranges is as much as 10.0 percent Cu. Similar zones occur to the east and west.

Tsagdaltyn Davaa Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (B.N. Podkolzin and others, written commun., 1990) occurs in 3.5 km^2 serpentinite massif. The ore minerals are magnetite, a black Ni mineral, chromite, and martite. Other minerals are ilmenite, limonite, chalcopyrite, pyrite, and pentlandite. The massif strikes northeast for 5.0 km, and ranges up to 0.7 km wide. Chrisotile-asbestos stringers range up to 0.5 cm thick. Grab samples contain 0.016 to 0.24 percent Ni (average of 0.175 percent); 0.003 to .023 percent Co (average of 0.008 to 0.013 percent), and up to 0.02 percent Cu. In the central part of the serpentinite massif pyroxenite us replaced by amphibole. Pyroxenite contains up to 0.4 percent, Cr, 0.02 to 0.06 percent Ni, 0.01 to 0.02 percent Co, and 0.02 to 0.1 percent Cu. One sample contains 0.003 g/t Au. Gold occurs in pan concentrates of stream sediment samples from small valleys in the massif.

Origin and Tectonic Controls for Lake Metallogenic Belt

The magmatic deposits of belt are interpreted as having formed in the Late Neoproterozoic through Early Cambrian Dzhida-Lake island arc. The sediment-hosted deposits are interpreted as having formed during sea floor spreading volcanism and related mafic-ultramafic magmatism.

Pribaikalskiy Metallogenic Belt of Carbonate-Hosted Pb-Zn (Mississippi Valley Type) Deposits (Belt PrB) (Russia, Western Transbaikalia)

This Riphean metallogenic belt occurs along the juncture of Paleoproterozoic Akitkan active continental margin, consisting of a volcanic-plutonic belt, with sedimentary rock of the Baikal-Patom fold- and thrust-belt that is the southern part of the North Asian craton. The belt extends along the northwestern coast of Lake Baikal for 170 km and ranges from 30 to 50 km wide. The tectonic setting of the belt is defined by tectonic and magmatic processes associated with the Akitkan volcanic-plutonic belt along the margin of North Asian craton. This Paleoproterozoic volcanic-plutonic belt consists of subalkaline, siliceous lava, minor basalt porphyry, and subaerial volcanic and sedimentary rock. Also occurring are comagmatic diorite, granodiorite, and granite, and rapakivi granitoids in the Primorsky Complex with an isotopic age of 1,690 ± 40 Ma. The overlap assemblage consists of clastic and carbonate sedimentary rock of the Baikal series (Goloustenskaya and Uluntuy suites) that extend along the margin of the craton for 1,000 km with monoclinal northwest dips. The sedimentary rocks consist of fine-grained limestone, unequigranular micro- and coarse-crystalline limestone with oolite-like internal structure, sedimentary and diagenetic dolomite, talc rock, and talc-carbonate rock. The monoclinal dip is complicated by longitudinal S folds and higher-order folds. The deposit controls are folds and regional shear zones that consist of lenses and sublaminated bodies of talc rock, and quartz and aragonite veins. The shear zones formed during overthrusting of the deposit-enclosing sequence over the older volcanic rock. The major deposit in the belt is at Barvinskoye.

The main references on the geology and metallogenesis of the belt are Tychinsky and others (1984), and Tychinsky (1986).

Barvinskoye Carbonate-hosted Pb-Zn (Mississippi Valley type) Deposit

This deposit consists mainly of sulfides in layers, lenses, veins, and disseminations (Tychinsky and others, 1984) that occur along concordant ruptures and shears that control the deposit. Also occurring are crossing verins. Sphalerite, galena, fluorite ore is the most productive. The host rocks exhibit widespread are metasomatic alteration. The deposit is interpreted as having formed during hydrothermal activity.

Origin and Tectonic Controls for Pribaikalskiy Metallogenic Belt

The belt is interpreted as having formed along shear zones and faults that occurred along an ancient active continental margin on the southern margin of the North Asian craton.

Prisayanskiy Metallogenic Belt of REE (Ta, Nb, Fe) Carbonatite; Mafic-Ultramafic Related Ti-Fe (+V); Diamond-Bearing Kimberlite; and Talc (magnesite) Replacement Deposits (Belt PrS) (Russia, East Sayan)

This Late Neoproterozoic metallogenic belt is related to the following units in the Onot granite-greenstone, Sharizhalgay tonalite-trondhjemite gneiss, and Urik-Iya greenschist terranes (1) mafic-ultramafic plutons in the Ziminsky complex; (2) upper part of Onot terrane that consists of interbedded amphibolite, and magnesite and talc layers; and (3) ultramafic alkaline plutons; and (4) sparse micaceous kimberlite dikes. The age range of metallogenic belt is interpreted as Late Neoproterozoic. The belt occurs in southwest of Irkutsk Oblast in the East Sayan Mountains and trends northwest along the junction of the North Asian craton and Sayan Mountains. The belt is 400 km long and has an average width 50 to 60 km.

The Sharyzhalgay terrane consists of Archean biotite-hornblende, biotite-hypesthene gneiss, schist, amphibolite, pyroxene plagiogneiss, sillimanite schist, ferruginous quartzite, coarse-grained marble, and granulite and charnockite. The lower part of the Onot terrane consists mainly of calc-alkaline, bimodal, volcanic rock, and the upper part consist of metamorphosed sedimentary rock with interbedded amphibolite, magnesite rock, and talc rock. These units are intruded by gabbro of the Arbansky complex and rapakivi granitoids of the Paleoproterozoic Shumikhinsky complex. The Urik-Iya terrane consists of Paleoproterozoic schist, phyllite, metasandstone, amphibolite, and spillite and keratophyre.

The belt contains deposits and occurrences in large districts with REE, Ti, and talc replacement deposits and small diamond occurrences. The major deposits are at Belo-Ziminskoye, Sredne-Ziminskoye; Zhidoyskoye; Ingashinskoye; and Onotskoye. The diversity of deposits suggests that this belt is fairly promising for discovery of new, large REE, Ti, magnesite, and talc-replacement deposits.

The main references on the geology and metallogenesis of the belt are Frolov (1975), Levitsky (1994), Emelyanov and others (1998), and Mekhonoshin (1999).

Beloziminskoye REE (Ta, Nb, Fe) Carbonatite Deposit

This deposit (Pozharitskaya and Samoilov, 1972; Frolov, 1975; Emelyanov and others, 1998) consists of a stockwork calcite carbonatite body that occurs in a core of an alkaline ultramafic pluton. The stockwork extends more than 10 km^2, forms an northwest-trending ellipse, and extends to about 750 m depth. The stockwork is surrounded by a carbonatite vein zone that is about 100 m thick and extends up to 1 km long. Carbonatite contains relics of silicate rock in the peripheral part of the stockwork. The carbonatite consists of apatite, magnetite, and phlogopite. The deposit formed in four stages and the second stage is the most economic. Outward to inward, the major mineral zones are pyroxene, forsterite, mica, and monomineral calcite. REE minerals include disanalite, baddeleyite, zirkelite, hatchettolite, and pyrochlore. Baddeleite, dizanalite, and zirkelite occur only in peripheral parts adjacent to host rock. Hatchettolite is widespread in the external zone, and pyrochlore occurs in the internal zone. The deposit is large and has an average grade of 0.39 percent; Nb_2O_5 and 0.015 to 0.017 percent Ta_2O_5.

Onotskoe Talc (Magnesite) Replacement Deposit

This deposit (Korenbaum, 1967; Romanovich and others, 1982) (fig. 11) occurs in the western part of the Onotsky graben that contains early Proterozoic volcanic and carbonate rock. Most of the talc is in carbonate in the Kamchadal sequence. Two productive horizons occur (1) a lower horizon is 100 to 150 m thick and consists of dolomite and magnesite in lenses in limestones and various metamorphic rock, and (2) an upper horizon is 20 m thick and consists of magnesite. The deposit occurs in the lower horizon that is sheared and deformed into recumbent steeply dipping folds. The deposit hosts seven large ore bodies of different morphology and composition. Of economic significance are veins and swells that form 32 ore bodies with thicknesses from a few to 50-80 m, lengths of 200 to 600 m, and depths of more than 260 m. Ore minerals are talc, magnesite, chlorite, graphite, dolomite, serpentine, hematite, sagenite, apatite, and quartz. The origin is interpreted as an apomagnesite talc deposit with massive structure (steatites). The structure is thin to scaly. The ore quality is high, and the color varies from white to light green to light gray. Chemical composition is 59.8 percent SiO_2; 1.8 percent Al_20_3, 0.3 percent Fe_20_3, 1.4 percent FeO, 0.2 percent TiO_2, 33.9 percent MgO, 0.4 percent CaO. The deposit is medium size.

Ingashinskoye Diamond-Bearing Kimberlite Deposit

This deposit (Pechersky, 1965; Prokopchuk and Metelkina, 1985; Sekerin and others, 1993) occurs in a dike field of nine small bodies (0.08-1.0 by 50-850 m) that intrude Paleoproterozoic schist. The dikes are composed mainly of olivine and phlogopite, and minor minerals are serpentine, talc, calcite, titanomagnetite, pyrope, and chrome-spinel, and rare ilmenite, apatite, diamond, chlorite, and volcanic glass, and local priderite, armalcolite, and alkaline amphibole. Most abundant are chrome spinel and orange almandine, and pyrope, and rare chrome diopside and magnetite. The dike thicknesses are extremely irregular, and the dike dip is subvertical. Dikes are subdivided into three types (1) calcite-lacking with glassy bulk mass (olivine lamproites); (2) calcite with phlogopite (micaceous kimberlite); and (3) low-calcite with olivine (transitional). An isotopic age for the dikes is 1268 Ma. The small Yuzhnaya pipe at Belaya Zima is composed of kimberlite-like breccia. Diamonds are rhombododecahedral

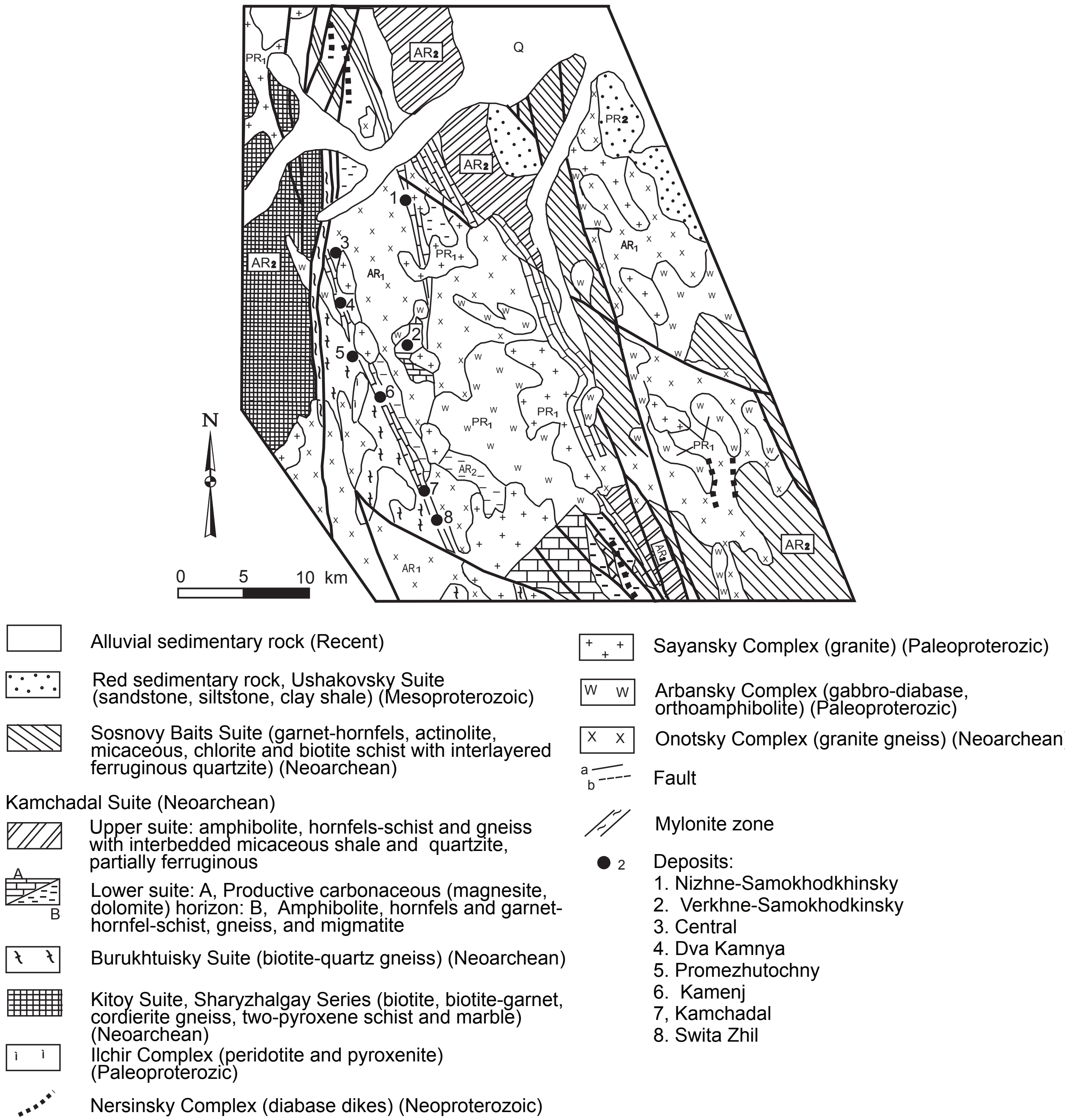


Figure 11. Generalized geologic map of Onotskoe talc (magnesite) replacement deposit, Prisayanskiy metallogenic belt. Adapted from Livitsky and others (1984).

and range up to 60 mg with green spots. A single crystal of balas diamond is known. The deposit occurs on the eastern flank of the Urik-Iisk graben where cut by the Urik-Tumanshet tectonic zone along the flank of the Birusinsky block. The deposit is small and low grade.

Origin and Tectonic Controls for Prisayanskiy Metallogenic Belt

The various deposits in belt are hosted in a variety of units in the Onot granite-greenstone and Sharizhalgay tonalite-trondhjemite gneiss terranes (1) mafic-ultramafic plutons in the Ziminsky complex; (2) the upper part of Onot terrane that consists of interbedded amphibolite, and magnesite and talc layers; (3) ultramafic alkaline plutonic rocks; and (4) sparse micaceous kimberlite dikes. The host terranes are uplifted parts of Precambrian craton crystalline basement of the North Asian craton.

Vorogovsko-Angarsk Metallogenic Belt of Sedimentary-Exhalative Zn, Pb (SEDEX), Carbonate-hosted Pb-Zn (Mississippi Valley type), and Fe Skarn Deposits (Belt VA) (Yenisei Ridge, North-Asian Craton Margin, Russia).

This Early Neoproterozoic metallogenic belt (also known as Yenisei Ridge polymetallic belt) occurs at the western margin of the Yenisei Ridge in the West Angara passive continental-margin terrane in the Bolshepit synclinorium. The belt is about 450 km long and varies from 100 km (to the south) to 25 km (to the north) wide. The largest Pb-Zn deposits occur in the southern belt in the Priangarsk ore district. The main types of deposits in this district are (1) hydrothermal-sedimentary deposits with pyrite, pyrrhotite, and sphalerite that are conformable with host clastic and carbonate rocks (Gorevskoye); and (2) galena and sphalerite streaks and disseminations that occur in algal limestone and dolomite (Moryanikhinskoye, Merkurikhinskoye, and others). To the north, in the Rassokhinskoye district (Lineinoye, Krutoye), and Bolshepitsk and Teneginsk districts are more than 300 deposits and occurrences that are mostly hosted in middle and late Riphean carbonaceous and clastic rock in a graben or syncline. Also occurring in this area are Pb-Zn silicate and oxide deposits in carbonate rock (Teneginskoye); polymetallic vein deposits adjacent to porphyry deposits; and large Fe-skarn deposits (Enashiminskoye, Lendakhskoye, Polkan Gora) that occur near a central anticlinorium. These deposits and occurrences are related to middle and late Riphean volcanism and eruption of rhyolite and andesite-basalt, and subsequent formation of skarn along contacts with the granitoid plutons (Matrosov and Shaposhnikov, 1988). Three environment are defined for the various hydrothermal-sedimentary and polygenic stratiform Pb-Zn deposits (1) deposition of proximal massive Pb-Zn sulfide deposits in local fault basins in clastic and carbonate sedimentary rock (Gorevskoye); (2) deposition of distal pyrite and polymetallic deposits in carbonaceous schist in deeper parts of basins (Lineynoye); and (3) deposition of carbonate-hosted Pb-Zn deposits hosted in carbonate reefs and sedimentary carbonate breccia horizons (Moryanikhinskoye, Merkurikhinskoye) (Ponomarev and others, 1991).

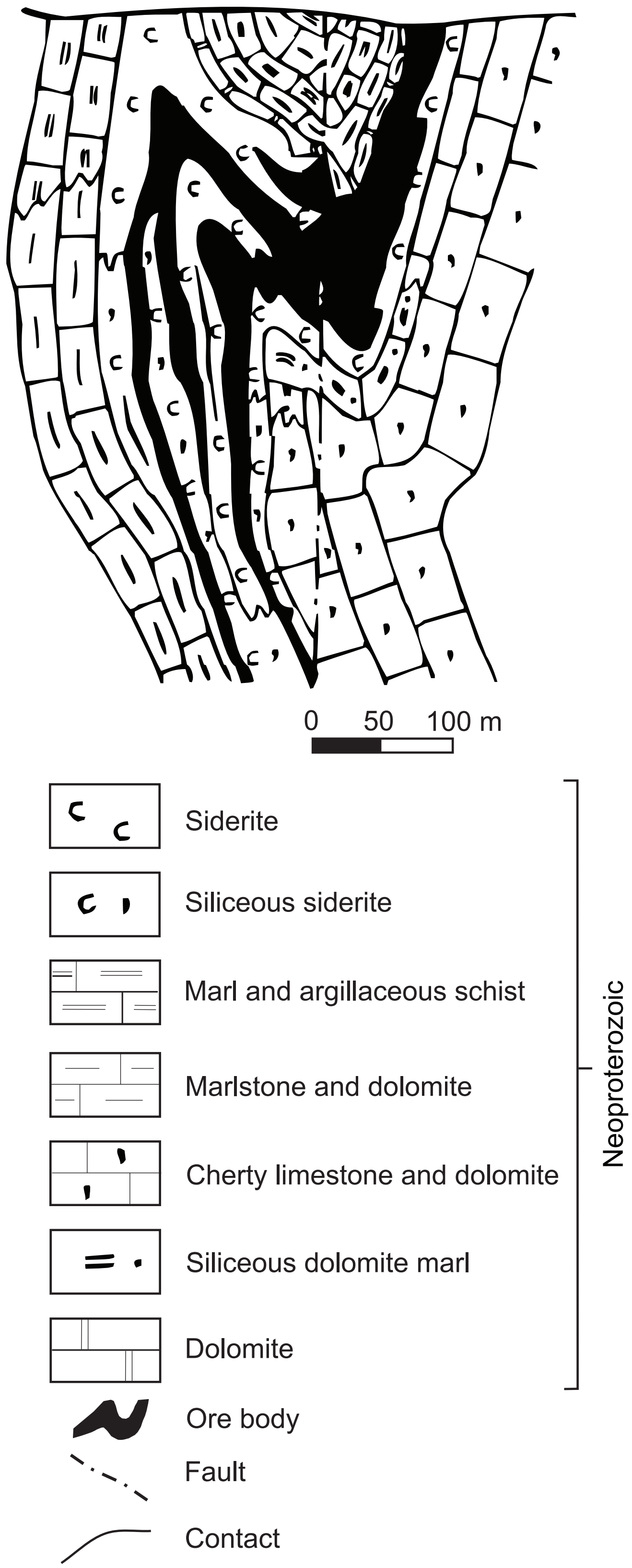
The main references on the geology and metallogenesis of the belt are Matrosov and Shaposhnikov (1988), Distanov (1985), Ponomarev and others (1991), and Obolenskiy and others (1999).

Gorevskoye Sedimentary Exhalative Pb-Zn (SEDEX) Deposit

This deposit (Distanov, 1985; Brovkov and others, 1985; Kuznetsov and others, 1990; Avdonin, 1997) (fig. 12) consists of concordant lensoid masses of Pb-Zn sulfides hosted in late Riphean clastic and carbonate rock. The deposit occurs in a small synclinal fold on the limb of a larger anticline that is cut by the Main fault and associated fracture and shear zones on the northeast limb. Host rocks consist of a uniform sequence of dark-gray lenticular limestone with thin interbedded marl and shale. Host rocks are intensely deformed and metamorphosed to greenschist facies. Also occurring are numerous diabase dikes up to 10 m thick and several hundred meters long. Three separate deposits occur and range from 20 to 150 m wide, extend northwest for up to 1200 m, form an en-echelon system, and dip at 75 to 85°. The deposits extend to 1000 m depth at the southeastern flank of the deposit. Host rock is mainly siliceous siderite rock. The ore mineral structures are lenticular, layered, streaky, massive, breccia, and disseminated. Main ore minerals are galena, pyrrhotite, and sphalerite, and lesser pyrite, marcasite, burnonite, boulangerite, jamsonite, arsenopyrite, ilmenite, rarely chalcopyrite, tennantite, argentite, pyrargirite, prustite, sternbergite, diskrasite, native silver, and lollingite. In decreasing abundance, the gangue minerals are quartz, siderite, ankerite, dolomite, calcite, biotite, muscovite, and garnet. Sphalerite occurs mainly in the hanging wall of the district, whereas galena is concentrated in the footwall. Ag, Cd, Ta, and Te occur in solid solution. A model Pb isotopic age for the deposit is 852 to 834 Ma. The deposit is a large, is world class, and has an average grade of 7.02 percent Pb and 1.36 percent Zn.

Moryanikhinskoye Carbonate-Hosted Pb-Zn (Mississippi Valley type) Deposit

This deposit (Ponomarev and others, 1991) consists of layered bodies of disseminated, streaky, and massive Pb-Zn sulfides hosted in late Riphean dolomite and limestone. The deposit occurs in a southeastern periclinal closing of an anticline complicated by a shear zone. Host rocks are 320 m thick and consist of dark-grey dolomite and algal ferruginous limestone with interbedded shale, marl and tuffaceous siltstone, with single beds of schistose metabasalt porphyry and blastoporphyritic quartz-sericite schist. A spatial relation



Figre 12. Schematic cross section of Gorevskoye sedimentary exhalative Pb-Zn (SEDEX) deposit, Vorogovsko-Angarsk metallogenic belt. Adapted from Kuznetsov and others (1999).

between Pb-Zn deposits and organic carbonate units exists. Five concordant layered deposits occur, and extend more than 500 m along strike and are as much as 600 m deep. The thickness of deposits ranges from 3.0 to 8.7 m, occasionally as much as 33 m. Boundaries of deposits are gradational, particularly for disseminated ores. Main ore minerals are galena, sphalerite, and pyrite, and rare pyrrhotite, chalcopyrite, bournonite, and fahl. The main gangue minerals are quartz and Fe-carbonate. Galena and sphalerite with a Zn:Pb ratio of 2:5 are predominant. Chalcopyrite and fahl are typical minerals in veins along with sphalerite, galena and pyrite. The deposit is interpreted as having formed under polygenous hydrothermal and sedimentary conditions. A model Pb isotopic age for the deposit is 849 to 740 Ma. The deposit is medium size and has an average grade of 2.5 percent Pb and 1.1 percent Zn.

Enashiminskoye 2 Fe Skarn Deposit

This deposit (Matrosov and Shaposhnikov, 1988) consists of layers and lenses of magnetite in metamorphosed middle Riphean volcanic, carbonate, and clastic rocks. Host rocks and Fe-ores are intruded by Chirimbinsk granitoid pluton. The contact zone is contact metamorphosed, carbonate-altered, and silicified and contains epidote-amphibole-garnet skarn. The district containing the deposit extends up to 4.7 km along strike and contains more than 20 deposits that vary from 5 to 70 m thick, are up to 700 m long, and are up to 650 m deep. The deposit minerals are magnetite, epidote, and amphibole. The deposit contains anomalous Ti, V, Cr, and Mn, and anomously low S and P. The deposit formation was polygenetic with initial formation of primary siliceous-carbonate and ferruginous sedimentary rocks that were regionally metamorphosed, contact-metasomatized. The deposit is large and has resources of 450 million tonnes grading 36 to 51 percent Fe.

Origin and Tectonic Controls for Vorogovsko-Angarsk Metallogenic Belt

The SEDEX deposits in the belt are interpreted as having formed along major fault depressions along transcrustal block in pericratonal subsidences. Carbonate-hosted Pb-Zn deposits formed in carbonate reefs. Volcanogenic-sedimentary Fe deposits are interpreted as having formed during marine volcanism and sedimentation. The metallogenic belt is interpreted as having formed during convergence along a middle to late Riphean continental margin (Obolenskiy and others, 1999). The principal structural control for the Gorevskoye deposit was the intersection between a system of northwest block-bounding faults and the transversal Irkeneevsk plate boundary fault. Host rocks and the coeval deposits have model Pb isotopic age of about 950 Ma. Approximate coeval units are collision-related granite plutons (Tatar-Ayakhta complex) and dolerite dikes.

Summary of Cambrian through Silurian (540 to 410 Ma) Metallogenesis

Metallogenic Belts with Granitoid-Hosted Deposits Related to Continental-Margin Arcs, Transpression, or Terrane Accretion

Several metallogenic belts possess geologic units favorable for major granitoid-hosted or related deposits, including the Bayanhongor belt (with Au in shear zone and quartz-vein, granitoid-related Au vein, Cu-Ag vein, Cu skarn deposits), the Hovd belt (with granitoid-related Au vein, Au skarn, and Cu skarn deposits), the Kizir-Kazyr belt (with Fe skarn and granitoid-related Au vein deposits), and the Martaiginsk belt (with granitoid-related Au vein and Au skarn deposits). The isotopic ages of the deposits or hosting units range from 490 to 420 Ma. The favorable geologic units and deposits are in the Altai and Yenisey-Transbaikal collage and are interpreted as having formed in a continental-margin arc or associated continental-margin turbidite terranes, back-arc basin associated with continental-margin arc magmatism, transform continental-margin faulting, island arc, or terrane accretion. The Kiyalykh-Uzen belt (with Cu skarn, W skarn, Fe skarn, W-Mo-Be greisen, stockwork, and quartz-vein deposits) and the Martaiginsk belt (with granitoid-related Au vein and Au skarn deposits) contain collisional granitoids that are interpreted as having been intruded during transpressive (dextral-slip) movement along the Kuznetsk Alatau fault or during terrane accretion.

Metallogenic Belts with Volcanic-Hosted Deposits Related to Continental-Margin or Island Arcs

Several metallogenic belts possess geologic units favorable for major volcanic-rock hosted deposits, including the Govi-Altai, Ozerninsky, and Uda-Shantar belts (with volcanogenic-sedimentary Fe, volcanogenic-sedimentary Mn, volcanogenic-hydrothermal-sedimentary massive sulfide, and sedimentary phosphate deposits). The fossil ages of the deposits or host units range from Cambrian through Silurian. The favorable geologic units and deposits are in the Mongol-Okhotsk, South Mongolia-Khingan, and Yenisey-Transbaikal collages and are interpreted as having formed in either continental-margin or island arcs, or in sea floor sedimentation. The Bedobinsk belt with sediment-hosted Cu deposits is hosted in early Paleozoic sedimentary units of the North Asia craton and is interpreted as having formed in an inland-sea basin during the post-saline stage of rock deposition.

Kimberlite Diamond Metallogenic Belts

Three metallogenic belts possess unique favorable geologic units for diamond-bearing kimberlite deposits in the Sino-Korean craton (East Liaoning belt), evaporite sedimentary gypsum deposits in platform sedimentary cover on the Sino-Korean craton (Hunjiang-Taizihe and Jinzhong belts), and banded iron formation (BIF) deposits in continental-margin sedimentary cover on the Sino-Korean craton (South Khingan belt). The latter two belts formed during sedimentation along a cratonal margin. The origin of the diamond-bearing kimberlite deposits is not well known.

Major Cambrian through Silurian (540 to 410 Ma) Metallogenic Belts and Host Units

The major Cambrian through Silurian metallogenic belts are the Bayanhongor-1, Bedobinsk, East Liaoning, Govi-Altai, Hovd, Hunjiang-Taizihe, Jinzhong, Kiyalykh-Uzen, Kizir-Kazyr, Martaiginsk, Ozerninsky, South Khingan, and Uda-Shantar belts (fig. 13, appendix C).

Bedobinsk Metallogenic Belt of Sediment-Hosted Cu Deposits (Belt BD) (Russia, Eastern Siberia, Yenisey Ridge area)

This Middle to Late Cambrian metallogenic belt occurs along the southwest margin of the North Asian craton along the margin of the Middle to Late Cambrian Priangarsk sedimentary basin. The belt contains the productive southern Priyenisei metallogenic district that extends from Angara to Podkamennaya Tunguska Rivers. The belt is 200 km long and 150 km wide (Bogdanov and others, 1973). The major Cu deposits occur in the middle and upper parts of carbonate and clastic rock in the Yeniseisk and Turamsk series that contains mottled anhydrite limestone and dolomite. More than 200 Cu ore occurrences occur in mottled carbonate and clastic rocks that contain the Cu-bearing Middle to Late Cambrian limestone, dolomite, siltstone, and sandstone of the Yeniseisk series. Eight Cu-bearing horizons ranging from 0.3 to 10 m thick are identified. The most significant deposit at Bedobinsk occurs in a horizon that is 2.1 m thick and consists of sandstone and mudstone with covellite, chalcocite, bornite, fahl, up to 1 percent in cuprite, and up to 0.5 percent malachite and azurite (Borzenko and Sklyarov, 1970).

The main references on the geology and metallogenesis of the belt are Bogdanov and others (1973), Narkelun and others (1977), Miroshnikov (1981), and Miroshnikov others (1981).

Bedobinskoye Sediment-Hosted Cu Deposit

This deposit (Narkelun and others, 1977) consists of stratiform Cu sulfides in the Middle to Late Cambrian argillaceous, clastic, and carbonaceous rock of the Evenkiisk suite. The Cu sulfide horizon is 2 to 3 m thick. Host lithologies are red aleurolite and siltstone. Host rocks are dolomitic sandstone, limestone, and marl. Ore minerals are chalcocite, pyrite, hematite, chalcopyrite, bornite, arsenopyrite, fahl, sphalerite, and native silver. Ore minerals occur mainly in cement of sedimentary rocks in disseminations, concretions, and thin laminae. The deposit is medium size and has an average grade of 0.1 to 0.6 percent Cu.

Kurishskoye Sediment-Hosted Cu Deposit

This deposit (Malich and others, 1987) consists of stratiform Cu minerals in Upper Riphean terrigenous red molasse. The most abundant Cu minerals occur in variegated sedimentary rocks formed in a coastal-marine and deltaic facies. Four Cu horizons range from 0.5 to 4.5 m thick and display features

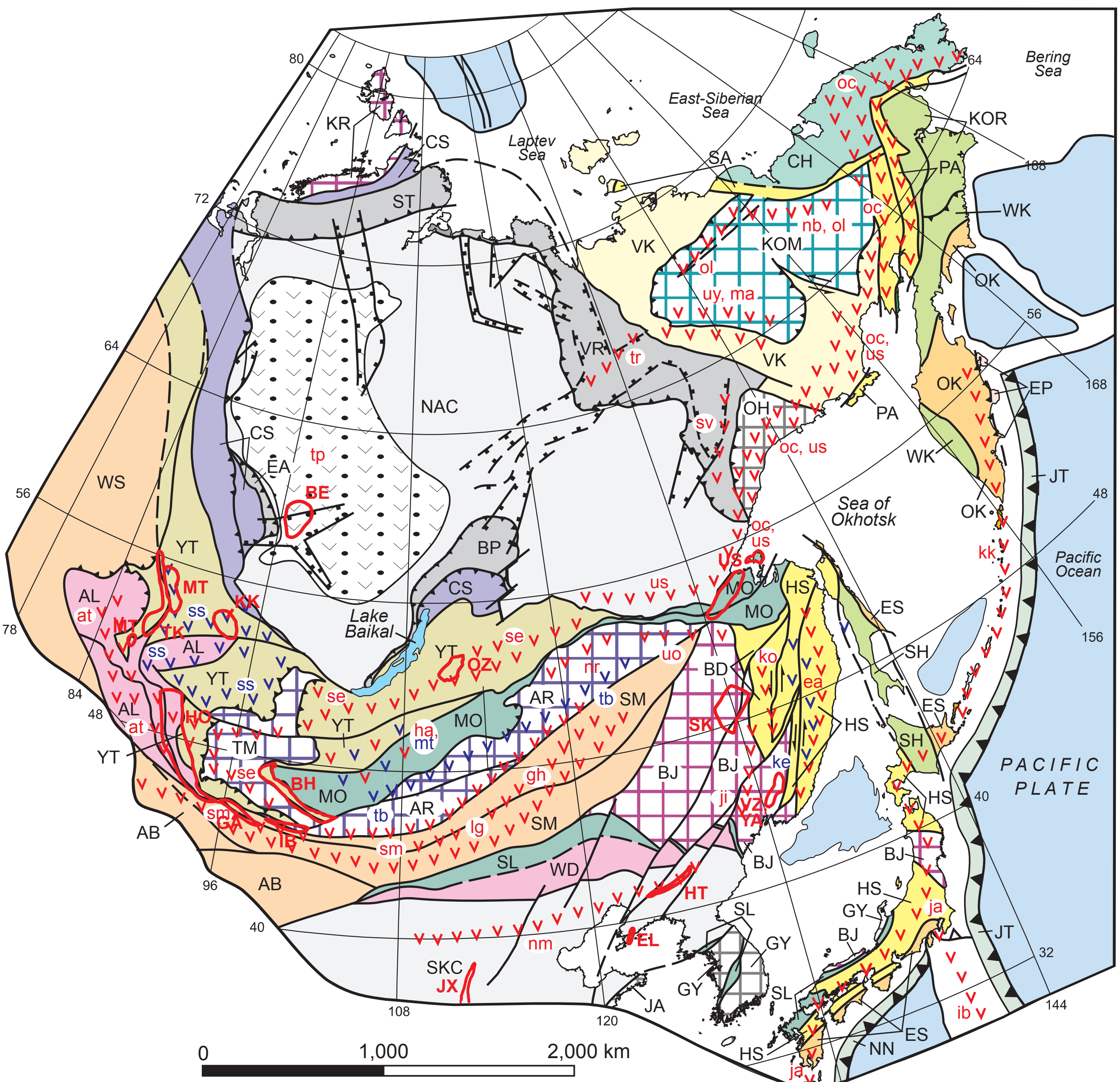


Figure 13. Generalized map of major Cambrian through Silurian metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area east of 144 ° E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

of high stability over a large area. The ore minerals are chalcocite and bornite, and rare chalcopyrite, covellite, malachite, and azurite. Fractured Cu-bearing rock along the southern margin of the North Asian craton may have been the source of copper. The deposit is medium size and has an average grade of 1 percent Cu.

Origin and Tectonic Controls for Bedobinsk Metallogenic Belt

The belt is interpreted as having formed in an inland-sea basin in a post-saline stage of rock deposition. The main source of Cu is interpreted as weathered Riphean rocks and lode deposits in the Yenisei Ridge; another source may be hydrothermal activity along deep-fault zones related to rifting. The mottled and red-bed carbonate and clastic Cu-bearing strata accumulated under arid conditions in a shallow-sea platform basin.

Bayanhongor-1 Metallogenic Belt of Au in Shear-Zone and Quartz-Vein, Granitoid-Related Au vein, Cu (±Fe, Au, Ag, Mo) Skarn and Cu-Ag Vein Deposits (Belt BH-1) (Central Mongolia)

This Late Ordovician metallogenic belt is related to veins cutting the Hangay-Dauria accretionary wedge and Orhon-Ikatsky continental-margin arc terranes, and the Zag-Haraa turbidite basin. The belt occurs in southwestern wing of the Hangay Mountain Range. The major Au deposits are at Bor khairhan, Khan Uul, and Dovont, and the major Cu deposits are at Jargalant, Bayantsagaan 1, and Burdiingol.

The main references on the geology and metallogenesis of the belt are Zabotkin and others (1988), Chikao and others (1998), and Tomurtogoo and others (1999).

Cu-Ag Vein Occurrences

Cu-Ag vein occurrences are related to regional metamorphism and occur in the Bayanhongor ophiolite complex (Zabotkin and others, 1988). The occurrences consist of a quartz and quartz-carbonate linear stockwork composed of pyrite and chalcopyrite that is developed in Vendian through Early Cambrian gabbro, spillite, diabase, basalt, andesite porphyry, and chlorite-silica and silica-chlorite schist. Pyrite and chalcopyrite occur in the center of the stockwork, whereas pyrrhotite, galena, and sphalerite occur in the marginal parts. The stockwork is conformable with host rocks that are intensely foliated, silicified, and altered to carbonate and pyrite. The average thickness of quartz stringers is approximately 1 to 2 cm. Local quartz veins range up to 1.5 to 2 m thick. Average Cu grade is mainly 0.001 to 0.1 percent Cu, but 1 to 2 m thick intervals contain from 0.6 percent to 0.8 percent Cu. The average Ag grade is mainly 3 to 10 g/t Ag. Stockwork dimensions are 200 by 500 m.

Au in Shear-Zone and Quartz-Vein Occurrences

Gold occurrences (Zabotkin and others, 1988) consist of quartz-carbonate vein and stockwork occurrences that are conformable with host greenschist in the Zag-Haraa turbidite and the Orhon continental-margin arc terranes. Au grade is variable and ranges from 0.1 g/t to several tens g/t Au. Veins and stringers and host rocks are multiply folded and faulted so that surface and down dip extensions are difficult to determine. Metamorphic age of a foliated metamorphosed Vendian through Early Cambrian mudstone in the Olziitgol Formation in the Orhon terrane has K-Ar isotopic ages 447 and 453.9 Ma. Placer Au deposits are closely related spatially to quartz-carbonate vein and stockwork type Au deposits.

Origin and Tectonic Controls for Bayanhongor Metallogenic Belt

The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the North Asian cratonal margin and during subsequent transpression-dextral-slip faulting and regional metamorphism associated with accretion of Bayanhongor and Baydrag terranes.

Chagoyan Metallogenic Belt of Sedimentary Exhalative Pb-Zn (SEDEX) Deposits (Belt Chn) (Russia, Far East)

This Cambrian(?) metallogenic belt occurs in the Bureya metamorphic terrane that is bounded by strike-slip faults. The terrane consists mainly of an early Paleozoic metamorphic core complex that contains two units. The lower unit consists of gneiss, schist, marble, quartzite, and amphibolite that are metamorphosed to amphibolite facies. The upper unit consists of marble, quartzite, and metasandstone that are metamorphosed at greenschist facies. Weakly metamorphosed deposits are (1) silicic and intermediate volcanic rock, sandstone, and siltstone; (2) Neoproterozoic limestone; and (3) Cambrian clastic rock and limestone. Younger overlap units are Middle and Late Devonian clastic marine rocks. Widespread early Paleozoic and Mesozoic granitoids intrude the terrane. The major deposit is at Chagoyan.

The main references on the geology and metallogenesis of the belt are I.G. Khei'vas (written commun., 1963), and V.A. Stepanov (this study).

Chagoyan Sedimentary Exhalative Pb-Zn (SEDEX) Deposit

This deposit (I.G. Khel'vas, written commun., 1963) (fig. 14) consists of a galena-sphalerite aggregate that occurs as cement between grains in sandstone. Veinlets are also common. The deposit is about 270 m long and 1 m thick and is hosted in quartz-feldspar sandstone that underlies Cambrian(?) limestone and dolomite. Galena and sphalerite are the dominant ore minerals, with subordinate pyrite, pyrrhotite, and chalcopyrite. Post-ore dikes and stocks of Early Cretaceous diorite and granodiorite cut the deposits. The Mesozoic igneous rocks intrude the stratiform deposit and locally exhibit hydrothermal silica, sericite, and tourmaline alteration. The deposit occurs on the northern bank of the Zeya River and is small. Average grades are 1.42 percent Pb, 5.16 percent Zn, and up to 3,000 g/t Ag. The deposit contains estimated reserves of 65,000 tonnes Zn.

Origin and Tectonic Controls for Chagoyan Metallogenic Belt

The belt is interpreted as having formed during rifting and submarine hydrothermal activity along the continental margin of the Gobi-Amur microcontinent. The belt formed during generation of hydrothermal fluids during rifting and intrusion of intermediate composition dikes, and chemical marine sedimentation.

East Liaoning Metallogenic Belt of Diamond-Bearing Kimberlite (Belt EL) (Northeastern China)

This Ordovician(?) metallogenic belt is related to kimberlite intruding Sino-Korean craton-Jilin-Liaoning-East Shandong terrane, and it occurs in the East Liaoning Peninsula in Northeastern China. The kimberlite intrudes Archean crystalline rocks, trends northeast, and is about 80 km long and 30 km wide. The significant deposit is at Fuxian.

The main reference on the geology and metallogenesis of the belt is Deng Chujun and others (1994).

Fuxian Deposit of Diamond-bearing Kimberlite

This deposit (Deng, Chujun and others, 1994) occurs in the Fuzhou Basin in the Eastern Liaoning uplift of North China Platform. The basement rocks consist of Archean granite and gneiss that is overlain by Paleozoic and Mesozoic sedimentary rock that occur in a north-northeast-trending synclinorium. Kimberlite occurs along east-west striking faults in the basement and the northeast-striking faults in overlying rocks. The major Tanlu fault zone is the main structure. Eighteen kimberlite pipes and 58 kimberlite dikes occur in an area of 28 km (east-west) long and 18 km wide (north-south). Kimberlite pipes are complicated, irregular, and are exposed in areas ranging from 200 to 41,200 m^2. Eight pipes are economic and has an average grade of 50 mg/m^3. A maximum grade of 308 mg/m^3 occurs in pipe no. 50. Kimberlite dikes occur along fractures that strike north-northeast and dip at 70 to 80°. The dikes are parallel to each other, and 8 intensely carbonate-altered dikes contain diamonds. Dike no. 69 is the richest, with a grade of 327 mg/m^3. Kimberlite contains 33.78 percent SiO_2, 27.96 percent MgO, 1.04 percent K_2O, 0.13 percent Na_2O, 33.91 percent Al_2O_3, and 1.61 percent TiO_2. The main rock-forming minerals are olivine, phlogopite, garnet, chromite, moissanite, and ilmenite. The accessory minerals in kimberlite with relatively high diamond grade are rather complex and include rutile, anatase, pyrope, chrome, and spinel. The diamond hardness is more than 88,000 kg/mm^2. Most diamonds are transparent and with a strong adamantine luster. The deposit is small.

Origin and Tectonic Controls for East Liaoning Metallogenic Belt

This metallogenic belt is hosted in kimberlite pipes and dikes, including gabbro, amphibolite, serpentinite, peridotite, websterite, and peridotite. The dikes occur in swarms. The kimberlites and associated intrusions occur along the northeast-trending regional Tanlu fault at the northern margin of the Sino-Korean Platform. The age of intrusion of kimberlite is well defined. Inclusions of Cambrian limestone occur in kimberlite pipes. The isotopic age of kimberlite is about 455 to 340 Ma and the isotopic age of kimberlite at the Shandong Peninsula is 490 to 460 Ma. The age of kimberlite intrusion is interpreted as Late Ordovician (Deng Chujun and others, 1994). The kimberlite and other intrusions are mainly controlled by the major northeast-trending Tanlu fault that cuts the the northern margin of the Sino-Korean craton.

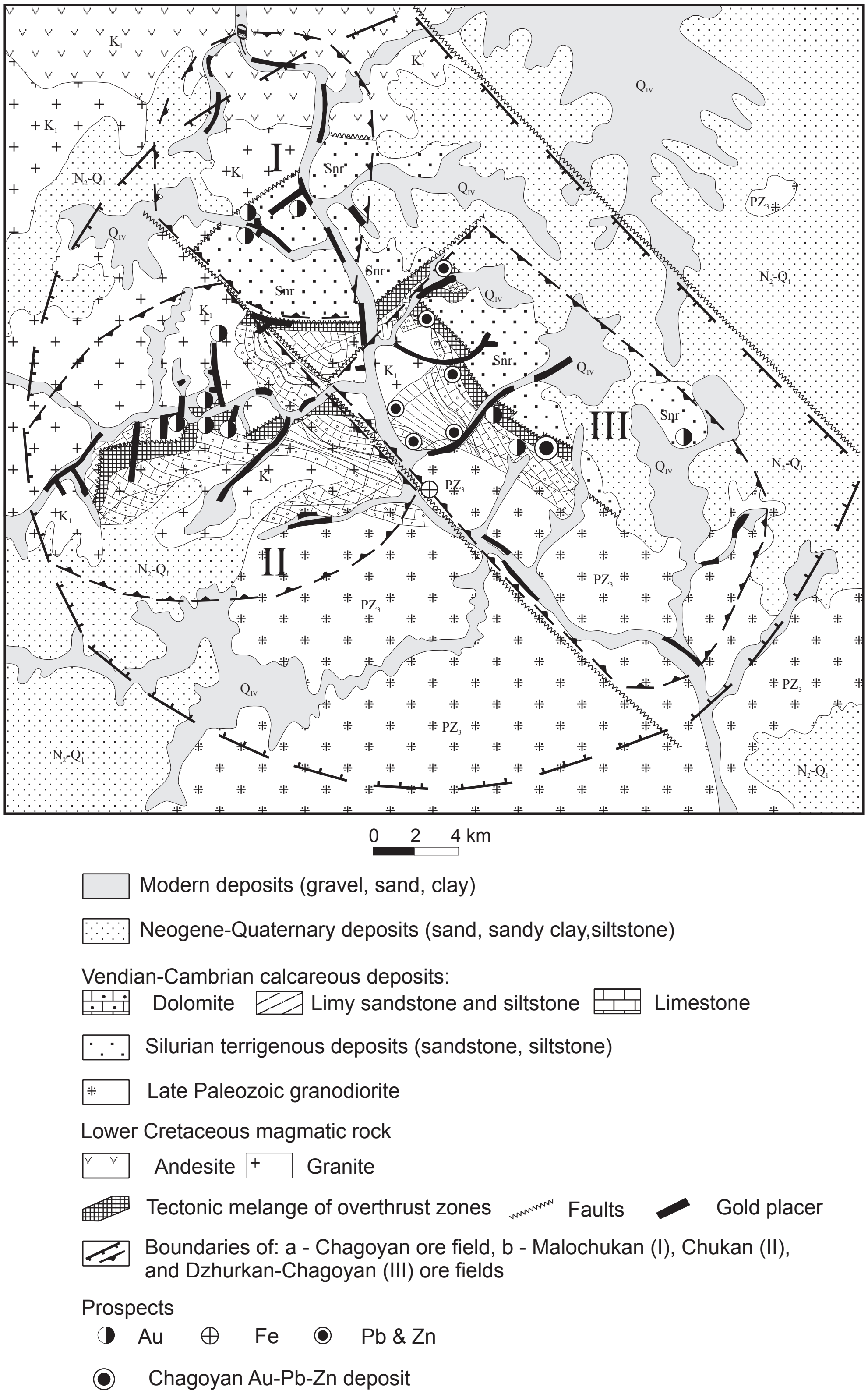
Govi-Altai Metallogenic Belt of Volcanogenic-Sedimentary Fe and Mn Deposits (Belt GAI) (Southwestern Mongolia)

This Middle Cambrian to Early Ordovician metallogenic belt is hosted in the western Govi-Altai continental-margin turbidite terrane (Tomurtogoo and others, 1999). The belt is 40 km wide and 150 km long. The metallogenic belt consists of amphibole schist in the Early and Middle Cambrian Togrog Formation and in intercalated quartzite, phyllite, tuffaceous siltstone, and sericite-chloritic schist in the Middle Cambrian through Early Ordovician Uhin Ovoo Formation. Both formations contain Fe-and Mn-bearing quartzite horizons that range up to several meters thick and extend up to several kilometers long. The Fe, Fe-Mn and Mn occurrences of the belt were discovered by 1:200,000 scale geological mapping and general prospecting (A.A. Rauzer and others, written comun., 1987). The major Fe deposit is at Uhin Ovoo, and the major Mn deposits are at Tahilgat Uul and Sharturuutiin gol.

The main references on the geology and metallogenesis of the belt are A.A. Rauzer and others (written comun., 1987) and Tomurtogoo and others (1999).

Tahilgat uul Volcanogenic-Sedimentary Mn Deposit

This deposit (A. Rauzer and others, written commun., 1987) consists of pyrolusite, magnetite, and martite in a



Fgure 14. Generalized geologic map of Chagoyan sedimentary exhalative Pb-Zn (SEDEX) district, Chagoyan metallogenic belt. Adapted from Melnikov (written commun., 1963).

quartzite bed in amphibolite and schist of the Early to Middle Cambrian Togrog Formation. The bed is 0.5 to 1.0 m thick and extends for 2,000 m. Grade ranges from 3 to 20 percent Mn. Grab samples contain up to 0.015 percent Co, up to 0.02 percent Mo, and up to 0.01 to 0.25 percent Cu. The deposit is medium size and contains resources of 2 million tonnes Mn and 3 million tonnes Fe.

Uhiin Ovoo Volcanogenic-Sedimentary Fe Deposit

This deposit (A.A. Rauzer and others, written commun., 1987; Jargalsaihan and others, 1996) consists of magnetite and hematite bearing beds hosted in Middle Cambrian through Early Ordovician chlorite-sericite slate. Beds are 5.0 to 10.0 m by 50.0 to 70.0 m thick and extend up to 4,000 m along strike. Analyses of three grab samples yield 20.5 to 48.4 percent Fe, 1.5 percent Mn, up to 0.08 percent V, and up to 0.01 percent Cu.

Origin and Tectonic Control for Govi-Altai Metallogenic Belt

The belt is interpreted as having formed during sedimentation along an early Paleozoic continental slope close to the deformed Dzhida-Lake island arc.

Hovd Metallogenic Belt of Granitoid-related Au Vein, Au Skarn, and Cu (±Fe, Au, Ag, Mo) Skarn Deposits (Belt HO) (Western Mongolia)

This Ordovician through Late Silurian metallogenic belt contains granitoid-related Au vein, Au skarn, and Cu and Fe occurrences related to the Khovd and Turgen granitoid complex that intrudes an Ordovician sedimentary-volcanic-plutonic overlap assemblage in the Hovd continental-margin turbidite terrane and a Silurian sedimentary-volcanic-plutonic overlap assemblage (too small to depict on map at 5 million scale) (Tomurtogoo and others, 1999). The granitoid complex consists of gabbro, diorite, granodiorite, and biotite-amphibole granite. The metallogenic belt was first defined by Tcherbakov and Dejidmaa (1984) as the Harhiraa Au belt. The major deposits and occurrences are at Hovd, Sharhooloi, Tsetsegnuur, Tsagaantolgoi, Hagshirbulag, Yolochka, and Antsavyn.

The main references on the geology and metallogenesis of the belt are Tcherbakov and Dejidmaa (1984), Dergunov (1989), Byamba and Dejidmaa (1999a,b), and Tomurtogoo and others (1999).

Yolochka Cu (±Fe, Au, Ag, Mo) Skarn Deposit

This occurrence (L.B. Chistoedov and others, written commun., 1990) occurs along the major Tsagaan Shiveet fault zone in the western margin of the Nuuryn terrane. The occurrence is hosted in the Vendian through Early Cambrian Tsol Uul Formation, Early Silurian Khutsbulag Formation, and Upper Silurian Hovd intrusive complex. The Tsol Uul Formation consists of andesite, basalt, andesite porphyry, tuff, volcanic breccia, spilite, and limestone. The Khutsbulag Formation consists of sandstone, siltstone and greywacke. The Hovd complex is a small intrusive and consists of a first phase of fine-grained diorite and a second phase of medium-grained granodiorite. Also occurring are abundant dikes of granodiorite porphyry, syenite porphyry, and diabase porphyry, two fault zones that vary from 20.0 to 200.0 m wide, and small fracture zones that vary from 0.1 to 1.0 m wide. Quartz and siderite veins occur in the fault zones and contain chalcopyrite, chalcocite, malachite, and azurite. Hydrothermal replacements consist of skarn, and alteration to epidote and silica. The skarns vary from 0.4 to 2.5 m wide and 20.0to 00.0 m long. Some skarns contain pyrite and chalcopyrite. Gangue minerals are epidote, quartz, calcite, and garnet. The average grades in skarn are 0.4 to 1.0 g/t Au, 0.1 to 0.5 percent Cu, up to 0.06 percent Zn, up to 0.2 percent Pb, and up to 2.5 g/t Ag.

Origin and Tectonic Controls for Hovd Metallogenic Belt

The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the Siberian Continent margin and during subsequent transpression-dextral-slip faulting. The Hovd terrane is part of the Ordovician Tsagaanshiveet continental-margin arc that is built on the Vendian through Cambrian Lake island-arc terrane, and it is linked to the Late Ordovician, subduction-related Turgen complex consisting of gabbro, diorite, granodiorite and biotitic, biotite-amphibolic granite.

Hunjiang-Taizihe Metallogenic Belt of Evaporate Sedimentary Gypsum Deposits (Belt HT) (Northeastern China)

This Cambrian through Ordovician metallogenic belt is hosted in the Sino-Korea craton sedimentary cover and occurs in the East Liaoning and East Jilin Provinces, Northeastern China. The belt occurs in the Hunjiang River, East Jilin, Taizihe River, and East Liaoning Provinces. The belt is hosted in the Cambrian and Ordovician overlap sedimentary assemblages of the Jilin-Liaoning-East Shandong terrane. The evaporate sedimentary gypsum deposits occur in the Early Cambrian Mantou Formation in dolomite mudstone, dolomite, and limestone. The metallogenic belt is 300 km long and 20 to 30 km wide. The significant deposit is at Rouguan.

The main reference on the geology and metallogenesis of the belt is Ren and Cai (1989).

Rouguan Evaporate Sedimentary Gypsum Deposit

This deposit (Ren and Cai 1989) consists of thin, concordant gypsum beds in Early Cambrian carbonate in the Mantou Formation. Four horizons occur and the main horizon is 2,800 m long and 5.5 m thick. The ores are carbonate and sulphate type with a simple mineralogy. The main minerals are gypsum, karstenite, dolomite, calcite, quartz, illite, and minor montmorillonite. The sedimentary environment is interpreted as a super-tidal vaporizing Sabkha or high saline basin. The deposit is medium size.

Origin and Tectonic Controls for Hunjiang-Taizihe Metallogenic Belt

Gypsum deposits in the belt are interpreted as having formed in a super-tidal sabkha sedimentary environment (Ren and Cai, 1989). The host Cambrian and Ordovician sedimentary rock are part of the overlap sedimentary assemblages on the Archean Jilin-Liaoning-East Shandong terrane and consist mainly of very thick carbonates and clastic rock. During the Early Cambrian period, the limited Hunjiang-Taizihe Basins formed along a northeast trend.

Jinzhong Metallogenic Belt of Evaporate Sedimentary Gypsum (Belt JZ) (North China)

This Cambrian through Silurian metallogenic belt is hosted in sedimentary units in the the Sino-Korea craton sedimentary cover and occurs in the central part of southeast Shanxi Province, Northern China. The belt is hosted in an overlap sedimentary assemblage deposited on the Archean West Liaoning-Hebei-Shanxi terrane. The belt trends north-south, is more than 600 km long, and ranges from 20 to 30 km wide. The gypsum deposits are hosted in limestone horizons in Early and Middle Ordovician strata. The most significant deposit is at Taiyuan.

The main references on the geology and metallogenesis of the belt are Wang Hongzhen (1985) and Tao Weiping and others (1994).

Taiyuan Evaporate Sedimentary Gypsum Deposit

This deposit (Yuan, Jianqi, and Cai, Keqin, 1994) consists of gypsum-bearing strata in evaporate rocks in the Early Ordovician Majiagou Formation. The gypsum-bearing strata range from 118 to 207 m thick. The strata are divided into the following members: (1) lower limestone; (2) lower gypsum; (3) middle limestone; (4) upper gypsum; (5) interbedded dolomite and limestone; and (6) upper limestone. Ten layers of gypsum occur, with nine layers in the upper gypsum member and one in the lower gypsum member. The average thickness of each layer is 1.0 to 2.49 m. Generally, where the gypsum member is thicker, the thickness of gypsum layer is correspondingly larger. The gypsum layers occur continuously along strike for several thousand meters and extend downdip to more than 1,000 m. Some laminated and banded gypsum layers frequently contain halite pseudomorphs and mud cracks. However, most gypsum layers consist of crystalloblastic, coarse-grained gypsum replacing anhydrite. The deposit is interpreted as evaporate layers that formed in a tidal zone. The deposit is large.

Origin and Controls for Jinzhong Metallogenic Belt

The gypsum deposits in the belt are interpreted as having formed in a large epicontinental marine basin that comprises the most extensive sedimentary cover on the North China Platform. The metallogenic belt is the most significant in the North China Platform and is hosted in Middle Ordovician limestone and gypsum formations that contain multiple cycles with a group of large gypsum deposits (Wang, 1985; Tao and others, 1994).

Jixi Metallogenic Belt of Banded Iron Formation (BIF, Algoma Fe), Homestake Au, Metamorphic Graphite, and Metamorphic Sillimanite Deposits (Belt JX) (Northeastern China) (Started in Neoproterozoic (See above description)

Kiyalykh-Uzen Metallogenic Belt of Cu (±Fe, Au, Ag, Mo) Skarn, W±Mo± Be Skarn, Fe Skarn, and W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposits (Belt Kiy) (Kuznetsk Alatau, Russia, Southern Siberia)

This Early Ordovician through Early Silurian metallogenic belt is related to the Tannuola plutonic belt located in the Altai-Sayan back-arc basin (Mrassu-Bateni unit) and occurs along the southeastern slopes of the Kuznetsk Alatau Ridge. The belt is oval and trends sublongitudinally for 150 km and ranges from 50 to 80 km wide. The deposits are concentrated in early Paleozoic granitoids that intrude Vendian and Cambrian carbonate and clastic shelf rocks, and rarely in Cambrian volcaniclastic and carbonate sedimentary rock. The deposits occur in (1) contact zones of granitoid intrusions and as skarn in large xenoliths of host rocks; and (2) endocontact zones and cupolas of granitoid plutons in greisens and veins. The deposits are controlled by zones of intersection of northwest- and northeast-trending faults. Cu skarn deposits are predominant. Most deposits are small. The Kiyalykh-Uzen, Juliya Mednaya Cu (±Fe, Au, Ag, Mo) skarn and the Tuim W (±Mo±Be) skarn deposits are mined.

The main references on the geology and metallogenesis of the belt are Kuznetsov and others (1971), Sotnikov and others (1995, 1999), Berzin and Kungurtsev (1996), and Alabin and Kalinin (1999).

Kiyalykh-Uzen Cu (±Fe, Au, Ag, Mo) Skarn Deposit

This deposit (Kuznetsov and others, 1971; Levchenko, 1975) consists of a lensoid body that occurs along the contact of the Tuim granitoid pluton and intruded-Cambrian carbonate rock. Garnet, pyroxene-garnet, magnetite skarn, hornfels, and quartzite occur along the contact zone. The deposit occurs in a district that is 900 m long and ranges from 1 to 50 to 80 m thick. Some economic deposits occur. The major lens like deposit is 550 m long and ranges from 4 to 76 m thick. The ore minerals are magnetite, chalcopyrite, pyrite, arsenopyrite, pentlandite, sphalerite, pyrrhotite, molybdenite, fahl, galena, enargite, and scheelite. The ore minerals occur in veinlets, masses, and disseminations in skarn. Also occurring are quartz-sulfide veinlets. Molybdenite occurs in zones in silicified granitoid in quartz veinlets containing disseminated molybdenite, chalcopyrite, and other sulfides. The deposit has been mined. The deposit is small.

Tuim W±Mo±W±Mo±Be Skarn Deposit

This deposit (Kuznetsov and others, 1971; Levchenko, 1975) is hosted in pyroxene-garnet and garnet skarn that occurs along the margine of large roof pendants of Cambrian limestone that are intruded by the early Paleozoic Tuim granitoid pluton. The ore minerals are scheelite, pyrite, chalcopyrite, molybdenite, pyrrhotite, and galena. Scheelite occurs both in skarn and quartz veinlets in disseminations and masses. Sulfides, including molybdenite, occur in quartz veinlets. In the district containing the Tuim deposit are numerous quartz veins (that vary from 0.3 to 0.4 m thick) with disseminated scheelite and wolframite. These veinlets are related to a small granite pluton. The deposit is small.

Verhne-Askizskoye W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Amshinsky and Sotnikov, 1976) consists of quartz-scheelite veins that occur in a fracture zone cutting an Early Cambrian syenite and diorite pluton that contains numerous Vendian and Cambrian xenoliths. The veins occur in a 100-m-wide band. Five main sublongitudinally trending, steeply dipping quartz veins range from 80 to 440 m long and from 0.4 to 1.4 m thick. The major vein mineral is quartz. Also occurring are carbonate, albite, epidote, muscovite, and chlorite. Ore minerals are pyrite, scheelite, chalcopyrite, sphalerite, pyrrhotite, galena, and argentite. The deposit is small.

Turtek W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (V.I. Sotnikov, this study) consists of numerous quartz veins and veinlets in Cambrian and Ordovician granitoids that are altered to greisen. The deposit is 150 to 200 m thick and extends up to several km with interruptions. The deposit contains veins and veinlets that range from 5 to 50 cm wide. Individual veins range up to 300 to 500 m wide. Ore minerals occur in greisen zones in host rocks. The ore minerals are scheelite, molybdenite, pyrite, and galena, and rare chalcopyrite, bismuthine, and gold. The deposit is small.

Samson Fe Skarn Deposit

This deposit (Kuznetsov and others, 1971; Kalugin and others, 1981) consists of six steeply dipping lensoid skarn-magnetite deposits that occur along a contact zone between a Paleozoicgranitoid and Early Cambrian marble. The deposits range from 100 to 600 m long, extend from 320 to 610 m depth, and range up to 5 to 30 m thick. Ore assemblages are magnetite, magnetite-silicate, and magnetite-sulfide. Associated minerals are: pyrite, pyrrhotite, chalcopyrite, and arsenopyrite. Gangue minerals are garnet, pyroxene, amphibole, calcite, epidote, and minor scapolite. Average grade is 44.28 percent Fe, 0.15 percent P_2O_5, 0.83 percent S, and minor Co, Cu, and As. The deposit is medium size amd has reserves of 23,300,000 tonnes ore.

Origin and Tectonic Controls for Kiyalykh-Uzen Metallogenic Belt

This metallogenic belt is related to early Paleozoic collisional granitoids (Berzin and Kungurtsev, 1996). The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the Siberian Continent margin and during subsequent transpression-dextral-slip faulting along the Kuznetsk Alatau fault. The host rocks were intensely altered during both prograde and retrograde stages of intrusion of granitoid plutons. Two age groups of granitoid plutons with different suites of deposits are recognized. An older suite of mainly skarn deposits is hosted in the Martaiga complex granitoid batholith that contains diorite, granodiorite, syenite, and diorite (Kuznetsov and others, 1971). An $^{40}Ar/^{39}Ar$ age is 480 to 460 Ma and initial $^{87}Sr/^{86}Sr$ ratio is 0.70430 to 0.70436 (Sotnikov and others, 1995, 1999). A younger suite of REE and vein and stockwork deposits is hosted in a granite and leucogranite sequence that has an $^{40}Ar/^{39}Ar$ age of 440 to 420 Ma.

Kizir-Kazyr Metallogenic Belt of Fe Skarn, Volcanogenic-Sedimentary Fe, and Granitoid-related Au Vein Deposits (Belt KK) (Eastern Sayan Ridge, Altai-Sayan folded area, Russia)

This Cambrian through Ordovician metallogenic belt is related to the Tannuola plutonic belt and occurs in the Altai-Sayan back-arc basin (Mrassu-Bateni unit) in the East Sayan

Mountains. The belt extends northwest for 90 km and is about 90 km wide. The belt occurs in Ordovician gabbro, diorite, and granodiorite plutons (Polyakov, 1971). Host rocks of the Fe deposits are mainly Early to Middle Cambrian volcanic and sedimentary rocks with abundant basalt. Fe-skarn deposits occur along the exocontact zones of gabbro, diorite, and granodiorite plutons, and replace large xenoliths of host rocks. Granitoid-related Au-vein deposits occur along the contacts of granitoid intrusions that metasomatize and contact metamorphose Cambrian rocks. Granitoids are mainly multistage gabbro, diorite, and granodiorite intrusives. Fe and Au deposits occasionally occur in clusters. The major deposits are at Irbinskoye, Belokitatskoye, and Olkhovskoye.

The main references on the geology and metallogenesis of the belt are Polyakov (1971), Andreev and Kurceraite (1977), Dymkin and others (1975), and Berzin and Kungurtsev (1996).

Irbinskoye Fe Skarn Deposit

This deposit (Dymkin and others, 1975; Kalugin and others, 1981; Sinyakov, 1988) consists of lensoid and layered magnetite in garnet and pyroxene-garnet skarn and aposkarn. Gangue minerals are amphibole, epidote, and chlorite. The skarn occurs in the contact zone of Ordovician gabbro, diorite, and granodiorite plutons that intrude Early Cambrian volcanic and sedimentary rock and in xenoliths. The main district containing the deposit is 5 km long, ranges from 300 to 400 m thick, and contain 50 deposits. Average size of an individual deposit is about 650 m along strike, 350 m deep and 60 m wide. Pyroxene-garnet-magnetite, garnet-epidot-magnetit,e and epidote-chlorite-magnetite skarns occur. Ores have high SiO_2 and CaO, and low MgO and P_2O_5. The principal ore mineral is magnetite. Also occurring are minor hematite and various sulfides: pyrite, chalcopyrite, pyrrhotite, sphalerite, galena, pentlandite, and arsenopyrite. The deposit has reserves of 95 million tonnes grading 38.8 percent Fe.

Belokitatskoye Volcanogenic-sedimentary Fe Deposit

This deposit (Andreev and Kurceraite, 1977; Kalugin and others, 1981) consists of lenticular and layered deposits of hematite and magnetite in Early Cambrian volcanic and sedimentary rock consisting mainly of interbedded tuff, sandstone, phyllite, and jasperite. The deposit occurs in the-Western and Eastern districts. The Western district is 1.5 km long and contains 10 deposits that vary from 0.75 to 9 m thick. The Eastern district contains ore layers that vary from 4.5 to 11.3 m thick and extend for 4 km. The deposits consist of alternating ore mineral of layers and jasperite. Ore layers contain magnetite, hematite, quartz, vermiculite, chamosite, and siderite, along with pyrite, pyrrhotite, and chalcopyrite. The deposits are interpreted as having been derived from metamorphosed volcanic and sedimentary units. The average grade is 0.2 to 1.5 percent P_2O_5, and up to 5.2 percent MnO. The deposit has reserves of 200 million tonnes grading 36 to 88.6 percent Fe.

Olkhovskoye Granitoid-related Au Vein Deposit

This deposit (Smirnov, 1978) occurs along the contact zone of the Ordovician Olchovsk granitoid pluton that intrudes Early and Middle Cambrian sedimentary and volcanic rock that is contact metamorphosed and metasomatized. Lenses and columns of sulfide deposits commonly occur in carbonate rock. Quartz and quartz-sulfide veins and dense networks of stockwork veinlets occur in contact metamorphic zones adjacent to granitoids. Also occurring in the pluton is disseminated Au. Wall rocks are altered to berezite, silica, sericite, and chlorite. Main ore minerals are pyrrhotite, pyrite, chalcopyrite, marcasite, sphalerite, galena, arsenopyrite, fahl, Bi-minerals, and native Au. Gold deposits are mainly associated with polymetallic sulfide deposits. The size of free Au grains ranges from 0.05 to 3 mm. Fineness of Au ranges from 688 to 358. The deposit is small.

Origin and Tectonic Controls for Kizir-Kazyr Metallogenic Belt

The belt is related to early Paleozoic collisional granitoids that intrude Vendian and Cambrian carbonate and volcanic rock along the margins of the East Sayanian and Minusa Basins and associated structures. The deposits are related to Ordovician gabbro and diorite intrusions (Berzin and Kungurtsev, 1996). The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the Siberian Continent margin and during subsequent transpression-dextral-slip faulting along the Kuznetsk Alatau fault.The composition of host rocks played an important role in ore genesis. The Early Cambrian volcanic and sedimentary rock in some districts was both favorable for formation of Fe skarn and also a source of Fe. The syngenetic Fe deposits are related to Early Cambrian volcanic rock as at the Belokitatskoye volcanogenic-sedimentary Fe deposit (Andreev and Kurceraite, 1977). The host Cambrian black shale may be a source of Au. The K-Ar age for deposit-hosting gabbro, diorite, and granodiorite intrusions in the Irbinskoye Fe district is 430 Ma (Dymkin and others, 1975). Younger, post-ore, Devonian granite and syenite intrusions crosscut and modify the deposits.

Martaiginsk Metallogenic Belt of Granitoid-related Au Vein and Au Skarn Deposits (Belt MT) (Kuznetsk Alatau to Gorny Altai Mountains, Russia, Southern Siberia)

This Late Ordovician and Early Silurian metallogenic belt is related to the Tannuola plutonic belt that intrudes the Kozhukhov, Kanim and Uimen-Lebed island-arc terranes, and the Altai-Sayan back-arc basin. The belt extends along the eastern slope of the Kuznetsk Alatau Ridge for up to 500 km with breaks and ranges from 30 to 60 km wide. The belt is 250 km wide in the Kuznetsk Alatau. Most of the Au deposits occur along the Kuznetsk Alatau branch of the belt. The belt occurs along the hanging wall of the Kuznetsk Alatau fault zone that exhibits complex relations between Precambrian and early Paleozoic sedimentary, extrusive, and intrusive rocks. The granitoid-related Au deposits occur in early Paleozoic granitoid batholiths, in relatively older gabbro and norite intrusions, in andesite, basalt, and andesite porphyry, and in complexly deformed volcanic and sedimentary rock (Alabin and Kalinin, 1999). Au skarn deposits occur along contact between the early Paleozoic granitoid plutons and companion stocks and consist of magnesium-silicate and calc-silicate skarn. The most abundant Au deposits occur in brecciated and recrystallized skarn. Au-rich wollastonite skarn at the Sinyukhinskoye deposit extends to 500 m depth. Also occurring are Au-sulfide-quartz veins in some Au-skarn deposits. This relation links the two types of Au deposits in the belt. The majority of Au-skarn deposits occur at the western part of the Martaiginskiy metallogenic belt where it overlaps with the Taidon-Kondomsk Fe-Mn metallogenic belt. Lode-Au deposits are the sources of numerous Au placers that have been mined during last 150 years. The major deposits are at Sarala, Natal'evskoye, Komsomolskoye, and Sinyukhinskoye.

The main references on the geology and metallogenesis of the belt are Sotnikov and others (1995, 1999), Berzin and Kungurtsev (1996), Sharov and others (1998), Shirokich and others (1998), and Alabin and Kalinin (1999).

Komsomolskoye Granitoid-Related Au Vein Deposit

This deposit (Denisov, 1968) (fig. 15) consists of quartz-sulfide veins hosted in Ordovician-Silurian gabbro and diorite stock that intrudes Cambrian carbonaceous and volcanic rock. The stock is oval with dimensions of 5 by 3.5 km. Multiple xenoliths of contact metamorphosed and skarn-altered host rock occur in gabbro and diorite massif. About 150 quartz veins occur in the five districts. Single veins range up to 1.5 km long and 5 m thick. Wallrock alterations are beresite alteration, silica alteration and sulfide alteration. The deposit minerals are pyrite, pyrrhotite, sphalerite, arsenopyrite, galena, chalcopyrite, scheelite, and native gold. Native gold is associated with arsenopyrite and galena. The deposit is small.

Sarala Granitoid-Related Au Vein Deposit

This deposit (Miroshnikov and Prochorov, 1974; Sazonov and others, 1997; Shirokich and others, 1998) consists of a group of quartz-carbonate and sulfide veins hosted in Early to Middle Cambrian volcanic and sedimentary rock that is metamorphosed and hydrothermally altered. The veins are related to early Paleozoic gabbro, diorite and granite intrusives. More than 250 veins occur in seven districts. Two types of veins are defined according to size (1) single veins that are up to 3 km long and 1.5 to 2 m thick (up to 4 to 5 m in swells) are the most economically important and comprise the bulk of Au reserves; and (2) more common veins that are several hundred meters long (rarely up to 1 km), are 0.2 to 0.6 m thick, and occur in berezite, silica, sericite and listvenite alteration zones. Grade of Au in altered wall rock varies from minor to 57 g/t Au. Ore minerals assemblages are quartz, pyrite, and scheelite; quartz, pyrite, and arsenopyrite; and quartz, pyrite, sphalerite, galena, and calcite. Average sulfide content is 4.75 percent. Native Au occurs mainly with arsenopyrite, sphalerite, and galena. Fineness of Au ranges from 483 to 911 (mainly 680 to 790). The deposit is medium size and has an average grade of 8.4 g/t Au.

Natal'evskoye Au Skarn Deposit

This deposit (Alabin and Kalinin, 1999) consists of a group of Au skarn bodies with a complicated mineral assemblage that occur along the contact of the Ordovician and Silurian Natal'evsk granitoid stock that intrudes Vendian and Cambrian andesite and basalt porphyry and tuff that are interbedded with chlorite and carbonaceous-siliceous schist, limestone, and dolomite. The skarn contains an older assemblage of magnesium-silicate minerals (diopside, spinel, phlogopite, and serpentine), and a younger assemblage of calcsilicate minerals (garnet, pyroxene, wollastonite, tremolite, and vesuvianite). Ore minerals are mainly magnetite, chalcopyrite, cubanite, and bornite, and lesser pyrite, pyrrhotite, sphalerite, galena, native Au, molybdenite, and native bismuth. Fineness of Au is of 760 to 820 pm. Sulfides comprise from 3 to 8 percent skarn. The main Au-minerals are chalcopyrite and bornite. Skarn, that is brecciated, recrystallized and slightly hydrothermally altered (albite, actinolite, and silica alteration), is most enriched in Au. The deposit is small.

Sinyukhinskoye Au Skarn Deposit

This deposit (Luzgin, 1974; Korobeinikov and others, 1997; Sharov and others, 1998) consists of quartz-carbonate and Au-Cu-sulfide skarns that occur in a contact zone of an Ordovician and Silurian granitoid pluton intruding Middle Cambrian volcanic and sedimentary rock. Various wollastonite, pyroxene, and garnet skarn occurs along contact of volcanic rock and rare dikes with carbonates. Various age dike complexes are widespread. The oldest diabase and spesartite dikes intrude skarn and also metasomatized. Younger quartz diorite porphyrye and felsite dikes are not metasomatized, but contain Au-sulfide deposits that contain economic Au that formed during post-skarn hydrothermal metasomatism that resulted in silica alteration and sulfide replacement. The Au-skarn deposits occur in irregular masses, nest, lenses, and stockworks. Individual skarn bodies range from ten to several hundred meters long. The thickness of ore veins ranges from 2

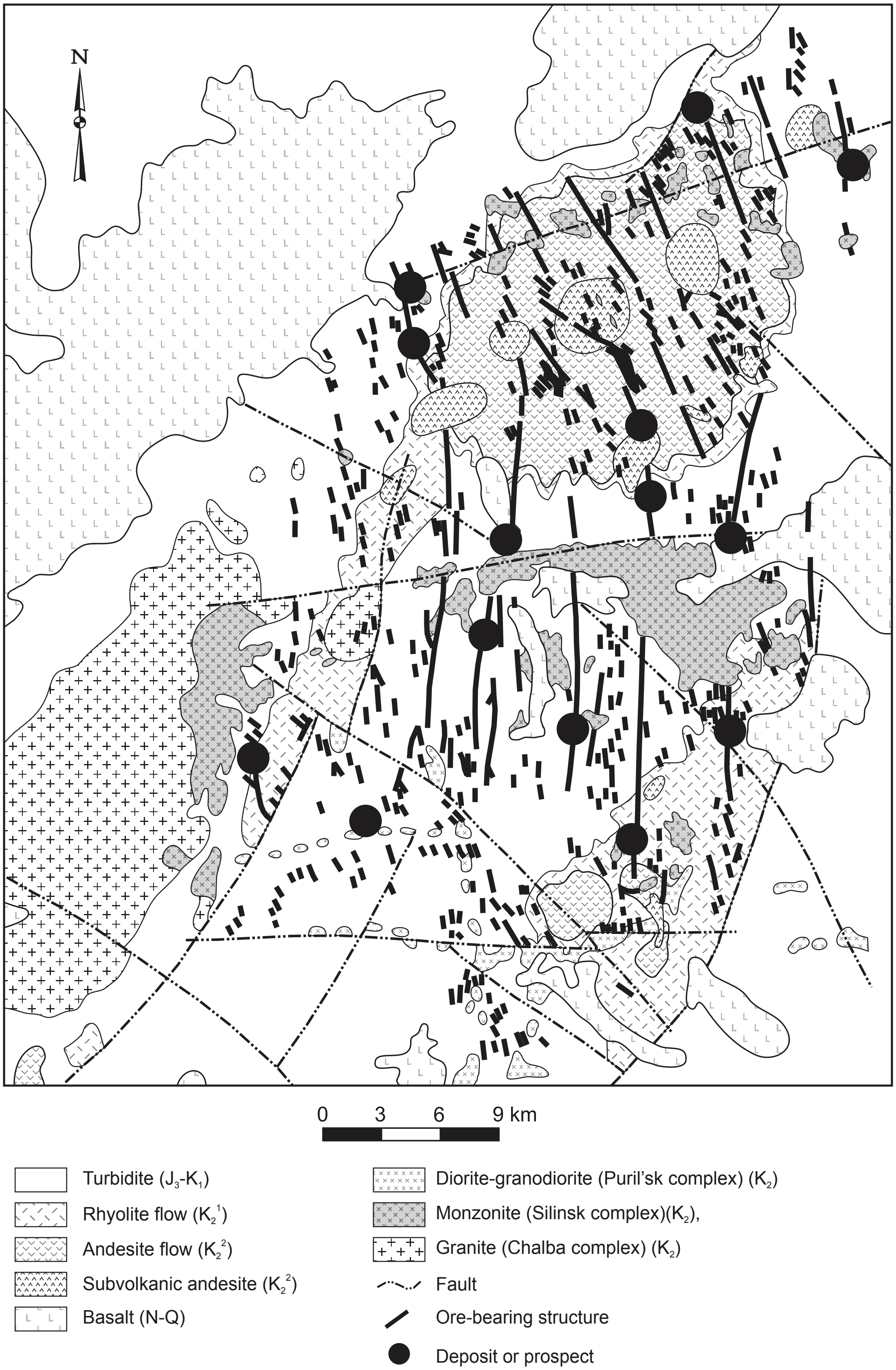


Figure 15. Generalized geologic map of Komsomolskoye Au district. Martaiginsk metallogenic belt. Adapted from Denisov (1968).

to 6 m. The veins occur mainly in skarn and to a lesser extent in magnetite masses and wall rocks. A gold-chalcocite-bornite assemblage is typical for upper part of deposit, and Au-chalcopyrite is typical in deeper levels. The deposit is medium size amd has reserves of 20 tonnes Au.

Origin and Tectonic Controls for Martaiginsk Metallogenic Belt

The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the Siberian Continent margin and during subsequent transpression-dextral-slip faulting. The deposits occur in clusters along branches of the Kuznetsk Alatau fault and along intersections with transversal sublatitudinal faults.

The belt occurs in a terrane collage of fragments of an island-arc system and an active continental margin (Berzin and Kungurtsev, 1996; Alabin and Kalinin, 1999). The granitoids consist of an older gabbro sequence and a younger granitoid sequence. The origin of Au-sulfide-quartz vein deposits (Centralnoye, Berikul, Komsomolskoye, Kommunar, Sarala) and Au skarn deposits (Natalevskoye, Sinyukhinskoye) is related to early Paleozoic collisional granitoid of the Martaiginsk and Lebed complexes (Berzin and Kungurtsev, 1996) that are interpreted as having been derived from calc-alkaline andesite mantle melt. The initial $^{87}Sr/^{86}Sr$ ratio in accessory apatite from granite ranges from 0.7043 to 0.7044 (Sotnikov and others, 1999). The $^{40}Ar/^{39}Ar$ isotopic age for granitoid of the Martaiginsk complex is 480 to 460 Ma (Sotnikov and others, 1995). Similar data occur for granite in the Lebed complex with a K-Ar isotopic age of 445 to 427 Ma. Rb-Sr isotopic ages for gangue minerals and metasomatite are 472 ± 10 Ma at Gavrilovskoye; 458 ± 4 Ma at Centralnoye; 444 ± 4 Ma for Komsomolskoye; and 433 ± 17 Ma for Sarala. Some studies suggest the Au deposits may be related to dike complexes superimposed on the Martaiginsk and Lebed granitoids (Shirokich and others, 1998).

Ozerninsky Metallogenic Belt of Volcanogenic-Hydrothermal-Sedimentary Massive Sulfide Pb, Zn (Cu), Sediment-Hosted Cu, and Volcanogenic-Sedimentary Fe Deposits (Belt OZ) (Russia, Western Transbaikalia)

This Cambrian metallogenic belt is hosted in the Eravna island-arc terrane that is overlapped by the Barguzin-Vitim and Transbaikalia sedimentary and volcanic-plutonic belts. The belt occurs in the central part of Vitim Lowland in the upper drainages of the Uda and Vitim Rivers. The belt extends for more than 150 km and ranges up to 75 km wide. The Eravna island-arc terrane consists of volcanic and sedimentary rocks of the Vendian and Cambrian Oldynda suite (Belichenko, 1969, 1977). The volcanic part is mainly rhyolite, dacite, andesite, and rhyolite, with minor diabase and basalt porphyry. Pyroclastic units predominate over flows. Also occurring are widespread subvolcanic stocks and sills of lava breccias and minor diabase and andesite porphyry dikes and sills. The sedimentary rocks are mainly limestone and minor carbonaceous and carbonataceous shale, siltstone, and sandstone. The carbonaceous rocks contain reefs, bioherms, and biostromes. Sedimentary rock of the Eravna terrane occur only as scattered, variable-size roof pendants in plutons in the large Barguzin-Vitim batholith with an isotopic age of 320 to 280 Ma (Yarmolyuk and others, 1997). The Ozerninsky roof pendant covers 200 km^2 and hosts the Ozerninsky metallogenic belt that contains more than twenty stratiform pyrite, polymetallic sulfide, and ferric Fe deposits and ore occurrences. The main deposits are the Ozernoye, Zvezdnoye, Ulzutuyiskoye, and Nazarovskoye volcanogenic hydrothermal-sedimentary Pb, Zn, Cu deposits, the Gundui and Turkal volcanogenic hydrothermal Cu deposits. The major deposits are at Ozernoye, Ulzutuyskoye, and Gundui.

The main references on the geology and metallogenesis of the belt are Belichenko (1969, 1977), Tarasova and others (1972), Distanov (1977), Nefediev (1986), Distanov and Kovalev (1996), Belichenko and others (1994), Tsarev (1995), and Yarmolyuk and others (1997).

Gundui Volcanogenic-Hydrothermal Cu Deposit

This metasomatic deposit (Tsarev and Firsov, 1988; Kovalev and Buslenko, 1992; Tsarev, 1995) occurs in an outlier of Early Cambrian carbonate and pyroclastic rocs along a contact with quartz-plagioclase porphyry. The deposit contains two large steeply dipping occurrences that range from 300 to 1000 m long, are 600 m deep, and vary from 8 to 105 m thick. Also occurring are three small occurrences along a major fault that also controls five Fe and Cu deposits. The ores minerals are chalcopyrite, barite, and magnetite. Lenses and layers of barite, chalcopyrite-barite, magnetite, apatite-magnetite, Cu-pyrite also occur and contain magnetite, chalcopyrite, pyrite, hematite, barite, siderite, pyrrhotite, sphalelite, galena, bornite, and apatite. Gangue minerals are ankerite, calcite, quartz, chlorite, epidote, and K-feldspar. Chalcopyrite occurs as disseminations in and in masses with magnetite. Metamorphism formed chalcopyrite and barite nests and veins. Local siliceous and quartz-albite-chlorite metasomatite occur. The deposit is medium size and has an average grade of 0.92 percent Cu, 22 to 31 percent Fe, and 27 to 46 percent barite.

Ozernoye 2 Volcanogenic-Hydrothermal-Sedimentary Massive Sulfide Deposit

This deposit (Distanov, 1977; Tsarev, 1995; Distanov and Kovalev, 1996) (fig. 16) consists of stratified bodies of layered, banded, lenticular and complex form.The bodies extend from 1300 to 2340 m, thickness from 1-2 to 30-45 m.The deposit occurs in layers and extends to a depth of 350 m. The deposit is interpreted as pyrite-polymetallic type. The deposit minerals are primarily Zn with admixture of galena. Major deposit minerals are pyrite, sphalerite, galena, barite, siderite and magnetite. Minor deposit minerals are arsenopyrite, chalcopyrite, pyrrhotite, marcasite, gray ore, native silver, argenite, gold, bornite, stannite. Gange minerals are quartz, calcite, dolomite, rhodochrosite and fluorite. On the surface, deposit minerals are oxidized. The deposit minerals occur in masses, bands, disseminations, veinlets and breccia. Local gradation exists and consists of pyrite through a zone of disseminated minerals into host rock. The host volcanic and carbonate sequence consists of Early Cambrian limestone, andesite, andesite-basalt and basalt poyrphyry, and tuff and tuffite that are intruded by granitoids of the Barguzin-Vitim batholith. The stratified sequence and granitoids are cut by dikes of siliceous porphyry, diabase and diorite porphyry, syenite porphyry and jointly with bodies are screened by the cover of siliceous volcanic rock. The siliceous-alkaline metasomatism is well displayed and consists of skarn, argillite and K-feldspar alteration. The average grade is 5.49 percent Zn, 1.02 percent Pb, 25.57 percent Fe0, and 13 percent S.

Origin and Tectonic Controls for Ozerninsky Metallogenic Belt

The belt is interpreted as having formed in the Dzhida-Lake island arc that was subsequently intruded by the Barguzin-Vitim batholith (Distanov, 1977; Distanov and Kovalev, 1996). The belt occurs in the northwestern margin of the Vendian and Cambrian Eravna island-arc terrane that formed on the margin of the Paleo-Asian Ocean and Siberian continent (Gordienko, 1987; Dobretsov and Bulgatov, 1991; Belichenko and others, 1994). The deposits occur in basins along northeast-striking fault zones.

Sulfides exhibit a fairly simple composition, even distribution in basins, and deep stratigraphic differentiation. Occurring in the belt are either pyrite, galena and sphalerite, or siderite beds. Cu-pyrite ores primarily consist of chalcopyrite, magnetite, and barite, and Fe ores consist of magnetite, martitized magnetite, and hematite. Host rocks are well persevered and regionally metamorphosed to low greenschist facies. Metamorphism resulted in skarn formation, silica-alkaline metasomatism, barite alteration, and siderite alteration, and metamorphism of ore minerals.

The majority of deposits formed during marine hydrothermal and sedimentary sedimentation activity. Host rocks and sulfide minerals exhibit gradational rhythmic turbidite structure. Gradational rhythmic layers exhibit all elements of Boume cycle. The coarse-grained part consists of greywacke or coarser sedimentary clastic material derived from volcanic rock. Bedded ore horizons occur near the top of gradational beds along the southeastern margin of the Ozerninsky roof pendant. Alternating, rhythmically bedded Fe oxides and sulfides occur in interlayered volcanic and sedimentary rocks. Multistage ore mineral occurrence is correlated with rhythmic structure of host rocks and with pulses of volcanic, seismic-tectonic, sedimentation, and hydrothermal activity (Tarasova and others, 1972).

South Khingan Metallogenic Belt of Banded Iron Formation (BIF, Superior Fe) Deposits (Belt S-Kh) (Russia, Far East)

This Neoproterozoic and Cambrian metallogenic belt occurs in the Malokhingansk accretionary wedge terrane that consists of an early Paleozoic metamorphic core complex that is metamorphosed to greenschist to amphibolite facies. Primary rocks are Neoproterozoic and Early Cambrian that form an ophiolite sequence and overlying shale, siliceous shale, phyllite, and limestone.This Neoproterozoic and Cambrian sequence is intruded by granitoids with K-Ar ages of 604 and 301 Ma. The major deposits are at South Khingan, Kimkanskoe, and Kostenginskoe.

The main references on the geology and metallogenesis of the belt are Kozlovsky (1988), and Kazansky (1972).

South Khingan Banded Iron Formation (BIF, Superior Fe) Deposit

The South Khingan deposit (V.A. Yarmolyuk and A.P. Glushkov, written commun., 1966) (fig. 17) consists of Fe- and Mn-bearing beds of magnetite-, hematite-, and magnetite-hematite-quartzite. Beds range from 18 to 26 m thick and are interlayered with chlorite dolomite breccia. Underlying sedimentary rock contains of braunite, hausmannite, and rhodochrosite that range from 2 to 9 m thick. The Fe-and Mn-bearing layers are overlain by a dolomite sequence that is overlain by shale, limestone, and dolomite. The deposit has not been developed because of difficulties with ore concentration and steeply dipping beds. The largest deposits at Kimkanskoe, Kostenginskoe, and South Khingan contain approximately 3 billion tonnes ore. Mineralogic and geochemical studies suggest a sedimentary-exhalative origin. The deposit is medium size.

Origin and Tectonic Controls for South Khingan Metallogenic Belt

The metallogenic belt is interpreted as having formed in a volcanic and sedimentation basin that was incorporated into an subduction-zone terrane along the continental margin of the Gobi-Amur microcontinent.

Uda-Shantar Metallogenic Belt of Volcanogenic-Sedimentary Fe, Volcanogenic-Sedimentary Mn, and Sedimentary Phosphate Deposits (Belt Ud-S) (Russia, Far East)

This early Paleozoic metallogenic belt occurs in the Galam accretionary wedge terrane that consists chiefly of Paleozoic rocks in an imbricate stack of thrust sheets. The terrane consists of three rock sequences (1) coherently bedded turbidite; (2)

Oldyndinsky Suite, northern sequence sedimentary rock (Early Cambrian)

Lower horizon calcareous tuff gravel, tuff, and tuff sandstone with interlayered limestone and carbonaceous tuff

Middle horizon rhythmically alternating carbonaceous and calcareous tuff, top sequence of pyrite ore

Upper horizon silicified and calcareous tuff with interlayered tuff sandstone

Gurvunursky Suite, bedded sequence (Early Cambrian)

Lower horizon siliceous lava, tuff

Middle horizon limestone, calcareous breccia, tuff with interlayered

Upper horizon agglomerate tuff, tuff, limestone, bed of pyrite lead-zinc ore in upper part of horizon

Ozerny bedded sequence (Early Cambrian)

Tuff-lava, andesite-dacite porphyry volcanic rock, tuff, and lenses and interlayered limey breccia, and calcareous and mineralized tuff

Tuff-lava, andesite-dacite porphyry, volcanic rock, tuff, and lenses of interlayered limey breccia and calcarous and mineralized tuff

First ore horizon limestone, calcareous breccia and gritstone with clasts of jasper rock, tuff, ignimbrite tuff, and five ore bodies

Second ore horizon limestone, calcareous breccia and gritstone, tuff, and four ore bodies

Crystal tuff horizon limestone, calcareous breccia, crystal tuff, and siliceous volcanic rock

Subvolcanic rock and dikes (Early Cambrian)

Rhyolite-dacite porphyry breccia

Diabase porphyry

Dacite porphyry

Andesite porphyry dikes

Syenite porphyry dikes

Diabase porphyry dikes

Agglomerate breccia (intermediate composition), and siliceous and alkaline volcanic rock and lava breccia

Pyrite lead-zinc ore bodies

Siderite ore bodies

Geological contact

Fault

Figure 16. Generalized geologic map of Ozernoye 2 volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn deposit, Ozerninsky metallogenic belt. Adapted from Tarasova and others (1972).

basalt, ribbon chert, and siliceous shale; and (3) olistostrome. Each rock sequence occurs in independent tectonic slices and sheets that are separated by ductile faults that occur parallel to bedding in the sheets. Internal parts of the sheets are comparatively weakly deformed. The significant deposit is the Gerbikanskoe volcanogenic-sedimentary Fe deposit. Other significant deposits are the North-Shantarskoe, Nelkanskoe, Ir-Nimiiskoe-2, and Lagapskoe sedimentary P deposits, and the Ir-Nimiiskoe-1, Milkanskoe, Galamskoe, Kurumskoe, and Itmatinskoe volcanogenic-sedimentary Fe and Mn deposits. The major deposits are at Gerbikanskoe, North-Shantarskoe, Ir-Nimiiskoe 1 and 2, Lagapsko, and Nelkanskoe.

The main references on the geology and metallogenesis of the belt are Shkolnik (1973) and Khanchuk (1993).

Gerbikanskoe Volcanogenic-Sedimentary Fe Deposit

This deposit (Shkolnik, 1973) (fig. 18) consists of two zones separated by a sequence of sandstone and siltstone. The zones consist of approximately 30 steeply dipping, sheeted and lenticular bodies of magnetite and hematite. Individual bodies range from several tens of m to 5 to 7 km long and are sometimes closely spaced in an en-echelon pattern. Thickness varies from 5 to 50 m and is commonly 8 to 28 m. Fe mineral layers vary from banded to thinly banded, lenticular, and bedded, and consist of finely dispersed hematite, magnetite, and rare pyrite and chalcopyrite. The deposit is large and has an average grade of 42 to 43 percent Fe (soluble Fe 33 to 53 percent), 1.8 percent Mn, and 9.6 percent P.

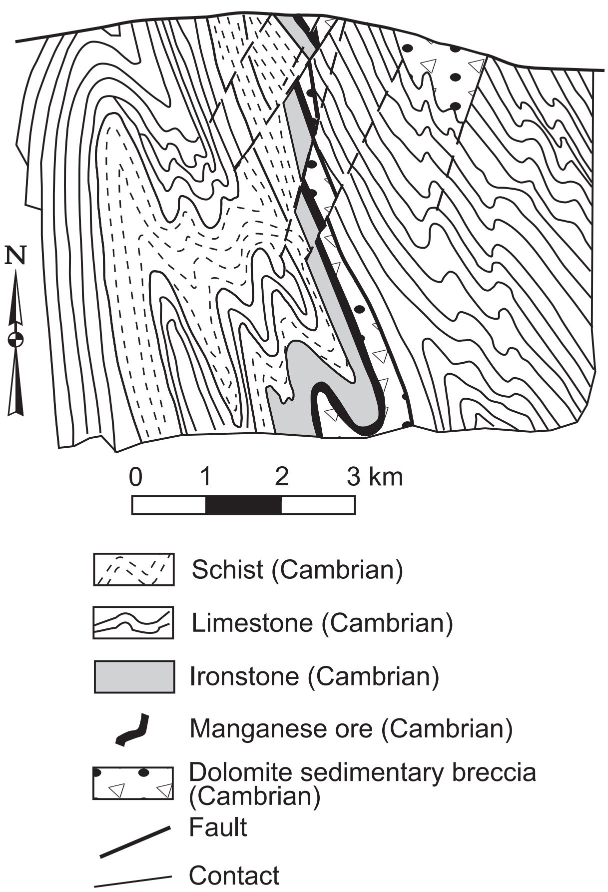


Figure 17. Schematic cross section of South Khingan banded iron formation deposit, South Khingan metallogenic belt. Adapted from V.A. Yarmolyuk and A.P. Glushkov (written commun., 1966)

North-Shantarskoe Sedimentary Phosphate Deposit

This deposit (Shkolnik, 1973) consists of phosphorite deposits that occur in a sedimentary breccia with indistinct borders. The deposit ranges up to 15 to 16 m thick and is hosted in carbonate rock in a sequence of chert and volcanic rock that are partially altered to quartz-carbonate rock. The sequence occurs for approximately 8 to 10 km at the northeast end of Bolshoi Shantar Island. The deposit is small with an average grade of less than 6 to 8 percent P_2O_5.

Nelkanskoe Sedimentary Phosphate Deposit

This deposit (Shkolnik, 1973) consists of a phosphorite sedimentary breccia that occurs in a steeply dipping sequence of jasper and volcanic rock that is exposed in an erosional window below gently dipping Jurassic sedimentary rock. Host rocks are silicified dolomite and limestone. Phosphorite beds range up to 1.8 km long, however, some are only several tens of meters long. Thickness varies from 2 to 41 m. The deposit drilled to almost 300 m. In addition to fragments of primary phosphorite, the deposit contains fragments of silicified carbonate rocks that range from 0.5 to 2 cm wide and are cemented by phosphate and hydromica. Phosphates are radioactive. The deposit is small. The grade ranges from 4 to 30 percent P_2O_5 and averages 7 to 11 percent.

Ir-Nimiiskoe-2 Sedimentary Phosphate Deposit

This deposit (S.G. Kostan'yuan and others, written commun., 1973) consists of numerous and unusual phosphorite bodies that occurs in a sedimentary breccia formed in atoll fans and seamounts. The deposits occur in an area 25 to 30 km long and 6 to 8 km wide and are hosted in complex, steeply dipping, and folded rocks that comprise a reef edifice. Some carbonate is silicified. Boundaries of deposits are gradational due to variable amount of fragments of primary phosphorite in dominant host limestone, dolomite, and siliceous carbonate, and in rare jasper, volcanic rock, and siliceous claystone fragments. Primary phosphorite occurs mainly in thin beds and small lenses of coquina that consists predominantly of inarticulate brachiopods with phosphate shells and some Cambrian trilobites. Phosphorite breccia occurs at various stratigraphic levels with no clear boundaries. The margin is determined by sampling. Approximately 30 phosphorite layers are identified. Layers range from several tens of m to several km long and are commonly discontinuous. The deposit generally has simple mineral composition. In addition to phosphorite, the deposit contains quartz, dolomite, calcite, rare pyrite, chert, and volcanic rock fragments. Thickness of the phosphorite ranges from 0.5 to 24 m, but varies greatly over short distances. The deposit is medium size. Phosphorus anhydrite ranges from 3 to 12 percent and averages 7 to 8 percent.

Lagapskoe Sedimentary Phosphate Deposit

This deposit (Zagorodnykh, 1984) consists of carbonate beds that contain phosphorite breccia with Cambrian fossils. Beds locally range up to 30 m thick, but generally range from several tens of cm to 20 m thick. Phosphorite breccia contains fragments of primary phosphorite, dolomite, limestone, and rare jasper, schist, and shale. Carbonate is commonly completely altered to quartz-carbonate layers intercalated with jasper, shale, schist, siltstone, spilite, basalt, and basalt tuff. The deposit is medium size and contains from 4 to 30 percent anhydrous phosphorous and averages 5 to 7 percent.

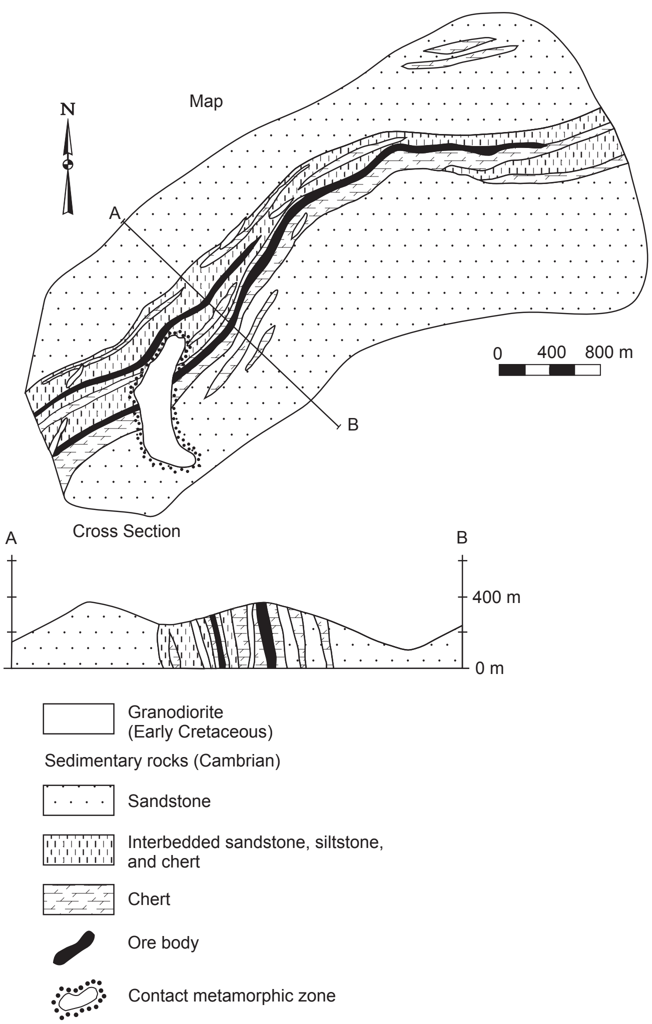


Figure 18. Generalized geologic map and schematic cross section of Gerbikanskoe volcanogenic-sedimentary Fe deposit, Uda-Shantar metallogenic belt. Adapted from Shkolnik (1973).

Ir-Nimiiskoe-1 Volcanogenic-sedimentary Mn Deposit

This deposit (Shkolnik, 1973) consists of partly metamorphosed, steeply dipping, lenticular and sheeted, bedded Mn bodies that occur in a diverse Early Cambrian sequence of jasper, shale, spilite, basalt, and basaltic tuff that overlies a carbonate reef complex and seamounts. Mn bodies range from several tens to several hundred m long, and vary from 1.5 to 120 m thick. Bodies vary from massive and banded to thinly banded. Mn bodies consist of oxidized braunite, hausmannite-rhodochrosite, rhodochrosite, and rhodonite-rhodochrosite. Bodies also contain quartz and minor magnetite, hematite, manganite, sulfides, piedmontite, manganophyllite, viridine, amphiboles, muscovite, and plagioclase. Mn content varies greatly, extending up to 50 to 56 percent Mn in oxidized ore and 47 percent Mn in carbonate ore, along with 0.01 to 0.12 percent P, up to 3 percent Fe, and 9 to 70 percent SiO_2. The deposit is small. The average grade is about 22.4 percent Mn.

Origin and Tectonic Controls for Uda-Shantar Metallogenic Belt

The belt is interpreted as having formed during sea floor hydrothermal activity associated with basaltic volcanism that was accompanied by chert deposition in basins. The volcanogenic-sedimentary Fe deposits in the belt consist of numerous lenticular and sheeted magnetite bodies that consist of conformable, steeply dipping layers. The volcanogenic-sedimentary Mn deposits consist of partly metamorphosed, steeply dipping, lenticular and sheeted, bedded Mn bodies that occur in a diverse Early Cambrian sequence of jasper, shale, schist, spilite, basalt, and basalt tuff that overlays a carbonate reef complex with seamounts. The sedimentary P deposits are interpreted as having formed in limestone caps that formed in two stages on accreted seamounts, atolls, and guyots.

The host units and deposits were subsequently incorporated into the host Galam accretionary-wedge terrane that was tectonically linked to the Devonian North Okhotsk (Uda) magmatic arc that formed along the Stanovoy block of the North Asian craton.

Voznesenka Metallogenic Belt of Korean Pb-Zn Massive Sulfide Deposits (Belt VZ) (Russia, Far East)

This Cambrian through Ordovician metallogenic belt occurs in layers in marine sedimentary units in the Voznesenka passive continental-margin terrane of the Khanka superterrane that is a fragment of a Paleozoic active continental-margin arc. The Voznesenka terrane consists of two major units. (1) Cambrian sandstone, pelitic schist, rhyolite, felsic tuff, limestone, and dolomite that range up to several thousand meters thick, are intensely deformed, and are intruded by Ordovician collision biotite and Li-F protolithionite granitoids with Rb-Sr and Sm-Nd isotopic ages of 450 Ma; and (2) Ordovician through Early Silurian conglomerate and sandstone. Overlapping assemblages range from Early Devonian through Late Permian. The massive sulfide deposits generally occur conformable to organic-rich, bituminous limestone near a contact with overlying marl. Banded magnetite associated with algae bioherms is a peculiar association with stratiform sulfide deposits of the Voznesenka metallogenic belt. The significant deposits are at Voznesenka-I and Chemyshevskoe.

The main references on the geology and metallogenesis of the belt are Androsov and Ratkin (1990), Khanchuk and others (1996, 1998), Bazhanov (1988), and Belyatsky and Krymsky (1999).

Voznesenka-I Korean Pb-Zn Massive Sulfide Deposit

This deposit (Androsov and Ratkin, 1990) (fig. 19) consists of massive and thick-banded sphalerite and magnetite-sphalerite layers in Early Cambrian bedded limestone turbidite. The deposits are lenticular, 1 to 2 m thick, 20 to 100 m long, and occur in dolomitic limestone and marl. The sulfide bodies and host rocks are folded and regionally metamorphosed. The sulfide bodies were locally altered to skarn and greisen during emplacement of a Silurian granitic stock that intrudes the carbonate unit. The deposit is medium size and has an average grade of 4 percent Zn.

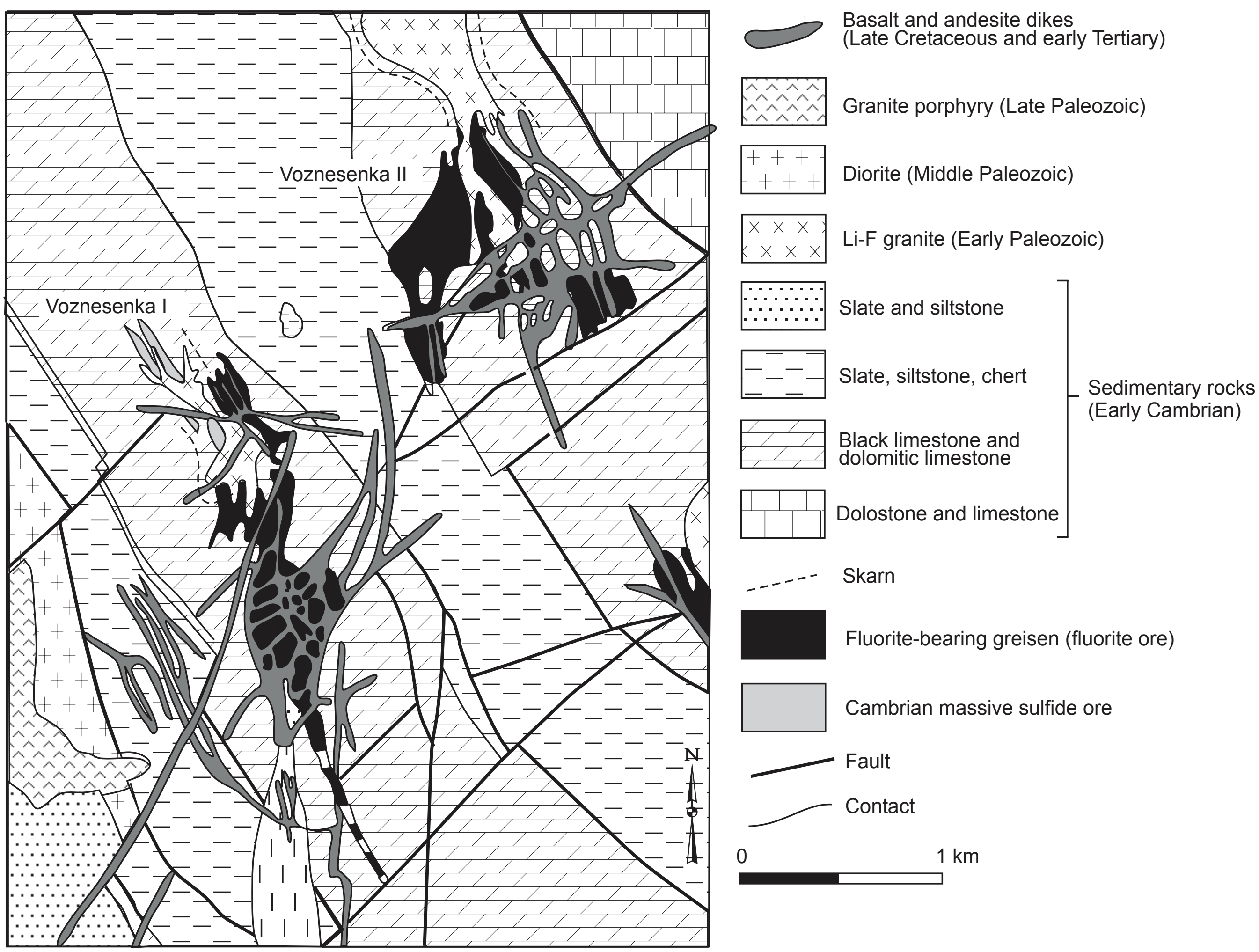


Figure 19. Generalized geologic map of Voznesenka-1 Korean Pb-Zn massive sulfide deposit, Voznesenka metallogenic belt. Adapted from Ratkin (1995).

Chernyshevskoe Korean Pb-Zn Massive Sulfide Deposit

This deposit (Bazhanov, 1988) consists of layered assemblage of pyrrhotite, arsenopyrite, pyrite, galena, and sphalerite that occurs at the contact of a limestone sequence with overlying Early Cambrian siltstone. Rare conformable zones of disseminated sulfide occur in the limestone away from the contact. The sulfide bodies are 1 to 2 m thick and have a surface exposure of 100 by 200 m. The deposit was drilled to a depth of about 100 m. The deposit is small and has an average grade of 1.5 to 6.5 percent Pb and 0.7 to 2.5 percent Zn.

Origin and Tectonic Controls for Voznesenka Metallogenic Belt

The belt is hosted in theVoznesenka terrane in limestone turbidite that contains the Voznesenka-I and Chernyshevskoe Korean Zn-Pb massive sulfide deposits. The deposits are interpreted as having formed from hydrothermal fluids that intruded into the upper part of an Early Cambrian continental slope. The belt is interpreted as having formed during rifting and submarine hydrothermal activity along the continental margin of the Gobi-Amur microcontinent that was part of the passive continental margin of Gondwanaland.

Yaroslavka Metallogenic Belt of Fluorite Greisen and Sn-W greisen, Stockwork, and Quartz-Vein Deposits (Belt YA) (Russia, Far East)

This Late Cambrian and though Devonian metallogenic belt is hosted in numerous Paleozoic granitoid plutons that intrude in Cambrian clastic and limestone units of the Vosensenka continental-margin terrane of the Khanka superterrane. The Li-F alaskite granite that hosts the Voznesenka-II deposit has Rb-Sr isotopic ages of about 512 to 475 Ma. The formation of the deposits is interpreted as being related to intrusion of Late Cambrian leucogranite. The major fluorite greisen deposit is at Voznesenka-II, and the major Sn-W greisen, stockwork, and quartz-vein deposit is at Yaroslavka.

The main references on the geology and metallogenesis of the belt are Govorov (1977), Androsov and Ratkin (1990), Khetchikov and others (1992), Ryazantzeva and Shkurko (1992), Khanchuk and others (1996, 1998), and Ryazantzeva (1998).

Yaroslavskoe Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Govorov, 1977) (fig. 20) occurs mainly in greisen that mainly replaces skarn, limestone, and shale, and to lesser extent granite and granite porphyry that has a Rb-Sr isotopic age of 408 Ma and an initial Sr ratio of 0.7136. Sn quartz and quartz-tourmaline veins also replace skarn along with greisen. The Sn bodies occur in three mineral assemblages (1) tourmaline and quartz; (2) tourmaline and fluorite; and (3) sulfide, tourmaline, and quartz with subordinate cassiterite, polymetallic sulfides, and chlorite. The sulfides are mainly pyrite, arsenopyrite, galena, and sphalerite. The deposit occurs along the contact of a early Paleozoic biotite granite (with an approximate isotopic age of 400 Ma) that intrudes Early Cambrian shale, siltstone, sandstone, and limestone. The relatively older pyroxene-scapolite, vesuvianite-garnet, and epidote-amphibole skarns replace limestone and shale along granite contacts, and in rare limestone inclusions in the granite. More than forty Sn occurrences occur in the metallogenic belt. The deposit is medium size and has an average grade of 0.52 percent Sn. The deposit was mined from the 1950s to the 1970s.

Voznesenka-2 Fluorite Greisen Deposit

This deposit (Androsov and Ratkin, 1990) (fig. 21) consists of massive to disseminated fluorite that occurs above the apex of a 1.5-km-wide intrusion of Late Cambrian Li-F alaskite granite with an isotopic age of 512 to 475 Ma. The deposit consists of vein and greisen that occurs along a north-south-trending fault. The deposit consists of muscovite-fluorite aggregates that occur along the periphery, whereas vein greisen occurs in the middle. Greisen is often brecciated, indicating a two-stage origin. Fragments of breccia consist of mica and fluorite, fluorite limestone, greisen, and granite altered to greisen. Fragments are cemented by quartz-topaz-micaceous-fluorite aggregate that formed during a second stage. The deposit is interpreted as having formed during metasomatic replacement of Early Cambrian black organic limestone and alteration to greisen. The deposit is large and contains 450 million tonnes fluorite ore and has an average grade of 30 to 35 percent fluorite. The deposit has been mined since the 1960s, and currently is the largest producer of fluorite in Russia.

Origin and Tectonic Controls for Yaroslavka Metallogenic Belt

The belt is interpreted as having formed in a collisional arc that formed along the passive margin of a fragment of Gondwanaland. The host leucogranite hosting the fluorite and Sn-W greisen, stockwork, and quartz-vein deposits is Li-F-REE enriched. The extensive deposits occur in the apical parts of plutons that are altered to quartz-mica-fluorite-REE greisen. The host leucogranite plutons are interpreted as having formed during anatectic melting of older granitic gneiss and Cambrian sedimentary rock. The anatectic melting is interpreted as having occurred during early Paleozoic collision of the Voznesenka and Kabarga terranes. The host leucogranite plutons intrude Early Cambrian limestone of the Voznesenka passive continental-margin terrane that is interpreted as being a fragment of a Neoproterozoic through early Paleozoic carbonate and rich sedimentary-rock sequence that formed on a passive continental margin.

Neoproterozoic through Silurian Metallogenic and Tectonic Model

During the Neoproterozoic through Silurian (1000 to 410 Ma), the major tectonic events were (1) opening of the Paleo-Asian ocean and formation of passive continental margins along the North Asian craton; (2) formation of Neoproterozoic, Vendian-Cambrian and Early Paleozoic magmatic arcs, tectonically related subduction zones and associated metallogenic belts in the eastern part of the Paleo-Asian ocean; (3) closure of the eastern part of the Paleo-Asian ocean as a result of the oceanic plate subduction and terranes accretion towards the North Asia craton and cratonal margin at the end of the early Paleozoic; and (4) destruction of the accretionary-collision-related continental margin and opening of new oceanic basins between the early and middle Paleozoic. As described below, major metallogenic belts formed during each tectonic event.

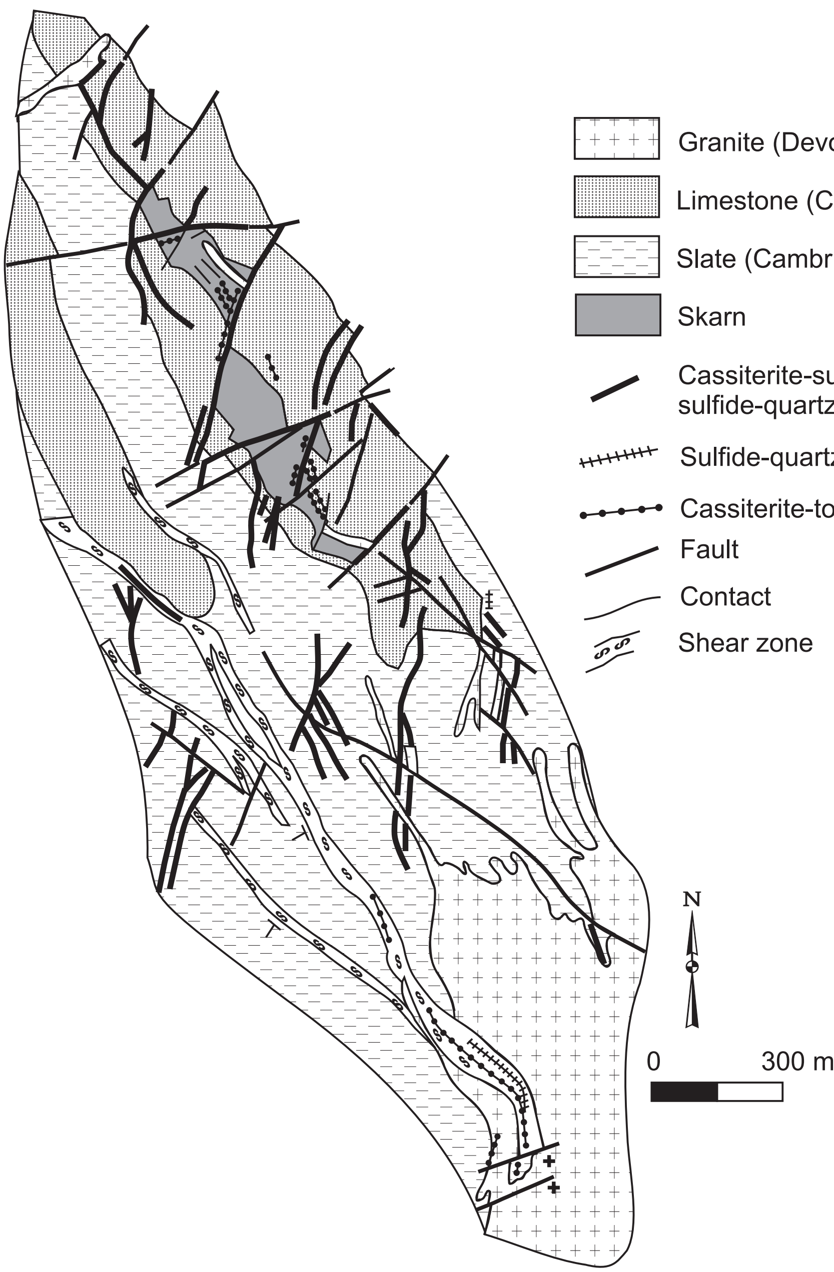


Figure 20. Generalized geologic map of Yaroslavskoe Sn-W greisen, stockwork, and quartz-vein deposit, Yaroslavka belt. Adapted from Govorov (1977) and Ryazantzeva (1998).

Early to Middle Neoproterozoic (1000 to 650 Ma) Metallogenic and Tectonic Model

Cratons, Passive Continental-Margin, and Cratonal Terranes

The major tectonic events in the Neoproterozoic for cratons, passive continental margins, and cratonal terranes (fig. 22) were as follows.

1. Passive continental margins formed on the submerged margins of the North-Asian craton, including the East Angara (NAE), Baikal-Patom (NAP), and Verkhoyansk (fold- and thrust-belt) terranes (NAV), and associated terranes, including the Argunsky, Central Angara, Idermeg, West Angara passive continental-margin terranes;

2. Widespread intracontinental rifting was initiated along the passive continental margins;

3. Platform cover accumulated onto the inner parts of the North-Asian craton;

4. Shallow-water marine sediments accumulated on the Sino-Korean craton; and

5. Several major island-arc systems and tectonically linked subduction zones formed offshore or far away from the North Asian craton, including the Near-Yenisey, Baikal-Muya, and Zavhan magmatic arcs.

Near-Yenisey Island Arc

Remnants of the late Proterozoic Near-Yenisey arc are preserved in the Circum-Siberia collage (figs. 2, 22; appendix B), that is Proterozoic and accreted in the Neoproterozoic, in the Isakov (IS) and Predivinsk (PR) island-arc terranes (Kuzmichev, 1990; Vernikovskiy, 1996, 2002). The terranes are overthrust eastward onto either the West Angara (WAG) passive continental-margin terrane or older units of the North Asian craton (NAC). The polarity of the subduction zone based on the structural position of the ophiolite-clastic melange is interpreted as dipping oceanward, away from continent (fig. 22). The age of the arc is still a question. Dating of island-arc plagiogranite and volcanic units has yielded ages ranging from 700 to 630 Ma (Vernikovskiy, 2002). The Isakov terrane is unconformably overlapped by the Neoproterozoic-Vendian sediments of the Vorogovka-Chapa Basin (Sovetov, 2001).

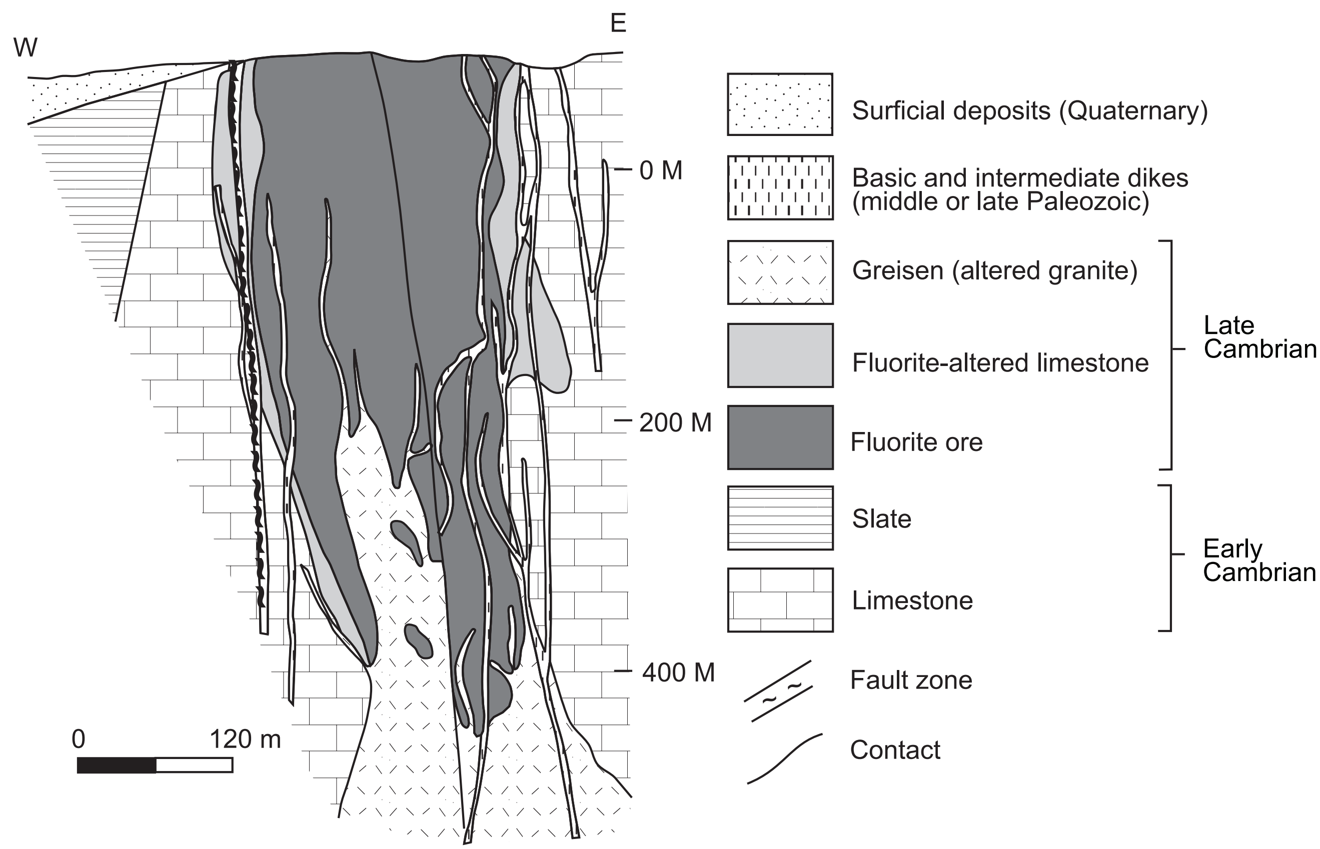


Figure 21. Schematic cross section of Voznesenka-2 fluorite fluorite greisen deposit, Yaroslavka belt. Adapted from Androsov and Ratkin (1990) and Ryazantzeva (1998).

Baikal-Muya Island Arc

Remnants of the Neoproterozoic Baikal-Muya arc are part of the Tuva-Mongolia superterrane that is late Riphean and older and accreted in the late Neoproterozoic (figs. 2, 22; appendix B) in the Baikal-Muya (BM) and Sarkhoy (SR) terranes in the Transbaikal region and northern Mongolia (Berzin and Dobretsov, 1994; Konnikov and others, 1994; Kuzmichev and others, 2001; Obolenskiy and others, 1999). Remnants of the arc are unconformably overlapped by Vendian-Cambrian rocks of the Upper Angara Basin and Huvsgol-Bokson overlap assemblage.

Tectonically paired to the Baikal-Muya island arc was a subduction zone that is now preserved in the Hug (HU) and Olokit-Delunuran accretionary-wedge (OD) terranes (fig. 22). The position of accretionary-wedge terranes relative to the island-arc igneous-rock units, and the lack of the subduction signs at the periphery of the Baikal-Patom passive continental margin suggest that the subduction zone dipped to the southeast under the island arc (fig. 22) (Berzin and Dobretsov, 1994). Strike-slip faulting occurred between the Baikal-Muya and Near-Yenisey arcs along the Main Sayan strike-slip fault (fig. 22). The arc is associated with back-arc, forearc, rift, and mélange units in the Kuvai terrane (KUV). The terrane is unconformably overlapped by the Vendian-Cambrian sediments of the Mana Basin (Khomentovskiy and others, 1978).

Zavhan Magmatic Arc

A fragment of the Late Proterozoic Zavhan magmatic arc occurs in Central Mongolia in the Zavhan (ZA) active continental-margin terrane (Tomurtogoo, 2002) that is also a part of the Circum-Siberia collage (figs. 2, 22, appendix B) that is Proterozoic and accreted in the Neoproterozoic. The initial relation of the magmatic arc to the adjacent Baydrag (BY) cratonal terrane is unknown. The Zavhan and Baydrag terranes are unconformably overlapped by the latest Neoproterozoic through Middle Cambrian Huvsgol-Bokson (hb) sedimentary assemblage (Il'in, 1982). The subduction zone was southwest of the magmatic arc. Alpine-type ultramafic and associated units in the Tasuul terrane (TS) form part of an accretionary wedge assemblage that was obducted onto western margin of the Zavhan terrane (Tomurtogoo, 2002). The western and eastern ends of the magmatic arc occurred along dextral shear zones that were subparallel to the continental margin (fig. 22).

Metallogenesis

The major Neoproterozoic metallogenic belts formed in a variety of tectonic environments (figs. 3, 22; appendix C).

In the Angara-Pit belt (AP, figs. 3, 22; appendix C), the sedimentary Fe-oxide deposits are interpreted as having formed during Upper Riphean preorogenic subsidence of the North Asian cratonal margin in a back-arc (interland) sedimentary basin.

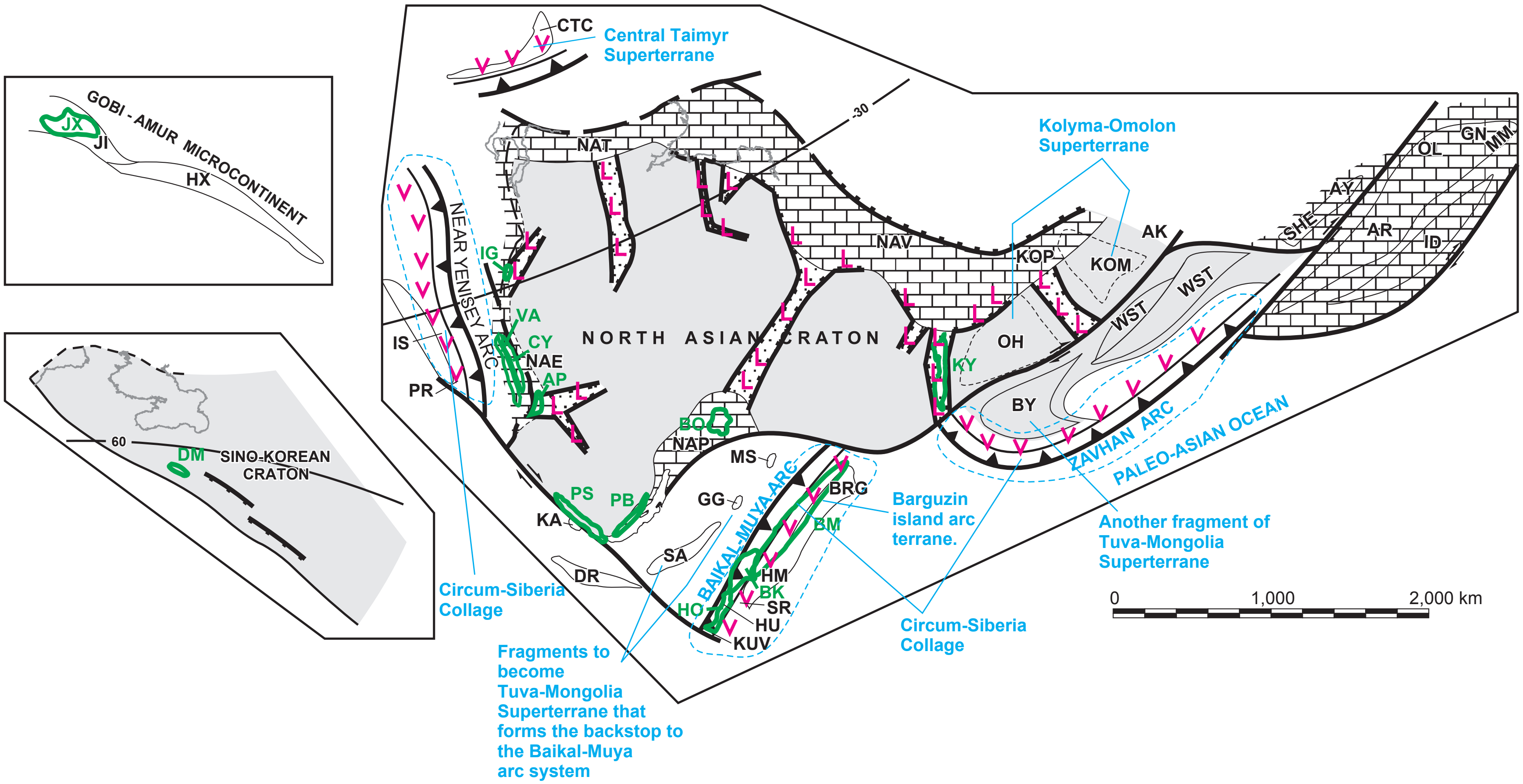
The Baikalo-Muiskiy belt (BM, figs. 3, 22; appendix C) is hosted in the Yenisey-Transbaikal collage and Tuva-mongolia superterrane, and it contains volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn (±Cu), polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite, and serpentinite-hosted asbestos deposits. These deposits are interpreted as having formed in the Baikal-Muya island arc (part of the Tuva-Mongolia superterrane), or during Riphean accretion of the Muya metamorphic and Olokit-Delunuran subduction-zone terranes.

The Bodaibinskiy belt (BO, figs. 3, 22; appendix C) contains Au in black shale deposits that are interpreted as having formed in the Baikal-Muya island arc or during Riphean accretion of terrane with the Muya metamorphic terrane and Olokit-Delunuran subduction-zone terrane. Initial gold deposition occurred during sedimentation and during later metamorphism and hydrothermal activity. Subsequent Neoproterozoic post-collisional magmatic and hydrothermal activity formed economic deposits. Subsequent formation of gold-silver-sulfosalt deposits occurred during magmatic and hydrothermal activity in the middle and late Paleozoic. The formation of these Au deposits began from early syngenetic sedimentary stage in the Riphean and continued with formation of nappes and folds, and intrusion of collisional granitoids and associated metamorphism in the Vendian and Early Cambrian, and continued with anorogenic granitoid magmatism in the Mississippian.

The Bokson-Kitoiskiy belt (BK, figs. 3, 22; appendix C) is hosted in the North Asian cratonal margin, Patom fold- and thrust-belt and contains sedimentary bauxite, magmatic nepheline, and serpentine-hosted asbestos, and Au in shear-zone and quartz-vein deposits that are interpreted as having formed in multiple events. The metallogenic belt is a composite that includes several mineral-deposit types. The belt is hosted in metamorphic, oceanic, subduction-zone, and tonalite-trondhjemite-gneiss terranes that underwent Cambrian through Silurian metamorphism, hydrothermal alternation, and plutonic intrusion.

The Central-Yenisei belt (CY, figs. 3, 22; appendix C) contains Au in black shale, Au in shear-zone and quartz-vein, and clastic-sediment-hosted Sb-Au deposits that are hosted in the Central Angara passive continental-margin terrane, part of Central Siberia collage. The gold deposits are interpreted as having formed during collisional development of the late Riphean continental margin of the North Asian craton. Gold initially occurring in black shale was subsequently concentrated and remobilized during collision-related metamorphism, granitoid intrusion, and hydrothermal activity. Most of the large Au and Au-Sb deposits in the Yenisei Ridge consist of multistage polygenetic sedimentary, metamorphic, and hydrothermal origins with primary accumulation of gold in black shales and subsequent concentration and remobilization during metamorphism and granitoid-related hydrothermal activity (Li, 1974a,b; Berger, 1981; Nekludov, 1995).

The Damiao belt (DM, figs. 3, 22; appendix C) contains mafic-ultramafic related Ti-Fe (V), zoned mafic-ultramafic Cr-PGE deposits that are hosted in mafic-ultramafic plutons intruding the West Liaoning-Hebei-Shanxi granulite-orthogneiss terrane in the Sino-Korean craton. The belt is interpreted



GEOLOGIC UNITS

AK - Avekov terrane
AR - Argunsky terrane
AY - Ayansk terrane
BRG - Barguzin terrane
BY - Baydrag terrane
CTC - Chelyuskin terrane
DR - Derba terrane
GG - Gargan terrane
GN - Gonzha terrane
HM - Hamar-Davaa terrane
HX - Hutaguul-Xilinhot terrane
HU - Hug terrane
ID - Idermeg terrane
IS - Isakov terrane
JI - Jiamusi terrane
KA - Kan terrane
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KUV - Kuvai terrane
MM - Mamyn terrane
MS - Muya terrane
NAE - North Asian Craton Margin (East Angara fold and thrust belt
NAP - North Asian Craton Margin (Patom-Baikal fold and thrust belt
NAT - North Asian Craton Margin (South-Taimyr fold belt
NAV - North Asian Craton Margin (Verkhoyansk fold and thrust belt
OH - Okhotsk terrane
OL - Oldoy terrane
PR - Predivinsk terrane
SA - Sangilen terrane
SHE - Shevli terrane
SR - Sarkhoy terrane
WST - West Stanovoy terrane

METALLOGENIC BELTS

AP - Angara-Pit
BK - Bokson-Kitoiskiy
BM - Baikalo-Muiskiy
BO - Bodaibinskiy
CY - Central-Yenisei
DM - Damiao
HO - Hovsgol
IG - Igarsk
JX - Jixi
KY - Kyllakh
PB - Pribaikalskiy
PS - Prisayanskiy
VA - Vorogovsko-Angarsk

EXPLANATION

Craton

Passive continental margin on subsided craton

Microcontinent

Continental slope

Intracontinental sedimentary basin

Collage of accreted terranes and overlap assemblages

Ocean or sea underlain by oceanic crust; includes continental margin and slope units

Sea underlain by continental crust

SUBDUCTION-RELATED ISLAND ARCS AND CONTINENTAL MARGIN ARCS

Mainly volcanic and lesser plutonic units

Mainly plutonic and lesser volcanic units

TRANSFORM-PLATE BOUNDARY, INTRA-PLATE (PLUME) MAGMATIC UNITS

Subalkaline and alkaline volcanic and plutonic belts

Plateau basalt, trap

Rift-related bimodal volcanic and plutonic rocks

Intraplate granitoids

COLLISIONAL GRANITOIDS

CONTACTS, FAULTS, AND SYMBOLS

Subduction zone and its accretionary wedge

Thrust

Strike-slip fault

Normal fault

Fold-and thrust belt formed on the subsided craton margin

Stratigraphic contact

OH Metallogenic belt with abbreviation

Chukotka Collage — Outline and name of tectonic collage or name of major tectonic feature

Figure 22. Neoproterozoic (850 Ma) metallogenic and tectonic model for Northeast Asia. Model and Explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

as having formed during interplate magmatism related to rifting of a Neoproterozoic continental margin along the north margin of the Sino-Korean craton.

The Hovsgol belt (HO, figs. 3, 22; appendix C) contains sedimentary phosphate, volcanogenic-sedimentary Mn, and sedimentary Fe-V deposits that are hosted in the Huvsgol-Bokson sedimentary overlap assemblage deposited on the Tuva-Mongolia superterrane that contains various fragments of the the Baikal-Muya island arc. The belt is interpreted as having formed during shallow-water sedimentation in a carbonate-dominated basin along a continental shelf in the Minusa-Tuva back-arc basin.

The Igarsk belt (IG, figs. 3, 22; appendix C) contains sediment-hosted Cu deposits that are interpreted as having formed in a residual terrigenous marginal basin spatially related to the North Asian cratonal margin.

The Jixi belt (JX, figs. 3, 22; appendix C) contains banded iron formation (BIF, Algoma Fe), Homestake Au, metamorphic graphite, and metamorphic sillimanite deposits that are hosted in the Jiamusi metamorphic terrane and Zhangguangcailing (continental-margin arc) superterrane that is part of the Gobi-Amur microcontinent. The belt is part of a khondalite that is interpreted as derived from Al-rich mudstone and carbonates of the Mashan and the Xingdong groups that were deposited in a shallow sea and isolated oceanic basin and lagoon. The belt is interpreted as having formed on the continental margin of the microcontinent.

The Kyllakh belt (KY, figs. 3, 22; appendix C) contains carbonate-hosted Pb-Zn (Mississippi valley type) deposits that are interpreted as having formed on the passive margin of the North Asian craton in the Vendian.

The Pribaikalskiy belt (PB, figs. 3, 22; appendix C) contains carbonate-hosted Pb-Zn (Mississippi Valley type) deposits that are interpreted as having formed along shear zones and faults that occur between an ancient active continental margin along the North Asian (Baikal-Patom) cratonal margin.

The Vorogovsko-Angarsk belt (VA, figs. 3, 22; appendix C) contains sedimentary exhalative Pb-Zn (SEDEX), carbonate-hosted Pb-Zn (Mississippi valley type) and Fe skarn deposits that are hosted in the West Angara passive continental-margin terrane, part of Circum-Siberia collage. The SEDEX deposits are interpreted as having formed along transcrustal block-bounding faults in the margin of the platform. The carbonate-hosted Pb-Zn deposits are hosted in reefs. The Fe skarn deposits formed during contact metasomatism of marine volcanic and sedimentary rocks.

Late Neoproterozoic (Vendian) to Early Cambrian (650 to 520 Ma) Metallogenic and Tectonic Model

The major tectonic events in the late Neoproterozoic (Vendian) to Early Cambrian (fig. 23) were as follows.

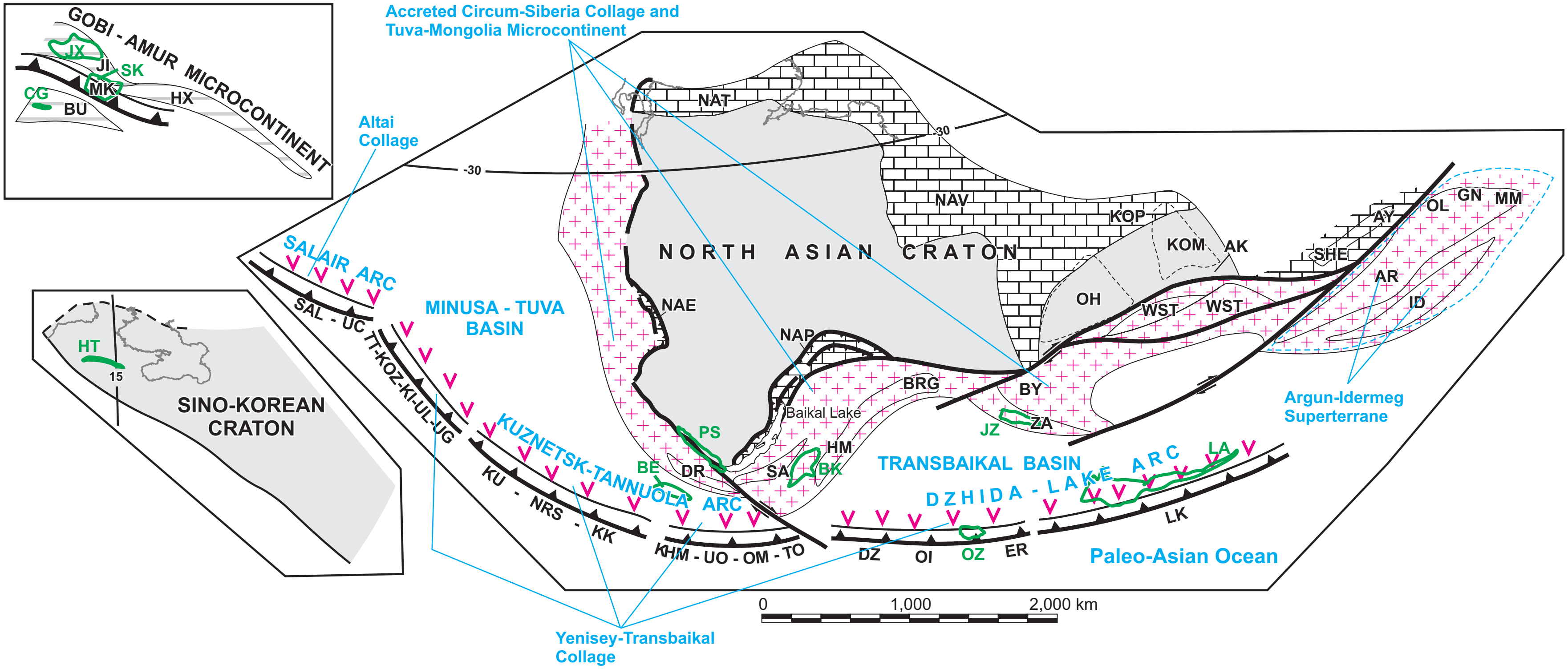
1. Completion of Neoproterozoic accretion of several major island-arc systems and tectonically linked subduction zones onto the North Asian craton, including the Near-Yenisey, Baikal-Muya, and Zavhan magmatic arcs.
2. Formation of new island-arc systems, including the Salair, Kuznetsk-Tannuola and Dzhida-Lake arcs and tectonically linked subduction zones. The island arcs consist mainly of Vendian ophiolites and Vendian through Early and Middle Cambrian igneous rock-units. The Salair arc also includes Late Cambrian and early Early Ordovician igneous rock-units (Berzin and Kungurtsev, 1996). These late Neoproterozoic through Early Cambrian magmatic arcs formed a sublatitudinal system that extended along the northern border of the Siberian continent (ancient coordinates) (fig. 23) and was located, according to paleomagnetic data, close to the equator (Berzin and Kungurtsev, 1996; Kazanskiy, 2002; Kungurtsev and others, 2001).
3. Associated with these arcs was subduction of the Paleo-Asian ocean plate to form the Alambai (AL), Amil (AI), Borus (BS), Dzhebash (DZE), Ih Bogd (IB), Kurtushiba (KRT), and Teletsk (TL) oceanic and accretionary-wedge terranes (fig. 23). Behind the island arcs were the Minusa-Tuva and the Transbaikal marginal seas that are interpreted as the fragments of an oceanic plate separated by island arcs. The most intense island arc activity occurred in the Early and the beginning of the Middle Cambrian.
4. Passive continental margins formed on the submerged margins of the North-Asian craton (East Angara, Baikal-Patom, South Taimyr and Verkhoyansk (fold- and thrust-belt) terranes).
5. Intracontinental rifting occurred on the eastern part of the North Asian craton (Omolon and Kharaulakh rifts). On the western part of the North Asian craton, a shallow-water basin was filled with lagoonal sediments with evaporites, whereas in the eastern part, a deep-water basin accumulated black shales (Bulgakova, 1997). The basins were separated by the Anabar-Sinsk barrier reef, one of the largest worldwide (Sukhov, 1997).

Dzhida-Lake Island Arc

Remnants of the Dzhida-Lake island arc are preserved in the Yenisey-Transbaikal collage (figs. 2, 23; appendix B). This collage has an age range of Vendian through Devonian and a timing of accretion of Vendian through Early Ordovician. The collage occurs in Transbaikalia, and in Northern and Central Mongolia. The collage includes the Lake, Eravna, Orkhon-Ikatsky, and Dzhida terranes that are separated by dextral strike-slip faults that have resulted in major modification of original positions (compare figures 22 and 23).

Kuznetsk-Tannuola Island Arc

Remnants of the Kuznetsk-Tannuola island arc occur in a Z-shaped belt that is part of the Yenisey-Transbaikal collage (figs. 2, 23; appendix B). The arc consists of the Telbes-Kitat



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Terranes

AK - Avekov terrane
AR - Argunsky terrane
AY - Ayansk terrane
BRG - Barguzin terrane
BU - Bureya terrane (Metamorphic)
BY - Baydrag terrane
DR - Derba terrane
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GN - Gonzha terrane
HM - Hamar-Davaa terrane
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
JI - Jiamusi terrane
KHM - Khamsara terrane (Island arc)
KI - Kanim terrane (Island arc)
KK - Kizir-Kazir terrane (Island arc)
KOM - Kolyma-Omolon superterrane
KOP - Prekolyma
KOZ - Kozhukhov terrane (Island arc)
KU - Kurai terrane (Island arc)
LK - Lake terrane (Island arc)
MK - Malokhingansk terrane (Accretionary wedge, type B) (Neoproterozoic and Cambrian)
MM - Mamyn terrane
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
OI - Orhon-Ikatsky terrane (Continental margin arc)
OL - Oldoy terrane
OM - Ondum terrane (Island arc)
SA - Sangilen terrane
SAL - Salair terrane (Island arc)
SHE - Shevli terrane
TO - Tannuola subterrane (Island arc)
TT - Telbes-Kitat terrane (Island-arc)
UC - Ulus-Cherga terrane (Island arc)
UG - Ulgey terrane (Island arc)
UL - Uimen-Lebed terrane (Island arc)
UO - Ulugo terrane (Island arc)
WST - West Stanovoy terrane
ZA - Zavhan terrane (Continental margin arc) (Late Neoproterozoic)

METALLOGENIC BELTS

BE - Bedobinsk
BK - Bokson-Kitoiskiy
CG - Chagoyan
HT - Hunjiang-Taizihe
JZ - Jinzhong
JX - Jixi
LA - Lake
PS - Prisayanskiy
OZ - Ozerninsky
SK - South Khingan

Figure 23. Early Cambrian (545 Ma) metallogenic and tectonic model for Northeast Asia. Refer to figure 22 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

(TT), Uimen-Lebed (UL), North Sayan (NRS), Khamsara (KHM), Ulugo (UO), Ondum (OM), and Tannuola (TO) terranes (figs. 2, 23; appendix B). Oceanward of, and parallel to the Kuznetsk-Tannuola island arc were tectonically linked accretionary-wedge terranes, including the Teletsk (TL), Dzhebash (DZE), Amil (AI), Borus (BS), and Kurtushiba (KRT) terranes that consist of Late Neoproterozoic and Early Cambrian oceanic crustal rock, upper mantle rock, and turbidite deposits. Blueschist facies assemblages occur in the Borus and Kurtushiba terranes. During the Vendian and Early and Middle Cambrian, mainly sedimentary rocks were deposited in the Minusa-Tuva basin that separated the island arc from the North Asia cratonal margin.

Salair Island Arc

Remnants of the Salair island arc are preserved in the Altai collage (figs. 2, 23; appendix B) in the Salair (SAL) and Ulus-Cherga (UC) island-arc terranes that are tectonically linked to the Alambai (AL) and Baratal (BR) accretionary-wedge terranes. The Salair arc is the western-most extent of the Late Neoproterozoic and Cambrian island-arc system.And as with the eastern segments of the Late Neoproterozoic and Cambrian island-arc systems that occurred south of the North Asian craton and margin, the major igneous activity in the Salair arc occurred in the Early Cambrian.

Origin of Late Neoproterozoic (Vendian) and Early Cambrian Island Arcs

The late Neoproterozoic and Early Cambrian island-arc units are interpreted by most workers as having formed from subduction of the Paleo-Asian oceanic plate (Al'mukhamedov and others, 1996; Belichenko and others, 1994; Berzin and Dobretsov, 1994; Gordienko, 1987; Dergunov, 1989; Didenko and others, 1994; Mossakovskiy and others, 1994; Pecherskiy and Didenko, 1995; Sengör and Natal'in 1996; Zonenshain and others, 1990**).** The island arcs commenced activity after the formation of the late Neoproterozoic accretional-collisional belt along the continent and after the migration of the subduction zone towards the Paleo-Asian Ocean. The underthrusting of oceanic plate occurred northward (present-day coordinates), toward the Siberian continent, as indicated confirmed by the spatial arrangement of island-arc, accretionary and turbidite terranes**.** At this time, blique subduction (a combination strike-slip and underthrusting) was already occurring in this area (Berzin, 1995).

Associated with magmatic arcs are the Minusa-Tuva and Transbaikal back-arc basins that were separated by island arcs and fragments of oceanic plates. During the Vendian and Early Cambrian, dominantly carbonate-terrigenous rocks closely associated with underlying sediments were deposited. Coeval sediments unconformably overlapped the Neoproterozoic terrane collage along the periphery of the North Asian craton. These units are preserved in the Mana (ma), Huvsgol-Bokson (hb), Upper Angara (ua), Gazimur (ga), and Argun (ags) overlap units.

The formation of the island arcs is interpreted as having ended in the early Middle Cambrian when oblique subduction changed into dextral-slip faulting along the outboard (oceanward) margin of arcs (Berzin, 1995).

Metallogenesis

The major Late Neoproterozoic through Early Cambian metallogenic belts formed in a variety of tectonic environments (figs. 13, 23, 24; appendix C). Some of the belts continued to form throughout the Cambrian (fig. 24).

The Bedobinsk belt (BE, figs. 13, 23; appendix C) is hosted in the North Asian craton, contains sediment-hosted Cu deposits, and is interpreted as having formed in an inland-sea basin during post-saline stage of rock deposition. The main source of copper was weathered Riphean rocks as well as lode deposits in the Yenisei Ridge, and from hydrothermal activity along deep-fault zones related to rifting.

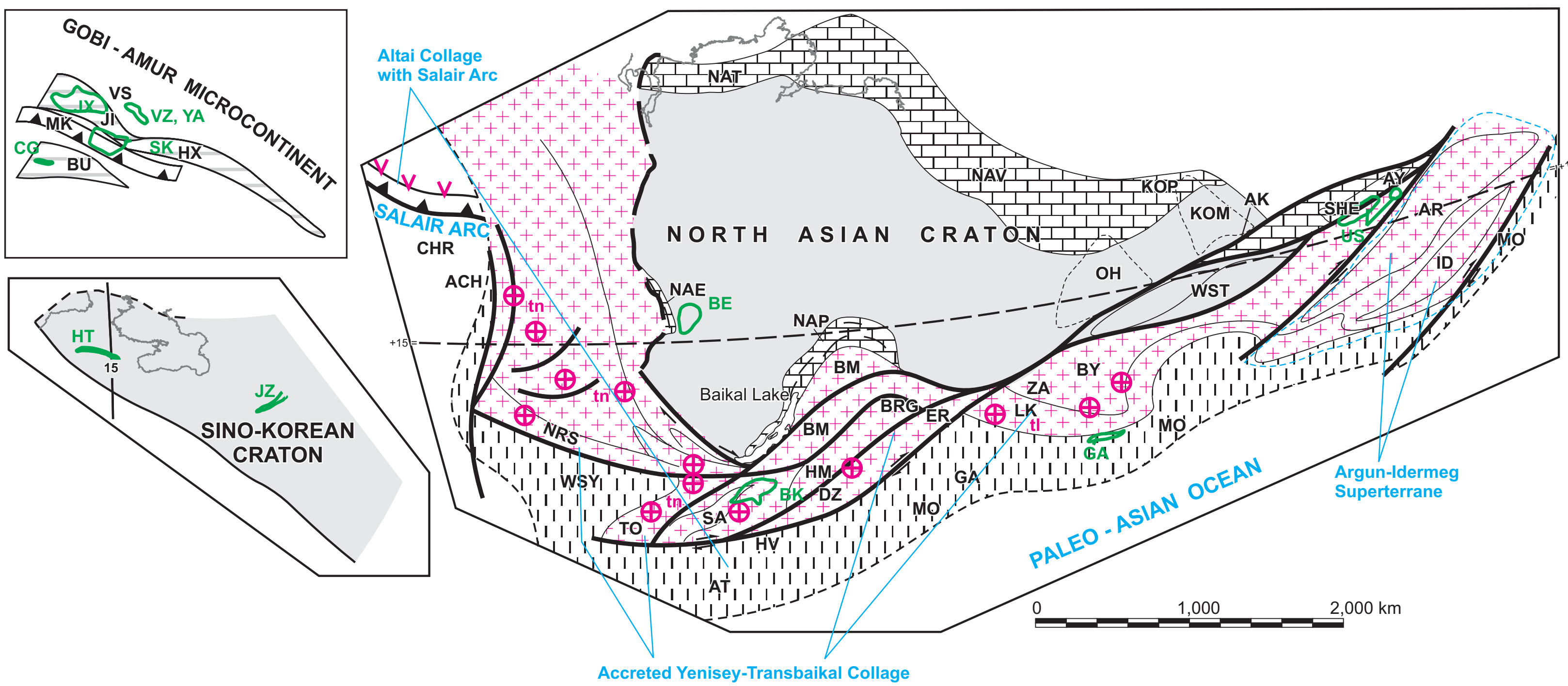
The Chagoyan belt (CG, figs. 13, 23, 24; appendix C) contains sedimentary exhalative Pb-Zn (SEDEX) deposits that are hosted in metasedimentary units in Bureya metamorphic terrane that is interpreted as part of the Gobi-Amur microcontinent. The belt is interpreted as having formed during rifting and submarine hydrothermal activity that included intrusion of intermediate composition dikes, and during chemical marine sedimentation along the continental margin of the Gobi-Amur microcontinent.

The Hunjiang-Taizihe belt (HT, figs. 13, 23, 24; appendix C) contains evaporite sedimentary gypsum deposits and is hosted in platform sedimentary cover on Sino-Korean craton. The belt is interpreted as having formed in a super-tidal sabkha sedimentary environment.

The Jixi belt (JX, figs. 13, 23, 24; appendix C), that started in the Neoproterozoic, continued to form. This belt contains banded iron formation (BIF, Algoma Fe), Homestake Au, metamorphic graphite, and metamorphic sillimanite deposits that are hosted in the Jiamusi metamorphic terrane and Zhangguangcailing (Continental margin arc) superterrane that is part of Gobi-Amur microcontinent. The belt is part of a khondalite that is interpreted as having been derived from Al-rich mudstone and carbonates of the Mashan and the Xingdong groups that were deposited in a shallow sea and isolated oceanic basin and lagoon.

The Lake belt (LA, figs. 13, 23; appendix C) contains volcanogenic Cu-Zn massive sulfide (Urals type), volcanogenic-sedimentary Fe; podiform Cr; mafic-ultramafic related Ti-Fe (+V); Cu (±Fe, Au, Ag, Mo) skarn, Fe skarn, granitoid-related Au vein, Cyprus Cu-Zn massive sulfide, and mafic-ultramafic related Cu-Ni-PGE deposits. The magmatic deposits are interpreted as having formed in the Dzhida-Lake island arc. The sediment-hosted deposits are interpreted as having formed during sea floor spreading volcanism and related mafic-ultramafic magmatism.

The Prisayanskiy belt (PR, figs. 3, 23; appendix C) contains REE (±Ta, Nb, Fe) carbonatite and mafic-ultramafic



GEOLOGIC UNITS

North Asian Craton Margin

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NAT - South-Taimyr
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AK - Avekov terrane
AR - Argunsky terrane
AT - Altai terrane (Continental margin turbidite) (Precambrian and Cambrian through Devonian)
AY - Ayansk terrane
BM - Baikal-Muya terrane (Island arc) (Neoproterozoic)
BRG - Barguzin terrane
BU - Bureya terrane (Metamorphic)
BY - Baydrag terrane
CHR - Charysh terrane (Continental margin turbidite) (Cambrian through Devonian)
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
HM - Hamar-Davaa terrane
HV - Hovd terrane (Continental-margin turbidite) (Neoproterozoic through Silurian)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
JI - Jiamusi terrane
KOM - Kolyma-Omolon superterrane
KOP - Prekolyma
LK - Lake terrane (Island arc)
MK - Malokhingansk terrane (Accretionary wedge, type B) (Neoproterozoic and Cambrian)
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
SA - Sangilen terrane
SHE - Shevli terrane
TO - Tannuola subterrane (Island arc)
VS - Voznesenka terrane (Passive continentalal margin) (Cambrian through Permian)
WST - West Stanovoy terrane
WSY - West Sayan terrane (Continental margin turbidite) (Late Neoproterozoic through Devonian)
ZA - Zavhan terrane (Continental margin arc) (Late Neoproterozoic)

Overlap Continenta-Margin Arcs and Granite Belts

tl - Telmen plutonic belt (Middle Cambrian through Early Ordovician)
tn - Tannuola plutonic belt (Cambrian and Ordovician)

METALLOGENIC BELTS

BE - Bedobinsk
BK - Bokson-Kitoiskiy
CG Chagoyan
GA - Govi-Altai
HT - Hunjiang-Taizihe
JX - Jixi
JZ - Jinzhong
SK - South Khingan
US - Uda-Shantar
VZ - Voznesenka
YA - Yaroslavka

Figure 24. Late Cambrian (520 to 500 Ma) metallogenic and tectonic model for Northeast Asia. Figure adapted from Parfenov and others (chapter 9, this volume).

related Ti-Fe (±V) deposits. The belt occurs in enderbite-gneiss, tonalite-trondhjemite, and anorthosite-paragneiss units in terranes that are fragments of the craton crystalline basement. The belt is interpreted as having formed during Late Neoproterozoic rifting along the North Asian cratonal margin adjacent to the Paleo-Asian Ocean. Host terranes are uplifted parts of North Asian craton.

The Ozerninsky belt (OZ, figs. 13, 23; appendix C) contains volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn (±Cu) and volcanogenic-sedimentary Fe deposits that are hosted in the Eravna island-arc terrane, part of Yenisey-Transbaikal collage that contains the Dzhida-Lake island arc that was intruded by the Barguzin-Vitim batholith.

The South Khingan belt (SK, figs. 13, 23, 24; appendix C) contains banded iron formation (BIF, Superior Fe) deposits that are hosted in the Malokhingansk subduction-zone terrane, included in Sino-Korean craton.The belt is interpreted as having formed in a volcanic and sedimentation basin that was incorporated into a subduction-zone terrane along the continental margin of the Gobi-Amur microcontinent.

Middle and Late Cambrian (520 to 500 Ma) Metallogenic and Tectonic Model

Tectonics

The major tectonic events during the Late Cambrian (fig. 24) were as follows.

1 .Completion of accretion of the Late Neoproterozoic and Early Cambrian island-arc systems described above.
2. Start of formation of a passive continental margin along the northern and northeastern periphery of the North Asian craton in the South Taimyr (NAT) and Verkhoyansk (NAV) (thrust and fold belt) terranes.
3. Formaton of turbidite basins along the southern transform margin of the North Asian craton in the area of accreted terranes.
4 .Deformation of the accreted island arcs and back-arc basins that started at the end of Middle Cambrian and continued through Silurian in a transpressional and dextral-slip faulting environment. This deformation was accompanied by intrusions of granitoids, local high-temperature metamorphism, uplift and accumulation of marine and non-marine molasses. In some regions, high-temperature metamorphism (Fedorovskiy and others, 1995; Kozakov and others, 2002) resulted in obscuring of the initial characteristics of terranes. Parts of metamorphic terranes, as in the Hamar-Davaa terrane (HM) in the Baikal region, were subjected to such metamorphism (fig. 24). Layered gabbro-hyperbasite plutons intruded local zones of extension of litospheric blocks.
5. Accumulation flysch along the North Asian (Verkhoyansk) cratonal margin.
6. Formation of turbidite units related to a continental-margin arc along the southern margin of the North Asian craton in southern Siberia, central and northwestern Mongolia, and adjacent regions of China. These units are preserved in the Anui-Chuya (ACH), Charysh (CHR), West Sayan (WSY), Altai (AT), Hovd (HV) and Govi-Altai (GA) terranes. These turbidite-margin sediments also occur in the stratigraphic basement of the middle Paleozoic magmatic arcs in Rudny Altai (RA) and Mandalovoo-Onor (MO) terranes. The molasse basins were strongly deformed in a transpressive dextral-slip environment.
7. Formation of belts of orogenic granitoids, including the Tannuola plutonic belt (tn), Telmen plutonic belt (tl), and possibly the Khanka-Bureya (kbu) granitic belt and the Zhangguangcailing (zg) plutonic belt.

Metallogenesis

1. The Chagoyan belt (CG, figs.13, 24; appendix C) with sedimentary exhalative Pb-Zn (SEDEX) deposits continued from the previous time span.
2. The Govi-Altai belt (GA, figs. 13, 24; appendix C) contains volcanogenic-sedimentary Fe and volcanogenic-sedimentary Mn deposits that are hosted in the Govi Altai continental-margin turbidite terrane, part of South Mongolia-Khingan collage. The belt is interpreted as having formed during sedimentation along an early Paleozoic continental slope close to the deformed Dzhida-Lake island arc.
3. The Hunjiang-Taizihe belt (HT, figs. 13, 24; appendix C) with evaporite sedimentary gypsum deposits continued from the previous time span.
4. The Jinzhong belt (JZ, gs. 13, 24; appendix C) with evaporite sedimentary gypsum deposits continued from the previous time span.
5. The Jixi belt (JX, figs. 13, 24; appendix C) with banded iron formation (BIF, Algoma Fe), Homestake Au, metamorphic graphite, and metamorphic sillimanite deposits continued from the previous time span.
7. The Uda-Shantar belt (US, figs. 13, 24; appendix C) contains volcanogenic-sedimentary Fe, volcanogenic-sedimentary Mn, and sedimentary phosphate deposits that were incorporated into the Galam subduction-zone terrane, part of Mongol-Okhotsk collage. The belt is interpreted as having formed during sea-floor hydrothermal activity associated with basaltic volcanism that was accompanied by chert deposition in basins. The units and deposits were subsequently incorporated into the Galam accretionary wedge terrane tectonically linked to the Devonian North-Okhotsk (Uda) magmatic arc.
8. The Voznesenka belt (VZ, figs. 13, 24; appendix C) contains Korean Pb-Zn massive sulfide deposits that are hosted in marine sedimentatry units in the Voznesenka passive continental-margin terrane of the Khanka superterrane. The belt is interpreted as having formed during

rifting and submarine hydrothermal activity along the continental margin of the Gobi-Amur microcontinent. The host sedimentary rocks are part of the passive continental margin of Gondwanaland.

9. The Yaroslavka belt (YA, figs. 13, 24; appendix C) contains fluorite greisen and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in Paleozoic granitoid plutons that intrude in Cambrian clastic and limestone units of the Vosensenka continental-margin terrane of the Khanka superterrane. The belt is interpreted as having formed in a collisional arc that formed along the passive continental margin of a fragment of Gondwanaland.

Early Ordovician through Late Silurian (500 to 410 Ma) Metallogenic and Tectonic Model

Tectonics

The major tectonic events in the Early Ordovician through Late Silurian were (figs. 25, 26) as follows.

1. Continued formation of a passive continental margin along the northern and northeastern periphery of the North-Asian craton in the South Taimyr (NAT) and Verkhoyansk (NAV) (fold- and thrust-belt) terranes.
2. Continued accumulation of flysch along the continental margin with uplift and erosion and transport of clastic material into abyssal basins. During the filling with the abyssal sediments, the basins evolved into shallow-water types.
3. Continued deformation of accreted island arcs and back-arc basins in a transpressional and dextral-slip faulting environment. This deformation was accompanied by intrusions of granitoids, local high-temperature metamorphism, uplift and accumulation of marine and non-marine molasses. Layered gabbro-hyperbasite plutons intruded local zones of extension of litospheric blocks. Flysch continued to accumulate along the southern margin of the North Asian cratonal margin.
4. Formation of the Early and Middle Ordovician East Mongolia-Khingan continental-margin arc along the southern margin of the North Asian craton in southern Siberia, central and northeastern Mongolia, and in adjacent regions of China.
5. Continued formation of turbidite units related to the Early and Middle Ordovician East Mongolia-Khingan continental-margin arc that formed along the southern margin of the North Asian craton in southern Siberia, central and northwestern Mongolia, and in adjacent regions of China. These units are preserved in the Anui-Chuya (ACH), Charysh (CHR), West Sayan (WSY), Altai (AT), Hovd (HV) and Govi-Altai (GA) terranes. These turbidite-margin sediments also occur in the stratigraphic basement of the middle Paleozoic magmatic arcs in Rudny Altai (RA) and Mandalovoo-Onor (MO) terranes.
6. In the eastern North Asian craton, an active continental margin formed along with back-arc rifts (Bulgakova, 1997).

The position of the Sino-Korean craton relative to the North-Asian craton in the Late Neoproterozoic through Early Paleozoic is not resolved because there are no sedimentary or magmatic complexes of this age interval at the northern periphery of the Sino-Korean craton, which might indicate the closing of the Paleo-Asian ocean.

Fragments of a mainly Ordovician magmatic arc are preserved in terranes in the Wundurmiao collage (fig. 2, 25; appendix B). This collage, of Mesoproterozoic through Silurian age, with a timing of accretion of Late Silurian, occurs along the northern margin of the Sino-Korean craton (figs. 2, 25; appendix B). The major terranes are (1) Dongujimgin-Nuhetdavaa (DN), Nora-Sukhotin-Duobaoshan (ND), and Laolin (LA) island-arc terranes; (2) Tsagaan Uul-Guoershan (TG), and Zhangguangcailing (ZN) continental-margin arc terranes; and (3) the Wundurmiao (WD) and Helongjing (HE) accretionary-wedge terranes (fig.25). The formation of these arcs, in contrast to island arcs that were active in the northern Paleo-Asian Ocean, occurred mainly in the Ordovician. The size and time of the origination and duration of associated subduction zones is also unknown.

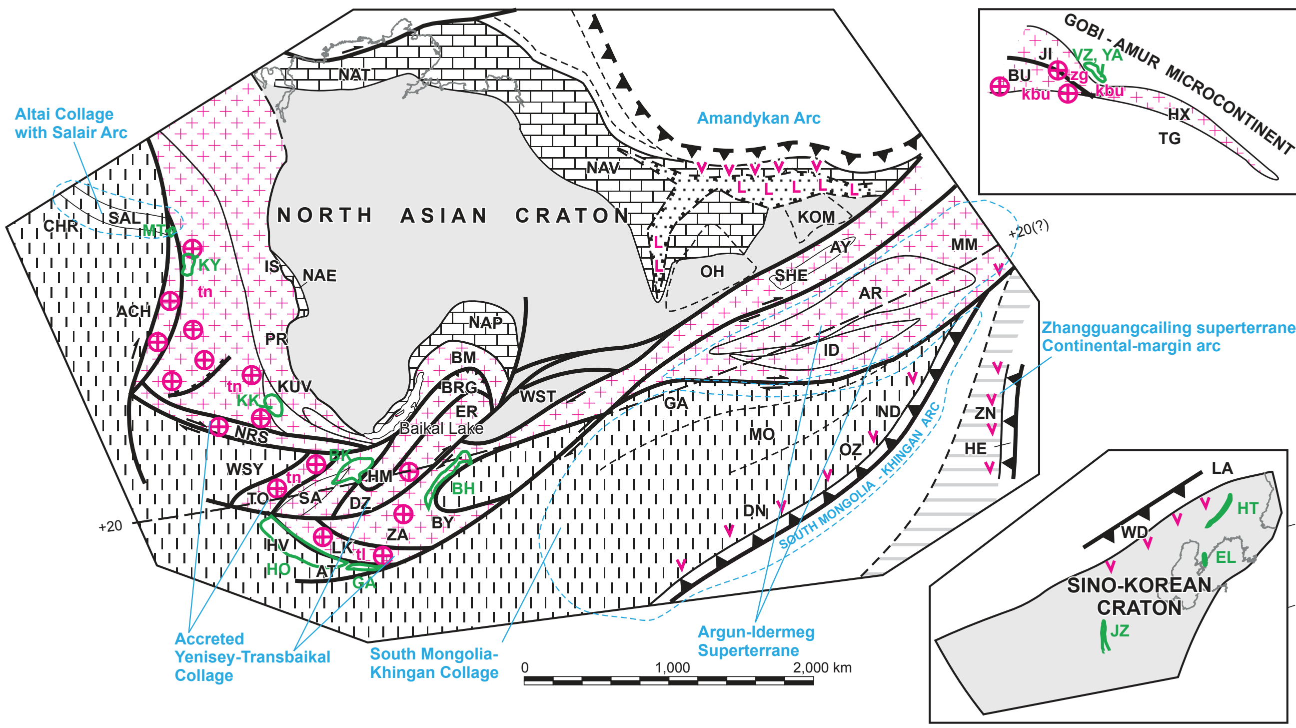
Metallogenesis

The major Ordovician through Silurian metallogenic belts formed in a variety of tectonic environments (figs. 13, 25, 26; appendix C).

1. The Bayanhongor belt (BH, figs. 13, 25; appendix C) contains Au in shear-zone and quartz-vein, and granitoid-related Au-vein, Cu-Ag vein, and Cu-(±Fe, Au, Ag, Mo) skarn deposits. The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the Siberian Continent margin and during subsequent transpression-dextral-slip faulting and regional metamorphism associated with accretion of Bayanhongor and Baydrag terranes.
2. The East Liaoning belt (EL, figs. 13, 25, 26; appendix C) contains diamond-bearing kimberlite deposits and is hosted in the Sino-Korean craton -- Jilin-Liaoning-East Shandong tonalite-trondhjemite-gneiss terrane. The Kimberlite and associated intrusions occur along northeast-trending regional, strike-slip Tanlu fault along the northern margin of the Sino-Korean Platform.
3. The Govi-Altai belt (GA, figs. 13, 24; appendix C) with volcanogenic-sedimentary Fe and volcanogenic-sedimentary Mn deposits continued from the previous time span.
4. The Hovd belt (HO, figs. 13, 25, 26; appendix C) contains granitoid-related Au vein and Au skarn deposits that are hosted in the Turgen granitoid complex that intrudes Hovd continental-margin turbidite terrane, part of the Altai collage. The belt is nterpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto

the Siberian Continent margin and during subsequent transpression-dextral-slip faulting.

5. The Hunjiang-Taizihe belt (HT, figs. 13, 25; appendix C) with evaporite sedimentary gypsum deposits continued forming from the previous time span.
6. The Jinzhong belt (JZ, figs. 13, 25; appendix C) with evaporite sedimentary gypsum deposits continued forming from the previous time span.
7. The Kiyalykh-Uzen belt (KK, figs. 13, 24; appendix C) contains Cu (±Fe, Au, Ag, Mo) skarn, W±Mo±Be skarn, Fe skarn, and W-Mo-Be greisen, stockwork, and quartz-vein deposits. The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the Siberian Continent margin and during subsequent transpression-dextral-slip faulting along the Kuznetsk Alatau fault. This major orogenic event resulted in intrusion of Telmen plutonic belt that hosts the dposits.
8. The Kizir-Kazyr belt (KK, figs. 13, 25; appendix C) contains Fe skarn, volcanogenic-sedimentary Fe, and granitoid-related Au-vein deposits and is hosted in the Tannuola plutonic belt, part of the Yenisey-Transbaikal collage. The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the southern North Asian cratonal margin and during subsequent transpression-dextral-slip faulting. The sediment-hosted deposits are interpreted as being part of the Kizir-Kazir island-arc terrane, part of the Yenisey-Transbaikal collage.
9. The Martaiginsk belt (MT, figs. 13, 25; appendix C) with granitoid-related Au vein and Fe skarn deposits is hosted in the Tannuola plutonic belt, part of the Yenisey-Transbaikal collage. The belt is interpreted as having formed during oblique accretion and collision of Kuznetsk-Tannuola and Dzhida-Lake island arcs onto the southern North Asian cratonal margin and during subsequent transpression-dextral-slip faulting. The sediment-hosted deposits are interpreted as part of the Kizir-Kazir island-arc terrane, part of the Yenisey-Transbaikal collage.
10. The Yaroslavka belt (YA, figs. 13, 24, 25, 26; appendix C) contains fluorite greisen and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in Paleozoic granitoid plutons that intrude in Cambrian clastic and limestone units of the Vosensenka continental-margin terrane of the Khanka superterrane. The belt is interpreted as having formed in a collisional arc that formed along the passive continental margin of a fragment of Gondwanaland.



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BY - Baydrag terrane
CHR - Charysh terrane (Continental margin turbidite) (Cambrian through Devonian)
DN - Dongwuzhumuqin-Nuhetdavaa terrane (Island arc) (Cambrian through Middle Devonian)
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
HE - Heilongjiang terrane (Accretionary wedge, type B) (Ordovician and Silurian)
HM - Hamar-Davaa terrane
HV - Hovd terrane (Continental-margin turbidite) (Neoproterozoic through Silurian)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
IS - Isakov terrane (Island arc) (Neoproterozoic)
JI - Jiamusi terrane
KOM - Kolyma-Omolon superterrane
KUV - Kuvai terrane (Accretionary wedge, type A) (Neoproterozoic)
LA - Laoling terrane (Island arc) (Late Ordovician through Silurian)
LK - Lake terrane (Island arc)
MM - Mamyn terrane
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
ND - Nora-Sukhotin-Duobaoshan terrane (Island arc) (Neoproterozoic through Early Carboniferous)
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
OZ - Orogen-Zalantun terrane (Metamorphic) (Proterozoic)
PR - Predivinsk terrane (Island arc) (Late Neoproterozoic)
SA - Sangilen terrane
SAL - Salair terrane (Island arc)
SHE - Shevli terrane
TG - Tsagaan Uul-Guoershan Terrane (Continental margin arc) (Paleoproterozoic through Permian)
TO - Tannuola subterrane (Island arc)
WD - Wundurmiao terrane (Accretionary wedge, type B) (Mesoproterozoic through Middle Ordovician)
WST - West Stanovoy terrane
WSY - West Sayan terrane (Continental margin turbidite) (Late Neoproterozoic through Devonian)
ZA - Zavhan terrane (Continental margin arc) (Late Neoproterozoic)
ZN - Zhangguangcailing superterrane (Continental margin arc) (Neoproterozoic through Devonian)

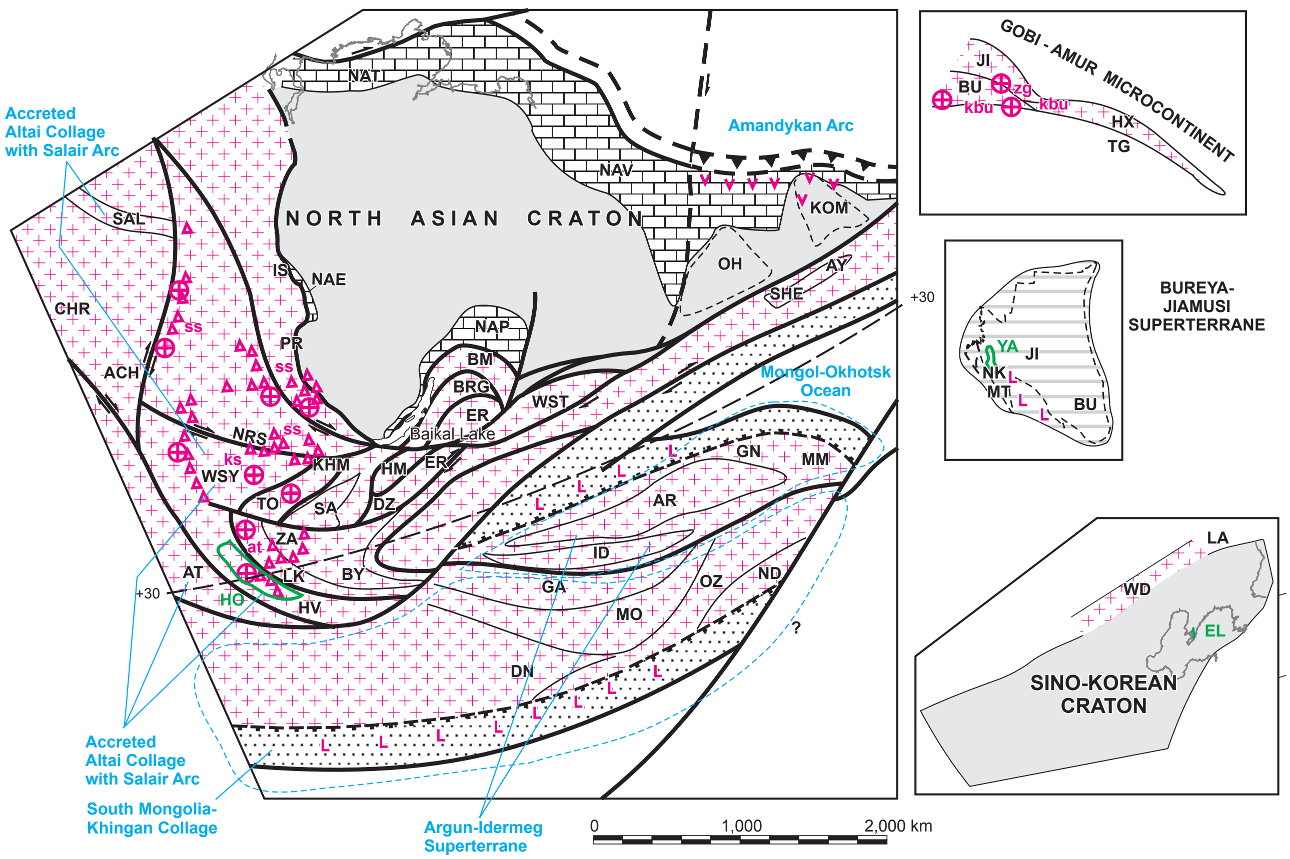
Overlap Continental Margin Arcs and Granite Belts

kbu - Khanka-Bureya granitic belt (Ordovician and Silurian)
tl - Telmen plutonic belt (Middle Cambrian through Early Ordovician)
tn - Tannuola plutonic belt (Cambrian and Ordovician)
zg - Zhangguangcailing plutonic belt (Silurian through Ordovician)

METALLOGENIC BELTS

BH - Bayanhongor
EL - East Liaoning
BK - Bokson-Kitoiskiy
GA - Govi Altai
HO - Hovd
HT Hunjiang-Taizihe
JZ Jinzhong
KK - Kizir-Kazyr
KY - Kiyalykh-Uzen
MT- Martaiginsk
VZ - Voznesenka
YA - Yaroslavka

Figure 25. Early to Middle Ordovician (500 to 450 Ma) metallogenic and tectonic model for Northeast Asia. Refer to figure 22 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Terranes

ACH - Anui-Chuya terrane (Continental margin turbidite)
AR - Argunsky terrane
AT - Altai terrane (Continental margin turbidite) (Precambrian and Cambrian through Devonian)
AY - Ayansk terrane
BM - Baikal-Muya terrane (Island arc) (Neoproterozoic)
BRG - Barguzin terrane
BU - Bureya terrane (Metamorphic)
BY - Baydrag terrane
CHR - Charysh terrane (Continental margin turbidite) (Cambrian through Devonian)
DN - Dongwuzhumuqin-Nuhetdavaa terrane (Island arc) (Cambrian through Middle Devonian)
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
GN - Gonzha terrane (Passive continental margin) (Late Archean(?), Paleoproterozoic(?), and early Paleozoic)
HM - Hamar-Davaa terrane
HV - Hovd terrane (Continental-margin turbidite) (Neoproterozoic through Silurian)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
IS - Isakov terrane (Island arc) (Neoproterozoic)
JI - Jiamusi terrane
KHM - Khamsara terrane (Island arc) (Cambrian)
KOM - Kolyma-Omolon superterrane
LA - Laoling terrane (Island arc) (Late Ordovician through Silurian)
LK - Lake terrane (Island arc)
MM - Mamyn terrane
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
MT - Matveevka terrane (Metamorphic)
ND - Nora-Sukhotin-Duobaoshan terrane (Island arc) (Neoproterozoic through Early Carboniferous)
NK - Nakhimovka terrane (Metamorphic)
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
OZ - Orogen-Zalantun terrane (Metamorphic) (Proterozoic)
PR - Predivinsk terrane (Island arc) (Late Neoproterozoic)
SA - Sangilen terrane
SAL - Salair terrane (Island arc)
SHE - Shevli terrane
TG - Tsagaan Uul-Guoershan Terrane (Continental-margin arc) (Paleoproterozoic through Permian)
TO - Tannuola subterrane (Island arc)
WD - Wundurmiao terrane (Accretionary wedge, type B) (Mesoproterozoic through Middle Ordovician)
WST - West Stanovoy terrane
WSY - West Sayan terrane (Continental-margin turbidite) (Late Neoproterozoic through Devonian)
ZA - Zavhan terrane (Continental-margin arc) (Late Neoproterozoic)

Overlap Continental-Margin Arcs and Granite Belts

at - Altai volcanic-plutonic belt (Devonian and Early Carboniferous)
kbu - Khanka-Bureya granitic belt (Ordovician and Silurian)
ks - Kuznetsk-Sayan plutonic belt (Early Silurian to Early Devonian)
ss - South Siberian volcanic-plutonic belt (Early Devonian)
zg - Zhangguangcailing plutonic belt (Silurian through Ordovician)

METALLOGENIC BELTS

EL - East Liaoning
HO - Hovd
YA - Yaroslavka

Figure 26. Late Silurian (420 to 410 Ma) metallogenic and tectonic model for Northeast Asia. Refer to figure 22 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume)

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Chapter 6

Devonian through Early Carboniferous (Mississippian) Metallogenesis and Tectonics of Northeast Asia

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Introduction

This article presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia for the Devonian through Early Carboniferous (Mississippian) (410 to 320 Ma). The major purposes are to provide a detailed summary of these features for readers who are unfamiliar with Northeast Asia. Several parts of this book on Northeast Asia provide background information. An overview of the geology, metallogenesis, and tectonics of the region, and other materials, such as a geologic time scale and standard geologic definitions, are provided in Chapter 1. The methodology for the metallogenic and tectonic analysis of this region is provided in Chapter 2. Descriptions of mineral deposit models are provided in Chapter 3. Additional information on project publications, descriptions of major geologic units, and summaries of metallogenic belts are provided in appendixes A-C.

Compilations Employed for Synthesis, Project Area, and Previous Study

The compilation of regional geology and metallogenesis is based on publications of the major international collaborative studies of the metallogenesis and tectonics of Northeast Asia that were led by the U.S. Geological Survey (USGS). These studies have produced two broad types of publications. One type of publication is a series of regional geologic, mineral deposit, and metallogenic belt maps and companion descriptions for the regions. Examples of major publications of this type are Obolenskiy and others (2003, 2004), Parfenov and others (2003, 2004a,b), Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006). The other type of publication is a suite of metallogenic and tectonic analyses of these same regions. Examples of major publications of this type are Rodionov and others (2004), Nokleberg and others (2000, 2004, 2005), and Naumova and others (2006). And detailed descriptions of lode deposits are available in Ariunbileg and others (2003). For more detail than is presented in this chapter, refer to the detailed descriptions of geologic units and metallogenic belts in the publications listed above.

The Northeast Asia project area consists of eastern Russia (most of Siberia and most of the Russian Far East), Mongolia, Northern China, South Korea, Japan, and adjacent offshore areas (fig. 1). This area is approximately bounded by 30 to 82° N. latitude and 75 to 144° E. longitude. The major participating agencies are the Russian Academy of Sciences; Academy of Sciences of the Sakha Republic (Yakutia); VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation; Mongolian Academy of Sciences; Mongolian University of Science and Technology; Mongolian National University; Jilin University, Changchun, China; the China Geological Survey; the Korea Institute of Geosciences and Mineral Resources; the Geological Survey of Japan/AIST; University of Texas Arlington, and the USGS.

The Northeast Asia project extends and is built on data and interpretations from a previous project on the "Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera" (fig. 1) that was conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada. A summary of

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the major products of this project is available online at: http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.pdf and in appendix A.

Major Geologic Units

The major Devonian through Early Carboniferous (Mississippian) geologic and tectonic units of Northeast Asia are cratonal margin units, sedimentary basins formed on craton and cratonal margins, and accreted terranes and superterranes (fig. 2, table 1). Short descriptions of map units are given in appendix B. Summary descriptions of the major units are provided in descriptions of metallogenic belts (below), and detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004), and Parfenov and others (2004b).

Major Cratonal margins and Craton-Margin Terranes

For an analysis of Devonian through Early Carboniferous (Mississippian) metallogenesis and tectonics, the cratonal units that contain major metallogenic belts are the North Asian Craton (NAC) and overlying Phanerozoic units, the North Asian (Verkhoyansk) Cratonal margin (VR) (fig. 2, table 1) that consists chiefly of a thick wedge of Mesoproterozoic, Neoproterozoic through Jurassic miogeoclinal deposits.

Figure 1. Regional summary geographic map for Northeast Asia showing major regions and countries

During the Devonian through Early Carboniferous, in the northern and eastern margins of the North Asian Craton, the Verkhoyansk and South Taimyr passive continental margins related to subsidence and deposition of carbonate and clastic sediments derived from the craton continued to form. Widespread intracontinental rifting appears to have initiated along these passive continental margins, which led to the formation of the Vilyui, Sette-Daban, and probably the Tungus and other basins. Carbonate rocks and clastic sediments that were accompanied by alkaline volcanic rocks fill these basins. These basins are interpreted as being failed arm or aulacogens of the rift-rift triple junction or three-armed graben (Gaiduk, 1988; Levashov, 1974). The development of extensive intracontinental rifting was related to the domal uplifts and mantle plume activity during the stable period of plate motion. The intracontinental rifting along the northern and eastern margins of the North Asian craton was responsible for the continued development of the Omulevka (KOV), Kotel'nyi (KY), and Nagondzha (KNG) terranes. The Omulevka and Kotel'nyi terranes are interpreted as a distal part of the passive continental margin of the North Asian craton. The Nagondzha terrane is interpreted as being a continental margin that formed during the opening of Oimyakon ocean basin.

The paleomagnetic data available suggest that the Omulevka terrane and the Okhotsk terrane formed part of the North Asia craton in the Early-Middle Paleozoic and were detached from it as a result of rifting by way of clockwise rotation (Parfenov, 1991; Neustroev and others, 1993; Prokopiev and others, 1999). The break up of the terranes from the Siberian continent and the opening of a minor ocean basin between them, the Oimyakon basin, occurred in the early Carboniferous.

Along the western and southern margin (in present-day coordinates) of the North Asian craton occur a wide collage of terranes that were accreted to the cratonal margins, principally during the Late Cambrian through Ordovician. The growth of the western and southern continental margin of the North Asian craton by terrane accretion is a significant feature of the tectonic history of the region. Most of the accreted terranes are herein interpreted as having been derived from various parts of cratons, cratonal margins, or from fringing island arcs and companion subduction-zone complexes. To the south, adjacent to the margin was a continental slope now preserved in the Hangay-Daurian subduction-zone terrane.

During the Devonian through Early Carboniferous, the western and southern margins of the North Asian craton were characterized by a transform margin environment and were accompanied by strike-slip faulting, formation of subalkaline and alkaline volcanic and plutonic belts, and associated sedimentary basins superimposed on the accreted terranes (Berzin and others, 1994; Obolenskiy and others; 1999). This transform fault system consists of several left-lateral strike-slip faults near the southern margin of the craton that oroclinally bend to the west. The right-lateral strike-slip fault that occurs along the northern boundary of this fault system splays out to the east into series of subparallel faults and is accompanied by the Nepsky overthrust- fault zone in Transbaikal area. The main basins are the Agul (ag), Khmelev (kh); Kolyvan-Tom (kt); Kuznetsk (kz), Minusa (mn), South Altai (sal) and Tuva (tv) that are composed mainly of shallow-marine sedimentary rocks with minor volcaniclastics. The volcanic-plutonic belts include the Altai (alv, alp), Deluun (dl), Sinegorsk (sg), South Siberian (ss, ssp), and Tes (te, tep) that chiefly contain diorite, granodiorite, subalkaline and alkaline granite, leucogranite, granosyenite, quartz syenite, and coeval basalt, andesite, dacite, rhyolite, tuff, and volcaniclastic rocks.

Superterranes

An analysis of Devonian through Early Carboniferous (Mississippian) metallogenesis and tectonics also includes the major Proterozoic through Permian Bureya-Jiamusi supterterrane (BJ) that occurs along the margins of the North Asian and Sino-Korean Cratons (fig. 2). The superterrane consists of a collage of early Paleozoic metamorphic, continental-margin arc, subduction-zone, passive continental-margin, and island-arc terranes. The superterrane is interpreted as being a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

The Bureya-Jiamusi superterrane consists of fragments of Archean through Cambrian metamorphic complexes, and it occurs in Northeastern China and the southern part of the Russian Far East. The superterrane contains the Bureya, Jiamusi, Matveevka, and Nakhimovka metamorphic terranes. The Bureya- Jiamusi superterrane also includes overlapping units of pre-Neoproterozoic volcanic and sedimentary rocks (Turans suite), Neoproterozoic limestone (Melgiysk suite), Cambrian archaeocyathes limestone (Allingsk and Chergelensk suites), and Paleozoic marine sediments (Kozlovsky, 1988, Natal'in, 1991; Khanchuk, 2000). The Bureya-Jiamusi superterrane is interpreted as being a separate block within a paleoocean plate southwest of the South Mongolia-Khingan island arc.

Tectonic Collages Between North Asian and Sino-Korean Cratons

The analysis of Devonian through Early Carboniferous (Mississippian) metallogenesis and tectonics between the North Asian and Sino-Korean Cratons reveals a series of accreted Devonian through Early Carboniferous tectonic collages. These tectonic collages were accreted successively from north to south during closures of the Paleo-Asian and Solon Oceans. Most of the tectonic collages contain one or more island arcs and tectonically-linked subduction zones. Because of successive accretions from north to south, the ages of collages generally young from north to south. However, this pattern is locally obliterated because some collages, or parts of collages, were interspersed due to subsequent strike-slip faulting.

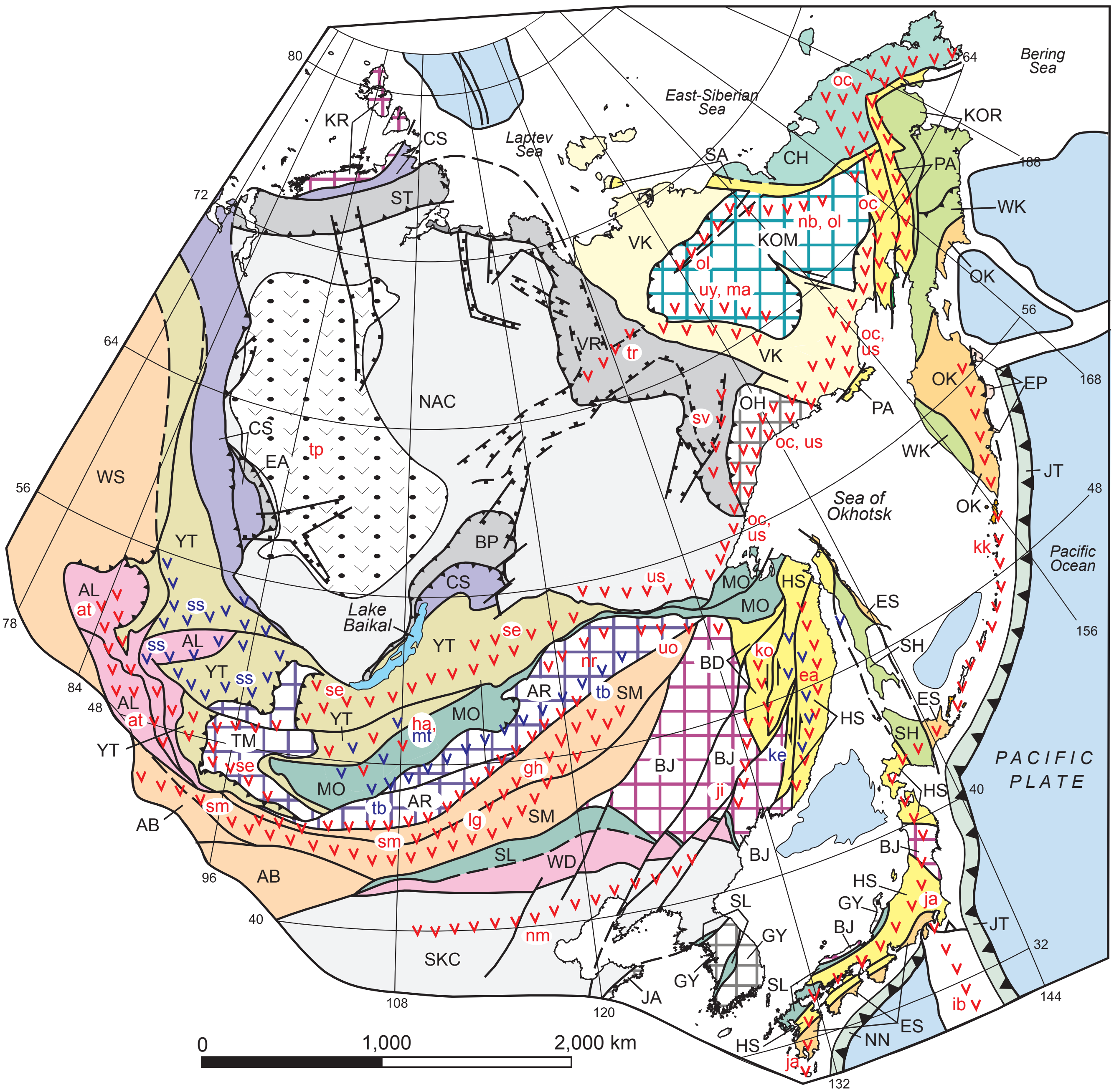


Figure 2. Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North Pacific tectono-stratigraphic terrane map at 10 million scale (Nokleberg and others, 1997). Map shows locations major geologic and tectonic units including cratons, cratonal margins, cratonal terranes and superterranes, tectonic collages, overlap and transform continental-margin arcs, island arcs, and sea and ocean units. Map. and Explanation. Refer to table 1 and text for unit descriptions.

EXPLANATION

Cratons and Cratonal Margins

Cratons: NAC - North Asian (Archean and Proterozoic); SKC - Sino-Korean (Archean and Proterozoic)

Cratonal Margin: BP - Baikal-Patom (Riphean through Cambrian and older basement; EA - East Angara (Riphean and older basement; ST - South Taimyr (Ordovician through Jurassic); VR - Verkhoyansk (Devonian through Jurassic).

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

AL - Altay (Vendian to Ordovician)
WD - Wundurmiao (Riphean through Ordovician)

AB - Atasbogd (Ordovician through Permian); SM - South Mongolia-Khingan (Ordovician through Carboniferous); WS - West Siberian (Ordovician through Carboniferous)

MO - Mongol-Okhotsk (Devonian through Late Jurassic); SL - Solon (Carboniferous and Permian)

Tectonic Collages Along the Northern and Eastern Margins of North Asian and Sino-Korean Cratons

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

BD - Badzhal (Triassic through Early Cretaceous); PA - Penzhina-Anadyr (Late Jurassic and Cretaceous); HS - Honshu-Sikhote-Alin (Jurassic and Early Cretaceous); SA - South Anyui (Permian through Jurassic);

KOR - Koryak (Late Jurassic through Paleocene; SH - Sakhalin-Hokkaido (Cretaceous); WK - West Kamchatka (Mid-Cretaceous through Early Tertiary)

ES - East Sakhalin (Late Cretaceous and Early Tertiary); OK - Olyutorka-Kamchatka (Late Cretaceous to Paleocene)

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

JT- Japan Trench (including Kuril-Kamchatka trench) (Miocene through Holocene; NN - Nankai (Miocene through Holocene)

Cratonal Terranes and Superterranes

Cratonal terranes (Archean and Proterozoic): GY - Gyeonggi-Yeongnam; JA - Jiaonan; OH - Okhotsk

Late Proterozoic and Cambrian superterranes: AR - Argun-Idermeg; TM - Tuva-Mongolia

Archean through Permian superterranes: BJ - Bureya-Jiamusi; KR - Kara

Jurassic Superterrane: KOM - Kolyma-Omolon (Archean through Jurassic)

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

at - Altay arc (Devonian and early Carboniferous, 381 to 290 Ma)
ea - East Sikhote-Alin arc (Late Cretaceous through early Tertiary, 96-65 Ma)
gh - Gobi-Khankaisk-Daxing'anling arc (Permian, 295 to 250 Ma)
ha - Hangay arc (Late Carboniferous and Early Permian, 320 to 272 Ma)
ji - Jihei arc (Permian, 295 to 250 Ma)
ko - Khingan arc (Early and mid-Cretaceous)
lg - Lugyngol arc (Permian and Triassic, 295 to 250 Ma)
ma Main granite belt (Late Jurassic, 144 to 134 Ma)
nb - Northern granite belt (Early Cretaceous, 138 to 120 Ma)
nm - North Margin (Late Carboniferous and Permian, 320 to 272 Ma)
nr - Norovlin arc (Devonian and Early Carboniferous, 410 to 255 Ma)
oc - Okhotsk-Chukotka arc (Late Cretaceous and early Tertiary, 96 to 53 Ma)
ol - Oloy arc (Late Jurassic, 154 to135 Ma)
se - Selenga arc (Permian through Jurassic, 295 to135 Ma)
sm - South Mongolian arc (Carboniferous through Triassic, 320 to 203 Ma)
ss - South Siberian arc (Devonian)
sv - South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157 to 93 Ma)
tr - Transverse granite belt (Early Cretaceous, 134 to 124 Ma)
uo - Umlekan-Ogodzhin arc (Cretaceous, 135 to 65 Ma)
us - Uda-Murgal and Stanovoy arc (Jurassic and Early Cretaceous, 203 to 96 Ma)
uy - Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154 to 120 Ma)

Plume-Related Igneous Province

tp - Tungus Plateau igneous province - (Late Permian and Early Triassic, 245 Ma)

Active Arcs

ib - Izu-Bonin (late Cenozoic, 20 to 0 Ma)
ja - Japan (late Cenozoic, 23 to 0 Ma)
kk - Kuril-Kamchatka (late Cenozoic, 11 to 0 Ma)

Transpressional Arcs

ke - Kema (Mid-Cretaceous)
mt - Mongol-Transbaikal (Late Triassic through Early Cretaceous, 230 to 96 Ma)
ss - South Siberian (Early Devonian, 415 to 400 Ma)
tb - Transbaikalian-Daxinganling (Middle Jurassic through Early Cretaceous,175 to 96 Ma)

Symbols, Faults, and Contacts

Overlap-continental-margin arc
Transform-continental-margin arc
Active subduction zone
Thrust
Strike-slip fault
Fault
Contact
Riphean aulacogen
Devonian aulacogen
Modern rift system (Gakkel Ridge)
OS Metallogenic belt

Figure 2.—Continued.

Table 1. Summary of major Devonian and Early Carboniferous (Mississippian) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit. Map Symbol	Type of unit (craton, terrane, overlap assemblage)	Age range	Tectonic environment	Tectonic linkage
		NORTH ASIAN AND SINO-KOREAN CRATONS AND OVERLYING PROTEROZOIC AND PHANEROZOIC UNITS		
North Asian. NAC Sino Korean. SKC	Craton	Archean through Mesozoic	Cratonal and passive continental margin	
		NORTH ASIAN CRATONAL MARGIN UNITS		
Baikal-Patom. BP Verkhoyansk. VR	Overlap assemblages	Neoproterozoic through Mesozoic	Passive continental margin	Original overlap assemblages on North Asian craton that were subsequently transformed into fold and thrust belts and terranes.
		SUPERTERRANES		
Argun-Idermeg. AR	Superterrane	Paleoproterozoic through late Paleozoic	Passive continental-margin	May be either exotic with respect to the North Asian craton or may be a rifted fragment of the craton. Accreted in Ordovician through Silurian.
Bureya-Jiamusi. BJ	Superterrane	Proterozoic through Permian	Composite	Consists of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island-arc terranes. Interpreted as being a fragment of Gondwanaland. Accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic.
		TECTONIC COLLAGES		
Atasbogd. AB	Collage	Ordovician through Permian	Composite	Consists of the Ordovician through Permian Waizunger-Baaran terrane, Devonian through Carboniferous Beitianshan-Atasbogd terrane, and Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. Collage is interpreted as being a southwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terrane. Accreted in Late Carboniferous or Early Permian.
South Mongolia-Khingan. SM	Collage	Ordovician through Carboniferou	Island arc and subduction zone	Consists of the South Mongolia-Khingan arc and tectonically-linked subduction-zone terranes. The collage is interpreted as being a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. Collage was separated from the North Asian craton by a large back-arc basin. Accreted in Late Carboniferous or Early Permian.

Table 1. Summary of major Devonian and Early Carboniferous (Mississippian) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan). —Continued

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit. Map Symbol	Type of unit (craton, terrane, overlap assemblage)	Age range	Tectonic environment	Tectonic linkage
		TECTONIC COLLAGES		
West Siberian. WS	Collage	Ordovician through Carboniferous	Island arc and subduction zone	Consists of the Late Silurian through Early Carboniferous Rudny Altai island arc and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. Collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage. Accreted in Late Carboniferous or Early Permian.
		Devonian and Carboniferous Continental-Margin Arcs Occurring on North Asian and Sino-Korean Cratons		
North Okhotsk	Overlap assemblage	Devonian through Early Carboniferous	Continental-margin arc	Occurs in the northeastern flank of the North Asian craton and preserved in various fragments of the Kolyma-Omolon superterane. Interpreted as having formed during subduction of the Ancestral Pacific ocean plate.
		Devonian through Early Carboniferous Island Arcs		
Norovlin arc nr	Overlap assemblage	Devonian through Early Carboniferous	Island arc formed on Argun-Idermeg superterrane	Interpreted as having formed during subduction of the northern part of Mongol-Okhotsk Ocean plate under the Argun-Idermeg superterrane.
South Mongolian (Khingan) sm	Overlap assemblage	Devonian through Early Carboniferous	Island arc formed on South Mongolian and Atasbogd collages.	Interpreted as having formed during subduction of the Paleoasian Ocean plate.
		Devonian Transpressional Arc		
Altai arc at	Overlap assemblage	Devonian and Early Carboniferous	Transpressional-margin arc	Occurs on the previously accreted Altai and Yenisey-Transbaikal collages. The arc is interpreted as having formed along an active continental margin in an oblique subduction zone environment.
South Siberian arc ss	Overlap assemblage	Early Devonian	Transpressional-margin arc	Interpreted as having formed along the southern margin of the North Asian craton and cratonal margin during Early Devonian rifting that successively evolved into a continental-margin transform margin and, subsequently, into a convergent margin.

The tectonic collages are as follows (fig. 2). Detailed descriptions of the terranes in each tectonic collage are provided in appendix B and in Parfenov and others (2003, 2004a, b).

1. The Atasbogd collage (AB) (Ordovician through Permian age and accreted in Late Carboniferous or Early Permian) consists of the Ordovician through Permian Waizunger-Baaran island-arc terrane, Devonian through Carboniferous Beitianshan-Atasbogd forearc and back-arc terrane, and Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. The collage is interpreted as being a northwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the deformed margin of the North Asian craton.
2. The South Mongolia-Khingan collage (SM) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the South Mongolia-Khingan arc (now a series of early and middle Paleozoic arc terranes), subduction-zone terranes, and back-arc basins. Tectonically linked to the South Mongolia-Khingan island arc was a subduction zone now preserved in the discontinuous collage of the Kalba-Narim and Zoolen subduction-zone terranes that occur outward (oceanward) of, and parallel to the South Mongolia-Khingan island arc. Also tectonically linked to the South Mongolia-Khingan island arc was an elongate back-arc basin now preserved in a discontinuous and disrupted collage of terranes in Southern Mongolia. These terranes are the Bayanleg (BL) and Mandah (MN) subduction-zone terranes. The South Mongolia-Khingan arc is interpreted as having formed during the Devonian through Early Carboniferous subduction of the Paleoasian ocean basin. The collage formed southwest and west (present-day coordinates) of the North Asian craton and previously accreted terranes.
3. The West Siberian collage (WS) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the Late Silurian through Early Carboniferous Rudny Altay island arc and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. The collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage.
4. The Yenisey-Transbaikal collage (YT) (Vendian through Devonian age and accreted in Vendian through Early Ordovician) consists of the Vendian through Middle Cambrian Kuznetsk-Tannuola, Dzhida-Lake island-arc terranes, tectonically-linked back-arc basins, and now tectonically eroded subduction-zone terranes. The collage is interpreted as being a linear array of island-arc systems that formed south (present-day coordinates) of the deformed margin of the North Asian craton. The eastern part of the collage also includes the West Stanovoy metamorphosed terrane that may be a displaced fragment of the North Asian craton or of another craton.

Devonian and Carboniferous Continental-Margin Arc Occurring on the North Asia Craton

The North Okhotsk continental-margin arc occurs in the northeastern flange of the North Asian craton and overlaps the Okhotsk cratonal (OH), Omolon cratonal (KOM) and Avekova cratonal (AK) terranes. The North Okhotsk continental-margin arc and associated subduction zone northward extended out from the continental margin and along the boundary of the ancestral Pacific Ocean and Angayucham Ocean. This part of the arc is interpreted as being an intraoceanic island arc formed above the subduction of the Ancestral Pacific ocean plate. In that case unknown back arc basin is expected behind of the oceanic island arc. Tectonically paired to the North Okhotsk arc was a subduction zone now preserved in a discontinuous collage of the Galam subduction-zone terrane in the northern part of the Russian Far East. The North Okhotsk arc is interpreted as having formed during the Devonian through Early Carboniferous subduction of the ancestral Pacific Ocean plate (Nokleberg and others, 2000). Remnants of this oceanic plate are now preserved in the discontinuous fragments of the Galam terrane, and remnants of the arc – on the Okhotsk, Omolon and Avekova terranes (Parfenov and Kuzmin, 2001; Parfenov and others, 2003). The Anagyucham ocean and/or back-arc basin was formed as a result of back-arc rifting and spreading behind the North Okhotsk arc. The Sette-Daban Basin also may have resulted from back-arc rifting.

Devonian through Early Carboniferous Island Arcs

South Mongoia-Khingan Arc

The South Mongolia-Khingan island arc (sm) (Middle Carboniferous through Triassic) overlies and intrudes the South Mongolian-Khingan and Atasbogd collages. The arc consists of a series of related Early and Middle Paleozoic arc terranes, including the Rudny Altai, Beitianshan-Atasbogd, Edren, Waizunger-Baaran, Gurvansayhan, Dongujimqin-Nuhetdavaa, Mandalovoo-Onor terranes. The Rudny Altai and Kalba-Narim terranes are underlain by fragments of accreted terranes that were rifted from the margin of the North Asian craton. The other terranes are built on oceanic crust or Ordovician through Silurian sedimentary wedges. The arc is interpreted as having formed during subduction of the Paleoasian Ocean plate under the South Mongolia-Khingan and Atasbogd collages.

Norovlin Island Arc

The Norovlin island arc (nr) (Devonian through Early Carboniferous) overlaps the Argun-Idermeg superterrane (Argunsky and Idermeg passive continental-margin terranes, part of the Atasbogd and South Mongolia-Khingan collages) (fig. 2). The arc consists of (1) Lower to Middle Devonian calc-alkaline andesite, dacite, rhyolite, tuff, conglomerate, sandstone, and siltstone intruded by gabbro and diabase bodies; and (2) Middle to Upper Devonian volcanoclastic rocks, chert, mudstone and minor reef limestone. The arc is interpreted as having formed during subduction of the Mongol-Okhotsk Ocean plate beneath northern margin (present-day coordinates) of the Argun-Idemeg superterrane (Atasbogd and South Mongolia-Khingan collages). This plate is preserved in discontinuous fragments in the older parts of the Ononsky terrane.

Transpressional Arc (Devonian through Cretaceous)

Two major transpressional continental-margin arcs occur on the south margin of the North Asian craton and collages and terranes accreted to the southern margin.

1. The Altai transpressional continental-margin arc (at) (Devonian and Early Carboniferous) occurs on the Altai and Yenisey-Transbaikal collages. The arc consists of the Devonian and Early Carboniferous Altai volcanic-plutonic belt (appendix B) that overlays the Altai collage. The arc is is interpreted as having formed along a transpressional continental margin where the convergence was oblique with respect to an outboard blocks. The tectonic environment consisted of lithospheric blocks (terranes) migrating along the margin of a continental plate.
2. The major South Siberian transpressional continental-margin arc (Early Devonian) (ss; fig. 2) occurs in Southern Siberia along the margins of the North Asian craton and various accreted collages and terranes to the south. The arc formation was associated with strike-slip faulting and local compression and extension. The arc consists of the Early Devonian South Siberian volcanic-plutonic belt (appendix B) that overlies the North Asian craton and adjacent accreted Yenisey-Transbaikal and Altaiy collages to the southwest.

Summary of Devonian through Early Mississippian (410 to 320 Ma) Metallogenesis

Major Devonian through Early Carboniferous Metallogenic Belts

The major Devonian through Early Carboniferous metallogenic belts are the Botuobiya-Markha, Bayangovi, Daldyn-Olenyok, Edrengiin, Edren-Zoolon, Hongqiling, Kizhi-Khem, Mamsko-Chuiskiy, Rudny Altai, Salair, Sette-Daban, Sorsk, Tsagaan-suvarga, Udzha, Ulziit, and Yaroslavka belts (fig. 3, appendix C).

Metallogenic Belts Related to Island Arcs

Four metallogenic belts possess geologic units favorable for a wide variety of island-arc magmatism-related deposits, including the Edrengiin, Rudny Altai, Salair, and Tsagaan-suvarga belts. The deposits types are volcanogenic Cu-Zn massive sulfide (Urals type), volcanogenic Zn-Pb-Cu massive sulfide, volcanogenic-sedimentary Mn, volcanogenic-sedimentary Fe, barite vein, volcanic-hosted metasomatite, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, porphyry Cu-Mo (±Au, Ag), porphyry Cu (±Au), porphyry Cu-Au, and granitoid-related Au vein. The fossil or isotopic ages of the deposits or hosting units range from Early Devonian through Early Carboniferous. The favorable geologic units are Edren island-arc terrane, part of the South Mongolia-Khingan collage; Rudny Altai island-arc terrane, part of West Siberian collage; the Altai volcanic-plutonic belt, part of the South Mongolia-Khingan island arc; and the Gurvansayhan island-arc terrane, part of South Mongolia-Khingan collage.

Metallogenic Belts Related to Terrane Accretion

Three metallogenic belts possess geologic units favorable for a wide variety of major collisional granite-hosted deposits and related vein deposits, including the Bayangovi, Edren-Zoolon, Muiskiy, Ulziit, and Yaroslavka belts (with granitoid-related Au vein; Au in shear-zone and quartz-vein; fluorite greisen; Sn-W greisen, stockwork, and quartz vein; carbonate-hosted Hg-Sb deposits). The fossil or isotopic ages of the deposits or hosting units range from Devonian through Early Carboniferous (440 to 396 Ma). The favorable geologic units and deposits are the Edren island arc and Zoolen subduction-zone terrane, both part of the South Mongolia-Khingan collage, granitoids and veins of the Barguzin-Vitim granitoid belt intruding the Baikal-Muya island arc and Muya metamorphic terrane, both part of the Tuva-Mongolia superterrane; granitoids intruding the Bureya-Jiamusi supterterrane; and vein replacements in the Govi-Altai continental-margin turbidite terrane, part of the South Mongolia-Khingan collage. These granitoids and veins are interpreted as having formed during regional metamorphism and vein emplacement associated with terrane accretion and generation of anatectic granitic plutons.

Metallogenic Belts Related to Transpressive Continental-Margin Arcs

Five metallogenic belts (Deluun-Sagsai, Kizhi-Khem, and Korgon-Kholzun, Sorsk, and Teisk) possess geologic units favorable for a wide variety of major granite-hosted deposits. The major deposit types are polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite; polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite; polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type); sediment-hosted Cu, volcanogenic-sedimentary Fe; porphyry Cu-Mo (±Au, Ag);

Ag-Pb epithermal vein; granitoid-related Au vein; W-Mo-Be greisen, stockwork, and quartz vein; granitoid-related Au vein; mafic-ultramafic related Ti-Fe (+V); porphyry Mo (±W, Bi); polymetallic (Pb, Zn, Ag); carbonate-hosted metasomatite; Fe-skarn; Zn-Pb (±Ag, Cu) skarn; and Ta-Nb-REE alkaline metasomatite. The host geologic units are the Deluun sedimentary-volcanic-plutonic belt (part of the South Siberian and Altai transpressional- margin arcs), and replacements and granitoids related to the South-Siberian volcanic-plutonic belt, and the Altai volcanic-plutonic belt. The isotopic ages of the deposits or hosting units range from Devonian through Early Carboniferous. The favorable geologic units and deposits are the South Siberian and Altai transpressive continental-margin arcs.

Metallogenic Belts Related to Transpressional Faulting

Two metallogenic belts (Hongqiling and Mamsko-Chuisky) possess geologic units favorable for major vein deposits or plutonic-hosted deposits. The major deposit types are mafic-ultramafic related Cu-Ni-PGE, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, and muscovite pegmatite deposits. The fossil ages of the deposits or hosting units are Devonian and Early Carboniferous, and the isotopic ages range from 416 to 330 Ma. The favorable geologic units that host the tracts and deposits are (1) mafic and ultramafic plutons intruding and overlapping the Zhangguangcailing superterrane and Laoling terrane, part of Bureya-Jiamusi supterterrane; and (2) veins and dikes in the Mamsky and Konkudero-Mamakansky complexes intruding the Chuja paragneiss terrane that is included in the Baikal-Patom cratonal margin. These units and deposits are interpreted as having formed during transpressional faulting and associated interplate rifting.

Metallogenic Belts Related to Rifting

Two metallogenic belts (Sette-Daban and Udzha) possess geologic units favorable for a wide variety of rift-related deposits. The major deposit types are sediment-hosted Cu, Basaltic native Cu (Lake Superior type), REE carbonatite, and carbonate-hosted Pb-Zn (Mississippi valley type deposits). The fossil ages of the deposits or host units are Devonian and Early Carboniferous. The favorable geologic units and deposits are interpreted as having formed during rifting of the North Asian craton or cratonal margin.

Unique Metallogenic Belts

Two unique metallogenic belts (Botuobiya-Markh and Daldyn-Olenyok) are hosted in Devonian diamond-bearing kimberlite intruding the North Asian craton. The origin of the diamond-bearing kimberlite deposits is not well known.

The unique Edrengiin belt (with volcanogenic Cu-Zn massive sulfide, volcanogenic-sedimentary Mn and Fe deposits) is hosted in the Edren island-arc terrane, part of the South Mongolia-Khingan collage, and is interpreted as being having formed during island arc marine volcanism.

Major Devonian and Early Mississippian (410 to 320 Ma) Metallogenic Belts and Host Units

Bayangovi Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt BG) (Southern Mongolia)

This Devonian metallogenic belt (Zabotkin and others, 1988) is related to replacements in the Govi-Altai continental-margin turbidite terrane. The deposits are mainly Au-quartz carbonate vein occurrences. The Govi-Altai turbidite terrane consists of mainly Ordovician through Silurian turbidite that is overlain by Devonian shallow marine sedimentary rock (Tomurtogoo and others, 1999). The metallogenic belt was defined by Dejidmaa and others (1996) and contains the Bayangovi Au district (Dejidmaa, 1996). Au quartz-carbonate-vein occurrences consist of concordant pyrite alteration zones with thin, ladder quartz veins that are spatially related with Early Devonian granitoid in the Nudenhudag gabbro, tonalite, and plagiogranite complex. The host Silurian and Early Devonian sedimentary rock is metamorphosed to greenschist facies. The major deposits are at Bayangovi, Oortsog, and other occurrences.

The main references on the geology and metallogenesis of the belt are Dejidmaa (1996), Dejidmaa and others (1996), Zabotkin and others (1998), and Tomurtogoo and others (1999).

Bayangovi Au in Shear-Zone and Quartz-Vein District

This deposit (D. Togtokh and others, written commun., 1991; A.A. Rauzer and others, written commun., 1987) consists of quartz veins in the Early Devonian Ulaan Khan uul, Gichigenet, and Khondolon Formations that are composed of sedimentary and volcanic rocks. The formations are intruded by concordant bodies of foliated quartz diorite, plagiogranite, and gabbro of the Nuden khudag Complex and by extensive subvolcanic bodies and dikes of andesite, basalt, gabbro, and diabase. Main faults strike to the northwest direction and they are cut by more late faults striking to the north and northeast. Intensive development of quartz veins and silicification are characteristic for the target area. There are few Au occurrences. Veins consist of milk-white, coarse- and medium-grained quartz in long extended zones. Chip samples contain 0.1 to 0.5 g/t Au. Also occurring are quartz stockworks and polymictic sandstone with chlorite cement. Pyrite occurs in

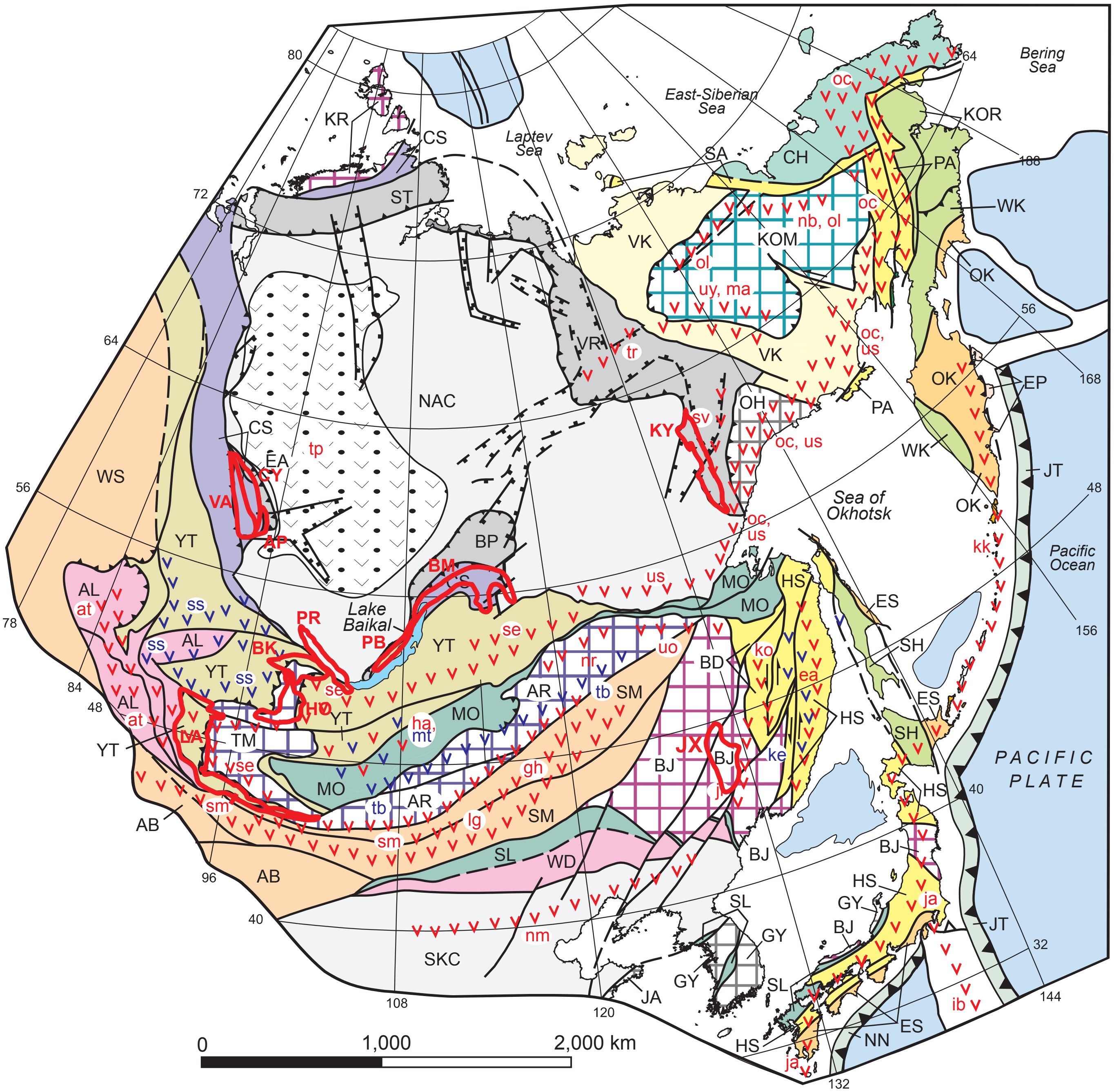


Figure 3. Generalized map of major Devonian and Early Carboniferous metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

margins of quartz stringers and in host sandstone, and it ranges up to 3 to 5 percent. Gold is fine-grained, and ranges from 0.1 to 0.2 mm and rarely up to 0.5-0.8 mm. Most gold forms plates, and some is intergrown with quartz and pyrite. Other ore minerals are galena and chalcopyrite. Also occurring is the similar Bayangovi II gold occurrence with a stockwork that grades 0.05 to 3.0 g/t Au. Also in the district is the Bituugiin khar occurrence with a quartz stockwork that is 2 m thick and 600 m long with channel samples grading 0.3 to 1.5 g/t Au.

Origin and Tectonic Controls for Bayangovi Metallogenic Belt

The belt is interpreted as having formed during regional metamorphism of the Govi-Altai terrane that occurred during accretion of the South Mongolia-Khingan collage with the accreting margin of the North Asian craton and cratonal margin.

Botuobiya-Markha Metallogenic Belt of Diamond-Bearing Kimberlite Deposits (Belt BM) (Russia, Central part of the Siberian platform)

This Devonian metallogenic belt is hosted in kimberlite intruding mainly early Paleozoic carbonate sedimentary rock in the North Asian craton. The belt extends 300 km in a southwest-northeast trend and contains several diamond-bearing kimberlite pipes of Devonian age. The major deposits are the Mir and Internatsional'naya pipes that intrude Cambrian and Ordovician carbonate and clastic rocks. The Mir pipe was mined from the 1950's until recently.

The main references on the geology and metallogenesis of the belt are Khar'kiv and others (1997), Brakhfogel' and others (1997), and Parfenov and others (1999, 2001).

Internatsional'naya Diamond-Bearing Kimberlite Deposit

This deposit (Khar'kiv and others, 1997) consists of a well-defined, funnel-shaped pipe in the upper part which changes at depth into an almost cylindrical diatreme with subvertical contacts. The size of the pipe is constant to a depth of 1000 m. The pipe intrudes horizontal Cambrian and Early Ordovician clastic and carbonate rocks and is overlain by Early Jurassic deposits that range from 2,200 to 9,200 m thick. A characteristic feature of the pipe rocks is sparse Ti minerals (picroilmenite, orange pyrope) and abundant Cr minerals (chrome spinel, chrome diopside, chrome pyrope). The deposit is large.

Mir Diamond-Bearing Kimberlite Deposit

This deposit (fig. 4) (Khar'kiv and others, 1997) consists of a pipe intruding Ordovician and Cambrian carbonate, terrigenous, and halogen-bearing rocks. The pipe is associated with two Late Devonian sills and a diabase dike. From the surface to a depth of 200 m, the pipe is funnel-shaped and at greater depth, down to 900 m, and it is cylindrically-shaped. At greater depths, the pipe grades into a feeding dike. Diamond forms are octahedra (61.2 percent), rhombododecahedra (9.7 percent), combined habit crystals (28.8 percent), and cubes (0.6 percent). The most common colors are colourless (75.4 percent), brown (7.2 percent), bluish-green (0.6 percent), lilac (2 percent) and smoky-grey (13.9 percent). Serpentine, carbonate, and chlorite are secondary minerals and comprise most of the kimberlite throughout the pipe. The deposit is large.

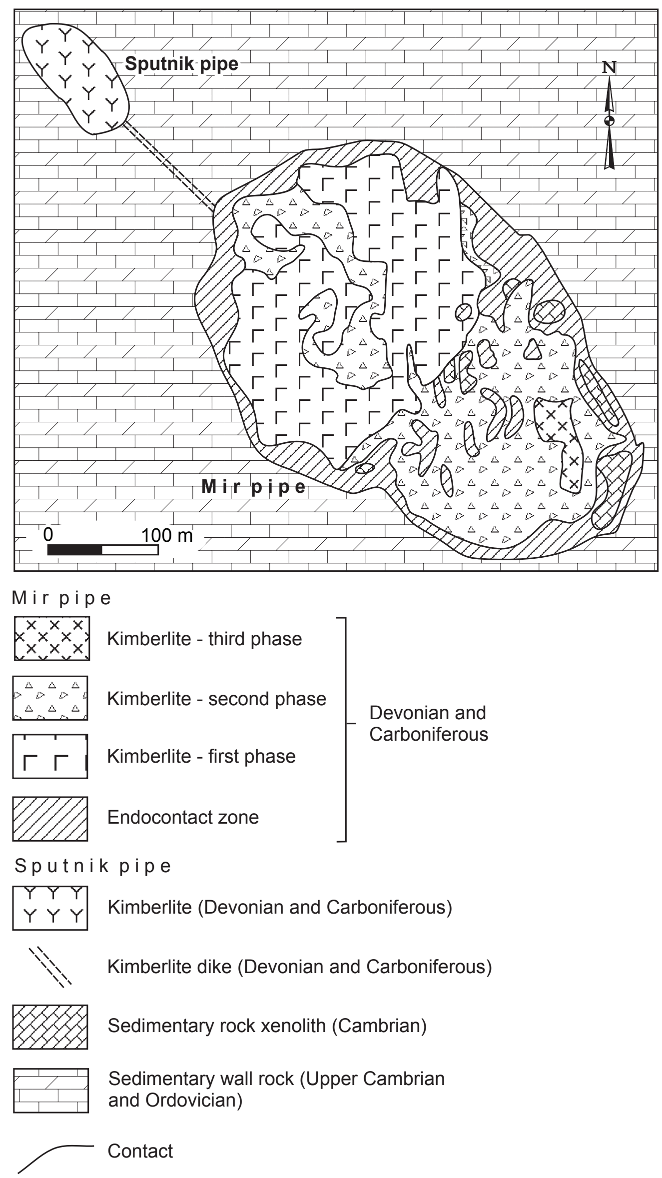


Figure 4. Geologic sketch map of the Mir diamond kimberlite pipe, Botuobiya–Markha metallogenic belt. Adapted from Khar'kiv and others (1997).

Origin and Tectonic Controls for Botuobiya-Markha Metallogenic Belt

The tectonic environment for the origin of the belt is unknown. Devonian kimberlite pipes intrude mostly Cambrian through Silurian carbonate sedimentary rocks of the North Asian craton.

Daldyn-Olenyok Metallogenic Belt of Diamond-Bearing Kimberlite Deposits (Belt DO) (Russia, Northeastern Siberian Craton)

This Devonian metallogenic belt is hosted in kimberlite intruding Phanerozoic sedimentary rock in the North Asian craton. The belt extends 800 km southwest-northeast and occurs north of the Botuobiya-Markha belt. The belt contains several diamond-bearing kimberlite pipes (Aikhal, Udachnaya, Ubileinaya, Sytykanskaya, and others) that intrude Cambrian through Silurian carbonate sedimentary rock of the North Asian craton. The major deposits are at the Aikhal, Udachnaya, Yubileinaya, and Sytykanskaya pipes.

The main references on the geology and metallogensis of the belt are Khar'kiv and others (1997), Brakhfogel' and others (1997), and Parfenov and others (1999, 2001).

Aikhal Diamond-Bearing Kimberlite Deposit

This deposit (fig. 5) (Brakhfogel' and others, 1997) consists of a kimberlite pipe hosted in Lower annd Middle Ordovician and Lower Silurian argillaceous carbonate sedimentary rock. The pipe is elongated to the northeast and has irregular outlines in plan view at different levels and in cross-section. The pipe narrows at depth and grades into a dike that is 2 to 3 m thick with swells. Also occurring are numerous kimberlite dikes that crop out at the surface (four dikes) and at various depths. The amount of deep-level, associated minerals is minor. The minerals are rare picroilmente and more abundant chrome-spinel, pyrope, and olivine. In breccia in the southwestern ore shoot and in tuff, the concentration of chrome-spinel is higher than pyrope, whereas in the central part of the pipe, the two minerals occur in equal amounts. Olivine only occurs in a third-phase breccia, up to 5 to 9 percent. The deposit is large.

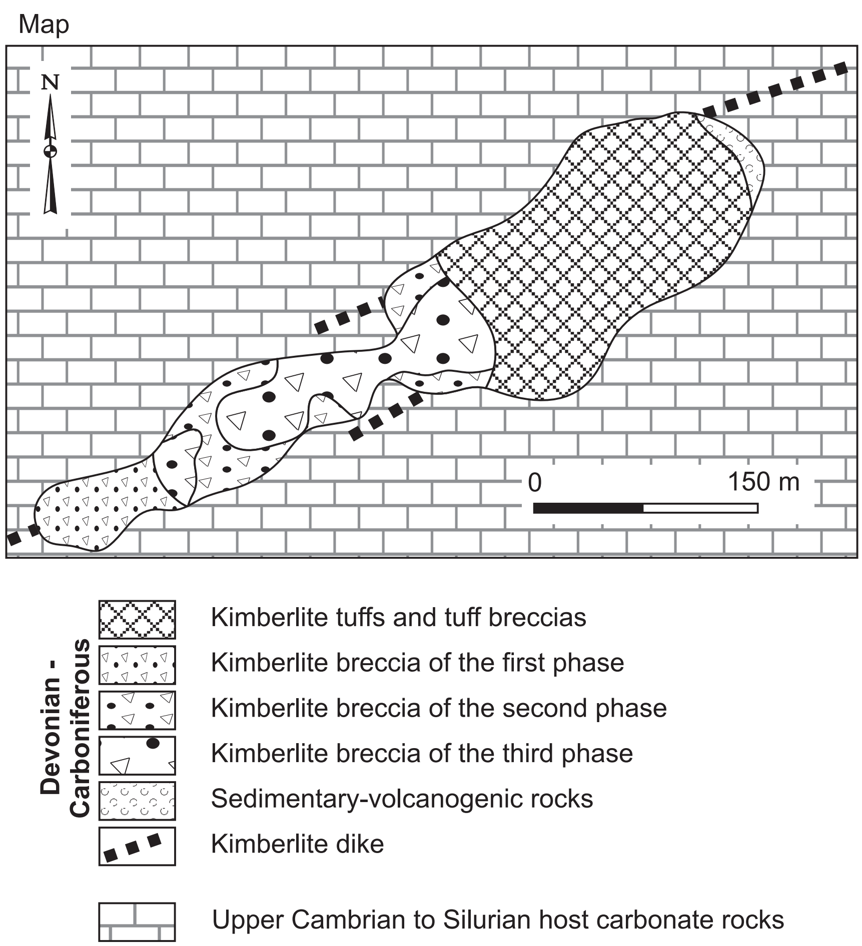


Figure 5. Geologic sketch map of the Aikhal diamond kimberlite pipe, Daldyn-Olenyok metallogenic belt. Adapted from Khar'kiv and others (1997) and Parfenov and others (2001).

Udachnaya Diamond-Bearing Kimberlite Deposit

This pipe (fig. 6) (Brakhfogel' and others, 1997) consists of two conjugate western and eastern bodies that are shaped like a distorted figure eight in plan view. The pipe extends downward to 1,400 m. In the upper levels, to a depth of about 250 to 270 m, the western and eastern bodies merge, but they separate again at deeper levels. At a depth of 280 m, both bodies are isometric and almost round in plan view. The pipe is Devonian. The host rocks are Early Ordovician and Late and Middle Cambrian massive dolomite, dolomitized limestone, marl, mudstone, silstone, sandstone, and calcareous conglomerate.

The kimberlites consist mainly of serpentine pseudomorphs after olivine and local fresh olivine. Pyrope and picroilmenite are relatively rare. The amount of sedimentary rock xenoliths is smaller in the eastern body than in the western body where deep rock xenoliths are more abundant. The content of autoliths ranges from 10-15 to 35-40 percent.

Xenoliths of sedimentary rocks consist of limestone, dolomite limestone, and dolomite with admixture of clay and sand, and marl and siltstone. The size of xenoliths ranges from fractions of a millimeter to 100 m. Most reseachers believe that the western body predated the eastern one. The bodies differ in the composition of their constituent kimberlite rocks.

Several independent phases of a kimberlite magma were emplaced in the western body. Kimberlite breccia in varous phases differ in the picroilmenite/pyrope ratio, morphological characteristics of diamonds, and chemical composition of the rocks. Late kimberlite phases occur at deeper pipe levels. Kimberlite breccias at deep levels are characterized by higher concentrations of pseudomorphs after olivine (15 to 30 percent), autoliths (up to 25 percent), and xenoliths of sedimentary rock (10 to 25 percent). The western body is strongly serpentinized throughout (to a depth of 1,400 m). Concentration of fresh olivine relics is somewhat higher at levels deeper than 400 m. The amount of hydrothermal formations of geodes and veinlets of calcite, celestite, barite, and other minerals decreases with depth.

The pipe contains a large amount of xenoliths of the basement metamorphic rock. Their maximum concentration occurs in the central part of the body. Both bodies of the Udachnaya pipe contain a high content of deep rock xenoliths. The most common are undulose garnet serpentinite (apolherzolite) that range up to 57.1 percent. Less frequent are equigranular garnet serpentinite xenoliths (31.1 percent), including apodunite, apoharzburgite, and apolherzolite.

The eastern body is unique and contains relatively abundant deep rock xenoliths (0.3 to 0.6 percent) and nodules. The xenoliths are irregularly distributed and tend to occur in central areas of the body; they include both small clasts and giant blocks weighing more than 100 kg. Morphology of diamond crystals does not regularly change with depth. The deposit is large.

Origin and Tectonic Controls for Daldyn-Olenyok Metallogenic Belt

The tectonic environment for the origin of the belt is unknown. Devonian kimberlite pipes intrude mainly Cambrian through Silurian carbonate sedimentary rocks of the North Asian craton.

Deluun-Sagsai Metallogenic Belt of Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite, Polymetallic Pb-Zn±Cu (±Ag, Au) Vein and Stockwork, Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type), Sediment-Hosted Cu, Ag-Pb Epithermal Vein, and Granitoid-Related Au Vein Deposits (Belt DS) (Western Mongolia)

This Early Devonian(?) to Early Carboniferous(?) metallogenic belt is related to granitoids and replacements in the Deluun sedimentary-volcanic-plutonic belt. The metallogenic belt occurs in the Mongol Altai area and is interpreted as being one of two belts that occur in a large metallogenic aureole related to Devonian calc-alkaline igneous rocks that constituted an Andean type active continental margin in north and northwestern Mongolia ((Berzin and others, 1994; Kovalenko and others, 1995). The metallogenic aureole contains two large metallogenic belts. The metallogenic belts and host Deluun overlap assemblage (Tomurtogoo and others, 1999) are intruded by Middle and Late Devonian calc-alkaline granitoids. This overlap assemblage (Byamba and Dejidmaa, 1999) stitches the Mongol Altai and Hovd terranes. An alternative interpretation is that the Deluun-Sagsai metallogenic belt formed during accretion (Dandar and others, 2001). The major deposits are the Dulaan khar uul Ag-Pb-Zn deposit, the Burged Cu-Pb-Zn occurrence, the Khatuugiin gol Cu occurrence, and the Nominy Am occurrences.

The main references on the geology and metallogenesis of the belt are Kovalenko and others (1995), Berzin, and others (1994), Byamba and Dejidmaa (1999), and Dandar and others (2001).

Dulaan khar uul Ag-Pb Epithermal Vein Deposit

This deposit (Shubin, 1984; V. Filonenko and others, written commun., 1991) occurs in the margin of a volcano tectonic caldera containing the Early to Middle Devonian Dulaankhar Formation that consists of rhyolite tuff, flows, tuffaceous sandstone, rhyolite and dacite porphyry subvolcanic bodies and dikes, and diabase dikes. The deposit occurs in layers and sheets of siliceous tuff breccia. Four bodies occur and vary from 200 to 700 m long and 10 to 40 m wide.

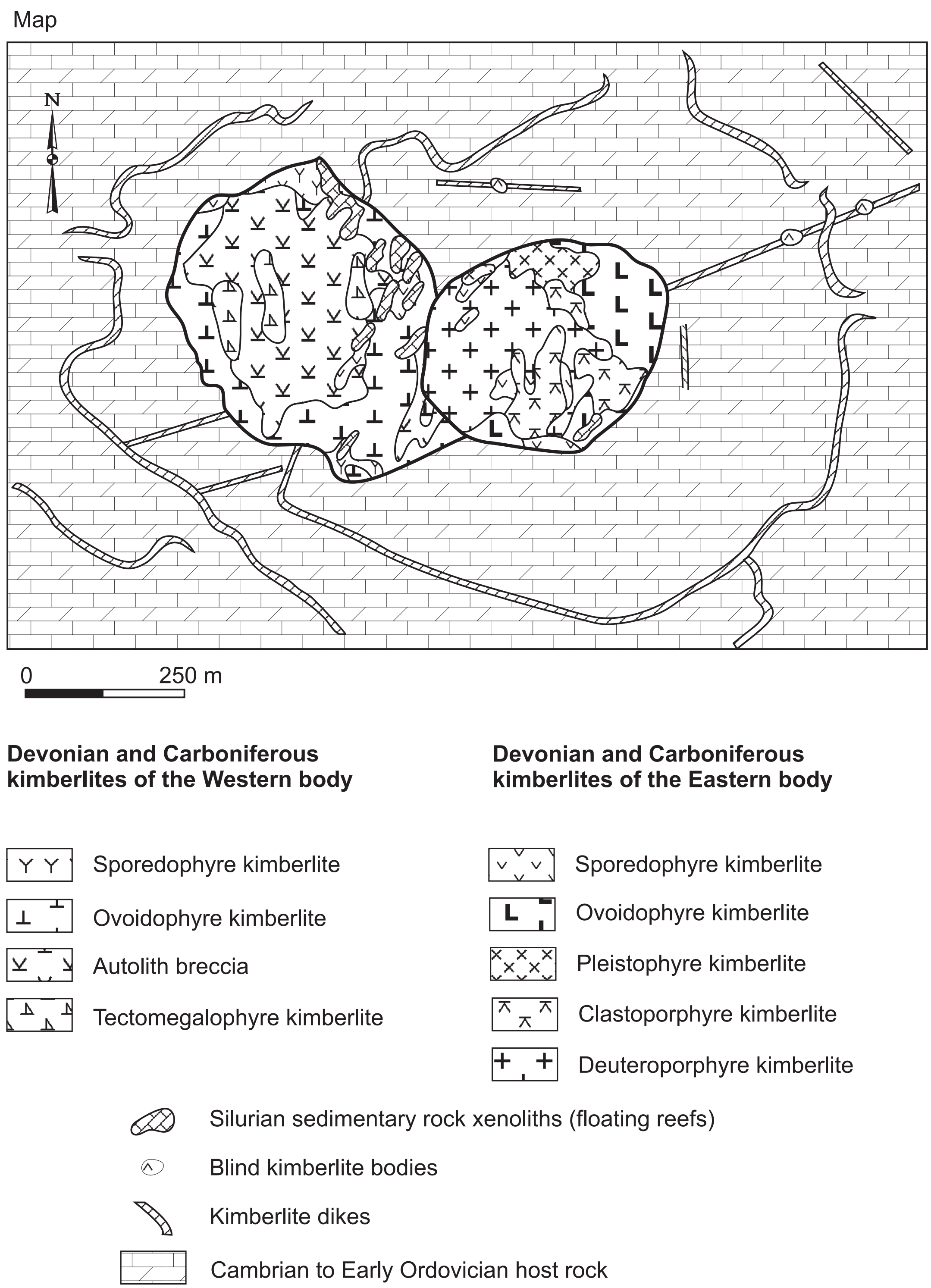


Figure 6. Geologic sketch map of the Udachnaya diamond kimberlite deposit, Daldyn-Olenyok metallogenic belt. Adapted from Khar'kiv and others (1997).

Primary ore minerals are sphalerite, galena, chalcopyrite, and gold. Sulfides occur in altered chlorite-sericite-quartz tuff and at the intersection of the Dulaankhar fault with a dike swarm that is 600 m wide. The sulfide bodies vary from 0.7 to 20 m thick, occur in layers, lenses, and veins; extend more than 100 m on surface, and downdip to a depth of 400 to 500 m. A large SP anomaly in the northeast part of the deposit has potential for new sulfide bodies. Oxidized parts of the deposit contain cerussite, calamine, galena, wulfenite, barite, fluorite, calcite, and malachite. Grades are 1.0 percent Pb, 1.0 to 10.0 percent Zn, 0.5 to 1.0 percent Cu, up to 2000.0 g/t Ag, and up to 0.2 percent Ba, from 0.2 to 4.0 g/t Au. A silica cap 700 m by 10 to 20 m occurs in the southwest part of the deposit and contains Cu oxides and hematite. The eastern and central parts of the deposit are hosted in tuff breccia. These areas contain anomalous Pb, Zn, Cu, Mo, and Co. Anomaly aureoles also occur in the western part. The deposit is large with resources of 665,000 tonnes Zn, 430,000 tonnes Pb, and 16.0 tonnes Au. Average grade is 2.05 percent Zn, 0.1to 1.76 percent Pb, 1.1 g/t Au, 1.0 to 45.0 g/t Ag, and 0.1 to 0.3 percent Cu.

Burgedtas Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (D. Dorjgotov, written commun., 1990) consists of zones in Devonian felsic volcanic and sedimentary rock (altered sandstone and siltstone). Wall rocks are hydrothermally altered to silica, sericite, and limonite. Sulfide zones are up to 3.2 km long and several hundreds meters wide. Ore minerals are pyrite, sphalerite, chalcopyrite, galena, arsenopyrite and oxide. Major gangue minerals are quartz, sericite, kaolinite, and chlorite. Average grade is 0.1 to 1.0 percent Cu, 0.2 percent Zn, and 0.2 to 1 percent Pb.

Khatuugiin gol Sediment-Hosted Cu Deposit

This deposit (B.N. Podkolzin and others, written commun., 1990) consists of sulfides in lenses and horizons in a zone that extends for several km in black shale of the Middle to Late Devonian Khatuu gol Formation along the eastern tributary of the Khatuugiin gol River. Sulfides are pyrite, pyrrhotite, and chalcopyrite in disseminations, small nests, and stringers. A unit of carbonaceous siltstone and sandstone with disseminated chalcopyrite extends 12 km from the Tsagaan gol River to the Asysan gol River. The unit varies from 1 to 7 m thick and contains up to 1.0 percent Cu, 0.1 percent As, 0.3 percent Sb, and 0.1 percent Ba. Quartz-biotite-chlorite veins, with chalcopyrite and pyrrotite occur in carbonaceous shale and contain up to 2.88 percent Cu, 0.07 percent Zn, up to 30.0 g/t Ag, and 0.01 g/t Au. The deposit has an average grade of 1.0 percent Cu.

Nominy Am Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (B.N. Podkolzin and others, written commun., 1990) consists of sulfides in quartz and quartz-barite veinlets in a breccia zone hosted in the Early to Middle Devonian Otogiin Formation that consists of dacite and andesite, tuff, tuff breccia, and quartz-calcite sandstone. The breccia zone strikes northwest and occurs at the intersection of northwest- and northeast-striking faults at the contact between volcanic and terrigenous rock. The breccia zone is 60 to 100 m wide and the 300 to 350 m long. Cataclastic host rock is intensely altered to silica and limonite. The quartz and quartz-barite veins vary from 0.1 m to 1.5 m thick extend for 60 to 70 m along strike. Ore minerals are chalcopyrite, pyrite, galena, arsenopyrite, malachite, and azurite. The largest vein is 1 to 1.5 m by 70 m and grades from 0.3 percent to 1.0 percent Cu, 0.0015 to 0.7 percent Pb, 0.007 to 0.5 percent Zn, up to 1 percent As, up to 1 percent Ba, 0.003 to 0.015 g/t Au, and 1.5 g/t to 500 g/t Ag. The average grade is 1.0 percent Cu.

Origin and Tectonic Controls for Deluun-Sagsai Metallogenic Belt

The belt is interpreted as having formed during granitoid magmatism that formed during transpressional faulting along the accreting southern margin of the North Asian craton. The polymetallic volcanic-hosted metasomatite deposits, as at Dulaanhar and Burgedtas, are related to Early to Middle Devonian basalt, andesite, and rhyolite. The sediment-hosted Cu deposits are in Middle to Late Devonian black shale, siltstone, and sandstone of the Sagsai Formation. Granitoid-related vein, stockwork, and replacement occurrences are at Sagsai and Dert tolgoi; others are hosted in volcanic and sedimentary rocks that are probably spatially and genetically related to small Late Devonian calc-alkaline granodiorite and granite stocks that occur along fault zones that control this collisional stitching complex.

Edrengiin Metallogenic Belt of Volcanogenic Cu-Zn Massive Sulfide (Urals type) and Volcanogenic-Sedimentary Mn and Fe Deposits (Belt ED) (Southwestern Mongolia)

This Early Devonian metallogenic belt is related to volcanic and sedimentary rock in the Edren island-arc terrane (Tomurtogoo and others, 1999). Massive Cu sulfides and volcanogenic-sedimentary Mn deposits occur in the Early Devonian Olgiibulag Formation that is composed of pillow basalt, chlorite shale, and siliceous sedimentary rock with quartzite layers. Cu and Mn occurrences are located in the northwestern part of the belt, trend northwest-southeast, and were discovered by Rauzer and others (1987). The major deposits are the Olgii nuruu Cu and Olgii bulag Mn occurrences.

The main references on the geology and metallogenesis of the belt are Rauzer and others (1987) and Tomurtogoo and others (1999).

Olgii nuruu Massive Sulfide Cu Occurrence

This occurrence (Rauzer and others, 1987) is hosted in a brecciated pillow basalt horizon that ranges up to 25 m thick and extends up to 2 km. Massive sulfide lenses range up to 2 m thick and consist of chalcopyrite and chalcocite in the central part of a pillow basalt horizon and disseminated sulfides in the marginal part. Fe-quartzite lenses and horizons occur parallel to pillow basalt and consist of massive magnetite lenses that range up to 1.5 m thick. Massive pyrite sheet-like bodies have dimensions to 0.25 to 0.5 by 100 m and occur adjacent to massive and disseminated Cu sulfides. Sulfides are strongly oxidized with widespread Fe oxides, malachite, and azurite.

Olgiibulag Volcanogenic-Sedimentary Mn Deposit

This deposit (A. Rauzer and others, written commun., 1987) consists of Mn minerals in quartzite lenses in a Early Devonian chert and quartzite bed that ranges up to 4 m thick in the Early Devonian Olgii Formation. Lenses range up to 1 m thick and 100 m long. The main ore minerals are pyrolusite and hematite. Grab samples contain 2 to 30 percent Mn, up to 0.4 percent Co, and up to 2.0 g/t Ag. The deposit is small and it has an average grade of 2.0 to 30 percent Mn+Fe and resources of 100,000 tonnes Mn.

Origin and Tectonic Controls for Edrengiin Metallogenic Belt

The belt is interpreted as having formed in island arc and ophiolite complexes that were part of the South Mongolia-Khingan collage and island arc. The deposits are hosted in pillow basalt and siliceous rock.

Edren-Zoolon Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt EZ) (Southern Mongolia)

This Late Devonian and Early Carboniferous metallogenic belt (Tcherbakov and Dejidmaa, 1984) occurs in veins and replacements in the Edren island-arc and the Zoolon subduction-zone terranes (Tomurtogoo and others, 1999). The belt consists of Au in shear-zone and quartz-vein deposits that are hosted in regionally metamorphosed rock. Numerous occurrences are in the Edren and Nemegt districts. The Edren island-arc terrane consists of Middle Devonian andesite, tuff, chert, siliceous tuff, limestone, Middle and Late Devonian basalt and andesite, and overlying Early to Middle Carboniferous molasse (Ruzhentsev and others, 1990). Early Devonian age pillow basalt and siliceous sedimentary rock of Olgiibulag Formation occur in the northwestern part of the terrane (Rauzer and others, 1987). The Zoolon terrane consists of tectonic sheets, slivers, and melanges of Silurian and Devonian volcanic rock, volcaniclastic rock, chert, and ultramafic rock that are metamorphosed to greenschist facies (Tomurtogoo and others, 1999). The major deposit is at Khadat Gunii khudag.

These Au quartz-carbonate vein and stockwork occurrences are mostly hosted in greenstone, greenschist, and local altered ultramafic rock (Dejidmaa, 1996; Dejidmaa and others, 1996, 2002). The quartz-carbonate veins are concordant with host shale. Vein size is variable and ranges from a few millimeters to several meters thick. Thin veins occur in linear zones that are about a hundred meters long and up to several tens of meters wide. Host rocks are mostly intensely altered to pyrite. Veins are low sulfide type. The major ore mineral is pyrite, and minor minerals are chalcopyrite and native Au. The deposits are mainly in the Edergenii nuruu and Nemegt Au districts (Dejidmaa, 1996). Related placer Au deposits occur in the Edren, Ongon Uul, and Nemegt districts where placer Au and placer Au-PGE deposits were mined in ancient times.

The main references on the geology and metallogenesis of the belt are Tcherbakov and Dejidmaa (1984), Rauzer and others (1987), Ruzhentsev and others (1990), Dejidmaa (1996), Dejidmaa and others (1996), Sharhuuhen (1999), and Tomurtogoo and others (1999).

Khadat Gunii khudag Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Podlessky and others, 1988) consists of a northeast-trending steeply dipping, quartz vein that ranges from 0.3 to 0.5 m thick and extends 100 m in chert and basalt in the Early Devonian Olgii Formation. Host rocks are weak altered to silica, carbonate, limonite, and epidote. Ore minerals are pyrite, chalcopyrite, galena, and rare gold. Heavy concentrate samples contain galena, arsenopyrite, sphalerite, pyrite, cerussite, anglesite, and gold that ranges from 0.1 to 0.9 mm in diameter. Rock-chip samples contain 0.1-30.0 g/t Au. A northeast-trending quartz-veinlet zone occurs 500 m to the southeast and consists of sericite-chlorite schist cut by quartz veinlets and stringers with pyrite, chalcopyrite, galena, and gold that range up to 3 mm. A rock-chip sample contains 10 g/t Au. Local placer Au deposits were exhausted in ancient times.

Origin and Tectonic Controls for Edren-Zoolon Metallogenic Belt

The belt is interpreted as having formed during regional metamorphism and vein emplacement associated with accretion of the Beitianshan-Atasbogd and Zhongtianshan terranes.

Hongqiling Metallogenic Belt of Mafic-Ultramafic Related Cu-Ni-PGE, Polymetallic (Pb, Zn±Cu, Ba, Ag, Au), and Volcanic-Hosted Metasomatite Deposits (Belt HQ) (Northeastern China)

The belt is interpreted as having formed during extension that occurred after accretion of the Zhangguangcailing superterrane to the basement of the Sino-Korean craton (Jilin-Liaoning-East Shandong terrane). In the Hongqiling, Changren, Piaohechuan, and other areas, the mafic and ultramafic plutonic intrusions, which occur in swarms, and consist of gabbro, pyroxenite, peridotite, orthopyroxenite, and cortlandtite. The mafic-ultramafic intrusions have isotopic ages of 331 to 350 Ma, and are controlled mainly by northwest-trending major faults that occur along the northern margin of the Sino-Korea Platform. The plutons intrude metamorphosed volcanic rock, terrigeneous, clastic, and carbonate rock of the early Paleozoic Hulan Group. However, new data indicate a possible Triassic age for the mafic-ultramafic plutons and related Cu-Ni deposits (new ^{40}Ar-^{39}Ar isotopic age is 250 Ma).The mafic-ultramafic plutonism and associated Cu-Ni deposits are herein interpreted as having formed during extension after accretion. The Early Carboniferous volcanic and sedimentary strata hosting the Guama deposit occur in an extensional basin that is interpreted as having formed after the accretion of the Zhangguangcailing superterrane. The Hongqiling Cu-Ni deposit may be related to major regional faults that controlled a back-arc basin (Fu, 1988).

The main reference on the geology and metallogenesis of the belt is Fu (1988).

Hongqiling Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Ge and others, 1994) consists of stratiform, tabular, and pod-like deposits in a mafic-ultramatic intrusion that intrudes the early Paleozoic Hulan group. The mafic-ultramafic intrusions consist of norite, pyroxenite, enstatotitite, and peridotite. The deposit is hosted in olivine pyroxenite. Ore minerals are pentlandite, pyrrhotite, chalcopyrite, pyrite, violarite, millerite, niccolite, maucherite, molybdenite, magnetite, and rutile. Pentlandite, pyrrhotite, and chalcopyrite are dominant. The mafic-ultramafic pluton is controlled by a major fault zone and has K-Ar isotopic ages of 331 to 350 Ma. The deposit is part of a district in the east-west-trending Tianshan-Xingan orogenic belt that occurs adjacent to the northern margin of the Sino-Korean Plate. The deposit is large and has reserves of 188,230 tonnes grading 2.3 percent Ni, <0.1ppm RGE, and 5 to 50 percent sulfides

Guanma Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (Wang, 1989) occurs in thin-bedded horizons of intermediate and siliceous tuff and marble in the lower part of the Early Carboniferous Lujuantun Formation. Most deposits occur in tuff, in stratiform layers and lenses and are concordant and codeformed with host rocks. Five separate deposits occur. The No. 1 deposit is 300 m long, extends 200 m downdip, and ranges from several meters to more than ten meters thick. The main deposit occurs in gray siliceous rock that contains minor arsenopyrite and pyrite and is sulphide-poor. Some Au deposits also occur in the intercalated siliceous tuff in marble and in siliceous tuff intercalated with marble. Silica alteration occurs in siliceous rocks along the contact of marble and tuff. Local diopside skarn and wollastonite-bearing marble occur in Au-bearing siliceous rock. From siliceous rock outwards into tuff, 20 to 50 m wide, sericite, chlorite and carbonate alterations are widespread, along with local talc and dolomite. The deposit is interpreted as having formed during sedimentary exhalation or hydrothermal alteration. The deposit is medium size.

Origin and Tectonic Controls for Hongqiling Metallogenic Belt

The belt is interpreted as having formed during extension that occurred after accretion of the Jilin-Liaoning-East Shandong terrane. The belt is hosted in Mississipian mafic-ultramafic plutons intruding the Shandong terrane. In the Hongqiling, Changren, Piaohechuan, and other areas, the mafic and ultramafic plutonic intrusions that occur in swarms, are composed of gabbro, pyroxenite, peridotite, orthopyroxenite, and cortlandtite. The mafic-ultramafic intrusions have isotopic ages of 331 to 350 Ma, and are controlled mainly by northwest-trending major faults along the northern margin of the Sino-Korea Platform. The plutons intrude metamorphosed volcanic rock, terrigenous, clastic, and carbonate rock of the early Paleozoic Hulan Group. However, new data indicate a possible Triassic age for the mafic-ultramafic plutons and related Cu-Ni deposits (a new ^{40}Ar-^{39}Ar age is 250 Ma).The mafic-ultramafic plutonism and associated Cu-Ni deposits are herein interpreted as having formed in magmatic events during extension after accretion. The Early Carboniferous volcanic and sedimentary strata hosting the Guama deposit occur in an extensional basin that is interpreted as having formed after the accretion of the Zhangguangcailing superterrane. The Hongqiling Cu-Ni deposit may be related to major regional faults that controlled a back-arc basin.

Kizhi-Khem Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz Vein, Porphyry Cu-Mo (±Au, Ag), Porphyry Mo (±W, Bi) (±W, Bi), Ta-Nb-REE Alkaline Metasomatite, and Granitoid-Related Au Vein Deposits (Belt KZ) (Northeast Tuva, Southern Siberia, Russia)

This Devonian through Pennsylvanian metallogenic belt is related to replacements and granitoids in the South-Siberian volcanic-plutonic belt that overlies and intrudes the Khamsara island-arc terrane. The belt occurs in northeast Tuva, and extends from east-west for about 300 km, and ranges from 40 to 60 km wide. The metallogenic belt occurs in the Ordovician through Carboniferou Kandat granitoid belt that extends latitudinally along the major Kandat fault for more than 500 km. The granitoids intrude mainly Vendian and Early Cambrian basalt, andesite, and dacite and Devonian volcanic and sedimentary rock. The porphyry Cu-Mo (±Au, Ag) and porphyry Mo (±W, Bi) deposits occur in the eastern part of the metallogenic belt, often along margins of Devonian basins. The host porphyry complexes consist of stocks of diorite, tonalite, and plagiogranite, and dikes of diorite and tonalite porphyry and granodiorite porphyry (Popov and others, 1988; Dobryanskiy and others, 1992). The deposits consist of streaks and disseminations in both Early Devonian porphyry stocks and granitoids. W-Mo-Be greisen, stockwork, and quartz vein deposits are related to small subalkalic leucogranite stocks and dikes (Danilin, 1968) and occur mainly in exocontact zones. The Okunevskoye deposit with the rare leucophane mineral is part of this group. More significant is the Aksug porphyry Cu-Mo (±Au, Ag) deposit. The Aryskanskoye Ta-Nb-REE alkaline metasomatite deposit also occurs in the metallogenic belt, but is older and has a recently-determined Late Ordovician isotopic age (454.6±1.4 Ma) (Kosticyn and others, 1998).

The main references on the geology and metallogenesis of the belt are Danilin (1968), Popov and others (1988), Dobryanskiy and others (1992), Berzin and Kungurtsev (1996), Kosticyn and others (1998).

Aksug Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (fig. 7) (Popov and others, 1988; Dobrjanskiy and others, 1992; Sotnikov and Berzina, 1993, 2000) consists of a stockwork with streaks and disseminations of Cu-Mo minerals in intensely-sheeted and hydrothermally-altered Early Cambrian volcanic rock that is intruded by the Aksug stock. The stock varies from gabbro and diorite in the periphyry to granodiorite and granite porphyry in the core. The dominant rocks are tonalite and Na-rich plagiogranite. The deposits occur in the outer zone of the porphyry intrusive around the quartz core. Two circular deposits occur. Host rocks are altered to K-feldspar, silica, and propylite. Cu deposits occur in hydrothermal quartz and sericite. Locally, Mo occurs in quartz-K-feldspar metasomatite. The ore minerals are chalcopyrite, pyrite, bornite, molybdenite, fahl, enargite, and magnetite. The deposit is medium size and has an average grade of 0.5 to 1.0 percent Cu and 0.02 percent Mo.

Dashkhemskoye Porphyry Mo (±W, Bi) (±W, Bi) Deposit

This deposit (V.I. Sotnikov, this study) consists of a Mo stockwork hosted in early Paleozoic silicified biotite granodiorite. Porphyry dikes occur in the district. The deposit occurs in seven areas that range from 1 to 10 m wide and up to 30 m long. The total area of Mo deposits is 400 m^2. Deposits consist of quartz-sulfide veins, veinlets (up to 1 cm thick), and fine molybdenite disseminations. Pyrite also occurs. Grade ranges up to 0.3 to 0.4 percent Mo. The deposit is small.

Okunevskoye W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This Be and fluorite deposit (Kachalo and others, 1976; Serdyuk and others, 1998) consists of masses and lenses of fluorite-altered rock with beryl in the exocontact zone of the

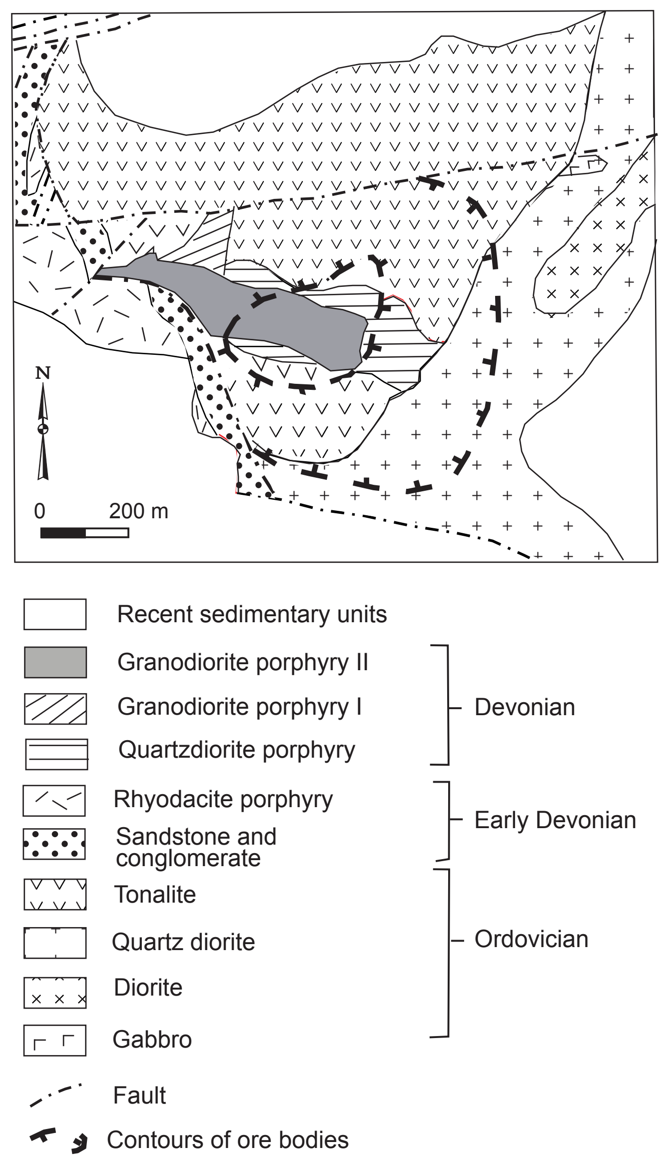


Figure 7. Geologic sketch map of the Aksug porphyry Cu-Mo deposit, Kizhi-Khem metallogenic belt. Adapted from Sotnikov and Berzina (2000)

alkalic Seibinsk granitoid pluton. The steeply dipping intrusive extends northeast for 2.5 km and is altered to albite and fluorite. Host rocks are marble, chert, and metamorphosed extrusive rock that locally are altered to skarn. Both host rocks and granite are altered to fluorite in the exocontact zone. Beryl deposits are closely associated with fluorite that contain leucophane and danalite. Deposits range from 1 to 3 m thick and extend along strike up to tens of meters. The deposit is small, has fluorite resources of 800,000 tonnes, and has an average grade of 30 percent fluorite.

Aryskanskoye 1 Ta-Nb-REE Alkaline Metasomatite Deposit

This deposit (Kudrin and Kudrina, 1959) contains albite metasomatite with zircon (malacon) and Ti-Ta-Nb minerals and occurs along a northwest-striking fault zone in the apical part of a middle Paleozoic granitoid massif. The deposit is 375 m long, varies from 15 to 70 m thick, and increases to 110 m thick at a depth of 250 m. Albite formed during intrusion of aegirine-riebeckite granite and granosyenite and has an isotopic age of 390 to 400 Ma. Three stages of formation of albite metasomatite are recognized. The first stage is albite-zircon (malacon) metasomatic veins with riebeckite. The second stage is priorite and fergusonite that are closely associated with albitite metasomatite. The largest vein is 170 m long and 0.45 m thick. The third stage is quartz veinlets with ilmenite, sulfides, native As, Ta-Nb minerals, and thorite. Ore minerals are priorite, fergusonite, pyrochlore, zircon (malacon), thorite, gadolinite, astrophyllite, xenotime, apatite, gagarinite, fluorite, bastnaesite, and native As. The deposit is small and has an average grade of 0.2 to 0.5 percent REE.

Origin and Tectonic Controls for Kizhi-Khem Metallogenic Belt

This belt is interpreted as having formed during granitoid magmatism associated with the South Siberian volcanic-plutonic belt that formed during transpressional faulting along the accreting southern margin of the North Asian craton. Deposit-related plutons intrude Early Cambrian volcanic rock of the Khamsara island-arc terrane and early Paleozoic granite of the Tannuola plutonic belt. The belt contains a broad variety of deposits that formed over a long period of time. The belt occurs along the major Kandatsk fault mainly in a large, early Paleozoic granitoid pluton that intrudes Vendian and Early Cambrian basalt of the Tuva ensimatic island arc, and is overlapped by Early Devonian extrusive rock that forms part of the South-Siberian volcanic-plutonic belt (Berzin and Kungurtsev, 1996). The formation of deposit-hosting granitoid complexes is followed by rift magmatism that formed trachybasalt and trachyrhyolite volcanic rock and subalkalic-leucogranite intrusions. The deposit-hosting porphyry intrusions structurally occur along edges of grabens that contain Early to Middle Devonian red-bed molasse. The $^{40}Ar/^{39}Ar$ isotopic age for the Aksug porphyry Cu-Mo (±Au, Ag) deposit is 380 to 400 Ma. Alaskite and alkalic granite hosting W-Mo-Be deposits cut the Silurian and Devonian granite and have a K-Ar isotopic age of 280 to 305 Ma (Danilin, 1968).

Korgon-Kholzun Metallogenic Belt of Volcanogenic-Sedimentary Fe, Fe-Skarn, Mafic-Ultramafic Related Ti-Fe (+V), and Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposits (Belt KKh) (Gorny Altai, Russia, Eastern Siberia)

This Devonian through Carboniferous metallogenic belt is related to the Altai volcanic-plutonic belt that overlaps and intrudes the Altai and Charysh continental margin turbidite terranes. The belt occurs in the northwest part of Gorny Altai and is related to a Hercynian volcanic-plutonic belt that formed along an active continental margin. The host Devonian volcanic and sedimentary rock and intrusions overlap the Altai and Charysh terranes. The belt extends northwest for 275 km and ranges from 60 to 70 km wide. The major Charysh-Terekta fault zone forms the northeast boundary of the belt. The southwest boundary of the belt is the Northeastern shear zone that contains a group of Permian through Jurassic granite intrusions (Vladimirov and others, 1977; Gaskov and others, 1991). Volcanogenic-sedimentary Fe deposits, as at Beloretskoye, Inskoye, and Kholzunskoye, and associated Mn and polymetallic-vein deposits are dominant in the belt. Small metasomatic Ag and polymetallic sulfide occurrences are hosted in Silurian carbonate and clastic rock (Charyshskoye). Low-sulfide Au quartz occurrences are hosted in skarn, and the large Kharlovskoye Fe-Ti deposit is hosted in a stratified gabbroid pluton in the northern part of the belt (Charysh-Inskaya).

The main references on the geology and metallogenesis of the belt are Kalugin (1976, 1985), Shokalskiy (1990), Vladimirov and others (1997), and Gaskov and others (1999).

Beloretskoye Volcanogenic-Sedimentary Fe Deposit

This deposit is hosted in a volcanic and sedimentary sequence of Eifelian age. The deposit consists of a layered volcanic and sedimentary magnetite body that is 1,400 long and 140 m thick. The ore horizon steeply extends for more than 1,150 m to depth (fig. 8). The Middle Devonian host rocks are volcanic and sedimentary silica-carbonate shale and sandstone, which are partly metamophosed by the Permian Tigirek granite pluton at depth. The ore minerals are layered, disseminated, massive, and brecciated. The main ore minerals are magnetite and muscovite with lesser actinolite, calcite, alite, ferro-salite, epidote, biotite, quartz, feldspar, chlorite, scapolite, turmaline, rare pyrhotite, pyrite, chalcopyrite, arsenopyrite, and sphalerite. The deposit is large and has reserves

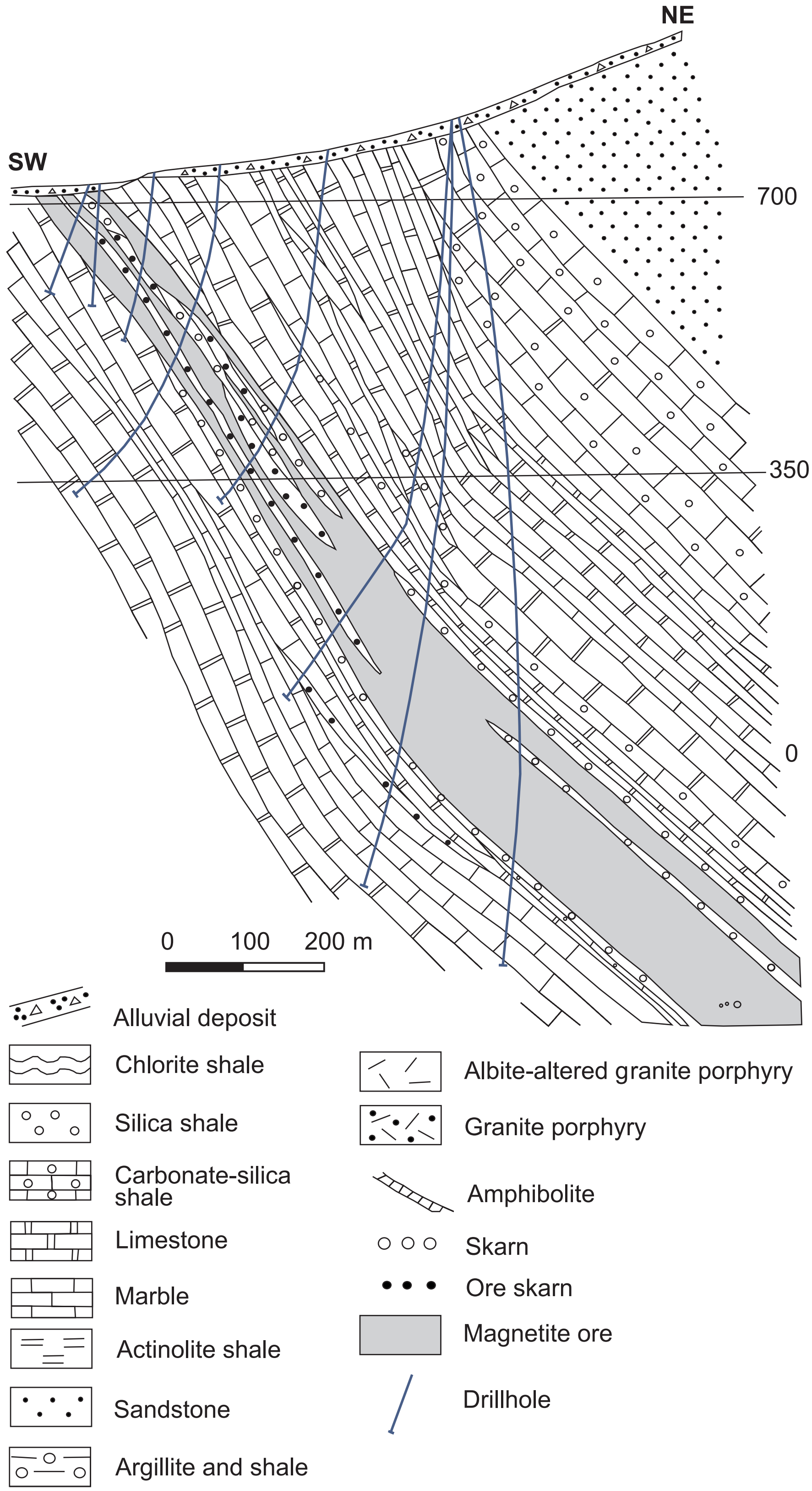


Figure 8. Schematic geologic cross section of the Beloretskoe volcanogenic sedimentary Fe deposit Rudny Altai metallogenic belt. Adapted from Kalugin and others (1981).

of 500,000,000 tonnes grading 33.5 percent Fe, 0.2 percent S, and 0.014 percent P_2O_5 (Kalugin and others, 1981).

Kholzunskoye Volcanogenic-Sedimentary Fe Deposit

This deposit is the largest in the metallogenic belt (Kalugin, 1976, 1985; Orlov, 1988) and consists of layered volcanogenic-sedimentary magnetite hosted in intensely deformed Middle Devonian rock. Host rocks are limestone, tuff, dacite, and interbedded trachydacite porphyry and quartz albitophyre. The deposit ranges from 300 to 600 m thick and extends for 25 km. Devonian host rocks are intruded by a Permian biotite granite pluton in the southwest part of the deposit. Host rocks contact metamorphosed to quartz-muscovite-feldspar hornfels adjacent to the intrusive. Individual masses occur from 0.5 to 1 km from the granite pluton. Pegmatoid granite dikes cut the magnetite ore. The ore horizon consists of closely-spaced layers and lenses. Individual masses extend more than 700 m along strike and depth and range up to 70 to 100 m thick. The ore minerals alternate with schistose and recrystallized sedimentary and volcanic rock. Ore minerals occur in plications, layers, lenses, and in rare streaks and nests. Ore minerals are hydrosilicate-magnetite with high grade apatite (prevale), actinolite, biotite, carbonate, and sulfides. Secondary minerals are epidote, quartz, dolomite, zeolite, anhydrite, barite, pyrite, and chalcopyrite. The deposit is high in silica and low in Mg. Extensive superimposed metasomatism modified stratiform Fe layers and host rocks. The deposit is large and has reserves of 600 million tonnes grading 29.7 percent Fe. Average grades are 0.10 percent V_2O_5, 1.77 to 3.49 percent S, and 0.25 to 0.34 percent P_2O_5.

Inskoye Fe-Skarn Deposit

This deposit (fig. 9) (Chekalin and Polovnikova, 1997; Orlov, 1998) consists of magntite layers hosted in an Eifelian volcanic and sedimentary sequence. The host rocks are intruded by the Permian Tigerek granitoid pluton. Along the contact with the granitoid, host rocks are recrystallized to hornfels and skarn. The deposit occurs in an economic deposit that extends 4.7 km and ranges from 100 to 400 m wide. The district contains four main deposits that each range from 180 to 1,000 m long, extend from 150 to 640 m deep, and have an average thickness of 8 to 40 m. Ore minerals occur in masses and bands and, rarely, in disseminations, spots, breccias, and streaks. The main ore assemblage is amphibole, pyroxene, and magnetite ore. Locally occurring are garnet, chlorite, epidote, carbonate, quartz, and scapolite. Associated ore minerals are pyrite, pyrrhotite, minor chalcopyrite, and sphalerite. One interpretation is formation during volcanism and sedimentation with subsequent regional and contact metamorphism (Kalugin, 1985). Another interpretation is formation during contact-metasomatism. The deposit is large and has reserves of 250 million tonnes and an average grade of 45.2 percent Fe and 0.06 percent P_2O_5.

Kharlovskoye Mafic-Ultramafic Related Ti-Fe (+V) Deposit

This deposit (Shabalin, 1976, 1982; Kalugin and others, 1981; Kuznetsov, 1982) consists of layers of titanomagnetite in a gabbroic lopolith pluton that covers about 10 km^2 (Shokalskiy, 1990). The pluton contains alternating melanocratic olivine gabbro, and nonmineralized leucocratic gabbro, norite, and anorthosite. Thickness of igneous layers ranges up to several tens of meters. Ten ore layers occur, range from 425 to 3700 m long, extend to a depth of 225 to 2,250 m, and are 16 to 140 m thick. Ore minerals are rarely disseminated. The main ore minerals are titanomagnetite (23 to 31 percent), ilmenite (1.5 to 5.2 percent), olivine (1.6 to 31.5 percent), pyroxene (18 to 25 percent), plagioclase (14 to 28 percent), and calcite (up to 0.9 percent). Lesser minerals are serpentine, garnet, biotite, chlorite, apatite, hornblende, and epidote. Ores exhibit high V (0.08 percent). The deposit is large and has reserves of 1.7 billion tonnes and resources of 4 billion tonnes. Average grades are 15.3 percent Fe and 5.9 percent TiO_2.

Origin and Tectonic Controls for Korgon-Kholzum Metallogenic Belt

The belt is interpreted as having formed interpreted during transpressional faulting along the accreting southern

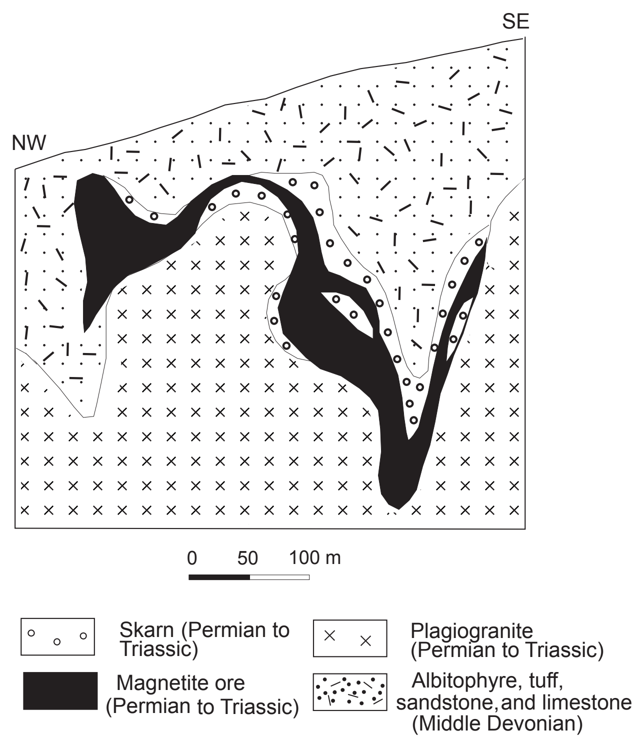


Figure 9. Schematic geologic cross section of the Inskoye Fe-skarn deposit, Korgon-Kholzun metallogenic belt. Adapted from Kuznetsov (1982).

margin of the North Asian craton, part of the South Siberian (Altai?) transform continental-margin arc during the Devonian and Carboniferous. The volcanic-plutonic belt had features similar to a cordillera type active continental margin (Kovalev, 1978). The belt contains widespread subalkalic basalt, andesite, and rhyolite sequences with siliceous volcanic rock being the most abundant. Subaeral and shallow water volcanic and sedimentary rock is typical. Metallogeny is related to volcanism and formation of Fe deposits (Kalugin, 1985; Gaskov and others, 1991). The main Fe deposits formed along tectonic sutures, as at Kholzunskoye and Timofeevskoye. Some large deposits (Inskoye, Beloretskoye) were later metasomatized during intrusion of collisional granitoids. The belt contains numerous small volcanogenic-sedimentary deposits (Korgonskoye, Kedrovskoye), magmatic-related deposits, and hydrothermal occurrences. Many deposits are Mn rich. Geodynamically, the Charysh terrane is interpreted as being a fragment of an Ordovician and Silurian passive continental margin that was weakly reactivated during the Devonian with formation of interfault basins and minor volcanism. The Eifelian and Jivetian volcanic rock consist of andesite, basalt, rhyolite, and dacite as in the Kur'ya and Novo-Firsovo Basins. Cutting the Ordovician and Silurian clastic and carbonate rocks are numerous Middle Devonian(?) subvolcanic andesite porphyry dikes and sills, small rhyolite and dacite stocks, granodiorite poprhyries, and layered intrusions of gabbro and anortosite (Shokalskiy, 1990).

Mamsko-Chuiskiy Metallogenic Belt of Muscovite Pegmatite Deposits (Belt MC) (Russia, Northern Transbaikalia)

This Devonian through Early Carboniferous metallogenic belt is related to veins and dikes in the Mamsky and Konkudero-Mamakansky complexes (too small to show at 10 M scale) that intrude the Chuja paragneiss terrane that is overlapped by the Patom fold and thrust belt of the North Asian cratonal margin. The belt occurs in the North Baikalian Highland near the north end of Lake Baikal, extends northeast for 375 km, and is 85 km wide. The Chuja paragneiss terrane forms part of the Baikal-Patom fold and thrust belt that occurs along a passive continental margin. The Chuja terrane consists of hypersthene-diopside-plagioclase-amphibole schist, gneiss, and amphibolite (Braminsky Complex), plagiogneiss with horizons of quartzite, limestone, biotite-amphibole gneiss and amphibolite (Chuja Series), biotite and biotite-amphibole gneiss, cordierite, and sillimanite and andalusite schist. The units are dated as Archean (Neelov and Podkovyrov, 1983).

Occurring in this metallogenic belt are a large number of muscovite pegmatite deposits that are related to the final stages of intrusion of the alkaline granitoids of the middle Paleozoic Mamsky and middle Paleozoic through late Paleozoic Konkudero-Mamakan Complexes. The largest deposits (mica-bearing fields) are at Vitimsky, Lugovka, Bolshoe Severnoye, Komsomolskoye, Sogdiondon, and Chuysky. Part of the metallogenic belt is controlled by the northeastern zone of regional metamorphism and granitization. The commercial mica pegmatite bodies occur in local domes that contain widespread features of migmatization, granitization and pegmatite formation (Vasilieva, 1983). Both synkinematic and late synkinematic pegmatites are recognized (Velikoslavsky and others, 1963). The former formed in place during folding and progressive metamorphism jointly with formation of metasomatic zones and mica. The latter pegmatite veins are related to retrogressive metamorphism and plastic deformations and are the most economic. The mica-bearing pegmatite contains plagioclase-microcline and plagioclase types that occur primarily in mica gneiss and clinopyroxene schist. The shape of the bodies is diverse and consists of veins, lenses, stocks, and pipes. Mica occurs in quartz-muscovite nests and is associated with beryl. In addition to muscovite, the belt is promising for granitoid-related Au-vein deposits as at the Mukodek occurrence. The major deposits are at Vitimskoye, Lugovka, Kolotovka, Bolshoye Severnoye, Komsomolsko-Molodezhnoye, Sogdiondonskoye, and Chuyskoye.

The main references on the geology and metallogenesis of the belt are Velikoslavsky and others (1963), Sryvtsev and others (1980), Neelov and Podkovyrov (1983), Vasilieva (1983), Gusev and Khain (1995), Ivanov and others (1995), Gusev and Peskov (1996), and Makrygina and others (1993).

Lugovka Muscovite Pegmatite Deposit

This deposit (Verkhozin and Kochnev, 1979; Kochnev, 1966, 1968, 1971; Rudenko and others, 1980) consists of two pegmatite fields and a series of veins that occur along a sublatitudinal tectonic zone and associated shear folds. Vein dimensions vary from small (920 to 950 by 1 to 5 m) to very large (200 to 500 by 10 to 30 m), at a depth of 115 m. The vein forms are concordant, plate-like, crosscutting, and pipe. Locally, the veins occur in clusters of extensive veins. Petrologic types are plagioclase-microcline pegmatite, quartz-muscovite and pegmatite, plagioclase pegmatite, and fractured biotite-muscovite (pegmatite). Host rocks are Mesoproterozoic two-mica gneiss and schist. Veins are associated with Mesoproterozoic through early Paleozoic granites. The deposit occurs in the central part of the Mamsky muscovite province. Twenty-two veins have been mined. Reserves are 150 kg/m^3 of large-scale muscovite with a raw muscovite content of 100 to 300 kg/m^3. The deposit is large and contains up 14 percent total mica in the Mamsky mica-bearing province.

Sogdiondonskoye Muscovite Pegmatite Deposit

This deposit (fig. 10) (Chesnokov, 1966; Tyurin, 1966, 1967; Galkin, 1969) consists of a series of veins (20 to 300 by 1 to 25 by 150 m) of various shapes with predominant crosscutting veins and dikes controlled by sublatitudinal fractures zones and flexures. The deposit consists of plagioclase-microcline pegmatite and quartz-muscovite pegmatite. The host rocks are Mesoproterozoic mica schist and gneiss and Mesoproterozoic-early Paleozoic pegmatite-bearing granitoids. The deposit is controlled by the Chuya-Sludianka structural zone and occurs along the intersection of the fault with a granite and migmatite dome in the northwest and central parts of the Mamsky muscovite province. The deposit contains rare large veins.

Origin and Tectonic Controls for Mamsko-Chuiskiy Metallogenic Belt

This belt is interpreted as having formed during intrusion of alkaline granitoid of the Mamsky and Konkudero-Mamakansky Complexes into the Chuja paragneiss terrane that formed part of a passive margin. The host granitoids are interpreted as having formed during post-accretionary magmatism in transpression zones related to transform microplate boundaries and within plate (plume) environment.

Muiskiy Metallogenic Belt of Granitoid-Related Au Vein, Au in Shear-Zone and Quartz-Vein, Carbonate-Hosted Hg-Sb-Sb, and Porphyry Sn Deposits (Belt MS) (Russia, Northwestern Transbaikalia)

This Devonian through Early Carboniferous metallogenic belt occurs in the granitoid complexes of the Barguzin-Vitim granitoid belt that forms a major suture complex. The belt occurs in the central part of the Vitim Highland and extends northwest along the Muysky Range, which is a watershed for Lake Baikal and the Vitim River. The belt is about 250 km long and 75 km wide. The granitoid belt intrudes the Baikal-Muya island arc, Olokit-Delunurian subduction-zone terranes, the Aldan cratonal, and Muysky terranes. The metallogenic belt contains various large metalliferous and nonmetalliferous deposits and small occurrences of various deposit types. The

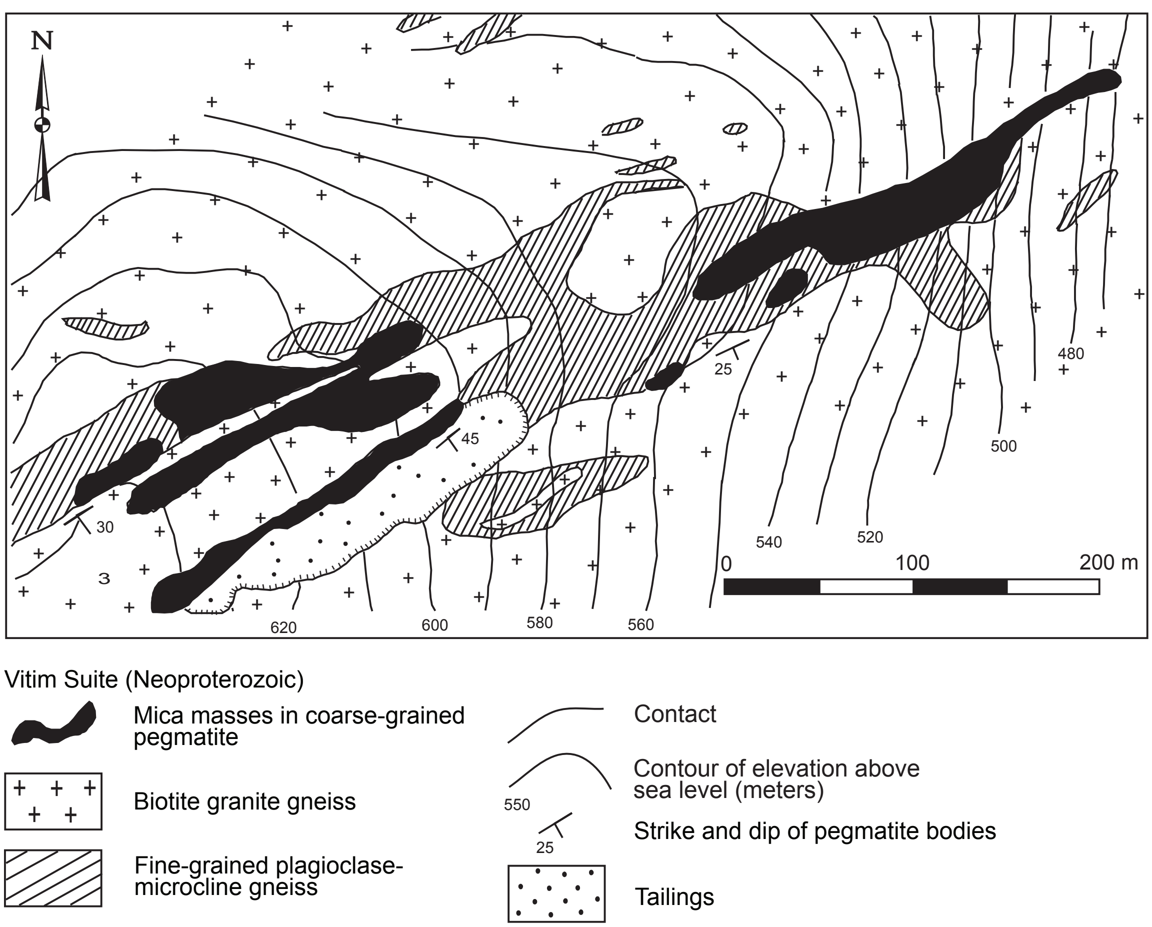


Figure 10. Geologic sketch map of the Sogdiondonskoye muscovite pegmatite deposit, Mamsko-Chuiskiy metallogenic belt. Adapted from Markov (1937).

belt occurs in two large districts, the North Muysky and South Muysky districts, both of which occur in the Muya terrane. The major deposits are at Irokindinskoye, Verkhne-Sakukanskoye, Mokhovoye, and Kelyanskoye. The belt is promising for undiscovered Au, Sn, and Hg deposits. The main references on the geology and metallogenesis of the belt are Berger and Murina (1972), Rubanov and others (1970), Bulgatov (1983), Dzasokhov (1985), Dobretsov and others (1989), Znamirovsky and Malykh (1974), Mitrofanova (1979), Mitrofanov and others (1983), Obolenskiy (1985).

The granitoid-related Au-vein deposits are hosted in Archean and Proterozoic basement as at Irokindinskoye and Kedrovskoye. The characteristics of the deposits are (1) occurrence of deposits in garnet-pyroxene, amphibole-pyroxene, and amphibole gneiss along the major Kelyano-Irokinda fault zone (Rubanov and others, 1970); (2) quartz-rich and sulfide-poor composition, with major sulfide minerals being pyrite, galena, sphalerite, pyrrhotite, and arsenopyrite; (3) sulfides comprising about 0.5 to 1.5 percent; (4) abundant quartz-vein generations (Dzasokhov, 1985); (5) occurrence of deposits along gently-dipping thrusts; (6) close age of deposits; (7) vein shape of deposits; and (8) interblock position of veins.

The major Au in shear-zone and quartz-vein deposits are at Verkhne-Sakukansky and Yubileynoye (Zhilyaeva and Naumov, 2000), Irbinskoye and Vitimkonskoye and occur in Precambrian sulfide-bearing schist and amphibolite in the Olokit-Delunuran subduction-zone terrane. The deposits occur in thick, hydrothermal zones of diaphtorites that occur along oblique-thrust-strike-slip faults. Common features are elevated Ag content and the occurrence of galena, pyrite, chalcopyrite, and sphalerite.

The carbonate-hosted Sb-Hg deposits are hosted in Vendian and Cambrian clastic and carbonate rocks and in Middle Carboniferous jasperoid dolomite in the Yangudsky Suite (Berger and Murina, 1972; Znamerovsky and Malykh, 1974). The deposits consist of layered zones (to 300 m thick) of intense silica alteration and brecciation that occur along thrusts (Obolensky, 1985). The deposits contain Au, Sb, pyrite, fluorite, and potassic hydromica. Major deposits are at Kelyanskoye, Sosnovskoye, and Anomalnoye.

The porphyry Sn deposits occur in Paleoproterozoic through Mesoproterozoic granitoid that is hosted in tectonically reworked blocks containing hematite-magnetite-feldspar metasomatite (Mitrofanova, 1979) and cassiterite-sulfide deposits. Examples are the Mokhovoye deposit and occurrences at Korotkoye and Goltsovoye. REE deposits with beryl and molybdenite occur in addition to chalcopyrite, bornite, pyrite, and arsenopyrite.

Kelyanskoye Carbonate-Hosted Hg-Sb Deposit

This deposit (Demidova, 1976) consists of a series of steeply-dipping zones that occur along a major thrust fault that cuts Early Cambrian dolomite. The zones consist of layers and lenses with dimensions of 160 to 450 by 2.8 to 4.0 m. They extend for a few tens of kilometers and consist of quartz dolomite breccia that is cemented by veins containing cinnabar. The vein minerals are quartz, calcite, and dolomite, and rare fluorite and barite. The ore minerals are cinnabar, antimonite, pyrite, galena, sphalerite, and chalcopyrite. Cinnabar is also disseminated in dolomite, and it also occurs in veins occurs irregularly. Cinnabar nests occur in areas of disseminations, crossing zones, and fractures. The deposit is large and has an average grade of 0.01 to 25.1 percent Hg, and 0.1to 0.78 percent Sb.

Irokindinskoye Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Namolov, 1980; Rubanov, 1980; Dzasokhov, 1985; Dzasokhov, 1987; Shelkovnikov, written commun., 1986) consists of 36 varibly oriented and gently lying quartz veins that occur to a depth of 480 m. The average length is 150 to 180 m, and the average thickness is 0.5 is 0.9 m. Veins contain about 0.2 to 0.5 percent sulfides that consist of pyrite (up to 78 percent), galena (up to 15 percent), sphalerite, chalcopyrite, pyrrhotite, arsenopyrite, hessite, argentite, and scheelite. Gangue minerals are quartz and carbonate (to 2 to 4 percent veins). Gold has high fineness and locally occur in nests that range to 1 to 5 mm thick. In veins gold locally occurs in pillars with dimensions of 50 to 400 by 10 to 60 m. The most productive veins cut garnet-pyroxene gneiss that is altered to quartz, pyrite, sericite, and chorite in a band that varies from 3 to 4 to 30- to 40 m wide. The deposit occurs within a tectonic block with an area of 75 km^2 that consists of Paleoproterozoic gneiss, limestone, and amphibolites. The deposit occurs in the central part of the Archean-Proterozoic Southern Muya terrane where cut by the submeridional, major Kilyaro-Irokindinsky fault. The deposit is medium size, and has an average grade of 0.7 to 133.8 ppm Au.

Mokhovoye Porphyry Sn Deposit

This deposit (Mitrofanova, 1979, 1981; Khrenov and others, 1983; Ignatovich and Martos, 1986; Skursky, 1996) consists of 23 lenses that range from 3 to 15 m thick and extend to 110 m depth. The deposit assemblages are: (1) cassiterite-hematite; (2) magnetite-feldspar metasomatite with chalcopyrite and rare bornite, pyrite, and scheelite; (3) micaceous-hematite-quartz in low-grade metasomatite (about 0.004 percent Sn); (4) arsenopyrite-carbonate-sericite in greisen; and (5) molybdenum with rare beryl in quartz vein. The first assemblage is more economically important and the second and third assemblages are secondary and occur along the edges of the deposit. The deposit occurs in a paleocaldera, with surface dimensions of 30 by 50 km, that consists of Riphean metavolcanic rocks, including basalt and rhyolite, which are intercalated with Vendian terrigenous calcareous sedimentary rock. The caldera is hosted in intensely deformed Mesoproterozoic granitoids that are alterted to K-feldspar and hematite. Metasomatism is most intense along northwest fracture zones and less intense along northeast-trending zones. The deposit contains traces of Cu, Co, Zn, and Mn. The deposit is medium size and has average grades of 1.0-2.0 percent Sn, rarely to 8 percent Sn, and up to 0.4 percent Cu.

Origin and Tectonic Controls for Muiskiy Metallogenic Belt

The belt is interpreted as having formed in granitoids and veins in the Barguzin-Vitim granitoid belt that was generated during collision of the Baikal-Muya terrane with the Muysky terrane in a transpression zone related to a transform microplate boundary.

Rudny Altai Metallogenic Belt of Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) and Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposits (Belt RA) (South-Russia, Eastern Siberia).

This Middle to Late Devonian metallogenic belt occurs in volcanic and sedimentary rocks of the Rudny Altai island-arc terrane that is interpreted as having formed on the sialic basement of the Ordovician and Silurian passive continental margin of the Siberian paleocontinent (Rotarash and others, 1982; Berzin and Kungurtsev, 1996; Distanov and Gaskov, 1999). The belt extends southeast-northwest for about 500 km and ranges up to 100 km wide. The belt contains about 50 economic deposits, 20 of which occur in the northwestern belt in Russia. Most of the base-metal deposits are hosted in Devonian volcanic and sedimentary rock, including basalt and rhyolite, and siliceous and clastic rock. Siliceous volcanic rock prevails. Subvolcanic porphyry intrusions, diabase porphyry (Devonian and Early Carboniferous), gabbro and diabase, and granitoid intrusions of various ages (Middle Devonian, Carboniferous, Permian, and Early Triassic) are widespread. The two principal mineral types of base-metal deposits are (1) pyrite and polymetallic sulfide (Korbalichinskoye, Stepnoye, Talovskoye, Rubtsovskoye, Zakharovskoye, Yubileinoe, and others); and (2) Au, Ag, barite, and polymetallic sulfide (Zarechenskoye, Zmeinogorskoye). The deposits occur in the Zmeinogorsk, Korbalihinskoye, Zolotushinsk, and Rubtsovsk districts.

The main references on the geology and metallogenesis of the belt are Rotarash and others (1982), Shcherba and others (1984), Gaskov and others (1991), Berzin and Kungurtsev (1996), and Distanov and Gaskov (1999).

Korbalihinskoye Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposit

This deposit (fig. 11) (Chekalin, 1985; Gaskov and others, 1991; Sharov and others, 1998) consists of lenses of pyrite and polymetallic sulfides that are hosted in Middle to Late Devonian volcanic and sedimentary rock. Host rocks are mainly basalt, rhyolite, siltstone, and sandstone. Numerous subvolcanic quartz porphyry, amygdaloidal diabase porphyry, gabbro, and diabase dikes occur. The deposit occurs in conformable lenses and ribbons, extends for 1,000 m along strike, and reaches a depth of 750 m. Six zones contain 90 percent of the total reserves. Mineral zonation occurs with (1) small barite and polymetallic sufides occurring in the hanging wall; (2) massive pyrite and polymetallic sulfides in a central part; and (3) Cu-sulfide pyrite in the footwall. The host rock exhibits chlorite, carbonate, talc, and sericite alteration. Main ore minerals are pyrite, sphalerite, galena, and chalcopyrite with lesser marcasite, fahl, and hematite. Gangue minerals are quartz, calcite, barite, and chlorite. Ore minerals occur in masses, breccias, disseminations, and layers. The Pb:Cu:Zn ratio is 1:0.6:3.6. Admixture elements are Au, Ag, Cd, Se, Te, Bi, Ga, In, Ta, and Ge. The deposit is large and has reserves of 497,800 tonnes Pb, 2,403,200 tonnes Zn, 360,100 tonnes Cu, and 1,360 tonnes Ag. Average grades are 2.01 percent Pb, 9.8 percent Zn, 1.46 percent Cu, and 54.2 g/t Ag.

Yubileinoe Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altay type) Deposit

This deposit (fig. 12) occurs in the Zolotushinsky ore district of the northwestern part of the Rudny Altai metallogenic belt. A monoclinal structure characterizes the area, which is underlain by volcanic and sedimentary rocks. The sedimentary rocks are siltstone, sandstones, and limestones. The deposit is related to Devonian multistage basalt-rhyolitic volcanism. The volcanic rocks are felsic lavas, tuffs, subvolcanic rhyolites, and rhyolite-dacite porphyries. The tuffs and lavas occur mainly at the top part of the deposit and are intercalated with layers of Middle Devonian limestones. The rhyolite porphyries are genetically and spatially associated with pyrite-polymetallic mineralization. Pre-ore lava flows, syn-ore subvolcanic rhyolite porphyries, and post-ore subvolcanic rhyolite-dacite porphyries occur. The pre-ore rhyolite Middle Devonian lava flows occur in lower horizons. The syn-ore Frasnian rhyolite porphyry bodies are spatially associated with polymetallic ores. The post-ore subvolcanic rhyolite-dacite and dacite porphyries occur in younger Famennian sediments that overlap the sulfide mineralization (Gaskov and others, 1991).

The sulphides of the Yubileinoe deposit form stratified, lenticular, and tabular shapes. In the lower part of the deposit, the sulfides occur mainly in veinlets and disseminations, and in the central and top parts of the deposit sulfides are massive to brecciated. Pyrite-polymetallic sulfides are predominante, and pyrite and polymetallic types are minor. Copper-pyrite and barite-polymetallic sulfides are rare. The total amount of ore at the Yubileinoe deposit is about 6 million tonnes.

Zarechenskoye Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposit

This deposit (Kuznetsov, 1982; Gaskov and others, 1991; Sharov and others, 1998) consists of lenses and stockwork with masses, streaks, and disseminations of barite and sulfides that are hosted in Eifelian volcanic and sedimentary rock. The deposit occurs in a narrow basin with steeply-dipping bedding. The bordering sublatitudinal fault zones control subvolcanic quartz albitophyre and gabbro and diabase dikes that range from 0.5 to 5 m thick. The host rock for the deposit is an argillite horizon that ranges from 50 to 80 m thick and is underlain by felsic tuff. The main deposit occurs along the contact between shale and limestone. The deposit extends more than 1 km along strike and ranges from 30 to 100 m wide. Individual lenses in the deposit are 40 to 180 m long, 1 to 1.5 m thick, and extend to a depth of 30 to 200 m. The ore-mineral assemblages are barite, Au-Ag minerals and barite, and barite and polymemetallic sulfides. Barite occurs in the hanging wall of the large lenses of barite and polymetallic sulfides. Commonly, massive sulfides occur in the hanging wall. Streaks and dissemination occur in breccia in fissures in the footwall. Wall-rock exhibits silica, chlorite, hematite, and pyrite hydrothermal alteration. Altered

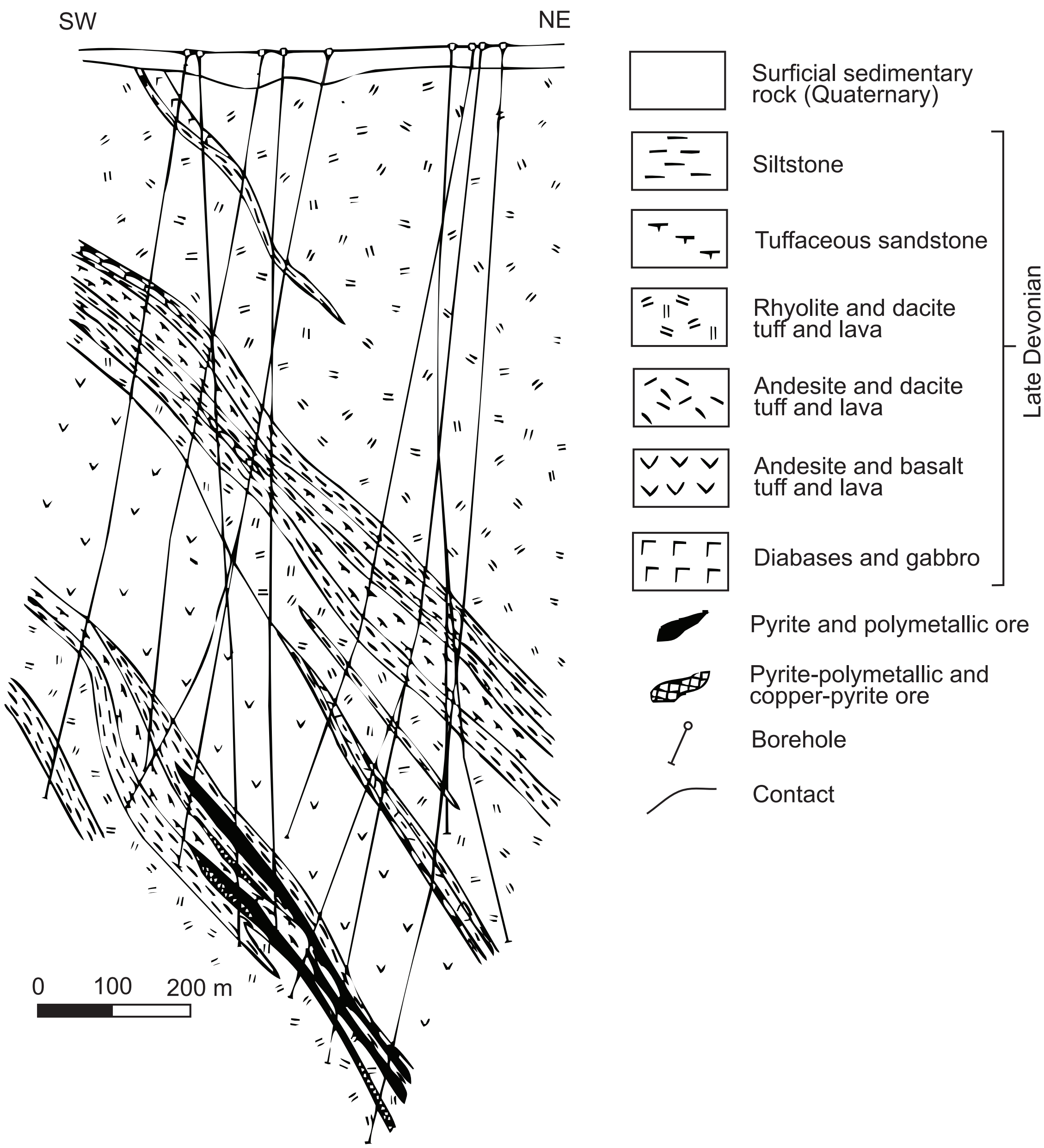


Figure 11. Schematic geologic cross section of the Korbalihinskoye volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type) deposit, Rudny Altai metallogenic belt. Adapted from Gaskov and others (1991).

rocks generally occur in the footwall. Main ore minerals are sphalerite, galena, fahl, chalcopyrite, bornite, chalcocite, native Au and Ag, electrum, argentite, silvanite, stromeyerite, jalpaite, pyrite, marcasite, and hematite. Gangue minerals are barite, quartz, calcite, dolomite, chlorite, and sericite. Ore minerals occur in masses, nests, breccia, streaks, and disseminations. The Cu:Pb:Zn ratio is 1:3.3:4.6. The deposit has been mined, is medium size, and has reserves of 11,2900 tonnes Pb, 44200 tonnes Zn, 10,000 tonnes Cu, 650,000 tonnes $BaSO_4$, and 432 tonnes Ag. Average grades are 2.89 percent Pb, 3.91 percent Zn, 0.89 percent Cu, 46.4 percent BaSO4, and 343 g/t Ag.

Origin and Tectonic Controls for Rudny Altai Metallogenic Belt

The belt is interpreted as having formed in the Rudny Altai island arc that was part of the greater South Mongolia-Khingan island arc in shallow marine volcanic rock on a shelf. Regularities in distribution of deposits and districts reveal a genetic relation between pyrite and polymetallic sulfide deposits and Devonian volcanism and formation in volcanic centers wit bimodal basalt and rhyolite (Shcherba and others, 1984; Gaskov and others, 1991; Distanov and Gaskov, 1999). The position of major volcanic centers is

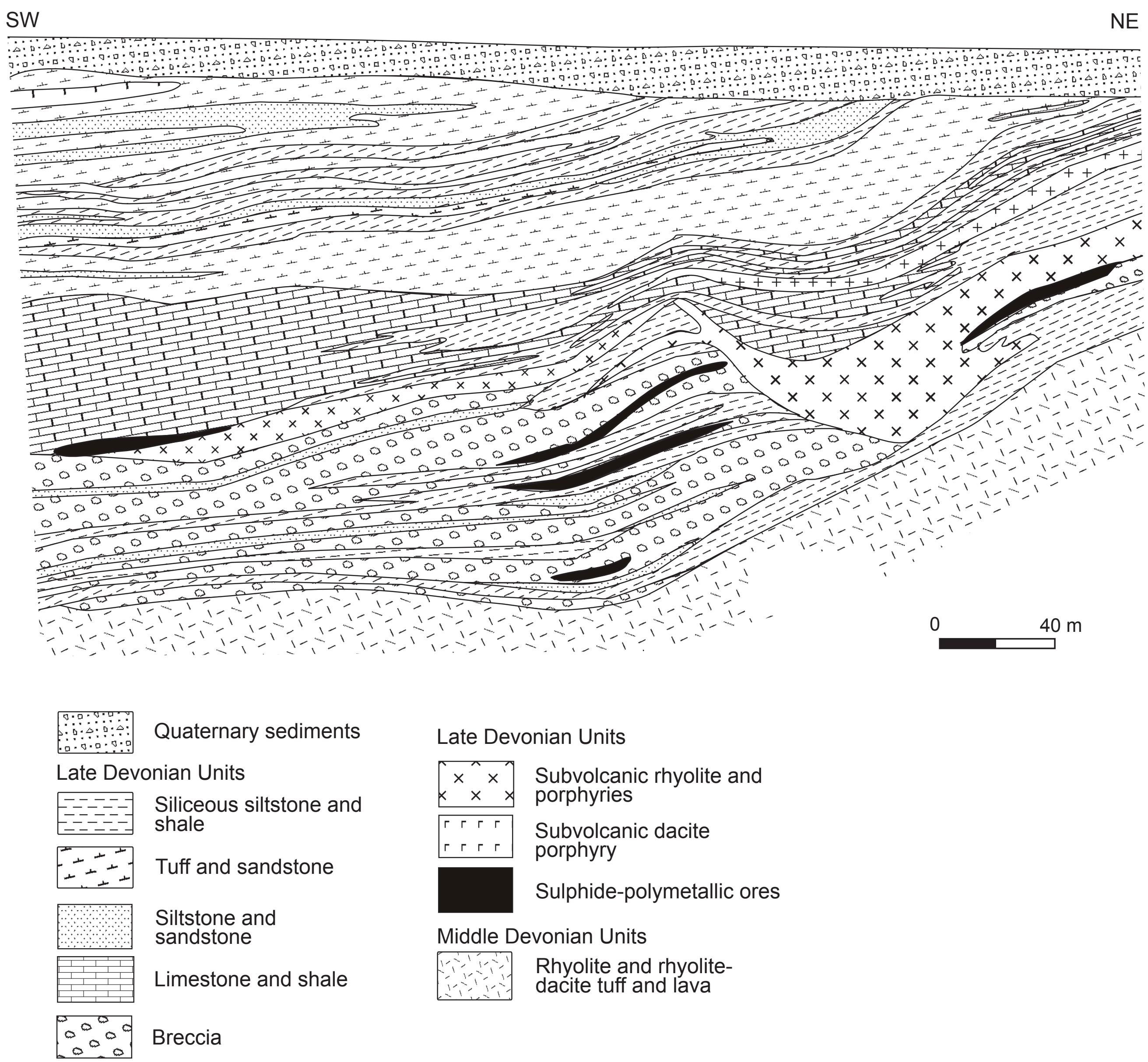


Figure 12. Schematic geologic cross section of the Yubileinoe volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type) deposit, Rudny Altai metallogenic belt. Adapted from Gaskov and others (1991).

controlled by sublatitudinal-striking transform faults as at the Orlovsk-Karaguzhikha, Alei-Tigirek, and Varshavskiy deposits. The main ore districts, as at Zmeinogorskiy, Zolotushinskiy, and Rubtsovskiy, are associated with the largest volcanic structures. In each district, the deposits occur at two or three startigraphic levels and are related to the final stage of volcanic activity. Metasomatic ore deposition and filling of cavities of weakly lithified sedimentary rock occurred. The deposits with Au, Ag, barite, and polymetallic sulfides formed during early, essentially siliceous volcanism in the Eifelian and Jivetian. The widespread pyrite and polymetallic sulfides are hosted mainly in Jivetian and Frasnian rhyolite, dacite, basalt, and andesite volcanism.

Salair Metallogenic Belt of Polymetallic (Pb, Zn, Cu) Metasomatic Volcanic-Hosted and Porphyry Cu-Mo (±Au, Ag) Deposits (Belt SL) (Russia, Eastern Siberia)

This Middle Devonian(?) to Early Carboniferous(?) metallogenic belt is hosted in porphyry intrusions and associated replacements that are related to the Altai volcanic-plutonic belt that overlies and intrudes the early Paleozoic Salair island-arc terrane. The belt occurs on the northeastern side of the Salair Range along the tectonic boundary between the Salair terrane and the Kuznetsk Basin. The belt extends northwest, is about 75 km long, and is 2.5 km wide. The age of a deposit-related quartz-porphyry intrusion is interpreted as being Middle Devonian through Early Carboniferous. The polymetallic deposits are hosted in volcanogenic and volcanic and sedimentary rock of the Early to Middle Cambrian Pechorkinskaya Suite. Host rocks are underlain by Early Cambrian limestone, are overlain by Middle Cambrian volcaniclastic rock, and are intruded by Cambrian subvolcanic diabase and dacite porphyries, and by small middle Paleozoic, Permian, and Triassic siliceous and mafic intrusions. Middle Devonian through Early Carboniferous rhyolite and dacite porphyry, Early Carboniferous gabbro and diabase and diabase porphyry, and Permian and Triassic diabase and diabase porphyry dike swarms are widespread in the metallogenic belt (Distanov, 1977; Lapukhov, 1966). The Cambrian sedimentary rock are deformed into isoclinal northwest-overturned folds and are cut by lengthwise faults that contain fissure and schistose zones that host diabase porphyry dike swarms that controlled hydrothermal activity. Large deposits in the Salair district have been explored and mined. The large deposits of the Urskoye district are explored in detail. The major varities of deposits are (1) barite-polymetallic (Salair district); (2) pyrite-polymetallic (Urskoye district, Uskandinskoye deposit); and (3) porphyry Cu (Kamenushinskoye deposit). Numerous small Au placer deposits also occur.

Salairskoye Polymetallic (Pb, Zn, Cu) Metasomatic Volcanic-Hosted Deposit

This deposit (Distanov, 1977, 1983; Lapukhov, 1966; Sharov and others, 1998) occurs in the southeastern part of the metallogenic belt and consists of massive, streaky, and disseminated barite-polymetallic metasomatite that is hosted in intensely schistose Early to Middle Cambrian volcanic rock. The deposit occurs in the Salair district in a large lens (4 by 1.5 km) of volcanogenic and subvolcanic porphyry that intrude Early Cambrian limestone. Deposits are hosted in rhyolite and dacite lava and tuff, porphyry, and argillaceous and carbonaceous shale. Stratified rocks are intruded by Devonian and Early Carboniferous rhyolite, and dacite quartz porphyries occur in the central and western parts of the district. Numerous diabase porphyry dikes occur in the district. The deposits occur in steeply-dipping, sublongitudinal shear zones. The deposits consist of complex lenses with masses, streaks, and disseminations. The major deposits occur in quartz porphyry intrusions in ore bodies that extend to depths of 400 to 450 m. The ore minerals are barite and polymetallic sulfide with low Fe-sulfides. The main ore minerals are pyrite, sphalerite, galena, chalcopyrite, and fahl. Minerals are argentite, magnetite, and hematite. Gangue minerals are barite, quartz, carbonate, albite, sericite, chlorite, and rare fluorite. The deposits are mainly massive banded quartz, barite, and sulfide that grade into spots, bands, and disseminations. Zone of oxidation is 25 to 170 m deep. An age of Middle Devonian through Early Carboniferous is interpreted for the quartz porphyry intrusion. The deposit has been mined, is large, and has reserves of 72,400 tonnes Pb, 545,700 tonnes Zn, 219 tonnes Ag, and 2,812,000 tonnes $BaSO_4$. The average grade is 0.13 percent Pb, 2.42 percent Zn, 8.5 g/t Ag, and 11.22 percent $BaSO_4$.

Kamenushinskoye Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit consists of bodies of disseminated and streaky-disseminated copper sulfides in shear zones in a dacite quartz-porphyry that intrudes tuff and tuff breccia. Host rocks are altered to silica, sericite, argillite, and propylite. Host and altered rock are cut by diabase and gabbro dikes that range from 0.5 to 45 m thick. The deposit dimensions are 100 by 300 by 500 m. The deposit contains some parallel and echelon-like lenses and ore layers that are concordant with host rocks and dip steeply. Individual deposit bodies extend from 40 to 420 m along strike. Ore minerals are pyrite and chalcopyrite and lesser tennantite, sphalerite, galena, pyrrhotite, and molybdenite. Gangue minerals are quartz and lesser chlorite, sericite, dolomite, calcite, ankerite, barite, and fluorite. A gossan occurs to 70 to 80 m depth. A weak zone of secondary enrichment occurs, is 1 to 3 m thick, and consists of bornite, chalcocite, and covellite. The deposit is small and has reserves of 110,000 tonnes Cu grading 1.71 percent Cu.

Origin and Tectonic Controls for Salair Metallogenic Belt

This belt is interpreted as having formed along the South Mongolia-Khingan island arc in which mafic dike swarms and small siliceous porphyries intruded. The belt occurs in a complicated nappe area that was deformed in several stages. The early Paleozoic Salair island arc was deformed and intruded in the middle Paleozoic during Hercynian development of an active continental margin that resulted in intrusion of mafic dike swarms and small and siliceous porphyry and formation of deposits. These deposits include Au-barite-polymetallic deposits of the Salair district, pyrite-polymetallic deposits of the Urskoye district, and associated Au quartz deposits (Distanov, 1977; 1983). Strike-slip zones and transverse faults controlled distribution of deposits.

Two interpretations exist about the origin of the Salair metallogenic belt. The first interpretation is that a relation exists between ore deposition and Cambrian volcanism, and a direct relation exists between ores and volcanic vents and subvolcanic quartz keratophyre intrusions (Distanov 1983). The second interpretation, which is from this study, suggests that the majority of the deposits younger and are related to Middle Devonian through Early Carboniferous rhyolite and dacite quartz porphyry and small gabbro and diabase and diabase intrusions that are controlled by the post-orogenic fissures and schistose zones (G.S. Labasin, G.L. Pospelov, E.G. Distanov, A.S. Lapukhov, written commun., 2000). The age of the Salair metallogenic belt is interpreted as being coeval with the Rudny Altai island arc and associated polymetallic metallogenic belt that occurs to the southwest (Distanov, 1983; Obolenskiy and others, 1999).

REFERENCES: Distanov; 1983; Lapukhov, 1966; Gladkov and others, 1969; Obolenskiy and others, 1999.

Sette-Daban Metallogenic Belt of Sediment-Hosted Cu, Basaltic Native Cu, REE (±Ta, Nb, Fe) Carbonatite, and Carbonate-Hosted Pb-Zn (Mississippi Valley type) Deposits (Belt SD) (Russia, Southern Verkhoyansk Fold and Thrust Belt)

This Middle Devonian through Early Carboniferous metallogenic belt is hosted in Middle and Late Devonian through Early Carboniferous clastic and carbonate sedimentary rock, alkalic basalt lava and tuff, and coarse clastic rock of the Verkhoyansk fold and thrust belt of the North Asian cratonal margin. The belt occurs in the central part of the Southern Verkhoyansk fold and thrust belt in a thick (up to 10,000 m) Vendian through middle Paleozoic sequence. The metallogenic belt contains two districts, the Dzhalkan-Menkyule district to the north, and the Sakhara district to the south. The Dzhalkan-Menkyule district contains several deposits and occurrences of stratiform Cu deposits at Kurpandzha, Dzhalkan, Kemyus-Yuryakh, Segenyakh, and Allakh-Yun'. Cu deposits in sandstone and shale tend to occur at the top of the section of the carbonate and clastic rock unit along with Middle Devonian and Early Carboniferous trachybasalt sheets. The basalt lava flows contain native copper occurrences. In the Sakhara ore district Ta, Nb, REE, and apatite deposits occurs in alkalic ultramafic and carbonatite plutons that are interpreted as having formed during Devonian rifting. A discontinuous chain (about 100 km long) of small plutons and dikes of alkalic ultramafic rock, carbonatite, and alkalic syenite intrudes early Paleozoic carbonate rock. Rb-Sr isotopic ages for the plutonic rocks range from 146 to 480 Ma. Most of the age determinations of carbonatite and alkalic syenite are Middle to Late Devonian and are supported by geological data. The major deposits are at Kurpandzha (sediment-hosted Cu), Dzhalkan and Rossomakha (basalt native copper), Gornoye Ozero, and Povorotnoye (REE (±Ta, Nb, Fe) carbonatite).

The main references on the geology and metallogenesis of the belt are Elyanov and Moralov (1973), Arkhipov (1979), Ioganson (1988), Kutyrev and others (1988), Entin and others (1991), and Parfenov and others (1999, 2001).

Dzhalkan Sediment-Hosted Cu Deposit

This deposit (Kutyrev and others, 1988) consists of disseminated Cu in Famennian basalt flows that are 180 m thick. The flows were erupted into a shallow-marine to subaerial environment. The deposit occurs in horizons from 0.5 to 2.0 m thick in breccia and amygdaloidal basalt at the top of flows. Ore minerals are native copper and cuprite with lesser bornite, chalcocite, and chalcopyrite. Epidote and quartz wallrock alteration occurs locally. Deposits range from 0.3 to 1.0 m thick and up to 100 m long. Areas of Cu deposits are separated by unmineralized areas that range up to several kilometers wide. Host basalt is folded, and fold limbs generally dip 40 to 60°. The average grade is 0.3 to 4.5 percent Cu.

Gornoye Ozero REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (fig. 13) (Samoilov, 1991; Entin and others, 1991; Tolstov and others, 1995) occurs in two carbonatite stages, early and late. The early stage occurs in steep veins up to 25 m thick and up to 150 m long. The veins are composed of augite, diopside, calcite, forsterite, calcite, and pyrochlore-betafite. The late stage consists of a small stock with an area of 1 km^2 that is composed of aegirine, dolomite, and ankerite along with bastnaesite, parisite, monazite, pyrochlore, and columbite. K-Ar isotopic ages range from 280 to 350 Ma. The stock is concentrically zoned and composed of 90 percent carbonatite along with pyroxenite, ijolite, and nepheline and alkalic syenite. The complex covers an area of 10.3 km^2. The age of deposits is interpreted as being probably 290 Ma. The ore body has no visible boundary and is defined by concentrations of Nb_2O_5 and Ta_2O_5. The deposit is large and has resources to a depth of 200 m of 5,423,000 tonnes of Nb_2O_5 (grading 0.10 to 0.12 percent), 246,500 tonnes Ta_2O_5 (grading 0.01 to 0.011 percent) and 223,446,491 tonnes REE. A range of 2.04 to 5.38 percent P_2O_5 occurs in carbonatite with average of 4 percent. Resources to a depth of 200 m are 24 million tonnes P_2O_5.

Average grades are 0.35 percent REE oxides, 0.09 to 0.36 percent Nb_2O_5, and 0.011 percent Ta_2O_5.

Segenyakh Carbonate-Hosted Pb-Zn (Mississippi Valley type) Deposit

This deposit (Kutyrev, 1984) consists of concordant horizons of disseminations, stringers, and bedded breccia of sphalerite and fluorite that are hosted in Late Silurian (Ludlovian) dolomite and limestone that is overlain by Pridolian marl. Deposit horizons consist of dolomite, calcite, fluorite, sphalerite, lesser galena, and common metasomatic quartz, microcline, hyalophane, and pyrite. Bedded breccia contains up to 20 percent sphalerite and 15 percent fluorite. Also occurring are cross-cutting breccia veins that contain up to 70 percent fluorite and up to 8 percent sphalerite. The two known deposit horizons trend north-south for 10 km and dip eastward from 40 to 60°. The distribution and concentration of sulfides is irregular.

Origin and Tectonic Controls for Sette-Daban Metallogenic Belt

The stratiform Cu deposits in the belt are interpreted as having formed during Devonian rifting. The REE and apatite deposits hosted in alkalic ultramafic and carbonatite plutons are also interpreted as having formed during Devonian rifting.

Sorsk Metallogenic Belt of Porphyry Mo (±W, Bi), Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite, and Zn-Pb (±Ag, Cu) Skarn Deposits (Belt SO) (Kuznetsk Alatau Mountains, Eastern Siberia, Russia)

This Early and Middle Devonian metallogenic belt is hosted in granitoids and associated replacements that are related to the South Siberian volcanic-plutonic belt, and it occurs on the eastern slope of the Kuznetsk Alatau Ridge. The belt extends sublongitudinally for about 200 km and ranges from 30 to 60 km wide. The belt is controlled by the north-northwest-striking major Kuznetsk-Altaisk fault and by north-east fractures. Porphyry Mo (±W, Bi) deposits are dominant. The largest deposit is the Sorskoye porphyry Mo (±W, Bi) deposit (Amshinskiy and Sotnikov, 1976; Pokalov, 1992) that has been discovered in 1937. The Agaskyrskoye and Ipchulskoye porphyry Mo (±W, Bi) deposits are also explored. These deposits are closely related to Devonian subalkalic porphyry stocks and dikes. The porphyry intrusions and related metasomatic rocks are hosted in older, early Paleozoic granitoid plutons and wall rocks. Skarn and polymetallic metasomatic deposits are hosted in Vendian and Cambrian carbonate shelf rocks along intrusive contacts of granitoid plutons. Other types of deposits are (1) large porphyry Mo deposits at Sorskoye,

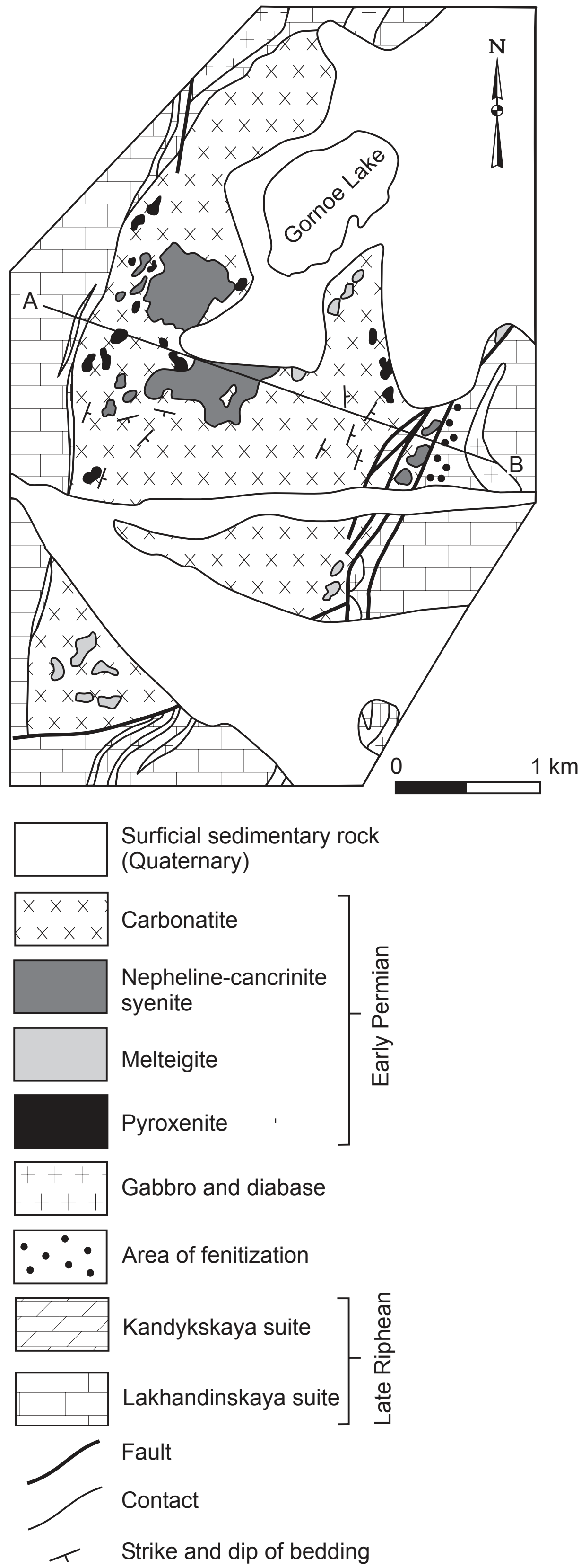


Figure 13. Geologic sketch map of the Gornoye Ozero REE (±Ta, Nb, Fe) carbonatite deposit, Sette-Daban metallogenic belt. Adapted from Korostylyov (1982)

Agaskyrskoye, and Ipchulskoye; (2) small Pb-Zn skarn deposit at Yulia Svintsovaya; (3) small polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposits at Karasuk and others; and (4) a small Ag-Sb vein deposit at Tibik.

The main references on the geology and metallogenesis of the belt are Amshinskiy and Sotnikov (1976), Rikhvanov and others (1987), Pokalov (1992), and Sotnikov and others (1984, 1985, 1995, 1999, 2004).

Sorskoye Porphyry Mo (±W, Bi) Deposit

This deposit (fig. 14) (Amshinskiy and Sotnikov, 1976; Pokalov, 1992; Sotnikov and others, 1995) consists of disseminations, streaks, and breccia that occur in intensely hydrothermally-altered gabbro and granitoid in the Cambrian and Ordovician Uibat pluton. The ore minerals are associated with numerous stocks and dikes of subalkalic granite porphyry. The host rocks are extensively hydrothermally altered to K-feldspar, quartz-biotite-K-feldspar, albite, sericite, and silica. Mafic rock is altered to chlorite. Dissemination and streaks are the most economic and consist of quartz-molybdenite veins and veinlets that range from less than 1 cm to 0.5 to 1.0 m thick. The associated stockwork in the central part of deposit extends to a depth of about 1 km, and decreases along the flanks to 300 to 500 m. Stockwork ores consists of molybdenite, pyrite, chalcopyrite, bornite, quartz, feldspar, and sericite. Average grade is 0.04 to 0.7 percent Mo and 0.2 to 0.3 percent Cu. The rich Cu contents are typical for the central part of deposit. Cu decreases along the flanks, and Mo is relatively constant. At depth, the Cu/Mo ratio decreases. Breccia ores also contains fluorite, galena, sphalerite, and fahl, and grade locally ranges from 0.5 to 1 percent Mo. The $^{40}Ar/^{39}Ar$ isotopic age is 385 to 400 Ma. The deposit is large and has an average grade of 0.04 to 0.07 percent Mo and 0.2 to 0.3 percent Cu.

Julia Svintsovaya Zn-Pb (±Ag, Cu) Skarn Deposit

This deposit (Bulynnikov, 1960; Levchenko, 1975) consists of Pb-Zn metasomatic layers and nests in the Cambrian limestone. Host limestone grades upward into intercalating limestone, shale, and tuff. Limestone is intruded by Devonian syenite, granosyenite, and granite. Garnet-diopside skarn occur along the intrusive contact and consists of layers, veins, and pipes that are concordant to host limestone. The major ore

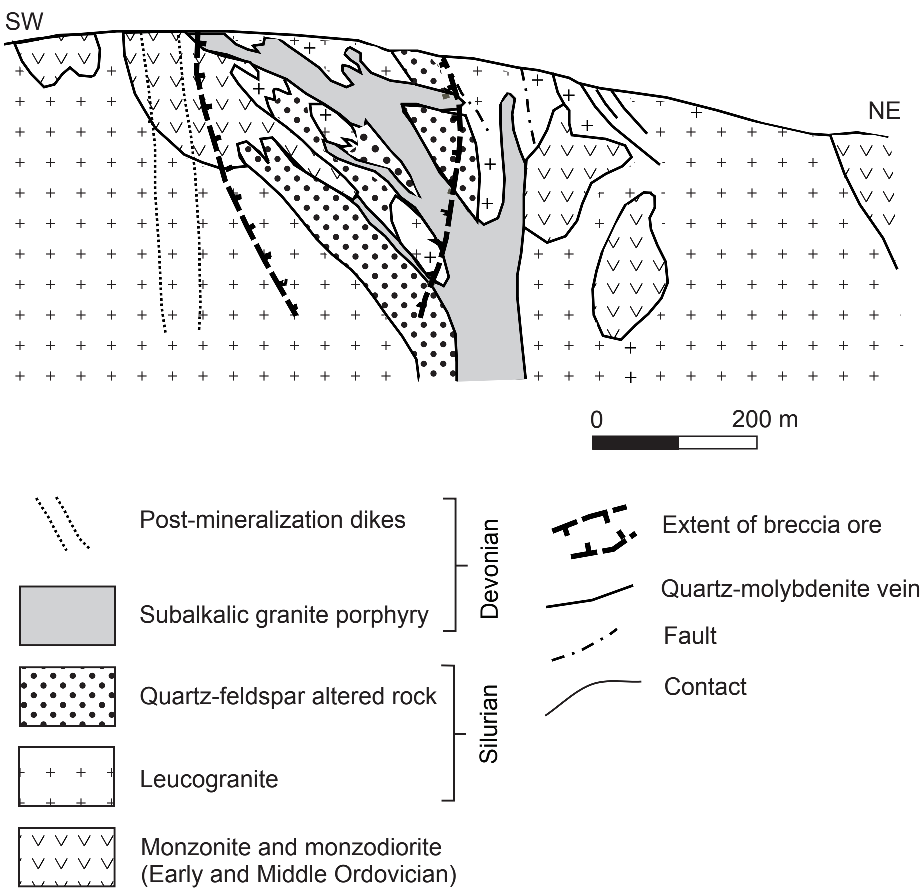


Figure 14. Schematic geologic cross section of the Sorskoye porphyry Mo (±W, Sn, Bi) deposit, Sorsk metallogenic belt. Adapted from Sotnikov and Berzina (2000).

minerals are galena, sphalerite, and pyrite, along with lesser chalcopyrite, pyrrhotite, tennantite, burnonite and molybdenite. Gangue minerals are siderite, quartz, ankerite, sericite, calcite, and rare fluorite and barite. A well-defined oxidation zone occurs. Ores contain up to 1 percent Bi and up to 0.6 ppm Au. The deposit is small.

Karasuk Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposit

This deposit (Bulynnikov, 1960; Levchenko, 1975) consists of Pb-Zn lenses and pipes in Cambrian limestone. The deposit occurs in a syncline formed in crystalline, microlaminated limestone interbedded with bituminous limestone and siltstone. Limestone is intruded by small granosyenite bodies surrounded by a wide zone of intrusive breccia. Quartz porphyry dikes cut the granosyenite. All intrusive rocks are interpreted as Devonian. The deposit occurs along the dike contact and ranges from 0.4 to 0.8 m thick. The major ore minerals are galena, sphalerite, and pyrite, and minor minerals are arsenopyrite, chalcopyrite, tetrahedrite, and marcasite, and native Au. Gangue minerals are calcite, quartz, ankerite, siderite, chlorite, sericite, and adularia. Ore minerals occur in masses, layers, and disseminations. Wall rocks display sideritie, silica, and pyrite alteration. A weak oxidation zone occurs. The deposit has been mined and is small.

Tibik Ag-Sb Vein Deposit

This deposit (Amshinskiy and Sotnikov, 1976) consists of quartz veins and quartz zones that occur in propylitically-altered Cambrian extrusive rock. Separate zones range from 50 to 800 m long and from 1.5 to 12 m thick. Zones are irregularly saturated with quartz veins and veinlets. The veins do not persist along strike or at depth. Deposits in veins and zones consist of disseminations and nests of ore minerals. Ore minerals are stibinite, allemontite, pyrite, marcasite, chalcopyrite, berthierite, and realgar. The deposit is small.

Origin and Tectonic Controls for Sorsk Metallogenic Belt

The belt is interpreted as having formed during Devonian subalkalic porphyry magmatism related to transpressional faulting along the the accreting southern margin of the North Asian craton. The belt is hosted in granitoids and associated replacements related to the South Siberian volcanic-plutonic belt (South Siberian arc). Devonian subalkalic porphyry magmatism is related to interplate rifting. The deposit-related porphyry intrusions intrude older, early Paleozoic granitoid plutons. Skarn and metasomatic polymetallic deposits are hosted in Vendian and Cambrian shallow-water marine carbonate rocks. The Devonian sedimentary and extrusive rock occurs in superimposed sedimentary basins and grabens. The volcanic rock consist of basalt, andesite, and trachyandesite porphyry and tuff, along with rare dacite, rhyolite, and trachyte porphyry. The K-Ar isotopic age is 396 Ma, a Rb-Sr isotopic age is 416±13 Ma, and the initial $^{87}Sr/^{86}Sr$ ratio is 0.7043 (Rikhvanov and others, 1987). Also occurring are Early to Middle Devonian granite and syenite intrusions along with widespread dikes. The K-Ar isotopic age for porphyry at the Sorskoye deposit and associated K-feldspar and albite metasomatite is 380 to 400 Ma. Based on the initial $^{87}Sr/^{86}S$ ratio of 0.70460 (Sotnikov and others, 1999), a mantle source is interpreted for the Sorsk ore-magmatic system.

Teisk Metallogenic Belt of Fe-Skarn, Volcanogenic-Sedimentary Fe, and Mafic-Ultramafic Related Ti-Fe ($\pm$V) Deposits (Belt TE) (Kuznetsk Alatau Mountains, Eastern Siberia, Russia)

This Early Devonian metallogenic belt is related to plutonic rocks in the South Siberian volcanic-plutonic belt and occurs in the eastern part of Kuznetsk Alatau. The sickle-shaped belt is about 120 km long, ranges up to 50 km wide, and occurs at the intersection of geological structures of Kuznetsk Alatau and the Devonian Minusa Basin. The structure of the metallogenic belt is complex and heterogeneous. The belt is hosted in Neoproterozoic limestone and quartzite; Early to Middle Cambrian tuffaceous shale and clastic and carbonate rocks; and Devonian trachyandesite, rhyolite, basalt, andesite extrusive rock, and sedimentary rock. Intrusive rocks are widespread in the Fe districts and consist of early Paleozoic gabbro and granitoids and Devonian gabbro and syenite and granosyenite (Polyakov, 1971). Fe-skarn deposits occur along contact zones of gabbro and albitite and granosyenite intrusions (Dolgushin and others, 1979; Mazurov, 1985; Orlov, 1998). Mafic-ultramafic related Ti-Fe deposits occur in layered syenite, gabbro, and pyroxenite plutons (Kuznetsov, 1982) and often are concentrically zoned. Main ore minerals are titanomagnetite and ilmenite; they occur in mafic layers, and comprise up to 5.5 to 15 weight percent of the rock. The major deposits are Fe-skarns at Teiskoye and Khaileolovskoye and zoned mafic-ultramafic Fe-Ti deposits at Patynskoye and Kul-Taiga.

The main references on the geology and metallogenesis of the belt are Polyakov (1971), Dolgushin and others (1979), Rikhvanov and others (1987), Mazurov (1985), and Orlov (1998).

Teiskoye Fe-Skarn Deposit

This deposit (Kalugin and others, 1981; Mazurov, 1985; Orlov, 1998) consists of magnesium-silicate skarn and occurs in pipes of explosive breccia in Early Cambrian dolomite and limestone. The deposits types are magnesium-silicate skarn, calc-silicate skarn, and aposkarn metasomatite. Magnesium-silicate skarn consists of forsterite and spinel. Calc-silicate skarn is younger, replaces magnetite skarn, and contains a complex mineral assemblage. The deposit forms a lens in plan view, extends more than 1,500 m along the strike, is 1,400 m deep, and is about 300 m thick. Mineral assemblages are serpentine and magnetite (60 percent), carbonate and magnetite (25 percent), magnetite (5 percent), gematite and magnetite (8 percent), and carbonate, serpentine, phlogopite, and magnetite (2 percent). Ore minerals occur in masses, disseminations, breccia, rhythmic layers, and colloform masses. The principal ore mineral is magnetite, with lesser hematite. From 1966 to 1977 total production was 39.2 million tonnes of ore, and has an average grade of 28.8 percent Fe. The deposit is large and has reserves of 136,400,000 tonnes grading 29.9 percent Fe.

Patynskoye Mafic-Ultramafic Related Ti-Fe (+V) Deposit

This deposit (Kuznetsov, 1982; Orlov, 1998) consists of titanomagnetite layers in the differentiated Patynsk gabbro pluton that intrudes and metamorphoses Proterozoic and Cambrian carbonaceous and volcanic rock. The pluton forms a lopolith that extends more than 100 km^2. The pluton contains layers that are rich in pyroxene, amphibole, titanomagnetite, olivine, and titanaugite. In the upper part of the pluton are twelve layers of titanomagnetite-gabbro. The layers vary from 1 to 100 m wide, extend for 100 m to 10 km along strike, and extend to a depth of 600 m. Titanomagnetite content ranges from 5 to 20 percent. Ore minerals are mostly disseminated. Small lenses (100 by 10 cm) of massive ore also occur. Associated minerals are olivine, sphene, apatite, actinolite, biotite, hornblende, epidote, and chlorite. Gabbro contains of 2.5 to 12.8 percent Fe, 0.5 to 7.8 percent TiO_2, and 0.01 to 0.12 percent V_2O_5. The deposit is large and has average grades of 2.5 to 12.8 percent Fe, and 0.5 to 7.8 percent TiO_2.

Chilanskoye Volcanogenic-Sedimentary Fe Deposit

This deposit (Belous and Klyarovskiy, 1969; Levchenko, 1975) consists of hematite layers hosted in Eifelian and Givetian sedimentary and volcanic rock and tuff. Low-grade layers contains about 27 percent Fe in a horizon up to 43 m thick. The horizon contains layers from 130 to 420 m long, and 4 to 10 m thick. The ore minerals are hematite, lepidocrocite, hydrogoethite, and limonite that forms a breccia cement. Hematite is concentrated in breccia zone that cuts Devonian host rock. Veinlets and nests of recrystallized, colloform hematite occur in fracture zones. A dense network of hematite veinlets occurs in overlapping sandstone and locally forms a stockwork. The deposit is large and has resources of 5,000,000 tonnes. The average grade is 27 to 48 percent Fe.

Origin and Tectonic Controls for Teisk Metallogenic Belt

This belt is interpreted as having formed during transpressional faulting along the the accreting southern margin of the North Asian craton in the South Minusa volcanic basin that is part of the South Siberian volcanic-plutonic belt. The deposit-related Early Devonian granosyenite plutons occur along marginal faults of Devonian basins. Two interpretations exist for the age of mafic-ultramafic intrusions hosting Fe-Ti deposits in the belt, either Ordovician and Silurian, or Early Devonian. K-Ar isotopic ages for syenite and diorite of the Malaya Kul-Taiga pluton are 411 to 438 Ma (Polyakov, 1971). Fe-skarn deposits of the belt are polygenetic and polychronous. In the Teisk district that occurs along the sublongitudinal major Teisk fault, Fe-skarn deposits are related to Late Cambrian gabbro and granitoid and Early Devonian granosyenite. Small plutons of Early Devonian granosyenite occur along the faults bounding Devonian basins and are associated with Devonian volcanic rock bordering the basins. Subvolcanic granite and syenite intrusions are interpreted as being comagmatic with trachyandesite and rhyolite volcanic rock (Polyakov, 1971). Explosive breccia is widespread in Fe-skarn districts. The final stage in formation of these deposits is related to the development of the South-Minusa rift volcanic basin. A K-Ar isotopic age for volcanic rock is 396 Ma; a Rb-Sr isotopic age is 416±3 Ma; and the initial $^{87}Sr/^{86}Sr$ ratio is 0.7043 (Rikhvanov and others, 1987).

Tsagaansuvarga Metallogenic Belt of Porphyry Cu (±Au) and Porphyry Cu-Mo (±Au, Ag) and Granitoid-Related Au-Vein Deposits (Belt TsS) (Southeastern Mongolia)

This Late Devonian through Early Carboniferous metallogenic belt is related to granitoids in the Gurvansayhan island-arc terrane. The major deposits are the Oyu Tolgoi porphyry Cu deposit, the Tsagaansuvarga Cu-Mo deposit, and the Oyut, Bor Ovoo, and other porphyry Cu-Mo occurrences, including the Alagtolgoi Au occurrence. Yakovlev (1977) first defined the Cu Tsagaansuvarga district, and Shabalovskii and Garamjav (1984) and Sotnikov and others (1984, 1985) assigned the district to the South Mongolian metallogenic belt that contains Early Carboniferous porphyry Cu (±Au) deposits, including the Tsagaan suvarga deposit. Various porphyry Cu-Mo (±Au, Ag) occurrences at Oyut, Bor Ovoo, Kharmagtai, and Khatavchiin tolgod occur in Ordovician volcanic and sedimentary rock, or in Early Devonian volcanic rock, and are closely related to intrusive porphyry dikes or small intrusive bodies. Various granitoid-related Cu vein-stockwork occurrences, as at Alagbayan, Zargyn Ovoo, Yamaat uul, and others, occur in Early Carboniferous basalt and andesite of the Sainshand khudag Formation.

The main references on the geology and metallogenesis of the belt are Berman and Vogdin (1968), Chebanenko and others (1968), Yakovlev (1977), Goldenberg and others (1978), Sotnikov and others (1980), Shabalovskii and Garamjav (1984), Sotnikov and others (1984, 1985), Byamba (1996), Lamb and Cox (1998), Perello and others (2001), and Kerwin and others (2005a,b).

Oyu Tolgoi Group of Porphyry Cu (±Au) Deposits

The Oyu Tolgoi (figs. 15*A, B, C, D*) group of deposits (Perello and others, 2001; Kirwin and others, 2005a; Bat-Erdene and others, 2006, Ivanhoe Mines Ltd, at http://www.ivanhoe-mines.com/s/OyuTolgoi.asp, written commun., 2009) is hosted in the middle to late Paleozoic Gurvansaihan island-arc terrane (Lamb and Bardach, 1997) that forms an arcuate belt across southern Mongolia and is about 200 km wide and more than 750 km long. The deposits are related to Late Devonian quartz monzodiorite intrusions that occur along a north-northeast trending zone that extends for 20 km (Khashgerel and others, 2006) and that is interpreted as being a deep crustal structure. The Oyu Tolgoi group of deposits are the Southwest Oyu, South Oyu, Central Oyu, and Hugo Dummett (North and South) deposits, and the newly discovered Heruga porphyry Cu-Au deposit. Kirwin and others (2005a) summarize the early exploration history for the Oyu Tolgoi project, that was done by BHP-Billiton and Ivanhoe Mines Mongolia, Ltd., from the late 1990s to 2005. The major references on this major new deposit in East-Central Asia are Perello and others (2001), Kavalieris and Wainwright (2005), Kirwin and others (2005a), Wainwright and others (2005), Khashgerel and others (2006), Oyungerel and others (2007), Bat-Erdene and others (2008), and Oyunchimeg (2008).

The Oyu Tolgoi group of deposits occurs in three main mineralized zones that are interpreted as three zones and two centers (figs. 15*A, B*). The central part of deposit consists of a multiphase hydrothermal breccia that crosscuts an altered, fine-grained feldspar porphyry. Advanced argillic alteration occurs with several assemblages of quartz, alunite, dickite, pyrophyllite, sericite, and other minerals that overprint older K-silicate and quartz-sericite-illite assemblages. The Cu deposit consists of a large supergene chalcocite blanket that replaces a pyrite-rich, hypogene chalcocite-covellite-tennantite suite that formed during advanced argillic alternation. Younger fine-grained granite dikes intrude the host volcanic rocks and are generally less-altered and mineralized than other rocks. Potassic alteration occurs mainly in intrusive rock in southern part of the deposit. At South Oyu, the deposit is magnetite-rich, pyrite-poor, and chalcopyrite dominant. At Central Oyu, advanced argillic alteration of quartz, alunite, dickite, pyrophyllite, sericite, zunyite, svanbergite, and fluorite occurs with high sulfidation pyrite and hypogene chalcocite, covellite, and tennantite.

Cu and Au grades exhibit a positive correlation with intensity of quartz stockwork. Disseminated Cu sulphides are also common. Magnetite, chalcopyrite and bornite are the principle hypogenal minerals along with with chalcocite. Oxidation extends to depths of 5 to 85 m and is underlain by weak supergene minerals. Cu sulfides are associated with the sericite and potassic alteration. Cu grade correlates positively with frequency of quartz veinlets. The group of deposits is large and has an estimated total measured and indicated resource of 1,397 million tones, grading 0.98 percent Cu and 0.24 g/t Au (Ivanhoe Mines Mongolia Ltd. 2006 Annual Information, p. 35-42, written commun., 2006)

The high-grade core of the Southwest Oyu deposit (Ivanhoe Mines Mongolia Ltd., at http://www.ivanhoe-mines.com/s/OyuTolgoi.asp, written commun., 2009) is a cylindrical shaped Cu-Au porphyry, 250 m in diameter, that extends vertically for more than 800 m. The deposit is centered on small 10-30 m wide quartz monzodiorite dikes and extends for more than 100 m into the adjacent host basaltic volcanics. Contorted, milky white quartz veins are developed in both the mineralized quartz monzodiorite and basaltic volcanics. The quartz veins appear to have formed largely as an early, relatively high-temperature event. Chalcopyrite and subordinate pyrite and bornite occur as disseminated and late fracture fillings within the quartz veins and host rocks. Gold to copper ratios increase from 2:1 to 3:1 at depth. Alteration within the quartz monzodiorite is predominantly quartz sericite with minor tourmaline and fluorite.

A K-Ar biotite age is 411±3 Ma from South Oyu suggests a Late Silurian age. Two K-Ar ages from supergene alunite veins from Central Oyu range from 93±1 to 177 Ma are as young as Cretaceous. The alunite veins are related to deep oxidation and formation of a secondary chalcocite-enrichment zone. Kirwin and others (2005a) report Re-Os age dates from molybdenite cutting quartz monzodiorite intrusions from Southwest and Central Oyu Tolgoi and from Hugo Dummett South that range from 370 to 373±1.2 Ma. Subsequent U-Pb age dates on zircon from similar intrusions (Wainwright and others, 2005; Khashgerel and others, 2006) also support a Late Devonian age.

Kavalieris and Wainwright (2005) described the stratigraphy and whole rock geochemistry of the main rock units. The porphyry-related intrusions are typically phenocryst-crowded, mainly quartz monzodiorite, and belong to a high K calc-alkaline suite. Augite basalt is the main host rock and is geochemically characterized by almost flat chrondrite-normalized REE patterns that are characteristic of a primitive calc-alkaline island arc. Oxygen-, H-, and S-isotope studies (Khashgerel and others, 2006) indicate that hydrothermal fluids involved in formation of muscovite (sericite), pyrophyllite and alunite are mainly of magmatic origin, and that alunite formed from a magmatic vapor condensate at temperatures of about 260º C. A study of the Hugo Dummett (figs. 15*C, D*) advanced argillic zone by Khashgerel and others (2006) shows that the alteration is hosted by dacitevolcanic rock, quartz monzodiorite, and augite basalt. The alteration occurs at the contact between dacite and basalt and is developed mainly in the augite basalt

The Hugo Dummett deposit (figs. 15*C, D*) is an exceptionally high-grade porphyry Cu-Au deposit with estimated reserves of 329 million tones, grading 3 percent Cu and 0.76 g/t Au (Oyungerel and others, 2007; Oyunchimeg, 2008). The deposit occurs at depths of 300 to 1,800 m and is related to a Late Devonian quartz monzodiorite intrusion that intrudes late Paleozoic basalt volcanic rocks that occur in a fold and thrust belt that formed during or soon after development of the porphyry system. The Hugo Dummett deposit is divided into two stages with overlapping stages of porphyry alteration and mineralization, and each sequence may contain multiple intrusions. Porphyry stage 1 consists of small dike-like intrusions with intense quartz veining, while porphyry stage 2 consists of larger dome-shaped intrusions that form the core of the northern part of the deposit. The intrusive complex is intensely overprinted by muscovite (sericite alteration) and advanced argillic alteration. Copper mineralization is bornite dominant, with subordinate chalcopyrite, and minor chalcocite, pyrite, enargite, and tennantite, and trace amounts of covellite, sphalerite, colusite, clausthalite, and hessite. The most common sulfide assemblage is bornite-chalcopyrite that comprises the

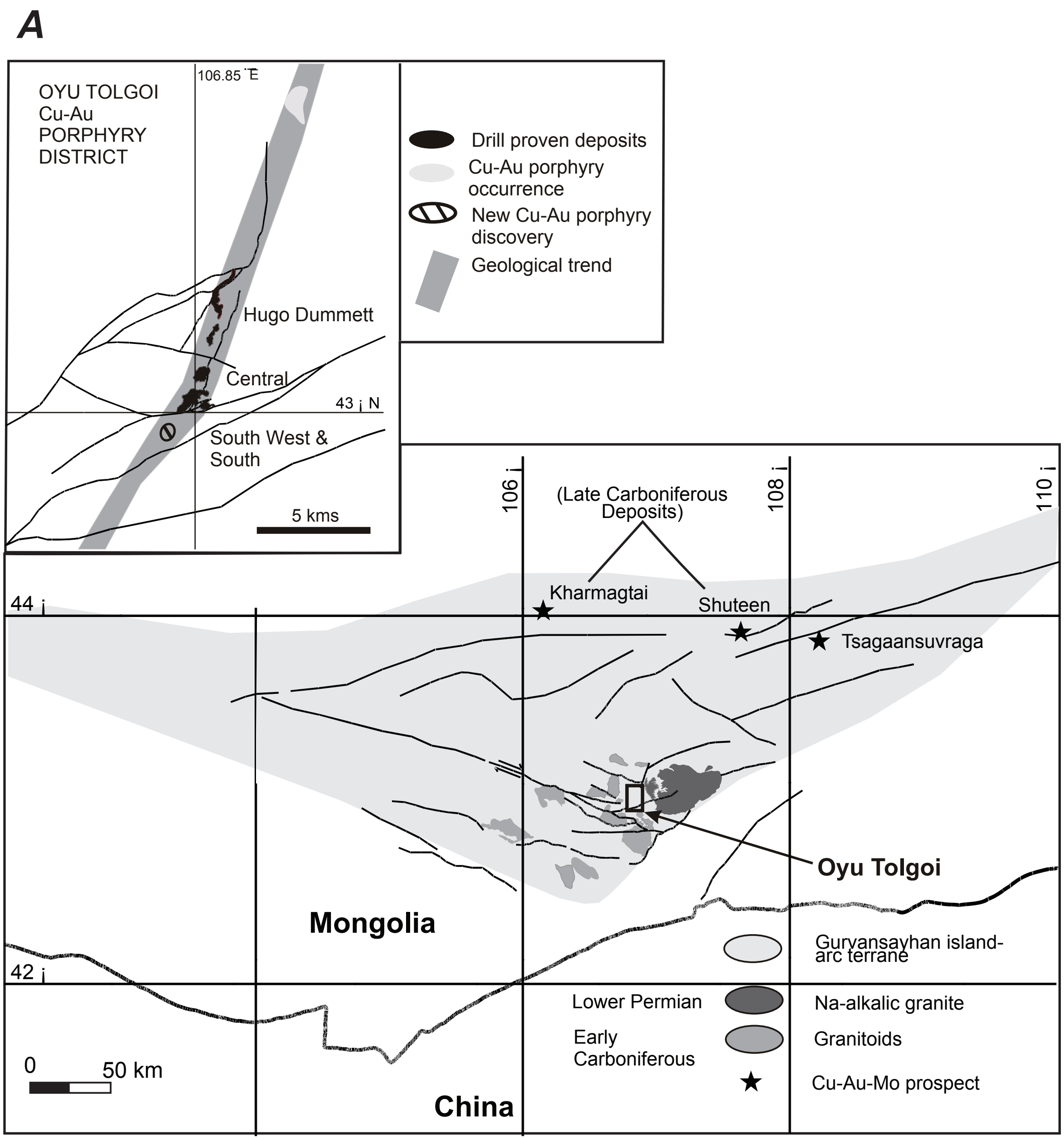


Figure 15*A*. Regional geologic sketch map of southern Mongolia showing location of Oyu Tolgoi group of deposits, Tsagaansuvarga metallogenic belt, and other major porphyry Cu-Mo-Au deposits in region. Adapted from published 1:20,000 geological map sheets, of Ivanhoe Mines Mongolia Ltd. exploration programs, 1990-2008.

B

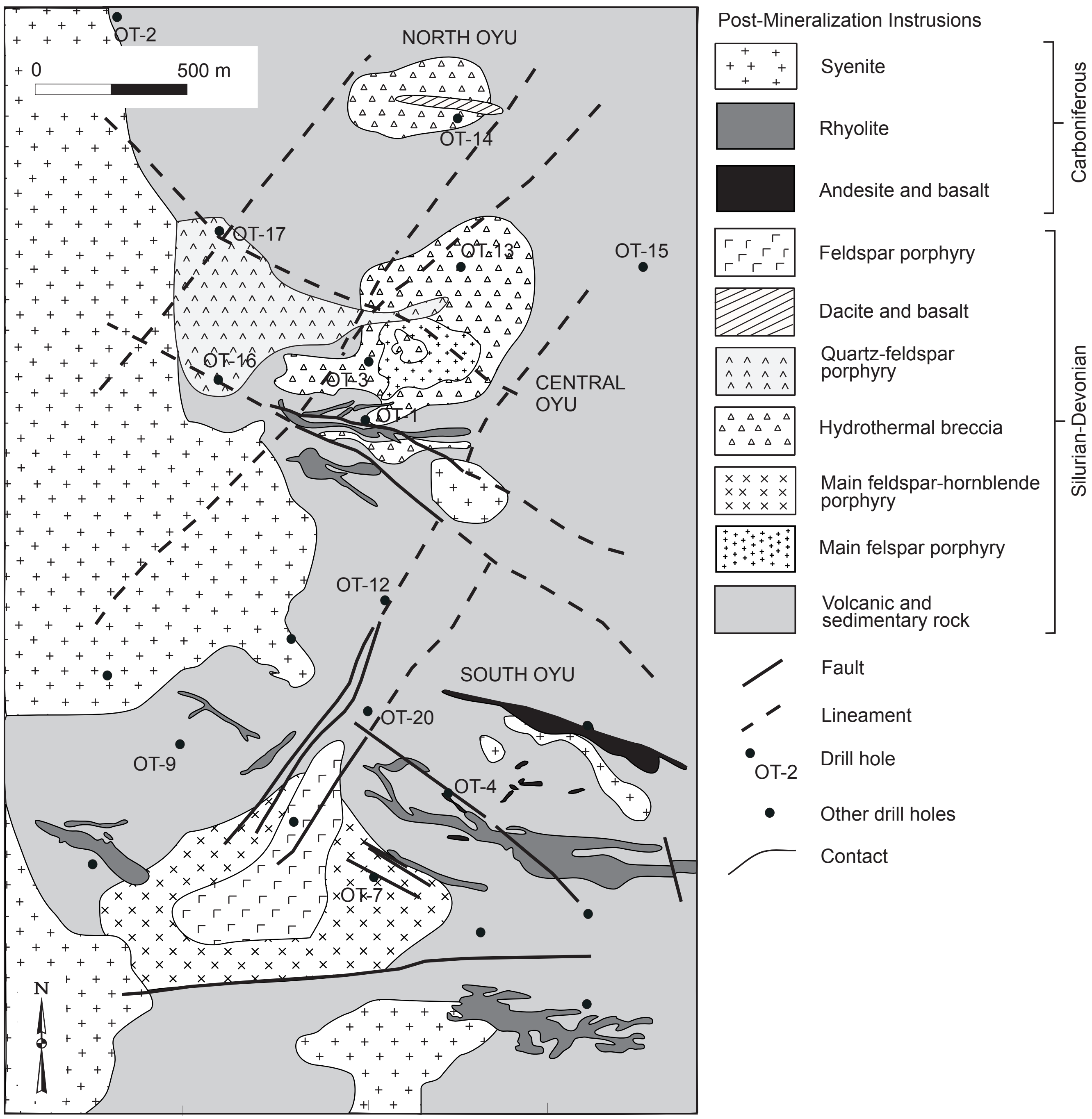


Figure 15*B*. Geologic sketch map of the Oyu Tolgoi group of porphyry Cu (±Au) deposits. Adapted from published 1:20,000 geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd. C. Simplified geologic map of Hugo Dummett deposit forming northern part of OyuTolgoi group. Map is drawn as a horizontal slice at 0 m elevation (surface is at 1170 m). The >2.5 percent Cu grade is projected from 700 m depth. Adapted from Kerwin and others (2005), Oyunchimeg (2008), and from unpublished 1:20,000-scale geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd.

main ore in both porphyry stages 1 and 2. Unusual assemblages include sooty bornite that consists of very fine bornite and chalcopyrite that are intimately intergrown with muscovite, and a minor assemblage that consists of pyrite and enargite that occurs on the margins of the ore body. The high-grade bornite mineralization (>2.5 percent Cu) is characterized by bornite in fractured quartz and zones of intense ductile deformation of bornite and chalcopyrite. Unusual features include alunite and molybdenite enclosed by high-grade bornite. The latest mineralization consists of gold-base metal Mn-carbonate quartz veins. Gold contains a high fineness (>800) and exhibits a close correlation to copper grade. Gold and minor electrum occur mainly with bornite and also with chalcopyrite in the deeper parts of porphyry stage 2. Gold typically occurs at contacts or grain boundaries of sulfides and varies in size from <1 to 170 microns, with most grains <20 microns.

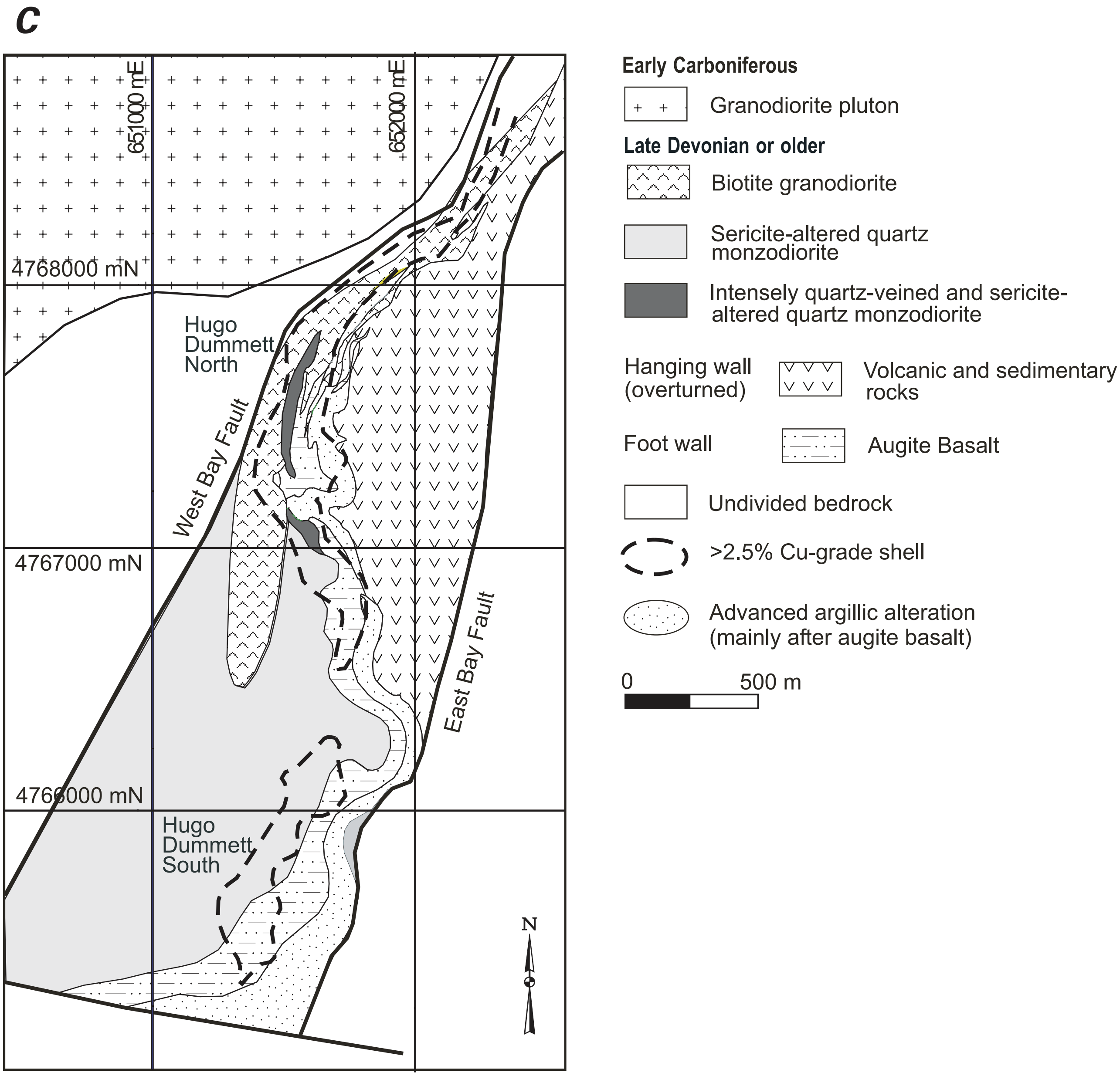


Figure 15*C*. Simplified geologic map of Hugo Dummett deposit forming northern part of OyuTolgoi group. Map is drawn as a horizontal slice at 0 m elevation (surface is at 1170 m). The >2.5 percent Cu grade is projected from 700 m depth. Adapted from Kerwin and others (2005), Oyunchimeg (2008), and from unpublished 1:20,000-scale geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd.

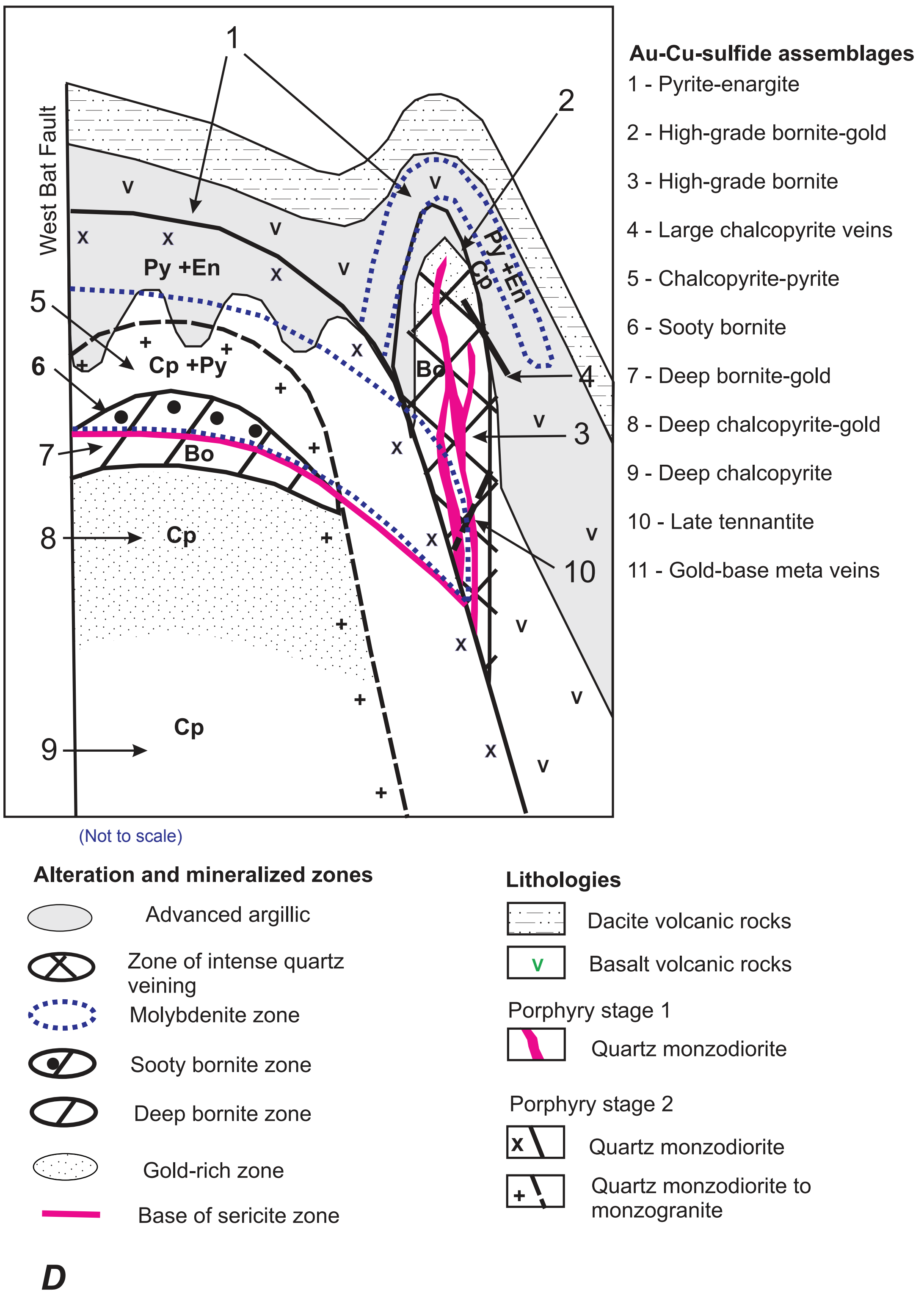


Figure 15*D*. Schematic cross section of Hugo Dummett deposit forming northern part of OyuTolgoi group. Adapted from Kerwin and others (2005), Oyunchimeg (2008), and from unpublished 1:20,000-scale geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd.

Tsagaansuvarga Porphyry Cu-Mo (±Au, Ag) Deposit

After the Oyu Tolgoi group of deposits is the Tsaagan Survarga deposit (fig. 16), where exploration drilling during the in the 1980s indicated a porphyry Cu-Mo with about 240 million tones, grading 0.53 percent Cu and 0.018 percent Mo (Yakovlev, 1977; Sotnikov and others, 1985; Gotovsuren 1991; Lamb and Cox, 1998; Watanabe and Stein, 2000; Perello and others, 2001). The deposit is hosted by Late Devonian intrusions with a Re/Os molybdenite age of 370.4±0.8Ma (Watanabe and Stein, 2000).

The deposit consists of stockwork veinlets and veins of quartz, chalcopyrite, and molybdenite that occur in or near porphyritic intrusions, and it is hosted in the Late Devonian Tsagaan-suvarga granosyenite and granodiorite porphyry stock that is overlain by Carboniferous volcanic and sedimentary rock. The deposit and host rocks are structurally controlled by an important northeast-striking fault. The pluton exhibits both potassic and sericite alteraton. Companion sulfide minerals are cut by felsic dikes and hydrothermal breccia. Cu and Mo minerals occur in centers of potassic alteration. Grade correlates positively with quartz veinlet intensity. Secondary Cu enrichment is minor. The alteration zone is 50 to 400 m wide and extends for 1 or 2 km. Major ore minerals are chalcopyrite, pyrite, barite, covillite, and local chalcocite and molybdenite. Gangue minerals are quartz, sericite, chlorite, azurite, malachite, and calcite. Alteration minerals are quartz, K-feldspar, sericite, and local biotite or chlorite. The highest-grade part of the deposit occurs in the potassic alteration zone that contains a well-developed quartz vein stockwork. Intensity of potassic alteration increases with depth. The deposit is developed over an area of 1,000 by 300 m and has been traced by drilling to a depth of 600 m. The deposit is large and has a newer estimated resource of 317.5 million tones, grading 0.53 percent Cu, 0.018 percent Mo, 119.68 tonnes Re, 26 tonnes Au, and 810 tonnes Ag.

Kharmagtai Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (fig. 17) (Yakovlev, 1977; Sotnikov and others, 1985; Kirwin and others, 2005b; Ivanhoe Mines Mongolia Ltd., written commun., 2009) is hosted in Early Carboniferous diorite and granodiorite (with a U/Pb zircon isotopic age of 330.2 Ma) that intrudes Devonain tuff, andesite, and tuffaceous sandstone and siltstone. The ore minerals are chalcopyrite, covellite, bornite, and molybdenite. Oxidation minerals are malachite, azurite, and cuprite. Associated minerals are pyrite and magnetite and peripheral sphalerite, galena, and gold. The deposit is related to subvolcanic bodies of diorite and granodiorite porphyry in two stocks and bodies explosive breccia. Each bodies ranges from 200 to 400 m wide, 900 m long. Surface grades are 0.05-0.4 percent Cu and 0.003-0.03 percent Mo over an area of 400 by 900 m. A zone 100 by 300m contains >0.3 wt percent Cu. Deposit extends at least to a depth of 250 m and is defined by stockwork veinlets of quartz with chalcopyrite and molybdenite that occur across the breccia pipe. Hydrothermal alteration minerals are weakly developed silica, sericite, K feldspar, chorite, epidote, and tourmaline. Sericite, potassic, and silicic alterations occur in the center of alteration zone, and chlorite and epidote alteration occurs along the periphery. Potassic alteration occurs mainly in the deeper part of deposit. The deposit is being drilled and assessed by Ivanhoe Mines Mongolia Ltd.

Origin and Tectonic Controls for Tsagaansuvarga Metallogenic Belt

The belt is interpreted as having formed in the South Mongolia-Khingan collage that was part of the South Mongolia-Khingan island arc. The Tsagaansuvarga pluton consists of gabbro, diorite, granodiorite, granosyenite, syenite and related dikes. An $^{40}Ar/^{39}Ar$ isotopic age of 364.9±3.5 Ma (Late Devonian) has been obtained for biotite alteration in the associated Tsagaansuvarga pluton and associated deposit (Lamb and Cox, 1998). The overlying volcanic and sedimentary strata are Early Carboniferous (Goldenberg and others, 1978). The host rock assemblage is interpreted as being part of a Late Devonian Andean magmatic belt (Lamb and Cox, 1998; Watanabe and Stein, 2000). The shape of the metallogenic belt is complicated by younger, late Paleozoic, Mesozoic and Cenozoic tectonic events. The belt occurs in two parts (1) a northeastern half that hosts the Tsagaan suvarga deposit and extends northeast-southwest; and (2) a western half that trends east-west and contains the Oyu Tolgoi, Bor-Ovoo Cu-Mo, and other Cu and Au occurrences.

Udzha Metallogenic Belt of REE (±Ta, Nb, Fe) Carbonatite Deposits (Belt UD) (Russia, Northeastern North Asian Craton)

This Devonian(?) metallogenic belt is hosted in carbonatite intruding late Precambrian sedimentary rock in the northern part of the North Asian craton. The belt age is interpreted as being Devonian. Host rocks have Rb-Sr and K-Ar ages of 240 to 810 Ma. The belt occurs in the Udzha uplift that contains the Riphean Udzha aulacogen; it is 30 km wide and extends longitudinally for 200 km. Several plutons of alkalic ultramafic rock and carbonatite occur in the belt, and the largest Tomtor pluton contains a deposit with a uniquely large Nb and REE resource. The Tomtor pluton is about 20 km in diameter, is almost circular in plan view, and is concentrically zoned. The central part consists of carbonatite surrounded by ultramafites and foidolites. The outer part contains alkalic nepheline syenite. The alkali ultramafic rock and carbonatite are interpreted as related to Devonian rifting. The major deposit is at Tomtor.

The main references on the geology and metallogenesis of the belt are Entin and others (1991), Orlov (1994), Tolstov and others (1995), and Parfenov and others (1999, 2001).

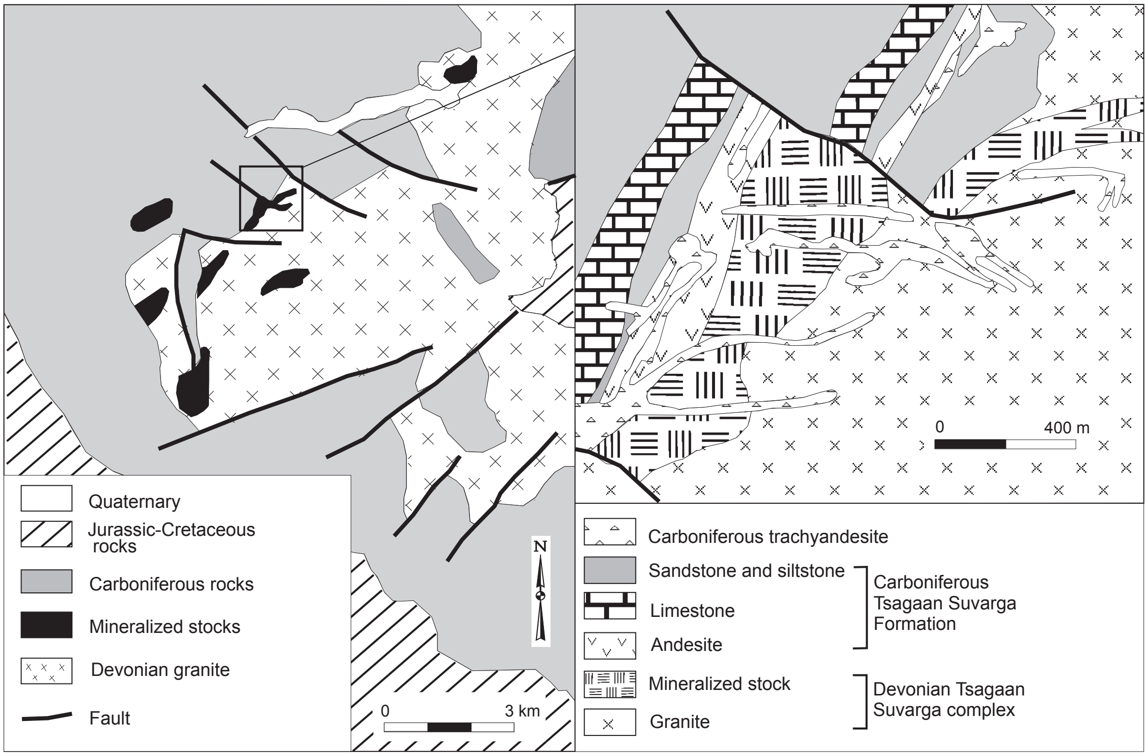


Figure 16. Regional and detailed geologic sketch maps of the Tsagaan Suvarga porphyry Cu-Mo (±Au, Ag) deposit, Tsagaansuvarga metallogenic belt. Adapted from Watanabe and Stein (2000).

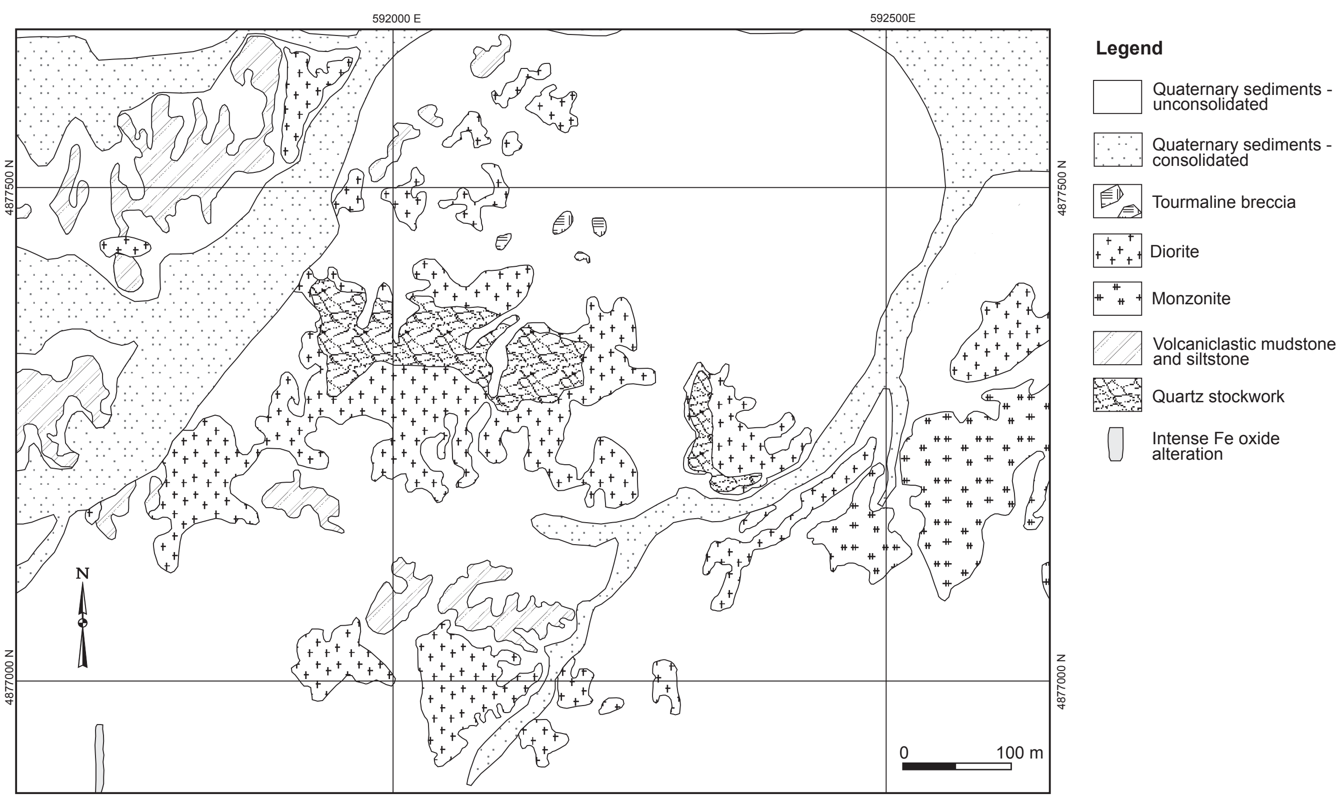


Figure 17. Geologic sketch map of Kharmagtai porphyry Cu-Mo deposit. Adapted from Ivanhoe Mines Mongolia Ltd. (written commun., 2009).

Tomtor REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (fig. 18) consists (Orlov, 1994; Tolstov and others, 1995) of a volcanic-plutonic assemblage comprised of three groups of rocks. (1) Carbonatite II comprise the bulk of the carbonatite core of the pluton with P_2O_5, Nb_2O_5, and TR_2O_3 values of 0.7 to 11.4, 0.1 to 0.78, and 0.45 percent, respectively. The carbonatite comprises the substratum for a weathering crust that constitutes a hypergene ore complex that forms a phosphorus-REE deposit. The weathering crust consists of alternating subhorizontal goethite-siderite, francolite, francolite-goethite-siderite, hematite, and groutite. (2) The francolite horizon consists of francolite (>60 percent), siderite, rhodochrosite, and goethite in varying proportions (up to 40 percent). Nb_2O_5 ranges from 0.2 to 2.4 percent, TR_2O_3 ranges from 0.8 to 4.5 percent, P_2O_5 ranges from 10 to 35 percent, Sc_2O_3 ranges up to 0.011 percent, Y_2O_3 ranges up to 0.09 percent, and V_2O_3 ranges up to 0.22 percent. (3) The goethite horizon contains goethite and hydrogoethite (70 to 80 percent), francolite (5 to 15 percent), siderite (up to 10 percent), and chlorite, francolite, siderite, hematite, and rhodochrosite. Nb_2O_5 varies from 0.1 to 3.0 percent, Tr_2O_3 varies from 1.3 to 5.4 percent, P_2O_5 varies from 0.2 to 8 percent, and Sc_2O_3 ranges up to 0.006 percent. The siderite horizon is made of siderite (50 to 80 percent), alumophosphates of the crandallite group (20 to 30 percent), goethite (up to 10 percent), and chlorite or kaolinite (up to 10 percent). Nb_2O_5 ranges from 0.3 to 0.8 percent, TR_2O_3 ranges from 0.8 to 1.3 percent, Sc_2O_3 ranges from 0.009 to 0.01 percent, P_2O_5 ranges up to 12 percent, and Y_2O_3 ranges up to 0.09 percent. The main upper ore horizon of the Tomtor deposit consists of thin-bedded alumophosphate pyrochlore monazite, alnoite, tinguaite, and carbonatite, and varies from a few meters to 12 to 15 m thick. Carbonate and ore breccia occur. The upper ore horizon is a weathering crust for the carbonanite III metasomatite substratum that is rich in REE and phosphates. Economic metals occur mainly in monazite and rhabdophanite (REE, Y, Sc), pyrochlore (Nb), and alumo- and ferro-alumophosphates (P_2O_5, Al_2O_3). The deposit is large and has estimated reserves of 500 million tonnes to a depth of 500 m. No commercial concentrations of P_2O_5 and Nb_2O_5 are known.

Origin and Tectonic Controls for Udzha Metallogenic Belt

The alkalic ultramafic rock and carbonatite that host the deposits are interpreted as having formed in Devonian rifting.

Ulziit Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt UZ) (Southern Mongolia)

This Devonian(?) metallogenic belt is related to replacements in the Govi-Altai continental-margin turbidite terrane that is part of the South Mongolia-Khingan collage. The metallogenic belt (Dejidmaa and others, 1996) contains Au quartz-carbonate vein occurrences (Goldenberg and others, 1978). The host Govi-Altai continental-margin turbidite terrane consists of mainly of Ordovician through Silurian turbidite that is overlain by Devonian shallow-marine sedimentary rock (Tomurtogoo and others, 1999). The major deposits are at Olon Ovoot, Khorimt hudag, Dayangar, An tsavyn, and Altagany uhaagchin hudag.

The main references on the geology and metallogenesis of the belt are Dejidmaa (1996), Dejidmaa and others (1996), Goldenberg and others (1978), and Tomurtogoo and others (1999).

Olon Ovoot Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Goldenberg and others, 1978; L. Dorligjav and others, written commun., 1993; Sillitoe and others, 1996; Jargalsaihan and others, 1996; Dejidmaa, 1996; Dejimaa and others, 1996) is hosted in the Silurian Mandal Ovoo Formation that contains siliceous sandstone and mudstone and is intruded by syn-orogenic gabbro-diorite and diorite sills. The deposit occurs in altered quartz diorite with sericite-quartz replacement and in quartz veins. Quartz diorite is altered to epidote, chlorite, sericite, and carbonate. Quartz veins consist of white, partly limonitized, massive and brecciated quartz with up to 10 percent carbonate and up to 2 percent ore minerals. More than 10 quartz veins occur in a 0.5 by 0.2 km area. Veins range up to 0.7 m thick and 80 m long. The main Tsagaantolgoi vein forms a saddle reef. The main ore mineral is pyrite with rare gold. The size of gold grains ranges from 0.0050 to 0.7 mm.

Origin and Tectonic Controls for Ulziit Metallogenic Belt

The belt is interpreted as having formed during regional metamorphism of Govi-Altai terrane during collision with the Idermeg terrane.

Yaroslavka Metallogenic Belt of Fluorite Greisen and Sn-W greisen, Stockwork, and Quartz Vein Deposits (Belt YA) (Russia, Far East)

This Late Cambrian through Devonian metallogenic belt is hosted in numerous Paleozoic granitoid plutons that intrude Cambrian clastic and limestone units of the Vosensenka continental-margin terrane of the Khanka superterrane. The Li-F alaskite granite that hosts the Voznesenka-II deposit has Rb-Sr isotopic ages of about 475 to 512 Ma. The formation of the deposits is interpreted as being related to intrusion of Late Cambrian leucogranite. The major fluorite greisen deposit is at Voznesenka-II, and the major Sn-W greisen, stockwork, and quartz vein deposit is at Yaroslavka.

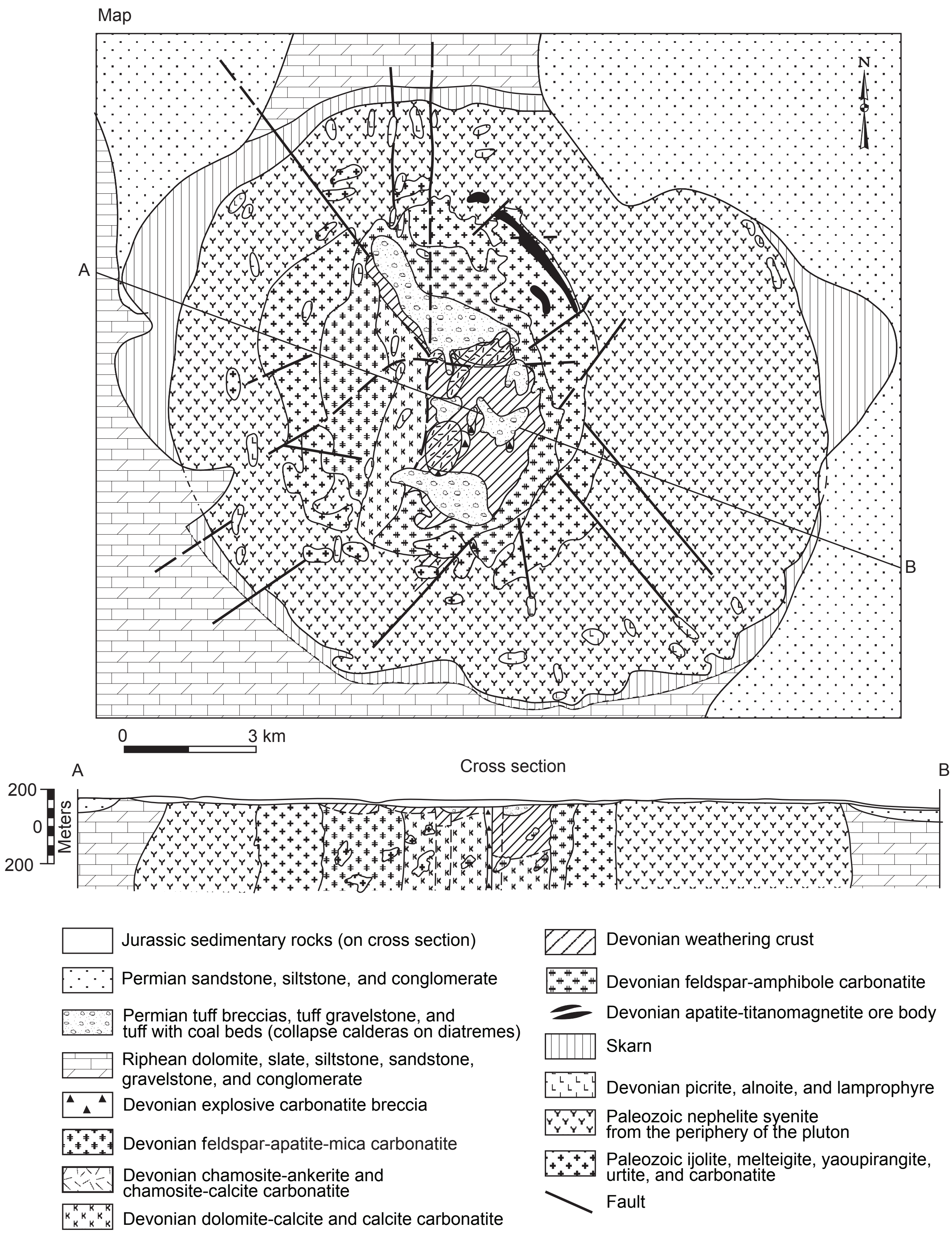


Figure 18. Geologic sketch map and cross section of the Tomtor weathering crust carbonatite REE-Zr-Nb-Li deposit, Udzha metallogenic belt. Adapted from Lapin and Tolstov (1995)

The main references on the geology and metallogenesis of the belt are Govorov (1977), Nokleberg and others (1997, 1998, 2003), Androsov and Ratkin (1990), Ryazantzeva and Shurko (1992), Ryazantzeva (1998), and Khanchuk and others (1996, 1998, 2000).

Yaroslavskoe Sn-W Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Govorov, 1977) occurs mainly in greisen that mainly replaces skarn, limestone, and shale and, to lesser extent granite and granite porphyry that has a Rb-Sr isotopic age of 408 Ma and an initial Sr ratio of 0.7136. Sn quartz and quartz-tourmaline veins also replace skarn along with greisen. The Sn bodies occur in three mineral assemblages (1) tourmaline and quartz; (2) tourmaline and fluorite; and (3) sulfide, tourmaline, and quartz with subordinate cassiterite, polymetallic sulfides, and chlorite. The sulfides are mainly pyrite, arsenopyrite, galena, and sphalerite. The deposit occurs along the contact of a early Paleozoic biotite granite (with an approximate isotopic age of 400 Ma) that intrudes Early Cambrian shale, siltstone, sandstone, and limestone. The relatively older pyroxene-scapolite, vesuvianite-garnet, and epidote-amphibole skarns replace limestone and shale along granite contacts and in rare limestone inclusions in the granite. More than forty Sn occurrences occur in the metallogenic belt. The deposit is medium size and has an average grade of 0.52 percent Sn. The deposit was mined from the 1950s to 1970s.

Voznesenka-II Fluorite Greisen Deposit

This deposit (Androsov and Ratkin, 1990) consists of massive to disseminated fluorite that occurs above the apex of a 1.5 km wide intrusion of Late Cambrian Li-F alaskite granite and has an isotopic age of 475 to 512 Ma. The deposit consists of vein and greisen that occurs along a north-south-trending fault. The deposit consists of muscovite-fluorite aggregates that occur along the periphery, whereas vein greisen occurs in the middle. Greisen is often brecciated, indicating a two-stage origin. Fragments of breccia consist of mica, fluorite, fluorite limestone, greisen, and granite altered to greisen. Fragments are cemented by quartz-topaz-micaceous-fluorite aggregate that formed during a second stage. The deposit is interpreted as having formed during metasomatic replacement of Early Cambrian black organic limestone and alteration to greisen. The deposit is large and contains 450 million tonnes fluorite ore and has an average grade of 30 to 35 percent fluorite. The deposit has been mined since the 1960s, and, currently, is the largest producer of fluorite in Russia.

Origin and Tectonic Controls for Yaroslavka Metallogenic Belt

The belt is interpreted as having formed in a collisional arc that formed along the margin of a fragment of Gondwanaland. The host leucogranite hosting the fluorite and Sn-W greisen, stockwork, and quartz-vein deposits is Li-F-REE enriched. The extensive deposits occur in the apical parts of plutons that are altered to quartz-mica-fluorite-REE greisen. The host leucogranite plutons are interpreted as having formed during anatectic melting of older granitic gneiss and Cambrian sedimentary rock. The anatectic melting is interpreted as having occurred during early Paleozoic collision of the Voznesenka and Kabarga terranes. The host leucogranite plutons intrude Early Cambrian limestone of the Voznesenka passive continental-margin terrane that is interpreted as being a fragment of a Neoproterozoic through early Paleozoic carbonate and rich sedimentary-rock sequence that formed on a passive continental margin.

Devonian through Early Carboniferous (Mississippian) Tectonic and Metallogenic Model

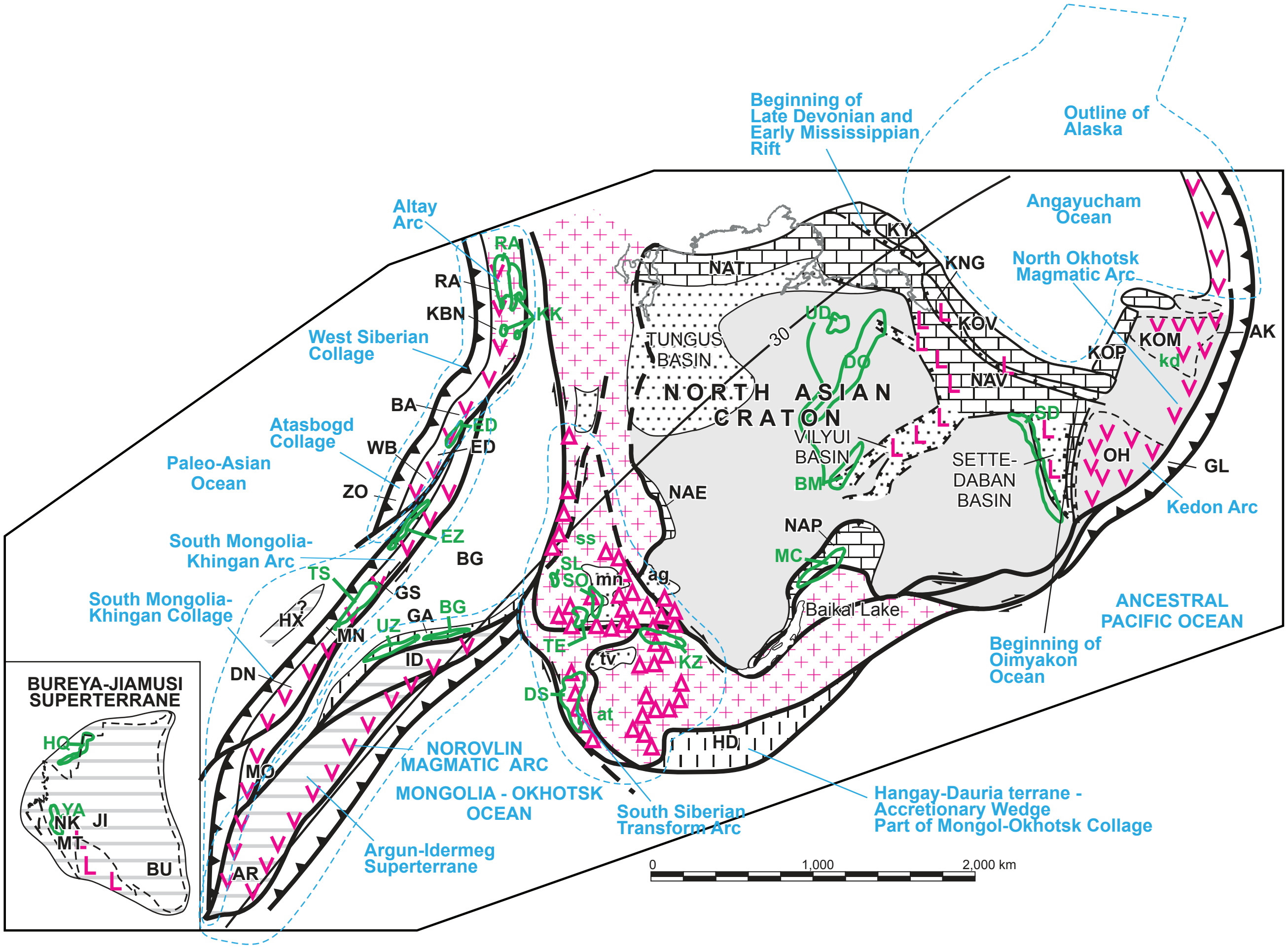
Major Metallogenic and Tectonic Events

For the Devonian through Early Carboniferous (420 to 320 Ma), the major-metallogenic tectonic events were (fig. 19; table 1): (1) formation of the South Mongolia-Khingan arc and associated subduction zone and associated metallogenic belts; (2) back-arc spreading behind the South Mongolia-Khingan island arc resulting in formation of the Bayanleg back-arc basin and associated metallogenic belts; (3) beginning assembly of cratonal and passive continental-margin terranes in the Russian Far East and Northeastern China to form the Bureya-Jiamusi superterrane and formation of associated metallogenic belts; (4) inception of the North Okhotsk continental-margin arc and associated subduction zones that were associated with subduction of the Mongol-Okhotsk ocean plate; (5) oblique-convergence between the Mongol-Okhotsk ocean plate and the North Asian craton, resulting in transform displacement and oroclinal wrapping of the southern and western margins of the North Asian craton and formation of the South Siberian and Altai transpressional arc and associated metallogenic belts; (6) continued sea-floor spreading in the Paleoasian, Mongol-Okhotsk, and Ancestral Pacific Oceans and formation of associated metallogenic belts; and (7) rifting and associated sedimentation and formation of rift-related deposits long the northeast continental margin of the North Asian craton.

The major Devonian through Pennsylvanian metallogenic belts in the Far East, Yakutia, Northern Transbaikalia, Southern and Eastern Siberia of Russia, and Mongolia and Northeastern China are shown on figure 3. The tectonic origins of the metallogenic belts are described below in alphabetical order of the belt name. The tectonic setting of each metallogenic belt is shown on figure 19.

Metallogenic Belts and Tectonic Origins

The Bayangovi belt (BG, figs. 3, 19) contains Au in shear-zone and quartz-vein deposits and is hosted in the



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental sedimentary basin

ag - Agul (Rybinsk) molasse basin (Middle Devonian to Early Carboniferous)
mn - Minusa molasse basin (Middle Devonian through Early Permian)
tv - Tuva molasse basin (Middle Devonian through Late Carboniferous)

Terranes

AK - Avekov terrane
AR - Argunsky terrane
BU - Bureya terrane (Metamorphic)
DN - Dongwuzhumuqin-Nuhetdavaa terrane (Island arc) (Cambrian through Middle Devonian)
ED - Edren terrane (Island arc) (Devonian and Early Carboniferous)GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
GL - Galam terrane (Subduction zone) (Cambrian through Early Carboniferous)
GS - Gurvansayhan terrane (Island arc) (Silurian through Early Carboniferous)
HD - Hangay-Dauria terrane (Subduction zone) (Silurian through Late Carboniferous)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
JI - Jiamusi terrane
KBN - Kalba-Narim terrane (Subduction zone) (Ordovician through Early Carboniferous)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
MN - Mandah terrane (Subduction zone) (Devonian)
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
MT - Matveevka terrane (Metamorphic)
NK - Nakhimovka terrane (Metamorphic)
OH - Okhotsk terrane
RA - Rudny Altai terrane (Island arc) (Late Silurian through Early Carboniferous)
WB - Waizunger-Baaran terrane (Island arc) (Ordovician through Permian)
ZO - Zoolen terrane (Subduction zone) (Ordovician(?) and Devonian)

Overlap Continental-Margin Arcs and Granite Belts

at - Altai volcanic-plutonic belt (Devonian and Early Carboniferous)
kd - Kedon volcanic-plutonic belt (Devonian and Early Carboniferous)
ss - South Siberian volcanic-plutonic belt (Early Devonian)

METALLOGENIC BELTS

BG - Bayangovi
BM - Botuobiya -Markha
DO - Daldyn-Olenyok
DS - Deluun-Sagsai
ED - Edrengiin
EZ - Edren-Zoolon
HQ - Hongqiling 331 to 350 Ma.
KK - Korgon-Kholzun
KZ - Kizhi-Khem
MC - Mamsko-Chuiskiy
RA - Rudny Altai
SL - Salair
SD - Sette-Daban
SO - Sorsk
TE - Teisk
TS - Tsagaan-suvarga
UD - Udzha
UZ - Ulziit
YA - Yaroslavka

Figure 19. Devonian and Early Carboniferous (370 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume)

EXPLANATION

Craton

Passive continental margin on subsided craton

Microcontinent

Continental slope

Intracontinental sedimentary basin

Collage of accreted terranes and overlap assemblages

Ocean or sea underlain by oceanic crust; includes continental margin and slope units

Sea underlain by continental crust

SUBDUCTION-RELATED ISLAND ARCS AND CONTINENTAL MARGIN ARCS

Mainly volcanic and lesser plutonic units

Mainly plutonic and lesser volcanic units

TRANSFORM-PLATE BOUNDARY, INTRA-PLATE (PLUME) MAGMATIC UNITS

Subalkaline and alkaline volcanic and plutonic belts

Plateau basalt, trap

Rift-related bimodal volcanic and plutonic rocks

Intraplate granitoids

COLLISIONAL GRANITOIDS

CONTACTS, FAULTS, AND SYMBOLS

Subduction zone and its accretionary wedge

Thrust

Strike-slip fault

Normal fault

Fold-and thrust belt formed on the subsided craton margin

Stratigraphic contact

OH Metallogenic belt with abbreviation

Outline and name of tectonic collage or name of major tectonic feature

Chukotka Collage

Figure 19.—Continued.

Govi-Altai continental-margin turbidite terrane, part of the South Mongolia-Khingan collage. The belt is interpreted as having formed regional metamorphism of the Govi-Altai terrane, part of the South Mongolia-Khingan collage, during collision with the Idermeg terrane.

The Botuobiya-Markha (BM, figs. 3, 19) and Daldyn-Olenyok (DO, figs. 3, 16; table 2) belts occur in northeast and in central Yakutia, respectively, and contain diamond-bearing Devonian kimberlite deposits. The tectonic origin of these metallogenic belts is unknown. The kimberlite pipes intrude mostly Cambrian through Silurian carbonate sedimentary rocks of the North Asian craton.

The Deluun-Sagsai belt (DS, figs. 3, 19) contains polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, polymetallic Pb-Zn±Cu (±Ag, Au) vein and stockwork, volcanogenic Zn-Pb-Cu massive sulfide, sediment-hosted Cu, Ag-Pb epithermal vein and granitoid-related Au-vein deposits and occurrences. The deposits and occurrences are hosted in granitoids and replacements related to the Deluun sedimentary-volcanic-plutonic belt, part of Altai and South Siberian transpressional continental-margin arc. The belt is interpreted as having formed during granitoid magmatism that occurred during transpressional faulting along the accreting southern margin of the North Asian craton as part of the South Siberian arc. This arc contained the South Siberian and West and North Mongolian volcanic-plutonic belts.

The Edrengiin belt (ED, figs. 3, 19) contains volcanogenic Cu-Zn massive sulfide and volcanogenic-sedimentary Fe and Mn deposits and is hosted in the Edren island-arc terrane, part of South Mongolia-Khingan collage. The belt is interpreted as having formed during the South Mongolian-Khingan island arc. The deposits are hosted in pillow basalt and siliceous rocks.

The Edren-Zoolon belt (EZ, figs. 3, 19) contains Au quartz-vein deposits. The belt is related to the Zoolen subduction zone of the South Mongoial-Khingan island arc. The belt is interpreted as having formed during regional metamorphism related to collision of the Govi-Altai turbidite and Idermeg continental-margin terranes.

The Hongqiling belt (HQ, figs. 3, 19) contains mafic-ultramafic related Cu-Ni-PGE and polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposits. The belt is hosted in Mississipian or possibly Triassic mafic and ultramafic plutons that intrude and overlap the Bureya-Jiamusi supterterrane. The belt is interpreted as having formed during extension of the Bureya- Jiamusi superterrane.

The Kizhi-Khem belt (KZ, figs. 3, 19) contains W-Mo-Be greisen, stockwork, and quartz vein, porphyry Cu-Mo (±Au, Ag); Ta-Nb-REE alkaline metasomatite; and granitoid-related Au vein deposits. The belt is hosted in replacements related to Devonian subalkalic porphyry granitoids that are part of the South-Siberian volcanic-plutonic belt and the Tannuola plutonic belt. The host units are interpreted as having formed during transpressional faulting along the accreting southern margin of the North Asian craton.

The Korgon-Kholzun belt (KKh, figs. 3, 19) contains volcanogenic-sedimentary Fe, Fe-skarn, mafic-ultramafic related Ti-Fe (±V) and polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposits. The belt is hosted in the Altai volcanic-plutonic belt that overlaps and intrudes the Altai and Charysh continental-margin turbidite terranes that are part of the Altai collage. The belt is interpreted as having formed during transpressional faulting along the accreting southern margin of the North Asian craton.

The Mamsko-Chuiskiy belt (MC, figs. 3, 19) contains muscovite- pegmatite deposits and is hosted in Devonian through Early Carboniferous veins and dikes in the Mamsky and Konkudero-Mamakansky complexes that intrude the Chuja paragneiss terrane, part of the Baikal-Patom cratonal margin. The belt is interpreted as having formed during intrusion of alkaline granitoids that formed during post-accretionary magmatism in transpression zones related to a transform microplate boundary.

The Muiskiy belt (MS, figs. 3, 19) contains granitoid-related Au vein, Au in shear-zone and quartz-vein, carbonate-hosted Hg-Sb, and porphyry Sn deposits that are hosted in granitoids and veins related to the Barguzin-Vitim granitoid belt that intrudes terranes accreted along the southern margin of the North Asian craton. The host granitoids are interpreted as having formed during post-accretionary magmatism in transpression zones related to a transform microplate boundary.

The Rudny Altai belt (RA, figs. 3, 19) contains volcanogenic Zn-Pb-Cu massive sulfide, barite vein, and volcanic-hosted metasomatite deposits that are hosted in the (Rudny) Altai island-arc terrane that part of the West Siberian collage The belt is interpreted as having formed in the same name island arc. The host rocks are interpreted as having formed in the South Mongolia-Khingan island arc.

The Salair belt (SL, figs. 3, 19) contains polymetallic (Pb, Zn, ±Cu, Au, Ag) volcanic-hosted metasomatite, and porphyry Cu-Mo(±Au,Ag) deposits that are hosted in the (Rudny) Altai island-arc terrane that is part of the West Siberian collage The belt is interpreted as having formed in the same name island arc. The host rocks are interpreted as having formed in the South Mongolia-Khingan island arc.

The Sette-Daban belt (SD, figs. 3, 19) contains sediment-hosted Cu, basaltic native Cu, REE (± Ta, Nb, Fe) carbonatite, and carbonate-hosted Pb-Zn deposits that are hosted in the Verkhoyansk (North Asian) cratonal margin. The deposits are interpreted as having formed during Devonian rifting in the passive continental margin of the North Asian craton. The sediment-hosted Cu deposits are hosted in Middle Devonian through Early Carboniferous carbonate and terrigenous rocks that also contain basalt lava flows with native Cu deposits. The REE and apatite deposits are hosted in alkali-ultramafic and carbonatite plutons that are also interpreted as having formed during Devonian rifting

The Sorsk belt (SO, figs. 3, 19) contains porphyry Mo, polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite, and Zn-Pb (±Ag, Cu) skarn deposits. The hosting Early and

Middle Devonian porphyry intrusions are part of the South Siberian volcanic-plutonic belt (South Siberian arc) and intrude older early Paleozoic granitoid plutons. The skarn and metasomatic polymetallic deposits are hosted in Vendian and Cambrian shallow-water marine carbonate rock. The belt is interpreted as having formed during Devonian subalkalic porphyry magmatism related to interplate rifting and transpressional faulting along the accreting southern margin of the North Asian craton.

The Teisk belt (TE, figs. 3, 19) contains Fe-skarn, mafic-ultramafic related Ti-Fe (±V), and volcanogenic-sedimentary Fe deposits that are hosted in plutonic rocks of the South Siberian volcanic-plutonic belt (part of the South Siberian arc). The belt is interpreted as having formed during transpressional faulting along the the accreting southern margin of the North Asian craton in the South Minusa volcanic basin. The Fe-skarn deposits are related to early Devonian granosyenite plutons that occur along marginal faults of Devonian basins.

The Tsagaan-suvarga belt (TS, figs. 3, 19) contains porphyry Cu-Mo (±Au, Ag), porphyry Cu (±Au), porphyry Au-Cu and granitoid-related Cu-Au vein deposits and occurrences that are hosed in the Gurvansayhan island-arc terrane, part of the South Mongolia-Khingan collage. This belt is interpreted as having formed in the South Mongolia Khingan island arc.

The Udzha belt (UD, figs. 3, 19) contains REE (± Ta, Nb, Fe) carbonatite deposits that are hosted in the North Asian craton. The belt is is interpreted as having formed during intrusion of alkali-ultramafic rock and carbonatite associated with Devonian rifting.

The Ulziit (belt UZ, figs. 3, 19) contains Au in shear-zone and quartz-vein deposits that are hosted in the Govi-Altai continental-margin turbidite terrane, part of the South Mongolia-Khingan collage. The belt is interpreted as having formed during regional metamorphism of Govi-Altai terrane during collision with the Idermeg terrane.

The Yaroslavka belt (YA, figs. 3, 19) contains Sn-W greisen, stockwork and quartz- vein deposits, and fluorite greisen deposits and occurrences. The belt is interpreted as having formed in a collisional arc that formed in a fragment of Gondwanaland. The host leucogranite plutons are associated with early Paleozoic collision of the Voznesenka and Kabarga terranes along the margin of Gondwanaland. The deposit-related granitoids intrude Cambrian clastic rocks and limestone

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Chapter 7

Late Carboniferous through Early Jurassic Metallogenesis and Tectonics of Northeast Asia

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Introduction

This paper presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia for the Late Carboniferous (Pennsylvanian) to Early Jurassic (320 to 175 Ma) and provides a detailed summary of these features for readers who are unfamiliar with Northeast Asia. Several parts of this book on Northeast Asia provide background information. An overview of the regional geology, metallogenesis, and tectonics of the region, and other materials, such an employed geologic time scale and standard geologic definitions, are provided in Chapter 1. The methodology for the metallogenic and tectonic analysis of this region is provided Chapter 2. Descriptions of mineral deposit models are provided in Chapter 3. Additional information on project publications, descriptions of major geologic units, and summaries of metallogenic belts are provided in appendixes A through C.

Compilations Employed for Synthesis, Project Area, and Previous Study

The compilation of regional geology and metallogenesis in this introduction is based on publications of the major international collaborative studies of the metallogenesis and tectonics of Northeast Asia that were led by the U.S. Geological Survey (USGS). These studies have produced two broad types of publications. One type is a series of regional geologic, mineral-deposit, and metallogenic-belt maps and companion descriptions for the regions. Examples of major publications of this type are Obolenskiy and others (2003, 2004), Parfenov and others (2003, 2004a,b), Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006). The other type is a suite of metallogenic and tectonic analyses of these same regions. Examples of major publications of this type are Rodionov and others (2004), Nokleberg and others (2000, 2004, 2005), and Naumova and others (2006). Detailed descriptions of lode deposits are available in Ariunbileg and others (2003). For more information, refer to the detailed descriptions of geologic units and metallogenic belts in these publications.

The Northeast Asia project area consists of eastern Russia (most of Siberia and most of the Russian Far East), Mongolia, Northern China, South Korea, Japan, and adjacent offshore areas (fig. 1). This study area is approximately bounded by 30 to 82° N. latitude and 75 to 144° E. longitude. The major participating agencies are the Russian Academy of Sciences, Academy of Sciences of the Sakha Republic (Yakutia), VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation, Mongolian Academy of Sciences, Mongolian University of Science and Technology, Mongolian National University, Jilin University, Changchun, China, the China Geological Survey, the Korea Institute of Geosciences and Mineral Resources, the Geological Survey of Japan/AIST, University of Texas Arlington, and the USGS.

The Northeast Asia project extends and builds on data and interpretations from a previous project on the *Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera* (below figure) that was conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys,

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and the Geological Survey of Canada. A summary of the major products of this project are available online at: http://pubs.usgs.gov/of/2006/1150/PROJMAT/ and in appendix A.

Major Geologic Units

The major Late Carboniferous (Pennsylvanian) to Early Jurassic geologic and tectonic units of Northeast Asia are cratons, craton-margins, tectonic collages, superterranes (microcontinents) and terranes, and overlap sedimentary basins and intrusive belts, including the Tungus Plateau unit of basalt, sills, dikes, and intrusions (fig. 2, table 1). Short descriptions of map units are given in appendix B. Summary descriptions of the major units are provided in descriptions of metallogenic belts (below), and detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004), and Parfenov and others (2004b).

Major Cratons, Cratonal Margins, and Cratonal-Margin Terranes

The backstop or core units for the region of Northeast Asia are the Archean and Proterozoic North Asian craton and Sino-Korean craton and their cratonal margins (Baikal-Patom, East Angara, South Taimyr, and Verkhoyansk (North Asian).

The North Asian craton (NAC) consists of Archean and Proterozoic metamorphic basement, and nondeformed, flat-laying platform cover consisting of late Precambrian, Paleozoic, and Mesozoic sedimentary and volcanic rock.

Figure 1. Regional summary geographic map for Northeast Asia showing major regions and countries.

The Sino-Korean craton (SKC) consists of several major Archean and Proterozoic metamorphic basement terranes and younger Paleozoic through Cenozoic overlap units.

The Baikal-Patom cratonal margin (BP) consists of a fault-bounded basin containing Riphean carbonate and terrigenous sedimentary rock, and younger Vendian and Cambrian sedimentary rock that discordantly overlie a fragment of the pre-Riphean basement of the North Asian craton.

The East Angara cratonal margin (EA) consists of late Riphean terrigenous-carbonate sedimentary rock (sandstone, siltstone, mudstone with interlayered dolomite and limestone) that overlie a fragment of the North Asian craton.

The South Taimyr cratonal margin (ST) consists chiefly of a thick wedge of Ordovician through Jurassic cratonal-margin deposits and deep basin deposits.

The Verkhoyansk (North Asian) cratonal margin (VR) consists chiefly of a thick wedge of Devonian through Jurassic miogeoclinal deposits.

Superterrane

The major Proterozoic through Permian Bureya-Jiamusi supterterrane (BJ) occurs along the margins of the North Asian and Sino-Korean cratons (fig. 2). The superterrane consists of a collage of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin, and island arc terranes. The superterrane is interpreted as a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

Tectonic Collages between North Asian and Sino-Korean Cratons

The North Asian and Sino-Korean cratons are a series of accreted Devonian through Early Carboniferous tectonic collages. These tectonic collages were accreted successively from north to south during closures of the Paleo-Asian and Solon Oceans. Most of the tectonic collages contain one or more island arcs and tectonically-linked subduction zones. Because of successive accretions from north to south, the ages of collages are generally young from north to south. However, this pattern is locally interrupted because some collages, or parts of collages, were interspersed because of subsequent strike-slip faulting.

The tectonic collages are described in alphabetical order as follows (fig. 2). More detailed descriptions of terranes in each tectonic collage are provided in appendix B and in Parfenov and others (2003, 2004a,b).

(1) The Atasbogd collage (AB) (Ordovician through Permian age and accreted in Late Carboniferous or Early Permian) consists of: the Ordovician through Permian Waizunger-Baaran terrane, the Devonian through Carboniferous Beitianshan-Atasbogd terrane, and (2) the Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. The collage consists of the Rudny Altay island arc and tectonically-linked subduction zones, including the Zoolen terrane.The collage is interpreted as a northwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and margin and previously accreted terranes. The collage was initially separated from North Asian craton by the large back-arc basin.

(2) The Mongol-Okhotsk collage (MO) (Devonian through Late Jurassic age and accreted in Late Paleozoic through Early Mesozoic) consists mainly of the Permian through Jurassic Selenga, Late Carboniferous and Early Permian Hangay, and Uda-Murgal and Stanovoy continental-margin arcs. These arcs are composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically-linked, outboard subduction-zone terranes. The arcs overlap the southern margin of the North Asian craton and margin, and previously-accreted terranes. The collage is interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean and oblique subduction of terranes beneath the southern North Asian cratonal-margin and previously-accreted terranes.

(3) The South Mongolia-Khingan collage (SM) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the South Mongoia-Khingan arc (now a related series of related Early and Middle Paleozoic arc terranes), subduction-zone terranes, and backarc basins. Tectonically linked to the South Mongolia-Khingan island arc was a subduction zone now preserved in the discontinuous collage of the Kalba-Narim and Zoolen subduction-zone terranes that occur outward (oceanward) of, and parallel to, the South Mongolia-Khingan island arc. Also tectonically linked to the South Mongolia-Khingan island arc was an elongate backarc basin now preserved in a discontinuous and disrupted collage of terranes in Southern Mongolia. These terranes are the Bayanleg (BL) and Mandah (MN) subduction-zone terranes. The South Mongolia-Khingan arc is interpreted as having formed during the Devonian through Early Carboniferous subduction of the Paleoasian ocean basin. The collage formed southwest and west (present-day coordinates) of the North Asian craton and previously accreted terranes.

(4) The Solon collage (SL) (Carboniferous through Permian age and accreted in Late Paleozoic through Early Mesozoic) consists of several subduction-zone terranes (1) Carboniferous and Early Permian North Margin terrane, (2) Late Carboniferous through Permian Solon terrane, (3) Devonian Imjingang terrane, (4) Paleozoic Ogcheon terrane, and (5) Silurian through Permian Sangun-Hidagaien-Kurosegawa terrane. Parts of the collage are interpreted as fragments of the Solon Ocean plate that were subducted to form the South Mongolian, Lugyngol, Gobi-Khankaisk-Daxing'anling, and Jihei continental-margin arcs. Other parts of the collage are interpreted as fragments of the Solon Ocean plate that were subducted to form the North Margin continental-margin arc on the Sino-Korean craton.

(5) The West Siberian collage (WS) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the Late Silurian through Early Carboniferous Rudny Altai island arc, and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane.

The collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage.

Late Carboniferous through Early Jurassic Continental-Margin Arcs Occurring Along Southeastern Margin of the North Asian Craton and Adjacent Accreted Terranes

Three major major continental-margin arcs occur along the southeastern margin of the North Asian craton or on adjacent

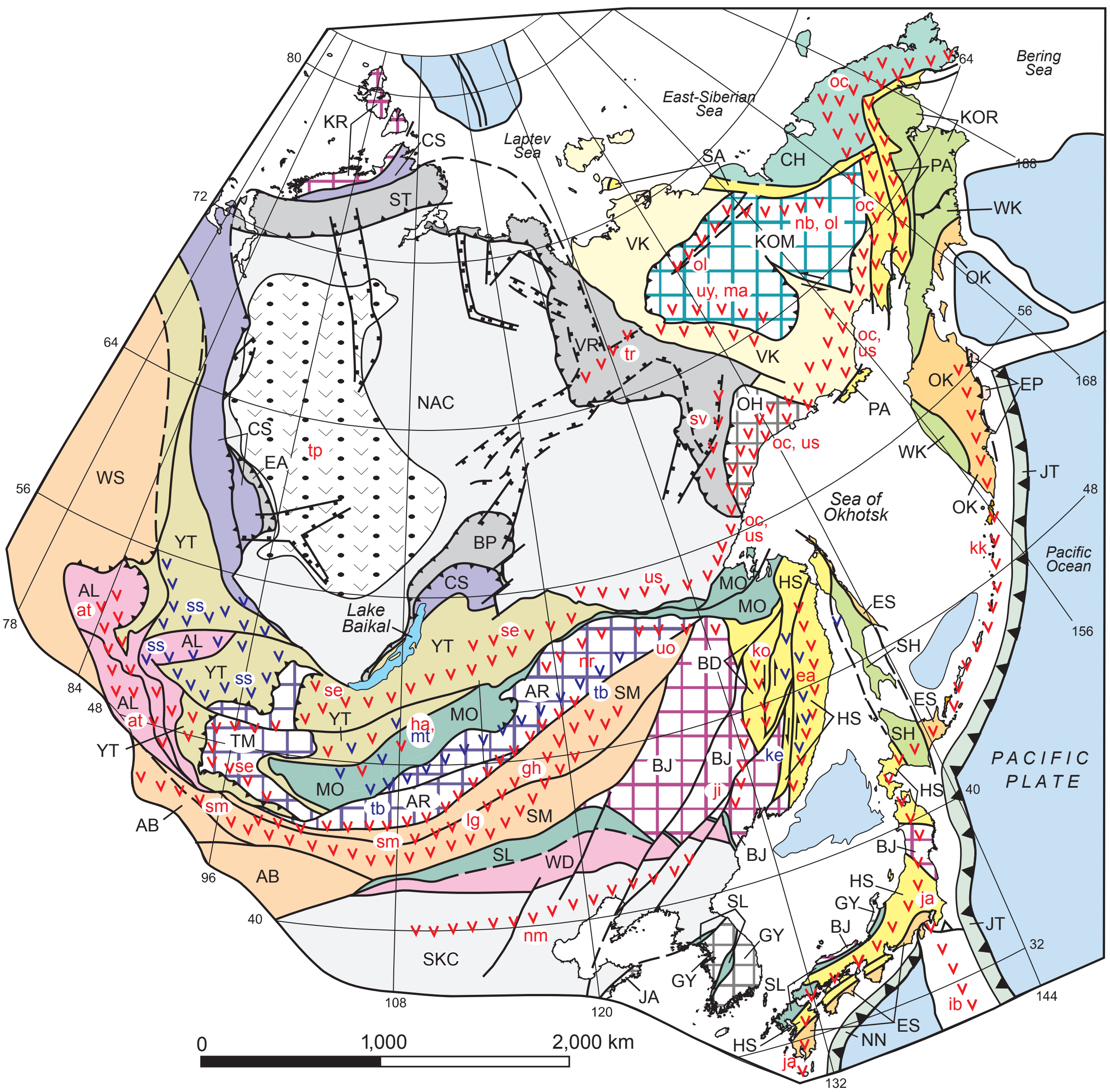


Figure 2. Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004a,b); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North Pacific tectono-stratigraphic terrane map at 10 million scale (Nokleberg and others, 1997). Map shows locations of major geologic and tectonic units including cratons and cratonal margins; cratonal terranes and superterranes; tectonic collages; overlap and transform continental-margin arcs; island arcs, and sea and ocean units. Refer to table 1 and text for unit descriptions.

EXPLANATION

Cratons and Cratonal Margins

Cratons: NAC - North Asian (Archean and Proterozoic); SKC - Sino-Korean (Archean and Proterozoic)

Cratonal Margin: BP - Baikal-Patom (Riphean through Cambrian and older basement; EA - East Angara (Riphean and older basement; ST - South Taimyr (Ordovician through Jurassic); VR - Verkhoyansk (Devonian through Jurassic).

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

AL - Altay (Vendian to Ordovician)
WD - Wundurmiao (Riphean through Ordovician)

AB - Atasbogd (Ordovician through Permian); SM - South Mongolia-Khingan (Ordovician through Carboniferous); WS - West Siberian (Ordovician through Carboniferous)

MO - Mongol-Okhotsk (Devonian through Late Jurassic); SL - Solon (Carboniferous and Permian)

Tectonic Collages Along the Northern and Eastern Margins of North Asian and Sino-Korean Cratons

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

BD - Badzhal (Triassic through Early Cretaceous); PA - Penzhina-Anadyr (Late Jurassic and Cretaceous); HS - Honshu-Sikhote-Alin (Jurassic and Early Cretaceous); SA - South Anyui (Permian through Jurassic);

KOR - Koryak (Late Jurassic through Paleocene; SH - Sakhalin-Hokkaido (Cretaceous); WK - West Kamchatka (Mid-Cretaceous through Early Tertiary)

ES - East Sakhalin (Late Cretaceous and Early Tertiary); OK - Olyutorka-Kamchatka (Late Cretaceous to Paleocene)

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

JT- Japan Trench (including Kuril-Kamchatka trench) (Miocene through Holocene; NN - Nankai (Miocene through Holocene)

Cratonal Terranes and Superterranes

Cratonal terranes (Archean and Proterozoic): GY - Gyeonggi-Yeongnam; JA - Jiaonan; OH - Okhotsk

Late Proterozoic and Cambrian superterranes: AR - Argun-Idermeg; TM - Tuva-Mongolia

Archean through Permian superterranes: BJ - Bureya-Jiamusi; KR - Kara

Jurassic Superterrane: KOM - Kolyma-Omolon (Archean through Jurassic)

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

at - Altay arc (Devonian and early Carboniferous, 381 to 290 Ma)
ea - East Sikhote-Alin arc (Late Cretaceous through early Tertiary, 96-65 Ma)
gh - Gobi-Khankaisk-Daxing'anling arc (Permian, 295 to 250 Ma)
ha - Hangay arc (Late Carboniferous and Early Permian, 320 to 272 Ma)
ji - Jihei arc (Permian, 295 to 250 Ma)
ko - Khingan arc (Early and mid-Cretaceous)
lg - Lugyngol arc (Permian and Triassic, 295 to 250 Ma)
ma - Main granite belt (Late Jurassic, 144 to 134 Ma)
nb - Northern granite belt (Early Cretaceous, 138 to 120 Ma)
nm - North Margin (Late Carboniferous and Permian, 320 to 272 Ma)
nr - Norovlin arc (Devonian and Early Carboniferous, 410 to 255 Ma)
oc - Okhotsk-Chukotka arc (Late Cretaceous and early Tertiary, 96 to 53 Ma)
ol - Oloy arc (Late Jurassic, 154 to135 Ma)
se - Selenga arc (Permian through Jurassic, 295 to135 Ma)
sm - South Mongolian arc (Carboniferous through Triassic, 320 to 203 Ma)
ss - South Siberian arc (Devonian)
sv - South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157 to 93 Ma)
tr - Transverse granite belt (Early Cretaceous, 134 to 124 Ma)
uo - Umlekan-Ogodzhin arc (Cretaceous, 135 to 65 Ma)
us - Uda-Murgal and Stanovoy arc (Jurassic and Early Cretaceous, 203 to 96 Ma)
uy - Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154 to 120 Ma)

Plume-Related Igneous Province

tp - Tungus Plateau igneous province - (Late Permian and Early Triassic, 245 Ma)

Active Arcs

ib - Izu-Bonin (late Cenozoic, 20 to 0 Ma)
ja - Japan (late Cenozoic, 23 to 0 Ma)
kk - Kuril-Kamchatka (late Cenozoic, 11 to 0 Ma)

Transpressional Arcs

ke - Kema (Mid-Cretaceous)
mt - Mongol-Transbaikal (Late Triassic through Early Cretaceous, 230 to 96 Ma)
ss - South Siberian (Early Devonian, 415 to 400 Ma)
tb - Transbaikalian-Daxinganling (Middle Jurassic through Early Cretaceous,175 to 96 Ma)

Symbols, Faults, and Contacts

Overlap-continental-margin arc
Transform-continental-margin arc
Active subduction zone
Thrust
Strike-slip fault
Fault
Contact
Riphean aulacogen
Devonian aulacogen
Modern rift system (Gakkel Ridge)
os Metallogenic belt

Figure 2.—Continued

Table 1. Summary of major Late Carboniferous (Pennsylvanian) to Early Jurassic (320 to 175 Ma) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit, map symbol	Type of unit (craton, terrane, overlap assemblage)	Age range	Tectonic environment	Tectonic linkage
		NORTHEAST ASIA CRATONS		
North Asian, NAC Sino Korean, SKC	Craton	Archean through Mesozoic	Cratonal and passive continental margin	Primary units.
		NORTH ASIAN CRATONAL-MARGIN UNITS		
Baikal-Patom, BP East Angara, EA South Taimyr, ST Verkhoyansk, VR	Overlap assemblages	Neoproterozoic through Mesozoic	Passive continental margin	Original overlap assemblages on North Asian craton that were subsequently transformed into fold and thrust belts and terranes.
		SUPERTERRANE		
Bureya-Jiamusi	Superterrane	Proterozoic through Permian	Composite	Consists of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island-arc terranes. Interpreted as a fragment of Gondwana. Accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic.
		TECTONIC COLLAGES		
Atasbogd, AB	Collage	Ordovician through Permian	Composite	Consists of: (1) the Ordovician through Permian Waizunger-Baaran terrane, (2) Devonian through Carboniferous Beitianshan-Atasbogd terrane, and (3) Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. Collage is interpreted as a southwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and margin and previously accreted terrane. Accreted in Late Carboniferous or Early Permian.
Mongol-Okhotsk, MO	Collage	Devonian through Late Jurassic	Composite	Consists mainly of the Permian through Jurassic Selenga, Late Carboniferous and Early Permian Hangay, and Uda-Murgal and Stanovoy continental-margin arcs. Composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically-linked, outboard subduction-zone terranes. Interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean with oblique subduction of terranes beneath of the southern North Asian cratonal margin and previously-accreted terranes.

Table 1. Summary of major Late Carboniferous (Pennsylvanian) to Early Jurassic (320 to 175 Ma) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).—Continued

South Mongolia-Khingan, SM	Collage	Ordovician through Carboniferous	Composite	Consists of the South Mongolia-Khingan arc and tectonically-linked subduction-zone terranes. The collage is interpreted as a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian craton and margin and previously accreted terranes. Collage was separated from the North Asian craton by a large back-arc basin. accreted in Late Carboniferous or Early Permian.
Solon, SL	Collage	Carboniferous through Permian	Composite	Consists of several subduction-zone terranes and terranes derived from the Solon Ocean plate.
West Siberian, WS	Collage	Ordovician through Carboniferous	Composite	Consists of the Late Silurian through Early Carboniferous Rudny Altai island arc, and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. Collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage. Accreted in Late Carboniferous or Early Permian.
CARBONIFEROUS AND PERMIAN ISLAND ISLAND ARCS				
Gobi-Khankaisk-Daxing'anling, gh	Overlap assemblage	Permian	Complex island-arc system	Complex island-arc system formed during subduction of Solon Ocean under Argun-Idermeg superterrane and South Mongolian and Atasbogd collages during final accretion to southern margin of North Asian craton.
Lugyngol. ji	Overlap assemblage	Permian		
South Mongolian, sm	Overlap assemblage	Middle Carboniferous through Late Triassic		
Jihei, ji	Overlap assemblage	Permian	Island arc	Occurs on the the southern margin of the Bureya-Jiamusi supterterrane. Interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin of the superterrane..
North Margin, nm	Overlap assemblage	Late Carboniferous through Permian	Island arc	Occurs on the northeastern margin of the Sino-Korean craton. Interpreted as having formed during subduction of the southern part of Solon Ocean plate under the northeastern margin of Sino-Korean craton.
LATE CARBONIFEROUS THROUGH EARLY JURASSIC CONTINENTAL-MARGIN ARCS				
Hangay, ha	Overlap assemblage	Pennsylvanian through Early Permian	Subduction-related continental-margin arc	Interpreted as having formed along the margin of the North Asian craton as a continental-margin transform system.
Selenga, se	Overlap assemblage	Permian through Jurassic	Transform continental-margin arc	Interpreted as having formed along the margin of the North Asian craton as a continental-margin transform system.
Uda-Murgal, us	Overlap assemblage	Jurassic through Early Cretaceous	Subduction-related continental-margin arc	Interpreted as having formed along the margin of the North Asian craton and cratonal margin during subduction of Ancestral Pacific Ocean.
LATE PERMIAN THROUGH EARLY TRIASSIC TRAP BASALT PROVINCE				
Tungus Plateau Igneous Province -- basalt, sills, dikes, and intrusions	Overlap assamblage	Permian through Triassic boundary (248.31 to 246.92 Ma)	Flood basalts and associated intrusions in an intraplate tectonic setting	Indicator of intraplate plume activity within North Asian Craton.

accreted terranes (fig. 2). The arcs are interpreted as beingrelated to subduction of the late Paleozoic and early Mongol-Okhotsk Ocean plate beneath the North Asian craton and margin. This ocean occurred between the North Asian craton to the north and the Argun-Idermeg superterrane to the south (present-day coordinates).

(1) The Hangay arc (ha) (Late Carboniferous through Early Permian) occurs on the Yenisey-Transbaikal collage and Mongol-Okhotsk collage. The arc is interpreted as having formed during subduction of the northern part of Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously-accreted terranes.

(2) The Selenga arc (se) (Permian through Jurassic) overlies and intrudes the Yenisey-Transbaikal collage and Tuva-Mongolia superterrane. The arc is interpreted as having formed during oblique subduction and transform-faulting of the Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously-accreted terranes.

(3) The Uda-Murgal arc (us) (Jurassic through Early Cretaceous) occurs on the southern margin of the North Asian craton. The arc is interpreted as having formed during subduction of the Ancestral Pacific Ocean plate beneath the eastern margin of the North Asian craton and cratonal margin.

Carboniferous and Permian Island Arcs Occurring South of North Asian Craton and on Sino-Korean Craton

Several major island arcs occur on migrating superterranes (microcontinents) or cratons. Three arcs are part of an extensive linear array that occurs along the southern (present-day) coordinates of the South Mongolian and Atasbogd collages (Argun-Idermeg superterrane) and Solon collage (fig. 2). This linear array of arcs are interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane. (1) The Gobi-Khankaisk-Daxing'anling arc (gh) (Permian) occurs on the Argun-Idermeg superterrane, South Mongolian collage, and Solon collage. (2) The Lugyngol arc (lg) (Permian) occurs on the South Mongolian and Solon collages. (3) The South Mongolian arc (sm) (Middle Carboniferous through Triassic) overlies and intrudes the South Mongolian and Atasbogd collages.

Two other island arcs were active in the Carboniferous through Permian. (1) The Jihei arc (ji) (Permian) occurs on the the southern margin (present-day coordinates) of the Bureya-Jiamusi supterterrane. The arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the superterrane and adjacent units. (2) The North Margin arc (nm) (Late Carboniferous through Permian) occurs on the northeastern margin (present-day coordinates) of the Sino-Korean craton. The arc is interpreted as having formed during subduction of the southern part of Solon Ocean plate under the northeastern margin (present-day coordinates) of Sino-Korean craton.

Tungus Plateau Igneous Province of Basalt, Sills, Dikes, and Intrusions Occurirng in Northern and Central Siberia

The Tungus Plateau igneous province consists mainly of massive basalt flows that formed on the North Asian Craton at the Permian-Triassic boundary. The unit is also named the Siberian trapps and is most widespread in the Tunguska Basin, with a total thickness of the lava sheets and tuff ranging as much as 3,000 m. In the eastern part of the platform are widespread intrusive traps consisting of extensive belts of sills and rare dikes that intruded major fault zones on the eastern margin of the Tunguska Basin and on the southwestern and northeastern slopes of the Anabar shield. Age of trap magmatism is late Permian and early Triassic. Special geochronologic investigation of the Siberian traps involving dating of their zircons and paleomagnetic studies indicate that trap magmatism occurred at the Permian-Triassic time boundary and continued for less than 1 Ma from from 248.31 to 246.92 Ma. This type of magmatism is best interpreted as having formed in a mantle plume originating at the core-mantle boundary with no relation to lithosphere structures. The eruption of the Siberian traps was among the largest surficial volcanic eruptions throughout the Phanerozoic history of the Earth. The total volume of the igneous material is estimated to be 2.106 to 3.106 km^3.

Summary of Late Carboniferous through Early Jurassic (320 to 175 Ma) Metallogenesis

Major Late Carboniferous through Middle Triassic Metallogenic Belts

The major Late Carboniferous through Middle Triassic metallogenic belts are the Angara-Ilim, Altay, Barlaksk, Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia, Duobaoshan, Harmagtai-Hongoot-Oyut, Hitachi, Kalatongke, Kolyvansk, Kureisko-Tungsk, Maimecha-Kotuisk, Mino-Tamba-Chugoku, Norilsk, Orhon-Selenge, and Shanxi belts (fig. 3, appendix C).

Metallogenic Belts Related to Superplume

Four metallogenic belts possess geologic units favorable for a wide variety of major trapp-magmatism-related deposits, including the Angara-Ilim, Kureisko-Tungsk, Maimecha-Kotuisk, and Norilsk belts (with mafic-ultramafic related Cu-Ni-PGE, Fe-Ti and phlogopite carbonatite, metamorphic graphite, basaltic native Cu (Lake Superior type), porphyry Cu-Mo, Fe-skarn, and weathering crust carbonatite REE-Zr-Nb-Li deposits). The isotopic ages of the deposits or hosting units range from Devonian through Early Carboniferous. The favorable geologic units and deposits are interpreted as having formed in a continental-margin or island arc or in associated arc margin terranes. The deposits are related to replacements associated with the Tungus plateau basalt, sills, dikes, and intrusions that intrude or overlie the North Asian craton The isotopic ages of the deposits or hosting units range from Permian through Triassic (260 to 200 Ma). The belts are interpreted as being related to widespread development of trapp magmatism on the North Asian craton that occurred during intrusion of a superplume. The Norilsk belt contains the famous mafic-ultramafic related Cu-Ni-PGE deposits in the Norilsk district in northern Siberia.

Metallogenic Belts Related to Selenga and South Mongolian Continental-Margin Arcs

Four metallogenic belts possess geologic units favorable for a wide variety of granitic magmatism-related

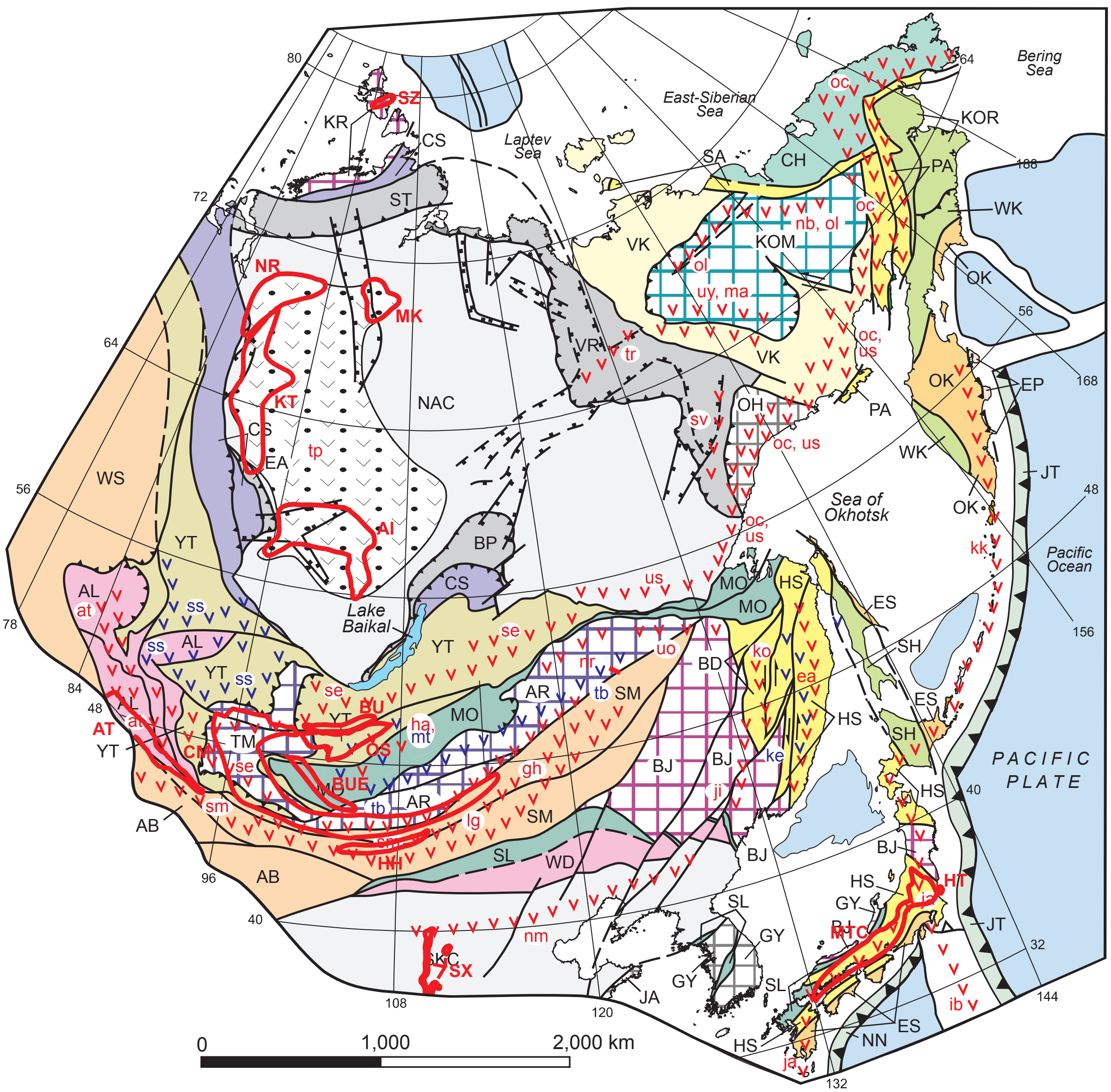


Figure 3. Generalized map of major Late Carboniferous through Middle Triassic metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004a,b). Metallogenic belts for areas to the east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

deposits, including the Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia and Orhon-Selenge belts [with Fe-Zn skarn, Sn-skarn, Zn-Pb skarn, W-skarn, Cu-skarn, porphyry Cu-Mo, porphyry Mo, Au-skarn; granitoid-related Au vein, W-Mo-Be greisen, stockwork, and quartz vein, peralkaline granitoid-related, REE-Li pegmatitem and basaltic native Cu (Lake Superior type) deposits]. The belts are hosted in granitoids in the Selenga sedimentary-volcanic plutonic belt that constitutes the Selenga continental-margin arc that formed on the Yenisey-Transbaikal and Tuva-Mongolia collages. The isotopic ages of the deposits or hosting units range from 240 to 285 Ma. The belts are interpreted as having formed during transform-faulting and oblique subduction of oceanic crust of the Mongol-Okhotsk Ocean plate under the southern margin of the North Asian craton and cratonal margin and previously-accreted terranes.

The Harmagtai-Hongoot-Oyut metallogenic belt (with porphyry Cu-Mo and Au, granitoid-related Au, and Au-Ag epithermal Au deposits) is hosted in granitoids related to South-Mongolian volcanic-plutonic belt and is interpreted as having formed in the South Mongolian continental-margin arc that formed along the northern margin (present-day coordinates) of the Mongol-Okhotsk Ocean.

Metallogenic Belts Related to Island Arcs

Three metallogenic belts possess geologic units favorable for a wide variety of granite- and mafic- plutonic-related deposits, and volcanogenic massive sulfide deposits, including the Duobaoshan, Hitachi, and Kalatongke belts (with porphyry Cu-Mo, granitoid-related Au vein, mafic-ultramafic related Cu-Ni-PGE, and volcanogenic Zn-Pb-Cu massive sulfide deposits). The isotopic ages of the igneous rocks that host the deposits range from Pennsylvanian through Permian. The belts are interpreted as having formed in a chain of island arcs that formed south (present-day coordinates) of the North Asian craton and margin and previously-accreted terranes. The island arcs were in the Duobaoshan terrane (part of the South Mongolia-Khingan collage), the South Kitakami terrane (part of the Bureya-Jiamusi supterterrane), and the Waizunger-Baaran terrane (part of the Atasbogd collage).

Metallogenic Belt Related to Collision of Cratons

The Altay metallogenic belt (with REE-Li pegmatite; Muscovite pegmatite deposits) is in veins, dikes, and replacements related to Late Carboniferrous granitoids in Altai volcanic-plutonic belt that intrudes the Altai continental margin turbidite terrane. The belt is interpreted as having formed during intrusion of collisional granite that formed during collision of Kazakhstan and North Asian cratons, resulting in high-grade metamorphism with crustal melting and generation of anatectic granite

Metallogenic Belt Related to Weathering

The Shanxi metallogenic belt (with sedimentary bauxite deposits) is hosted in Pennsylvanian stratiform units in the upper part of Sino-Korean platform overlapping Sino-Korean craton and West Liaoning terrane. The belt is interpreted as having formed during weathering of metamorphic rocks of the Northern China Platform. The bauxite deposits formed in karsts and lagoonal basins in a littoral-shallow sea.

Metallogenic Belt Related to Oceanic Crust

The Mino-Tamba-Chugoku metallogenic belt (with volcanogenic-sedimentary Mn, podiform chromite, and Besshi massive sulfide deposits) is hosted in the Mino Tamba Chichibu subduction-zone terrane, part of Honshu-Sikhote-Alin collage, that contains fragments of late Paleozoic and early Mesozoic oceanic crust in which these deposits originally formed.

Major Late Triassic through Early Jurassic Metallogenic Belts

The major Late Triassic through Early Jurassic metallogenic belts are the Central Hentii, Delgerhaan, Govi-Ugtaal-Baruun-Urt, Harmorit-Hanbogd-Lugiingol, Kalgutinsk, Mongol Altai, North Hentii, North Kitakami, North Taimyr, and Sambagawa-Chichibu-Shimanto belts (fig. 4; appendix C).

Metallogenic Belts Related to Transpressional Arc and Faults Caused by Closure of Mongol-Okhotsk Ocean

Collision caused by closure of Mongol-Okhotsk Ocean resulted in the formation of the Late Triassic through Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt along with formation of numerous intraplate strike-slip fault zones and related transpression and tranextension zones and related metallogenic belts.

In this area, (figs. 4), five metallogenic belts possess geologic units favorable for a wide variety of granite-related deposits, including the Central Henti, Delgerhaan, Govi-Ugtaal-Baruun-Urt, Harmorit-Hanbogd-Lugiingol, and North Hentii belts (with porphyry Cu; granitoid-related Au; Au in shear zone and quartz vein; Fe-Zn skarn; Cu-skarn, Zn-Pb-skarn; Sn-skarn; Sn-W greisen, stockwork, and quartz vein, W-skarn; Ta-Nb-REE akaline metasomatite; REE carbonatite; peralkaline granitoid-related Nb-Zr-REE; and REE-Li pegmatite deposits). The isotopic ages of the igneous rocks that host the deposits range from 242 to 199 Ma. The belts are hosted in the Late Triassic through Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt that constitutes a major part of the Mongol-Transbaikal transpressional arc that is interpreted as having formed during strike-slip faulting and rifting along the

Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.

Two more metallogenic belts possess geologic units favorable for a wide variety of granite-related deposits, including the Kalgutinsk and Mongol Altai belts (with W-Mo-Be greisen, stockwork, and quartz vein; Ta-Nb-REE alkaline metasomatite; and Sn-W greisen, stockwork, and quartz-vein deposits). The isotopic ages of the igneous rocks that host the deposits range from 204 to 183 Ma. The belts are hosted in small granitoids that intruded along major transpressional-fault zones (Hovd regional fault zone and companion faults) with a combination of strike-slip, extensional, and compressional displacements. The transpressional-fault zones strike northwest (present-day coordinates).

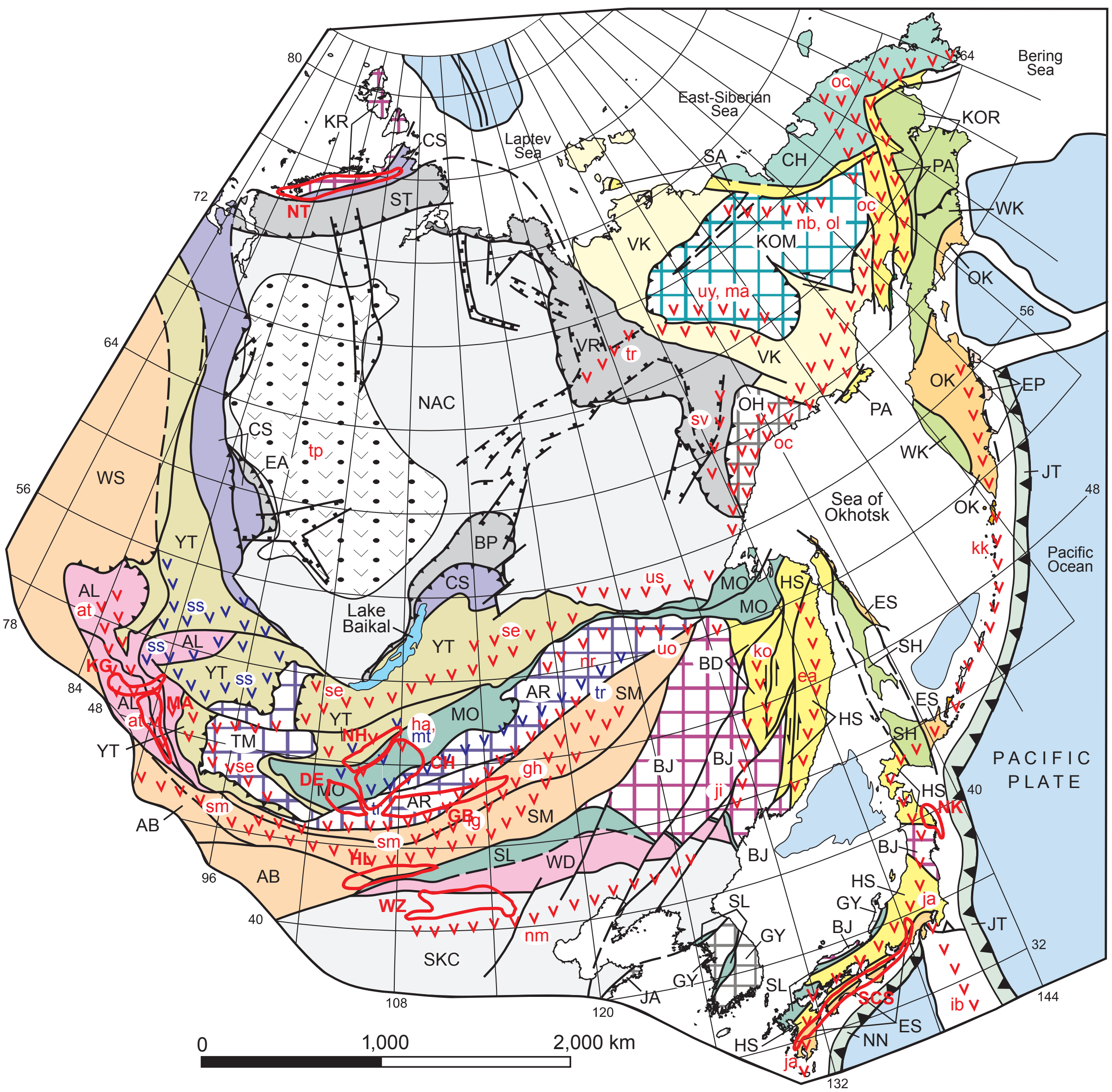


Figure 4. Generalized map of major Late Triassic through Early Jurassic metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004a,b). Metallogenic belts for areas to the east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

Metallogenic Belt Related to Superterrane Accretion

The North Taimyr metallogenic belt possesses geologic units favorable for granite-related deposits (W-Mo-Be greisen, stockwork, and quartz vein, W-skarn, and porphyry Cu-Mo). The isotopic ages of the host granitoids range from 233 to 223 Ma (Vernikovsky, 1996). The belt is interpreted as having formed during generation of granitoids during and after accretion of the Kara superterrane with the North Asian craton.

Metallogenic Belts Related to Oceanic Crust

The Sambagawa-Chichibu metallogenic belt possesses geologic units favorable for stratiform sediment-hosted deposits (Besshi Cu-Zn-Ag massive sulfide, volcanogenic-sedimentary Mn, Cyprus Cu-Zn massive sulfide) that are now preserved in younger subduction-zone terranes. These terranes are the Shimanto subduction-zone terrane (part of the Sakhalin-Hokkaido collage), Mino Tamba Chichibu subduction-zone terrane (part of Honshu-Sikhote-Alin collage), and Sambagawa metamorphic terrane (part of the Honshu-Sikhote-Alin collage. The age of the host rocks for the deposits is interpreted as Early Jurassic and younger. The Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor, and the Besshi (fig. 5) and Cyprus deposits are interpreted as having formed during submarine volcanism related to an ocean-spreading ridge.

The North Kitakami metallogenic belt possesses geologic units favorable for Besshi Cu-Zn-Ag massive sulfide, volcanogenic-sedimentary Mn, and Cyprus Cu-Zn massive sulfide deposits. The belt and deposits are hosted in the Mino Tamba Chichibu subduction-zone terrane, part of the Honshu-Sikhote-Alin collage. The Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor. The kuroko deposits formed in an island arc. The deposits were subsequently incorporated into the subduction zone.

Major Late Carboniferous (Mississippian) to Early Jurassic (320 to 175 Ma) Metallogenic Belts and Host Units

Angara-Ilim Metallogenic Belt of Trap-Related Fes-Skarn (Angara-Ilim type), REE (±Ta, Nb, Fe) Carbonatite, and Weathering Crust Carbonatite REE-Zr-Nb-Li Deposits (Belt AI) (Southwestern North Asian Craton, Russia)

This Late Permian through Early Triassic(?) metallogenic belt is related to replacements associated with the Tungus plateau basalt, sills, dikes, and intrusions that overlie and intrude the southern part of the North Asian craton. The belt forms a wide and elongated band about 40,000 km^2 at the southern closure of the Tungussk syncline. Fe-skarn deposits are associated with with Triassic explosive, intrusive basalt trapp complexes in central type diatremes (Fon-der-Flaas, 1981). The deposits occur mainly along exocontacts of subalkalic diabase intrusions and rarely in adjacent Early Cambrian through Early Triassic wall rock. Lithological factors control deposit distribution and include favorable composition of host clastic, carbonate (dolomite), and evaporite rock, and the screening effect of mafic trapp rock. REE (±Ta, Nb, Fe) carbonatite deposits are related to central-type alkalic ultramafic intrusions that are exposed on the slopes of the uplifted basement as at the Chadobetsk uplift (Lapin, 1992; Lapin and Tolstov, 1993).

The main references on the geology and metallogenesis of the belt are Fon-der-Flaas (1981), Seminsky (1985), Lapin (1992), Lapin and Tolstov (1993), and Dobretsov (1997).

Korshunovskoye Trap-Related Fe-Skarn (Angara-Ilim type) Deposit

The deposit (Antipov and others, 1960; Vakhrushen and Vorontsov, 1976; Momdzhi, 1976; Strakhov, 1978; Fon-der-Flaas, 1981; Seminsky and others, 1994) occurs in southwestern North Asian craton in the southern closure of the Tungussk syncline. The deposit consists of a stockwork (with plan dimensions of 2,400 by 700 m) composed of four partly merged layers that contain variable amount of hematite and martite in upper layers, calcite and magnetite in middle layers, and halite and magnetite in lower layers. In the first type of deposit, the major minerals are magnetite, pyroxene, chlorite, and minor epidote. Lesser minerals are amphibole, serpentine, calcite, and garnet, and rare quartz, apatite, and sphene. Ore minerals occur in oolites, druses, masses, and disseminations. In the second type of deposit, the calcite increases to 20 to 30 percent, and ore minerals occur in nets, streaks, disseminations, and layers. In the third type of deposit, halite, amphibole, Mn magnetite are more abundant and the ore minerals occur in incrustates and streaks. All deposits contain pyrite, chalcopyrite, and pyrrhotite. Magnetitite-rich deposits are polygenic-hydrothermal-metasomatic deposits and are associated with magmatic intrusion, and rare metamatite-martite deposits are hypergenic. Host rocks are Early Carboniferous limestone, Ordovician salt-bearing rock, and Permian through Triassic tuffaceous sandstone. The deposit is large, with resources of 637 million tonnes ore grading 26 percent Fe to a depth of 1,200 m.

Chuktukonskoye REE (±Ta, Nb, Fe) Carbonatite and Weathering Crust Carbonatite REE-Zr-Nb-Li Deposit

This deposit (Lapin, 1992, 1996; Lapin and Tolstov, 1993) consists of Nb-REE minerals and phosphate minerals that occur in weathered carbonatite that is part of the

Chadobetsk alkalic ultramafic complex. The carbonatite contains mainly calcite and dolomite and has an isotopic age of 260 to 200 Ma. The weathered crust varies from 70 to 100 to 350 m and more thick. Minerals in the crust are of goethite, hematite, psilomelane, pyrolusite, barite, monacite, florensite, gorceixite, cerianite, and pyrochlore. At the bottom of the crust is francolite, quartz, and hydromica. Nb-REE minerals occur in residual lateritic ochre that formed in a leach zone and contains from 1 to 1.5 percent Nb_2O_5, 3 to 6 percent TR_2O_3 (0.1 to 0.3 percent Y_2O_3). Phosphatic and Nb-phosphate minerals occur in francolite rocks in a cemented zone and contain from 10 to 30 percent P_2O_5 (average of 17 to 20 percent). Ore minerals formed in an epigenetic-altered weathered crust at the top of the deposit in a bleached horizon that is depleted in Fe and Mn and rich in Nb (as much as 3 to 5 percent Nb_2O_5) and REE (as much as 15 to 20 percent TR_2O_3). Thickness of this horizon ranges from 3 to 12 m. Ore minerals are monazite, florensite, crandallite, pyrochlore, anatase, pyrite, and goethite. The deposit is medium size.

Origin and Tectonic Controls for Angara-Ilim Metallogenic Belt

The belt is interpreted as being related to widespread development of trapp magmatism on the North Asian craton. Fe-skarn deposits associated with Triassic explosive and intrusive basaltic trapp complexes in diatremes. REE-Ta-Nb carbonatite deposits are associated with alkalic ultramafic intrusions. The deposits are interpreted as having formed during intrusion of mantle-derived mafic magma and are mainly controlled by the major sublongitudinal and sublatitudinal

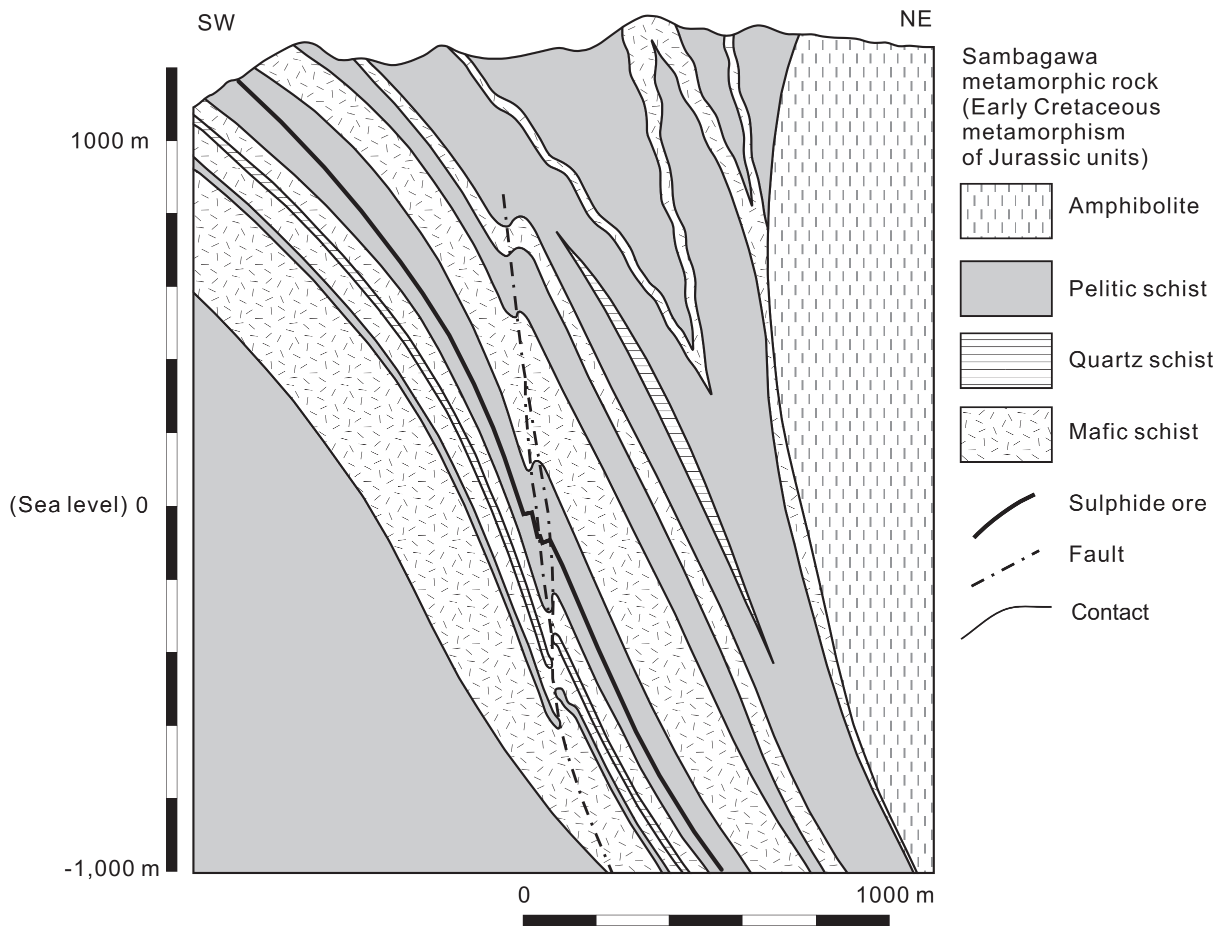


Figure 5. Schematic geologic cross section of Besshi Cu-Zn-Ag massive sulfide deposit, Sambagawa-Chichibu-Shimanto metallogenic belt. Adapted from Sumitomo Metal Mining Company (written commun., 1981).

regional faults. The belt occurs in two bow-shaped bands along the northern and southern boundaries of the Priangara syncline (Seminsky, 1985). The origin of the metallogenic belt is related to development of Permian and Triassic trapp magmatism in the Tungussk. Ancient, long-lived interblock basement fault zones were magmatic channels. Various districts occur in melanocratic and mesocratic igneous blocks in Platform basement rocks along local uplifted blocks. The widespread Permian and Triassic trapp magmatism is interpreted as being related to a mantle superplume (Dobretsov, 1997). The K-Ar isotopic age of alkalic ultramafic rock of the Chadobetsk Uplift ranges from 263 to 229 Ma.

Altay Metallogenic Belt of REE-Li Pegmatite, Muscovite Pegmatite, and Sn-W Greisen, Stockwork, and Quartz Vein Deposits (Belt AT) (Southwestern Mongolia)

This Late Carboniferrous metallogenic belt is related to veins, dikes, and replacements related to granitoids in the Pennsylvanian Altai volcanic-plutonic belt that intrudes the Paleoproterozoic Altai passive continental margin turbidite terrane in the Altay Mountain Range. More than 10,000 pegmatite veins occur in the metallogenic belt, and the belt contains numerous large and superlarge Li-, Be-, Nb-, Ta-pegmatite deposits and several tens of moderate to large muscovite pegmatite deposits. Muscovite reserves comprise more than 60 percent of the reserves for Mongolia. The belt trends northwest and is more than 450 km long and 70 to 80 km wide. The significant deposits are at Keketuohai and Ayoubulake.

The main references on the geology and metallogenesis of the belt are Rui and others (1993) and Tao and others (1994).

Keketuohai Li-REE Pegmatite Deposit

This deposit (fig. 6) (Lin and others, 1994; Editorial Committee of the Discovery History of Mineral Deposits, 1996) consists of (1) mitriform-pegmatite bodies that extend for 250 m, 250 m deep, and 150 m wide; and (2) gently dipping pegmatite veins that 2,000 m long, 1,500 m deep, and 40 m wide. The zoning of the mitriform pegmatite bodies from the margin to the center is: (1) graphic and graphic-like pegmatite; (2) sucrosic albite; (3) massive microcline; (4) muscovite-quartz; (5) cleavelandite-spodumene; (6) quartz-spodumene; (7) muscovite-lamella albite; (8) lamella albite-lepidolite; (9) central massive microcline and quartz zone. The pegmatite veins are divided into seven zones. The main alterations are biotite, Li-muscovite, Cs-biotite, Li-glaucophane, and fluorite alterations. The average grade in pegmatite is 6.5 percent muscovite, 0.05 percent lepidolite, 4.15 percent spodumene, 0.49 percent beryl, 0.05 percent pollucite. The mitriform pegmatite contains an average of 3,650 ppm LiO_2, 1,080 ppm Rb_2O, 190 ppm Cs_2O, 630 ppm BeO, 78 ppm Nb_2O_5, and 91 ppm Ta_2O_5. REE content is variable. The pegmatite bodies are related to Hercynian biotite microcline granite that is widespread and Ordovician biotite schist, staurolite schist, glaucophane schist that occur as relics in the granite intrusion. The granite also intrudes Paleozoic gabbro with an isotopic age of 330 Ma. The Keketuahai pegmatite no. 3 is a world class Be-Ta-Li pegmatite deposit. The deposit is large and has reserves of 244 tonnes Ta_2O_5. The average grade is 0.024 percent Ta_2O_5, 0.051 percent BeO, and 0.982 percent Li_2O.

Ayoubulake Muscovite Pegmatite Deposit

This deposit (Nie and others 1989; Ge and others, 1994) consists of 34 muscovite-pegmatite veins that range from 15 to 490 m long, extend several tens of meters downdip, and range from 0.5 to 15 m thick. Muscovite and quartz occurs in masses mainly in intermediate coarse-grained pegmatite. The host rocks are Ordovician staurolite schist, sillimanite schist, gneiss, and Hercynian biotite granite. An associated alteration zone is about 1 m wide and consists of muscovite, biotite, and toumaline. The deposit is large.

Origin and Tectonic Controls for Altay Metallogenic Belt

This belt is interpreted as having formed in during intrusion of anatectic granite that formed during collision of the Kazakhstan and North Asian cratons and resultant occurrence of high-grade metamorphism with crustal melting and generation of granite. The belt is hosted in postaccretionary mafic and ultramafic plutons that intrude along major east-west-trending faults. The host granite is mainly calc-alkaline and has a K-Ar isotopic age of 219 Ma. The granite intrudes both early Paleozoic metamorphic rock and Devonian through Early Carboniferous volcanic rock and turbidite that are regionally metamorphosed at moderate to low pressure and high temperature (Rui and others, 1993, Tao and others, 1994).

Battsengel-Uyanga-Erdenedalai Metallogenic Belt of Granitoid-Related Au Vein Deposits (Belt BUE) (Central Mongolia)

This Late Carboniferous through Permian metallogenic belt is related to small stitching plutons in the early stage of intrusion of the Hangay plutonic belt that intrudes Hangay-Dauria and Onon subduction-zone terranes. The metallogenic belt strikes northwest and is related Permian(?) granitoids, that from northwest to southeast intrude (1) the Hangay Dauria accretionary-wedge terrane, (2) the Onon accretionary-wedge terrane, and (3) the Permian Predhentey continental basin (part of Late Permian North Gobi overlapping assemblage) (Tomurtogoo and others, 1999) into which small Late Permian stocks and dikes of gabbro, diorite, granodiorite, and granite intrude coarse-grained sedimentary rock. Dejidmaa and others (1993) and Dejidmaa (1996) first studied and named this Au metallogenic belt as the Eastern Hangay belt that surrounds the Hangay Mountain Range to the northeast. The belt contains the Battsengel, Uyanga-Taragt, and Erdenedalai Au-bearing districts.The major deposits are at Mongot, Battsengel, Uyanga, Sharga Ovoo, and Tsagaan Ovoo.

The granitoid-related Au-vein occurrences consist of simple quartz veins and complicate metasomatitic zones with quartz veins and extend northwest. The occurrences are closely related to late Paleozoic diorite and granodiorite dikes and stocks. The occurrences are the sources for associated placer Au deposits The belt is bounded by the Orhon regional fault to northeast. The granitoid-related Au deposits are similar to those of the Ordovician Bayanhongor metallogenic belt described above. However, the age of granitoids hosting Au deposits in the Battsengel-Uyanga-Erdenedalai belt is not

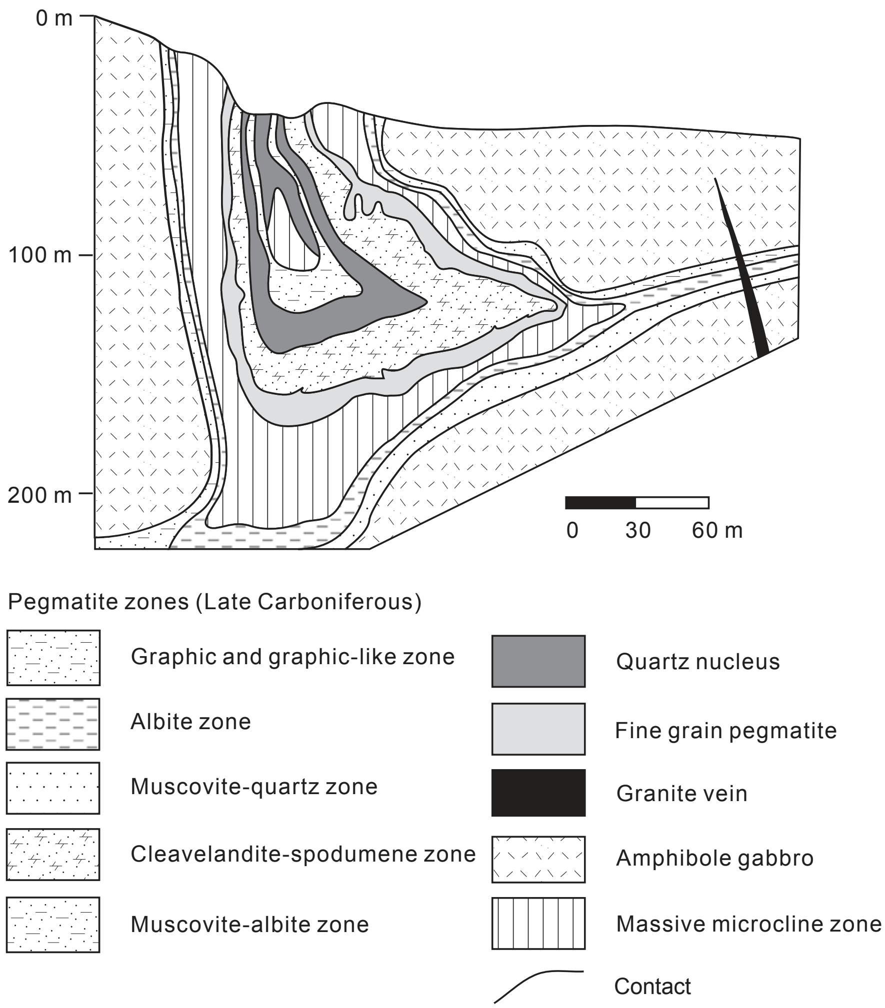


Figure 6. Geologic sketch map and cross section of Late Carboniferrous Keketuohai REE-Li pegmatite deposit, Altay metallogenic belt. Adapted from Lin and others (1994).

older than Late Permian as determined for the Sharga Ovoo and Tsagaan Ovoo Au occurrences in the southeastern part of the metallogenic belt. The Tsagaan Ovoo quartz-vein occurrence is in Permian sedimentary rock and is closely associated with an intruding diorite and granodiorite stock and dikes. Placer Au occurrences mined in ancient, small open pits are long known (Blagonravov and Shabalovskii, 1977).

The main references on the geology and metallogenesis of the belt are Blagonravov and Shabalovskii (1977), Dejidmaa and others (1993), Dejidmaa (1996), and Tomurtogoo and others (1999).

Sharga Ovoo Granitoid-Related Au-Vein Deposit

The deposit (O. Jamyandorj and others, written commun., 1972) is hosted in early Paleozoic gneissic granite and granodiorite that are intruded by granodiorite porphyry and diorite porphyry dikes and quartz veins. The quartz veins dip steeply, form a stockwork, occur along a northwest-trending weak shear zone, and form an en-echelon pattern. The stockwork consists of eight quartz veins, quartz veinlets, and local breccia, and varies from 40 to 300 m wide and 0.5 to 4.0 m thick. The host granite is silicified and cut by quartz stringers. The width of altered host rock varies from 1.0 to 20 m. Veins are white-grey, and contain coarse-grained quartz with pyrite, limonite, and rare gold. Gold is as much as 2 mm and is mostly fine-grained. Local visible gold occurs along selvages, especially in lower selvages. Channel samples contain from 0.1 g/t to 5.6 g/t Au, and rock-chip samples contain as much as 14.0 to 56.0 g/t Au.

Origin and Tectonic Controls for Battsengel-Uyanga-Erdenedalai Metallogenic Belt

The belt is interpreted as having formed along the Selenga transform continental-margin arc along the margin of the Mongol-Okhotsk Ocean with intrusion of subduction-related gabbro, diorite, and granodiorite stocks and dikes along the North Govi active continental-margin arc.

Buteeliin Nuruu Metallogenic Belt of Peralkaline Granitoid-related Nb-Zr-REE, REE-Li Pegmatite, W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposits (Belt BU) (North Mongolia)

This Early Permian metallogenic belt is related to high-alkaline granitic rock of the Selenga sedimentary-volcanic plutonic belt that intrudes the West Stanovoy terrane and to associated regional metamorphism. The belt extends 200 km and is about 30 km wide. The belt includes various deposits related to highly alkaline early Mesozoic granite stocks and associated rocks including U-Zr-REE, Ta-Nb-REE metasomatite, granitoid-related vein Bi, granitoid-related vein and stockwork U-Mo, Nb-Zr-REE peralkaline granite-hosted, Sn-W greisen, stockwork, and quartz-vein deposits. Many of these deposits occur in the northeastern late Paleozoic North Hangai REE metallogenic belt (Kovalenko and others, 1988, 1990; Kovalenko and Yarmolyuk, 1990) along the east-west trending Hangai regional fault. The early Permian age for the host granitic rocks is based on a U-Pb zircon isotopic age of 275 Ma for strongly foliated to mylonitized granite-gneiss. Contrasting K-Ar isotopic ages of 129 to 89 Ma exist for migmatite, gneissic granite, leucogranite, aplite, and pegmatite. The younger ages are herein interpreted as having formed during Late Mesozoic uplift and granitization. The major deposits are at the Bayangol district, Zelter Bi occurrences, and Arshivert occurrence.

The main references on the geology and metallogenesis of the belt are Luchitsky (1983), Kovalenko and others (1988), Kovalenko and Yarmolyuk (1990), Tsyba (1990), Kovalenko and others (1990), and Tomurtogoo and others (1999).

Bayangol District of Peralkaline Granitoid-related Nb-Zr-REE and REE-Li Pegmatite Occurrences

This district (Tsyba, 1990) occurs in the southwestern margin of the Buteeliinnuruu belt and is hosted in a granite-gneiss cupola with diameter of 12 km. The occurrence consists of quartz-K-feldspar-albite and albite metasomatite with high U, Th, REE, Zr, Ta, and Nb. The metasomatite occurs in weak fracture zones. The Gunondoriin Tsohio district is similar to the Bayangol deposit, occurs in the middle part of the belt, and consists of quartz-K-feldspar-albite metasomatite veins with high content of U, Th, Y, Yb, Nb, Ta, Zr, Ce, La, Hf, and Gd. This district forms an east-west-trending zone with surface dimensions of 3 by 13 km.

Bayangol 1 REE-Li Pegmatite Deposit

This deposit (Kudrin and Kudrina, 1959) consists of two spodumene pegmatite veins that are 100 to 200 m long and 10 to 20 m thick that cut Mesoproterozoic marble. The veins are composed of quartz, albite, spodumene, apatite, muscovite, beryl, columbite, pyrite, fergusonite, cassiterite, zircon, and lepidolite. Spodumene pegmatite occurs for 400 m along strike. The deposit is small.

Origin and Tectonic Controls for Buteeliinnuruu Metallogenic Belt

The belt is interpreted as having formed along the Selenga transform continental-margin arc along the margin of the Mongol-Okhotsk Ocean. The belt is hosted in an Early

Permian core complex containing granitoids of the Selenga sedimentary-volcanic plutonic belt that intrude granite-gneiss and mylonite in the West Stanovoy terrane. Alternatively, the belt may be related collisional granitoids generated during late Mesozoic closure of Mongol-Okhotsk Ocean.

Central Mongolia Metallogenic Belt of Fe-Zn Skarn, Sn-Skarn, Zn-Pb (±Ag, Cu) Skarn, W±Mo±Be Skarn, Cu (±Fe, Au, Ag, Mo) Skarn, Porphyry Cu-Mo (±Au, Ag); Porphyry Mo (±W, Bi), Granitoid-Related Au Vein, Cu-Ag Vein, W-Mo Greisen, Stockwork and Quartz Veins, and Basaltic Native Cu Deposits (Belt CM) (Central Mongolia)

This Early to Late Permian metallogenic belt is related to replacements and granitoids in the Selenga sedimentary-volcanic plutonic belt, occurs around the Hangay Mountain Range, and forms a large sickle shape in central Mongolia. The Selenga assemblage overlaps parts of the Late Archean and Paleoproterozoic Baydrag cratonal, Vendian through Middle and Late Cambrian Lake island arc, and Neoproterozoic through early Cambrian Idermeg passive marginal terranes (Tomurtogoo and others, 1999). The Central Mongolian metallogenic belt is dominated by skarn and porphyry deposits (Dejidmaa and others, 1996).

The major deposits are Menget and Sharain hudeg Fe-Zn skarn occurrences; Buyant group Fe-Sn skarn occurrences; Uzuur tolgoi, Berh Zn-Pb (±Ag, Cu) skarn occurrences; Chandmani Uul group and Buutsagaan Fe (Cu, Au) skarn occurrences; Buyant group W-skarn, Khohbulgiin hondii and Buutsagaan Au-Cu skarn occurrences; Saran uul porphyry Cu (±Au)-Au deposit, Tsahir hudag and Beger porphyry Cu (±Au) (Au, Ag) occurrences; Arynnuur porphyry Cu deposit, Naranbulag and Zost Uul porphyry Mo (±W, Bi) occurrences; Tsahir hudag and Chandmani uul group of granitoid-related vein and stockwork Cu occurrences; Oortsog, Olziit and Delgereh group of granitoid-related-vein and stockwork Au occurrences; Hatanbulag and Baga Bogd vein and stockwork Mo occurrences; and Buutsagaan group Cu basalt occurrences.

The skarn deposits are related to highly alkaline granitoids. Vein and stockwork Mo occurrences, as at Baga Bogd and Hatanbulag, occur in the central part of the belt in the Ih Bogd and Baga Bogd areas and are interpreted as having formed during intrusion of Permian subalkaline leucogranite stocks. Various porphyry Mo deposits and occurrences are related to granite porphyry stocks that are concentrated in the central part of the belt and are related to Late Carboniferous or Permian granodiorite and monzonite porphyry stocks. Granitoid-related vein and stockwork Cu occurrences are more extensive in the northern and central parts of the belt. Various basalt native-Cu occurrences in the Buutsagaan area are closely related to Permian basalt in the Hureemaral Formation.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Luchitsky (1983), Podlessky and others (1984), Sotnikov and others (1984, 1985), Dejidmaa and others (1996), and Tomurtogoo and others (1999).

Buutsagaan Au-Skarn Deposit

This deposit (Filippova and Vydrin, 1977; Podlessky and others, written commun., 1988; A.A. Rauzer and others, written commun., 1987) consists of magnesium skarn formed along the contact of Proterozoic schist and carbonate with a Permian granite massif. The deposit contains magnetite lenses and veins in an area of 0.25 by 0.75 km. The lenses and veins range from 6 m to 300 m long and 0.3 m to 4.5 m thick. Tourmaline, plagioclase, and quartz stringers also occur. Magnesium skarn is zoned intrusive to host metamorphic rocks with the following zones: granite replaced by pyroxene-plagioclase skarn; pyroxene-spinel skarn; pyroxene-spinel-forsterite skarn; forsterite-calcic skarn; and dolomite marble. Most magnetite is deposited in magnesium skarn. During calcic- skarn formation spinel-pyroxene skarn overprinted magnesium skarn and grossular-vesuvianite-salite-sulfide skarn along the endocontact of the granite massif. In Cu-sulfide skarn, the grade ranges as much as 150.0 g/t Au. Grab samples is as much as 2.0 percent Cu, 30.0 g/t Cd, 1.0 to 1.5 percent Zn, and 50.0 g/t Ag.

Zos Uul Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Bayandorj and others, written commun., 1980; Sotnikov and others, 1981, 1985a,b) consists of Late Permian and Early Triassic granitoids that intrude Paleoproterozoic metamorphic rock Early Proterozoic granite;, Cambrian gabbro; granodiorite; and granite; ; Early Devonian volcanic rocks; and Permian granosyenite and granite. The Late Permian and Early Triassic granitoids consist of a granodiorite and granite massif and porphyry in stocks and dikes. The porphyry stock and dikes and host rocks are intensively altered to silica, sericite, and pyrite. Quartz-sulfide vein and stockwork occur in altered rocks. The size of the stockwork is 2.0 by 2.2 km. Quartz-sulfide vein and veinlets are extensive in the western, eastern, and southern margins of the granite porphyry stock. The quartz-sulfide vein and stockwork contain rare molybdenite, quartz-molybdenite, and quartz-pyrite-chalcopyrite-molybdenite stringers and disseminations. Extensive hydrothermal alteration with quartz-sericite and quartz replacements in bodies ranging as much as 20.0 by 40.0 m also occur. Relicts of early-stage potassium feldspar alteration that is intensively developed in a granite-porphyry stock also occur. Also occurring are rare quartz-potassium feldspar veinlets with pyrite, garnet-epidote skarn that is overprinted by pyrite-chalcopyrite stringers. The deposit developed in the following stages: K feldspar-quartz, quartz-magnetite, quartz-sericite-chalcopyrite-molybdenite, quartz-polymetallic (sphalerite and galena), and post-ore chlorite-epidote-carbonate. Ore minerals are more abundant in quartz-sericite replacement. The deposit is small amd has a resource of 100,000 tonnes of Mo and average grades of 0.2 percent Cu and 0.01 percent Mo.

Erdenekhairkhan Cu (±Fe, Au, Ag, Mo) Skarn Deposit

This deposit (A. Enkhbayar and others, written commun., 1982; B.A. Samozvantsev and others, written commun., 1982) is hosted in Vendian and early Paleozoic carbonate rocks of the Tsagaanolom Formation that is intruded by a Permian syenite stock. According to a magnetic anomaly, the skarn is 600 m long and 300 to 400 m wide. The skarn is cut by two northeast-trending, steeply dipping faults that define three blocks. The central block is uplifted and more eroded; the northern and the southern blocks are downdropped. Three small openpits of size with surface dimensions of 2 by 70-80 m to 4 by 200 m occur in the central block. The deposit consists of disseminations and stringers of chalcopyrite and bornite. Host carbonate rock is locally altered to serpentinitie and recrystallized. Ore minerals are magnetite-hematite (5 to 70 percent), Fe oxides (as much as 7 percent), and minor chalcopyrite, bornite, chalcocite, malachite, native copper, covellite, native silver(?) and pyrrotite. Channel samples contain 0.89 to 2.34 percent Cu, and core-samples contain 0.2-1.0 percent Cu, as much as 1.8 g/t Au, and 0.4 g/t Ag . Grab samples grade from 0.1 to 1.0 percent to 7.88 percent Cu, 10.0 to 50.0-100.0 g/t Ag. Extensive northeast-trending quartz-carbonate veins occur in the eastern and south-eastern parts of the deposit and range from 0.2-0.5 m thick, and 20.0-100.0 m long. A Au soil anomaly occurs in an area 300 by 350 m, close to skarn. The average grades of the deposit are 1.3 to 1.4 g/t Au, 0.2 to 1.0 percent Cu, and 10.0 to 50.0 g/t Ag.

Origin and Tectonic Controls for Central Mongolia Metallogenic Belt

The belt is interpreted interpreted as having formed along the Selenga transform continental margin arc along the northern margin of the Mongol-Okhotsk Ocean. However, Tomurtogoo and others (1999) interpret the host Selenge assemblage as an intercontinental volcanic belt. Herein, the assemblage is herein interpreted as an overlapping Late Carboniferous through Late Permian continental margin arc that was tectonically linked to a subduction zone on the margin of Mongol-Ohotsk Ocean. Remnants of the ocean occur in a narrow band that extends for 3,000 km from central Mongolia to the Ohotsk Sea (Obolenskiy and others, 1999).

Duobaoshan Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag) Deposits (Belt DB) (Northeastern China)

This Pennsylvanian metallogenic belt is related to granitoids in the Nora-Sukhotin-Duobaoshan island-arc terrane, part of the South-Mongolia collage in the western Heilongjiang Province. The belt trends northeast and is about 130 km long and 30 km wide. The Nora-Sukhotin-Duobaoshan terrane is composed of (1) Cambrian metasandstone, and phyllite with the intercalation of the lenticulars of limestone; (2) Ordovician and Silurian metabasalt, metaandesite, metadacite and volcanic breccia with intercalated marble; (3) Early Devonian mudstone and tuff spilitic keratophyre; (4) Middle to Late Devonian sandstone, mudstone, and limestone; and (4) Late Carboniferous and Permian granite. The significant deposit is at Duobaoshan.

The main references on the geology and metallogenesis of the belt are Du (1980), Ge and others (1989), and Nei (2000).

Duobaoshan Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Ge and others, 1994) consists of disseminations, veinlets, and breccias in granodiorite and late Ordovician andesitic porphyry and tuff in the Duobaoshan Formation. The granodiorite forms a composite batholith with a surface exposure of 8 km^2. In the western part of the batholith is a granodiorite porphyry with a surface area of 0.16 km^2. Circular zonal alteration occurs around the silicified porphyry and consists of K-feldspar, sericite, and propylitic alteration zones from core to periphery. Main ore minerals are pyrite, chalcophyrite, and bornite, with minor molybdenite, chalcocite, magnetite, sphalerite, pyrrhotite, tetrahedrite, and galena. A K-Ar isotopic age for the batholith is 292 Ma and the ratio of K_2O/Na_2O is 0.5. The deposit occurs in a transitional uplift between the Daxinganling Mountain Range and the Songliao Basin. The deposit is large and has reserves of 2.37 million tonnes grading 0.45 percent Cu.

Origin and Tectonic Controls for Duobaoshan Metallogenic Belt

The belt is interpreted as having formed in a subduction-related Pennsylvanian granodiorite porphyry that formed in the Ordovician through Late Devonian Nora-Sukhotin-Duobaoshan island-arc terrane as part of the South-Mongolia-Khingan island arc. The subduction-type granodiorite porphyries that host the porphyry Cu-Mo (±Au, Ag) deposit and adamellite are Late Carboniferous. The Middle Ordovician andesite volcanic rock may also host part of the deposit (Du, Qi, 1980; Nei, Zhong-yao, 2000). Major faults strike northwest and are an important control for the Duobaoshan metallogenic belt.

Harmagtai-Hongoot-Oyut Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag), Porphyry Au, Granitoid-Related Au Vein, and Au-Ag Epithermal Vein Deposits (Belt HHO) (Southern Mongolia)

This Middle Carboniferous through Early Permian metallogenic belt is related to granitoids of the Mandah intrusive complex that form part of in the southern part of the South Mongolian volcanic-plutonic belt that intrudes the Mandalovoo-Onor island-arc and Mandah subduction-zone terranes. The Harmagtai-Hongoot-Oyut belt extends southwest-northeast for 450 km and ranges from 30 km to 60 km wide. Yakovlev (1977) first defined the Mandah Cu district. Subsequently, Shabalovskii and Garamjav (1984) and Sotnikov and others (1984, 1985a,b) defined the South Mongolian porphyry Cu (±Au) metallogenic belt.

The Mandah intrusive complex consists of monzo-diorite, granodiorite, granite, and deposit-hosting diorite porphyry and granodiorite porphyry stocks and dikes. The complex is coeval with andesite, dacite, and rhyolite volcanic rock of the Doshiin ovoo Formation. The Mandah complex was described as Late Carboniferous and Early Permian (Goldenberg and others, 1978) or as Middle and Late Carboniferous (Tomurtogoo, 1999). Geological and isotopic-age data indicate that plutons (South Mandah, Hongoot and others) in the eastern belt are Late Carboniferous (Sotnikov and others, 1984), whereas (Harmagtai and others) in the western belt are Late Carboniferous and Early Permian.

From east to west the belt contains the Oyut, Nariin hudag, Hongoot, and Kharmagtai districts. Special features of the belt are high Au in porphyry Cu-Mo (±Au, Ag) deposits and occurrences and a close spatial and genetic relation of porphyry Cu-Mo (±Au, Ag) and vein and stockwork Au-Ag-Cu deposits. The major deposits are the Hongoot porphyry Cu-Mo (±Au, Ag) occurrence, the Nariinhudag porphyry Cu (±Au) deposit, the Shuteen porphyry Cu-Au deposit, and the Uhaa hudag and Kharmagtai 2 porphyry Au occurrences, and the Shine, Hatsar, and other Au-Ag-Cu occurrences.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Goldenberg and others (1978), Luchitsky (1983), Shabalovskii and Garamjav (1984), Sotnikov and others (1984, 1985a,b), Tomurtogoo (1999), Tomurtogoo and others (1999), and Bignall and others (2005).

Shine Granitoid-Related Au Vein Occurrence

The occurrence (A.E. Shabalovskii and others, written commun., 1978; Sotnikov and others, 1985a,b) is related to the Oyut granitoid massif in Middle to Late Carboniferous Mandakh Complex at a distance of 400 to 1500 m from the contact. The deposit contains stringers and disseminations of epidote, pyrite, molybdenite, and chalcopyrite grading 0.3 to 3.38 percent Cu and average 0.008 percent Mo. The deposit is located in zone that dips northwest, and ranges from 100 to 120 m wide and 350 to 400 m long. The zone is hosted in Devonian brecciated andesite is altered to K feldspar, epidote, sercite, and chorite. The ore and replacement minerals are formed in following sequence: K-feldspar-epidote; molybdenite; chlorite-sericite; pyrite-chalcopyrite; calcite. The occurrence probably formed in the upper part of a magmatic system. Drill cores reach a depth of 82 m and contain 0.3-1.0 percent Cu, 0.01 to 1.0 g/t Au, and trace to 0.003 percent, Mo.

Kharmagtai 2 Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Yakovlev, 1977; Sotnikov and others, 1985a,b; Kerwin and others, 2005) is hosted in Late Carboniferous and Early Permian diorite and granodiorite that intrudes Devonain tuff, andesite, and tuffaceous sandstone and siltstone. The ore minerals are chalcopyrite, covellite, bornite, and molybdenite. Oxidation minerals are malachite, azurite, and cuprite. Associated minerals are pyrite and magnetite and peripheral sphalerite, galena, and gold. The deposit is related to subvolcanic bodies of diorite and granodiorite porphyry in two stocks and bodies explosive breccia. The bodies ranges from 200 to 400 m wide amd are 900 m long. Surface grades are 0.05 to 0.4 percent Cu and 0.003 to 0.03 percent Mo over an area of 400 by 900 m. A zone 100 by 300m contains >0.3 percent Cu. The deposit extends at least to a depth of 250 m and is defined by stockwork veinlets of quartz with chalcopyrite and molybdenite that occur across the breccia pipe. Hydrothermal alteration minerals are weakly developed silica, sericite, K feldspar, chorite, epidote, and tourmaline. Sericite, potassic, and silicic alterations occur in the center of alteration zone, and chlorite and epidote alteration occurs along the periphery. Potassic alteration occurs mainly in the deeper part of deposit. The deposit is not well studied. The deposit is small with resources of 0.8 million tonnes Cu grading 0.35 percent Cu.

Origin and Tectonic Controls for Harmagtai-Hongoot-Oyut Metallogenic Belt

The belt is interpreted as having formed in the South Mongolian continental margin arc. The volcanic-plutonic belt formed a continental margin arc overlapping the Mandalovoo-Onor island-arc terrane and Mandah subduction-zone terranes.

Hitachi Metallogenic Belt of Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposits (Belt Hit) (Japan)

This Permian metallogenic belt is related to strati-form units in the South Kitakami terrane (probably part of Sino-Korean craton) and it occurs in the southern end of the Abukuma Mountains in Northeast Japan. The belt is 15 by 10 km and the western margin of the belt is the Tanakura tectonic line. The metallogenic belt occurs in metamorphic rock (Paleozoic Hitachi Formation). Cretaceous granitoid occur north of the belt, and contact metamorphosed rocks occur in the northern belt. The eastern margin of the belt is covered by Neogene sedimentary rock. The metallogenic belt contains the Hitachi deposit, a Kuroko type Cu-Zn deposit. Tsuboya and others (1956) first defined this belt as the Abukuma metallogenic province. The Hitachi Formation consists mainly of mafic to siliceous volcanic rock, slate, and limestone. The formation strikes generally northeast, and metamorphic grade increases from east to west, as much as amphibolite facies grade (Tagiri, 1971).

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956), Tagiri (1971), and Minato and others (1979).

Hitachi Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type) Mine

This mine (Omori and others, 1986) consists of eight stratiform ore bodies that occur in the Fujimi and Fudoutaki groups according to stratigraphic position. Bodies are hosted in greenschist, biotite-quartz schist, sericite-quartz schist, and siliceous schist of Paleozoic Hitachi Metamorphic Rock. The Fujimi ore bodies occur at, or near the contact between siliceous schist and overlying mafic to intermediate schist. The Fudoutaki bodies occur in mafic and intermediate schist. Geochemical studies suggest an origin of basalt in a marginal basin. The presence of calc-alkaline rock also indicates an island-arc setting. The ore bodies extend about 3,000 m along strike and about 700 m down dip. Individual ore body range from 150 to 600 m along strike and are 10 to 80 m thick. The main ore minerals are pyrite and chalcopyrite. Other ore minerals are pyrrhotite, sphalerite, galena, magnetite, marcasite, cubanite, and valleriite. Gangue minerals are quartz, barite, biotite, chlorite, sericite, calcite, gypzum, and cordierite. Contact metamorphism adjacent to a Cretaceous granite is also recognized. Mining started in 1591 and ceased in 1981. The mine is medium size and has produced 440,000 tonnes of Cu and 40,000 tonnes of Zn grading 1.5 percent Cu.

Origin and Tectonic Controls for Hitachi Metallogenic Belt

The belt interpreted as having formed in a subduction-related island arc along the margin of the Sino-Korean craton.

Kalatongke Metallogenic Belt of Mafic-Ultramafic Related Cu-Ni-PGE and Granitoid-Related Au-Vein Deposits (Belt KL) (Northwestern China)

This Pennsylvanian metallogenic belt is related to mafic-ultramafic and granitic plutonic rocks in the Waizunger-Baaran island-arc terrane, part of the Atasbogd collage that contains the South Mongolia-Khingan island arc. The belt occurs in the Ertix and Ulungur River areas south of the Altay Mountains, trends northwest, is 500 km long, and is as much as 70 km wide. The mafic-ultramafic plutons host Cu-Ni-PGE sulfide deposits, and the granite plutons contain Au deposits. The significant deposits are at Kelatongke and Alatasi.

The main references on the geology and metallogenesis of the belt are Tang and Li (1991), Rui and others (1993), and Kong (1994).

Kalatongke Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Wang and others, 1992; Editorial Committee of The Discovery History of Mineral Deposits, 1996) consists of nine Carbonaceous mafic-ultramafic intrusions with the number 1 intrusion being the largest. The intrusion is lenticular in plan view, and is 640 m long and 35 to 350 m wide, trends northwest, and dips 20 to 28° NE. In cross section, the pluton is wedge-shaped with a wide upper part and narrow lower part. The margin of the upper part consists of biotite diorite, gabbro, and contains sparse sulfide. The center of the upper part is gabbro and norite facies consisting mainly of biotite amphibole norite, gabbro, and quartz-bearing amphibole norite and contains lean Cu-Ni sulfides at the base. The center of the lower part is biotite-amphibole norite, biotite-olivine norite, and peridotite with more abundant sulfides at depth. The marginal part of the lower part is biotite-amphibole diabase and gabbro, olivine-amphibole diabase and gabbro and contains lean sulfides. The intrusion is ultramafic with a Mg/Fe ratio of 2:3. Ore minerals are mainly pyrrhotite, chalcopyrite, pentlandite, pyrite, and magnetite and 60 other lesser sulphides and oxide minerals. Ore minerals occur in masses and and disseminattions. Autometamorphism is widespread with formation of serpentinite, talc, bioitite, and uralite. The deposit formed during intrusion of magma, injection of magma with subsequent hydrothermal and weathering. The deposit is large with reserves of 410,800 tonnes of Cu, 1.740 tonnes of Pt, and 2.161 tonnes of Pd. The average grade is 0.58 to 0.88 percent Ni, 1.40 percent Cu, 0.07 g/t Pt, and 0.09 g/t Pd.

Alatasi Granitoid-Related Au Vein Deposit

This deposit (Rui, 1993) trends northwest for about 70 km in the metallogenic belt and contains several tens of veins and altered zones that vary from 1 to 3 km long and 0.05 to 0.4 km wide. These zones, veins, and lenses are concordant to host strata, or crosscut host strata at low angles of 5 to 15°. The ore minerals occur in veinlets, disseminations, and stockworks with idiomorphic-hypidiomorphic and caulking textures. The main ore minerals are pyrite, galena, native Au, and magnetite. Alterations are pyrite, bericite, silica, carbonate, hydromica alterations. The host rocks are Middle Devonian andesitic and basalt tuff and tuffeous breccia; Late Devonian sandstone, siltstone, and mudstone; and local andesite, rhyolite, and trachyte. The host rocks and Au deposits are related biotite granite, granodiorite, potassic granite, granite porphyry, quartz porphyry, diorite, and diorite porphyry. The deposit is medium size.

Origin and Tectonic Controls for Kalatongke Metallogenic Belt

The belt is interpreted as having formed in the Waizunger-Baaran island-arc terrane, part of Atasbogd collage and the

South Mongolia-Khingan island arc. The Waizuger island-arc terrane consists of (1) Ordovician limestone with intercalated andesite, clastic rock, tuff, mafic and siliceous volcanic rock, and muddy limestone; (2) Silurian sandstone, conglomerate, limestone, pyroclasic rock; (3) Devonian mafic and intermediate and mafic volcanic rock that consist mainly of siliceous volcanic rock and tuff, fine-grained sandstone, siltstone, and limestone, (4) Carboniferous clastic rock; and (5) Permian continental volcanic and clastic rock with local coal. The calc-alkalic granite related to the Au deposits and the mafic-ultramafic volcanic-plutonic complex related to Cu-Ni sulfide deposits are interpreted as being part of the island arc that was tectonically linked to a subduction zone to the south in Wulungu River area (Kong, 1994 and Rui and others, 1993). Some authors interpreted the Cu-Ni sulphide deposits and related mafic-ultramafic plutonic rocks as having formed in an extensional basin controlled by major faults along the southern margin of the Altay continent with lithosphere thinning and upwelling of upper mantle rocks resulting in emplacement of the mafic-ultramafic plutons into shallow crust (Tang and Li, 1991).

Kureisko-Tungsk Metallogenic Belt of Fe-Skarn, Mafic-Ultramafic Related Cu-Ni-PGE, and Metamorphic Graphite Deposits (Belt KT) (Western North Asian Craton, Russia)

This Permian through Triassic metallogenic belt is related to replacements and plutons in the Tungus plateau basalt, sills, dikes, and intrusions and occurs in a wide band along the western margin of North Asian craton for more than 900 km (Malich and others, 1987). The belt contains Fe skarn deposits, Cu-Ni-PGE sulfide deposits related to mafic-ultramafic rock, and metamorphic graphite deposits. The belt is controlled by the area of the Triassic trapp magmatism and the major Yenisei sublongitudinal fault zone that occurs along the western border of the Tungussk syncline. The metallogenic belt is conjugated with the Norilsk metallogenic belt to the north. Fe-skarn deposits occur along exocontacts of subalkalic diabase and are rarely farther removed (Pavlov, 1961). The age of host rocks ranges from Early Cambrian through Early Triassic. Cu-Ni-PGE deposits are hosted in dunite, gabbro, troctolite, and diabase intrusions (Kavardin, 1976; Dyuzhikov and others, 1988). The graphite deposits occurs in areas of contact metamorphism of Permian coal-bearing sequences by Triassic trapp intrusions (Malich and others, 1987).

The main references on the geology and metallogenesis of the belt are Pavlov (1961), Malich and others (1974), Kavardin (1976), Dyuzhikov and others (1988), Surkov (1986), and Dobretsov (1997).

Suringdakonskoye Fe-skarn Deposit

This deposit (Pavlov, 1961; Kalugin and others, 1981) consists of a steeply-dipping magnetite body in Late Devonian limestone and Permian clastic rock of age intruded by trapp magma. The deposit is 1.9 km long and varies from 35 to 40 m thick. Along strike, massive ore grades into streaks and disseminations in a zone that extends for 1.5 km and ranges from 50 to 350 m thick. Host rock for streaks and disseminations is garnet-chlorite-carbonate metasomatite. Masses grade 58.43 percent Fe, and disseminations grade 20.39 to 47.07 percent Fe. The deposit is large and has resources of 600 million tonnes grading 20 to 59 percent Fe.

Bilchany River Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Kavardin and others, 1967; Kavardin, 1976.) consists of Cu-Ni sulfides in a Triassic dolerite intrusive. The sulfides occur in nests and disseminatons. Ore minerals are pyrrhotite, pentlandite, chalcopyrite, and pyrite. The deposit is small.

Noginskoye Metamorphic Graphite Deposit

This deposit (Malich and others, 1974, 1987) consists of beds of amorphous (cryptocrystalline) graphite in an Early Jurassic coal-bearing sedimentary sequence that is intruded by a stratified trapp Triassic intrusion. Host rock consist of graphite and contact metamorphosed and graphite shale. Two beds of high-quality graphite occur, a lower bed that ranges as much as 6.7 m thick and an upper bed that is 1.7 m thick. The beds extend for 1.2 km. Graphite occurs in crystalline form and comprises as much as 40 percent by volume. Small amounts of hydrothermal graphite occur in carbonate veinlets with sulfides. Graphite ores occur in columns, layers, masses, and breccia. The deposit is large and has average grades of 71.33 to 90.56 percent C, 8.53 to 24.34 percent ash, and 0.28 to 3.06 percent volatiles. The deposit was abandoned.

Origin and Tectonic Controls for Kureisko-Tungsk Metallogenic Belt

The belt is interpreted as being related to mantle-derived superplume magmatism that resulted in widespread development of trapp magmatic rocks on North Asian craton along the long-lived West-Siberian rift and major Yenisei sublongitudinal fault (Surkov, 1986; Dobretsov, 1997). This belt occurs in the intersection of two lithospheric plates, the oceanic West-Siberian plate and continental Siberian plates. The Priyeniseisk deep-fault zone contains numerous Triassic diabase intrusions and ore occurrences, mainly Fe-skarn (of Angara-Ilim type). The majority of deposits occur along intersections of sublongitudinal and sublatitudinal faults (Malich and others, 1987). Graphite deposits formed as a result of thermal metamorphism of the late Paleozoic coal-bearing sedimentary rock during intrusion by numerous diabase intrusions (Malich and others, 1974).

Maimecha-Kotuisk Metallogenic Belt of Fe-Ti (±Ta, Nb, Fe, Cu, apatite) Carbonatite, REE (±Ta, Nb, Fe) Carbonatite, and Phlogopite Carbonatite Deposits (Belt MK) (Northwest of the North-Asian Craton, Russia)

This Late Permian through Early Triassic metallogenic belt is related to volcanic flows of the Tungus plateau basalt that occurs in the northwestern North Asian craton. The eastern boundary is the western border of the Anabar Shield. Varied Permian and Triassic magmatic rocks are widespread in the belt and consist of tholeiite, diabase, trachybasalt, picrite, and melanonephelinite extrusive and intrusive rock, and ijolite, carbonatite, and kimberlite complexes (Egorov, 1970; Malich and others, 1987). More than twenty, central-type, alkalic ultramafic plutons with carbonatite occur in the belt. The largest of these are the Gulinskoe pluton (about 500 km^2), Odikhincha pluton (56 km^2), Magan pluton (42 km^2), Bor-Uryach pluton (17 km^2), Kugda pluton (16.5 km^2), Essey pluton (6 km^2), and Irias pluton (6 km^2). Ijolite and carbonatite are most prevelant rock types. Most alkalic ultramafic carbonatite intrusions contain magnetite, titano-magnetite, perovskite, REE, phlogopite, apatite, and nepheline deposits (Malich and others, 1987). Several groups of deposits occur in the belt (1) large-and average-size Fe-Ti carbonatite (Gulinskoye I), Magan I, Bor-Uryach and others; (2) large REE (±Ta, Nb, Fe) carbonatite (Gulinskoye I); and (3) medium-size phlogopite-carbonatite (Odikhimcha I and others).

The main references on the geology and metallogenesis of the belt are Egorov (1970), Samoilov (1977), Yaskevich and others (1980), Malich and others (1987), Basu and others (1995), and Zolotukhin (1997).

Gulinskoye 1 Fe-Ti (±Ta, Nb, Fe, Cu, apatite) Carbonatite Deposit

This deposit (Kalugin and others, 1981; Sinyakov, 1988) consists of titanomagnetite in the Gulinsk alkalic central type ultramafic pluton. Titanomagnetite occurs in pyroxenite and peridotite in a half-ring zone that is 30 km long and 100 m wide. Titanomagnetite occurs as dissemination and locally in veins, nests, lenses, and large deposits that comprise as much as 25 to 30 percent pyroxenite bodies by volume. Dimensions of discrete concentrations range from 100 to 200 m to 5 km along strike and from 10 to 30 to 600 m thick. The deposit is large. Resources are 1.8 billion tonnes to a depth of 100 m, and has an average grade of 22.4 percent Fe.

Gulinskoye 2 REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (Kavardin and others, 1967) consists of REE in alkalic ultramafic carbonatite plutons. Two carbonatite plutons, with outcrop areas of 3 km^2 and 5 km^2, occur around the Gulinskoye phlogopite deposit. The plutons consist of vertically-dipping, isometrical bodies of mainly ankaratrite, picrite, peridotite, and melilite. The deposits consist of irregular, fine-grained disseminations of ore minerals in calcite, calcite-magnetite, calcite-dolomite, and dolomite carbonatite. Pyrochlore occurs with magnetite, serpentine, and REE minerals. Perovskite occurs in nests with magnetite and melanite, and is more abundant in micaceous melanite and pyroxenite in the Gulinskii pluton. The deposit is large and world class.

Odikhincha 1 Phlogopite Carbonatite Deposit

This deposit (Prochorova and others, 1966; Dyadkina and Orlova, 1976; Malich and others, 1987) consists of phlogopite deposits in the central type Odikhincha alkaline-ultramafic pluton. Phlogopite formation occurred in the ijolite and carbonatite stages of the pluton. The major phlogopite concentrations occur in dunite and and along contacts with ijolite-melteigite. Dunite contains as much as 10 to 30 percent phlogopite. Monomineral phlogopite veins occur in fissure zones in dunite. The veins are as much as several tens of meters long and as much as 1.5 to 2 m thick. Veins also contain olivine, titanomagnetite, calcite, and perovskite. Diopside-phlogopite veins occur near the contact of the pluton with wallrock. Phlogopite also occurs in garnet-nepheline-pyroxene and nepheline-melilite pegmatite veins. The deposit is medium size.

Origin and Tectonic Controls for Maimecha-Kotuisk Metallogenic Belt

The belt is interpreted as being related to mantle-derived superplume magmatism that resulted in widespread development of trapp magmatism on the North Asian craton. Magmatic rocks include tholeiite, diabase, trachybasalt, and melanonephelinite volcanic and intrusive rock, and ijolite-carbonatite and kimberlite complexes. The belt occurs at intersection of the trans-Asian longitudinal Taimyr-Baikal lineament and the major Yenisei-Kotuisk sublatitudinal fault belt. The distribution of the plutons of alkalic and ultramafic rock is determined by intersections of the major faults. Abyssal differentiation of mantle olivine-melilite magma was a crucial factor in multistage development of deposit-hosting plutons. Their compositions were complicated by superimposed metasomatic processes (Egorov, 1970; Samoilov, 1977). According to the $^{40}Ar/^{39}Ar$ data, the age of deposit-hosting intrusions ranges from 253.3 to 249.88 Ma (Basu and others, 1995) that corresponds to the Early Triassic stage of development of trappean magmatism at the North Asian craton (Zolotukhin, 1997). The origin of alkalic ultramafic-carbonatite plutons and accompanying deposits is geodynamically related to continental rifting occurring above a hot spot in the southern flank of the Yenisei-Khatanga rift (Yaskevich and others, 1980).

Mino-Tamba-Chugoku Metallogenic Belt of Volcanogenic-sedimentary Mn, Podiform Chromite, and Besshi Cu-Zn-Ag Massive Sulfide Deposits (Belt MTC) (Japan)

This Permian (or older) to Jurassic metallogenic belt is hosted in structural units in the Mino-Tamba-Chichibu and Akiyoshi-Maizuru subduction-zone terranes. The belt occurs in the western part of Honshu Island in the Inner Zone of southwestern Japan, trends east-northeast to west-southwest for more than 900 km, and is as much as 150 km wide. The eastern margin of the belt is the Tanakura tectonic line. Tsuboya and others (1956) named the belt the Chichibu geosyncline Fe-Mn metallogenic province. The North Kitakami metallogenic belt is interpreted as being an eastern extension of this belt. The Mino-Tamba belt contains a large number of various types of deposits. Mn deposits are hosted in the Mino-Tamba-Chichibu terrane, and podiform chromite and Besshi Cu-Zn-Ag massive sulfide deposits are hosted in in the Akiyoshi-Maizuru terrane. The Mino-Tamba-Chichibu terrane is a Jurassic accretionary complex and Mn deposits are associated with Triassic and Jurassic chert. Podiform Cr deposits occur in ophiolite in the prePermian Sangun metamorphic complex. Massive sulfide deposits occur in the Permian forearc Maizuru group. The significant deposit is at Awano.

The main reference on the geology and metallogenesis of the belt is Tsuboya and others (1956).

Wakamatsu Podiform Chromite Mine

This deposit (Tsuboya and others, 1956) occurs in serpentinite derived from dunite of the Tari-Misaka ultramafic body in the Sangun belt. The ultramafic body is mostly composed of massive harzburgite and dunite. The ultramafic rocks are contact metamorphosed by a Cretaceous granite. The mine contains three main ore bodies. Main number 7 body is 190 m long, 60 m wide, and 30 m thick and yielded 1 million tonnes ore. The ore mineral is refractory grade chromite. Serpentine and olivine occur in ore. The deposit was discovered in 1899, and the mine closed in 1994. The deposit is medium size and produced 780,000 tonnes of ore grading 32 percent Cr_2O_3.

Yanahara Besshi Cu-Zn-Ag Massive Sulfide Mine

This mine (Mining and Metallurgical Institute of Japan, 1965; Dowa Mining Corporation, 1981) consists of the main Yanahara ore body and nine smaller ore bodies. The ore bodies are stratiform and lenticular, and occur in an area 4.5 by 2 km. The main Yanahara ore body contains the upper, lower, and lowest ore bodies. The upper body is 350 m long along strike, extends 1000 m down dip, and is as much as 100 m wide. The lower ore body is similar. The main ore mineral is pyrite; minor ore minerals are pyrrhotite, magnetite, chalcopyrite, and sphalerite. Gangue minerals are quartz, sericite, and chlorite. The deposit is hosted in rhyolite pyroclastic rock and mudstone of the Paleozoic Maizuru Group. The deposit occurs immediately above the basalt of the Yakuno Group. The mine started in 1916 and closed in 1991. The mine is medium size and has reserves of 3.7 million tonnes grading 44 percent Fe, 47 percent S, 0.2 percent Cu, and 0.3 percent Zn.

Hamayokokawa Volcanogenic-Sedimentary Mn Mine

This mine (Mining and Metallurgical Institute of Japan, 1968; Uemura and Yamada, 1988) is located in the Yokokawa (Shiojiri) Mn deposit district that contains 17 deposits. The Hamayokokawa deposit is the largest and contains six main ore bodies. The largest ore body is 50 m long, 8 m thick, and extends 120 m down dip. The ore bodies occur in Paleozoic and Mesozoic chert and slate of the Mino belt. The ore minerals are rhodochrosite, hausmannite, manganosite, rhodonite, tephroite, and braunite. The mine closed in 1984. The mine is medium size and produced 260,000 tonnes of ore grading 33 to 42 percent Mn.

Origin and Tectonic Controls for Mino-Tamba-Chugoku Metallogenic Belt

The belt is hosted in tectonic fragments in a subduction-zone complex that formed along the margin of the Sino-Korean craton. The subduction zone composed of marine sedimentary and volcanic rock and fragments of oceanic crust with ultramafic rock. Besshi deposits are interpreted as having formed along a spreading ridge. In the oceanic crustal fragments are podiform chromite deposits hosted in ultramafic rocks and chert-hosted Mn deposits. The deposits and host rocks were subsequently incorporated into an accretionary wedge of the Mino-Tamba-Chichibu subduction-zone terrane.

Norilsk Metallogenic Belt of Mafic-Ultramafic Related Cu-Ni-PGE, Basaltic Native Cu, and Porphyry Cu-Mo (±Au, Ag) Deposits (Belt NR) (Northwestern North Asian Craton, Russia).

This Early Triassic metallogenic belt is related to the Tungus plateau basalt, sills, dikes, and intrusions that extend sublongitudinally to the west and sublatitudinally to the east. The belt is about 600 km long and varies from 60 to 150 km wide. The belt occurs in the area of trapp magmatism. The shape of the belt is controlled by fault zones related to the West-Siberian and Yenisei-Khatanga rifts (Dodin and others, 1985; Dyuzhikov and others, 1988). The belt contains major Cu-Ni-PGE deposits. The largest Cu-Ni-PGE deposits (Norilsk, Talnakh, and Oktyabrskoye) are the very important for the mineral industry of Russia (Dodin and others, 1998, 1999). The deposit-hosting intrusions are differentiated, stratiform plutons that range from 80 to 400 m thick and composed of variable rock sequences that range from plagioclase dunite to gabbro and diorite. Cu-Ni-PGE sulfides occur both in magmatic rocks and Paleozoic host rocks adjacent to exocontacts. Basalt native-copper deposits (Arylakhskoye deposit) occur in the upper part of a Triassic welded tuff sequence. Cu deposits generally occur in basalt flows and in breccia. The Bolgochtonskoye porphyry Cu-Mo (±Au, Ag) deposit occurs in the endocontact and exocontact zones of a granitoid stock that intrudes a Silurian and Devonian argillaceous carbonate sequence.

The main references on the geology and metallogenesis of the belt are Zolotukhin and Vasiliev (1976), Dodin and others (1985, 1998, 1999), Dyuzhikov and others (1988), Dalrymple and others (1991, 1995), and Dobretsov (1997).

Norilsk I Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (fig. 7) (Godlevskiy, 1959; Ivanov and others, 1971; Smirnov, 1978) consists of Cu-Ni sulfide deposits hosted in the Triassic Norilsk differentiated mafic-ultramafic intrusive. The intrusive has a layered bed-like form that extends for 12 km and ranges from from 30 to 350 m thick (130 m average). The intrusive is composed of gabbro, diabase, and norite that intrude Permian sedimentary rock, trachydolerite, trachybasalt, andesite, and basalt. Sulfides occur in disseminations and nests of pyrrhotite, pentlandite, and chalcopyrite mainly in the lower olivine-rich picrite and diabase, and to a lesser extent in bands in diabase near the bottom of intusive. Veins of massive sulfides occur in the lower part of intrusive and in underlying rocks and consist of streaks and disseminations in wall rocks. These veins form an interrupted aureole around the intrusive

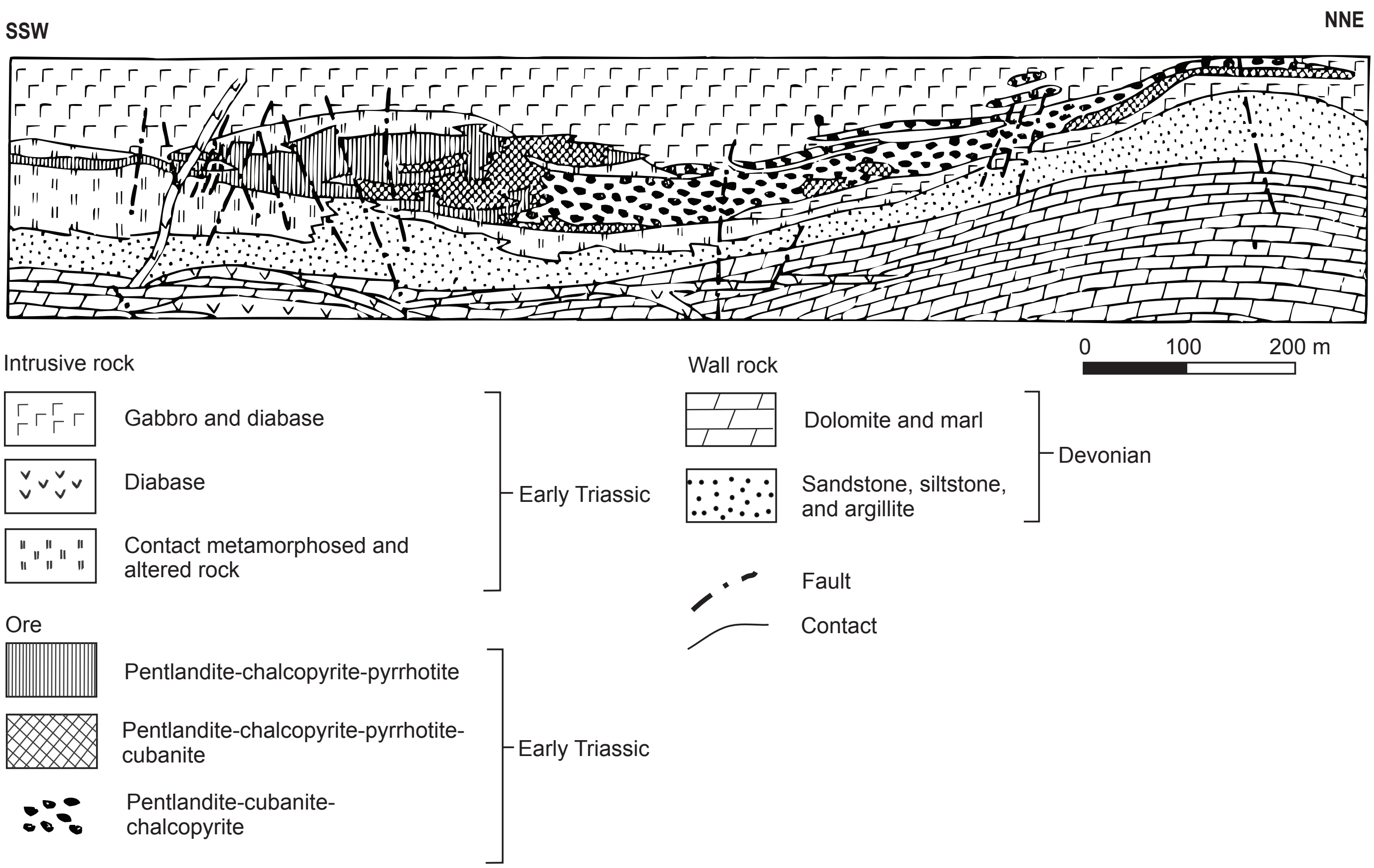


Figure 7. Schematic geologic cross section of Early Triassic Norilsk 2 mafic-ultramafic related Cu-Ni-PGE deposit, Norilsk metallogenic belt. Adapted from Smirnov (1978).

and extend for 15 km and range from 3 to 8 m thick. The sulfides mainly comprise form a stable layer that is concordant in plan view with the intrusive outline. The main mineral assemblages are pyrrhotite, chalcopyrite-pyrrhotite with pentlandite, cubanite-pentlandite-chalcopyrite, bornite-chalcocite, and millerite-pyrite. Elevated Pt in sulfides is characteristic. The oldest Cu-Ni sulfides are overprinted by low-temperature hydrothermal replacement with development of carbonate, chlorite, galena, and sphalerite. The deposit is large.

Norilsk II Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Zolotukhin and Vasil'ev, 1967) consists of Cu-Ni sulfides in a differentiated mafic-ultramafic intrusive that has a honolithe form, extends for 7 km, ranges from 100 to 300 m thick, and ranges from 100 to 800 m wide in plan view. The intrusion is layered and consists of gabbro and diabase at the top and olivine-biotite and picritic at the bottom. An irregular sulfide horizon occurs near the base of the intrusive, but often occurs in the footwall. The principal ore minerals are pyrrhotite, pentlandite, cubanite, and chalcopyrite; bornite, chromite, valleriite, pyrite, and PGE-minerals also occur. The ores are enriched in PGE. The deposit is a large and world-class.

Oktyabrskoye 3 Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Zolotukhin and others, 1975; Smirnov, 1978) consists of Cu sulfides-Ni deposits in differentiated mafic-ultramafic Talnakh intrusive. Intrusive composed of gabbro, non-olivine- and olivine-biotite gabbro, and diabase. The role of olivine-rich rocks increases to the intrusive floor. The deposit-hosting intrusive is at the 600 to 1,400 m depth and is hosted in metamorphosed rocks of Middle Devonian age. Three types of Cu sulfides-Ni ore are distinquished: massive, disseminated in intrusive rocks, and disseminated essentially Cu ores in host rocks. Massive sulfide ores compose a low-dipping deposit with area of about 4 km^2 and from 1 to 46 m thick. Disseminated ores compose some horizons at the base of intrusive having total thickness as much as 40 m. Disseminated essentialy Cu ores occur in the contact zone of the intrusive and are from 2 to 10 m thick. Principal ore minerals are: pyrrhotite, pentlandite, chalcopyrite, cubanite. Secondary minerals are magnetite, ilmenite, chromite, valleriite, bornite, and pyrite. The ores are by PGE-enriched. The deposit is large and world class.

Arylakhskoye Basaltic Cu (Lake Superior type) Deposit

This deposit (Dyuzhikov and others, 1976, 1977, 1988) consists of stratiform layers of native copper in Permian and Triassic carbonaceous breccia, in overlying basalt, and in underlying tuff. Ore minerals are native copper, cuprite, tenorite, chalcocite, and covellite. Gengue minerals are calcite, zeolite, chlorite, adularia, and quartz. The deposit and host rocks are regionally metamorphosed and exhibit carbonate, chlorite, and zeolite alteration. The Cu-bearing horizon is 2 to 10 m thick and extends for 40 km along the flank of the trapp basins. The highest concentration of native copper is in brecciated carbonate rocks. Native Cu occurs along the contacts of fragments in a carbonaceous matrix. Coarse grains (as much as 0.7 to 1 cm) and dendrite (as much as 3 to 5 cm) are widespread. The native copper occurs in veinlets, nests, fine disseminations, and amygdules. In tuff, Cu occurs as fine disseminations. Large aggregates (15 by 20 cm) and dendrite-like crystals (5 to 10 mm) of native copper occur in large amygdules and carbonate veins. The deposit is medium size.

Bolgokhtonskoye Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Matrosov and Shaposhnikov, 1988; Dyuzhikov and others, 1988) consists of Cu-Mo sulfides in veinlets and disseminations in hydrothermally-altered rock along contact of Bolgokhtokh granite pluton andin both the pluton and in adjacent intrusive rock. The granite-pluton stock intrudes Silurian and Devonian limestone, marl, and siltstone and Permian and Triassic volcanic rock and diabase. Metasomatite consists of calc-silicate-skarn, quartz-feldspar, quartz-sericite and quartz-calcite-chlorite rock. Two main districts occur. A Southern district occurs at depth and consists of streaks and lesser disseminations and nests. Thickness ranges as much as 0.8 to 1 cm. A Western zone crops out at the surface and consists of streaks and disseminations. Ore minerals are magnetite, molybdenite, chalcopyrite, sphalerite, pyrite, scheelite, bornite, fahl orewolframite, and galena. Gangue minerals are quartz, sericite, K-feldspar, and carbonate. Polymetallic sulfides increase in the propylite in the exterior part of the deposit. The deposit is medium size.

Origin and Tectonic Controls for Norilsk Metallogenic Belt

The belt is interpreted as being related to mantle-derived superplume magmatism that formed widespread of trapp magmatism on North Asian craton. The major Cu-Ni-PGE deposits occur in an area of orthogonal intersection of the Mesozoic Yenisei-Khatanga rift basin and the West-Siberian rift system. The deposits in the Norilsk district occur along ongitudinal linear structures that coincide with the major faults and axial zones of volcanic-tectonic basins. The major Norilsk-Kharaelakh fault is interpreted to be the major magmatic and deposit-controlling structure (Dyuzhikov and others, 1988). Magma generation is interpreted as being related to the mantle-derived superplume that resulted in widespread trapp magmatism on the North Asian craton (Dobretsov, 1997). Initial picrite magma is interpreted as being a source of mafic-ultramafic host for the Norilsk metallogenic belt (Zolotukhin and Vasil'iev, 1976; Dyuzhikov and others, 1988). $^{40}Ar/^{39}Ar$

isotopic age for basalt of the Norilsk ore district is 241.0 to 245.3 Ma, and the age for mafic-ultramafic intrusions is 248.7 to 248.9 Ma (Dalrymple and others, 1991, 1995). The $^{40}Ar/^{39}Ar$ isotopic age for Bolgokhtonsk granitoid that hosts the porphyry Cu-Mo (±Au, Ag) deposits is 223.3 Ma (Zolotukhin, 1997). The granitoid magmatism is interpreted as having resulted from evolution of the magmatic system during rifting (Dyuzhikov and others, 1988). Basalt native copper deposits formed later than the Ni-bearing mafic-ultramafic plutons (Dyuzhikov and others, 1988).

Orhon-Selenge Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag) Deposits (Belt OS) (Central Mongolia)

This Triassic metallogenic belt is hosted in granitoids in and stratiform layers in the Selenga sedimentary-volcanic plutonic belt. The belt occurs in northeastern half of the North Mongolian metallogenic belt of porphyry Cu-Mo (±Au, Ag) (Sotnikov and others, 1984, 1985a,b) in the northeastern part of North Mongolian volcanic belt that was named the Orhon-Selenge Basin (Mossakovskii and Tomurtogoo, 1976) The metallogenic belt contains the major Late Triassic through Early Jurassic Erdenet porphyry district (Sotnikov and others, 1985a,b) that is coeval with trachyandesite volcanic rock. In this part of Mongolia, the Selenge sedimentary-volcanic-plutonic belt consists of Precambrian metamorphic rock, Permian volcanic rock in the Hanui Group, Late Permian gabbro, granodiorite, granosyenite, and granite in the Selenge complex, Late Permian and Early Triassic trachyandesite, Late Triassic and Early Jurassic gabbro, diorite, and granite stocks, and the Erdenet porphyry complex. Porphyry stocks and dikes developed in Erdenet disrict are called the Erdenet complex (Sotnikov and others, 1985a,b).

The following districts occur from northeast to southwest in the metallogenic belt (Dejidmaa and others, 1996) (1) Darhan district with porphyry Cu-Mo (±Au, Ag) occurrences; (2) Baruunburen district with porphyry Cu (±Au) occurrences; (3) Erdenet districts with porphyry Cu-Mo (±Au, Ag) deposits and occurrences; and (4) Bulgan district with porphyry Cu-Mo (±Au, Ag) and basalt Cu occurrences. Most porphyry Cu-Mo (±Au, Ag) deposits and occurrences are in the Erdenet district. The major deposits are at Erdenetiin Ovoo, Central, Oyut Cu-Mo deposits; the Shand Cu-Mo deposit; and the Zuiliin gol Cu-Mo occurrence.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Luchitsky (1983), Gavrilova and others (1984, 1989), Sotnikov and others (1985), Dejidmaa andi Naito (1998), and Lamb and Cox (1998).

Erdenet Porphyry Cu-Mo (±Au, Ag) District

This district (fig. 8) (Khasin, and others, 1977; Gavrilova, and others, 1984; Sotnikov and Berzina, 1989; Gerel and Munkhtsengel, 2005) contains the world's largest porphyry Cu-Mo (±Au, Ag) deposit at Erdenetiin Ovoo. This and the Central, Zavsryn, and Oyut deposits occur along the northwest-striking Buhaingol fault zone into which are intruded porphyry stocks and dikes of the Erdenet Complex. Erdenet Complex contains two phases of granodiorite porphyry stocks and dikes of diorite porphyry, plagiogranite porphyry, dacite porphyry, syenite porphyry, and andesite porphyry. Syenite porphyry and andesite porphyry occur in post-ore dikes. Quartz-sericite metasomatite at the Erdenetiin Ovoo deposit has a K-Ar isotopic age of 210 to 190 Ma and an explosive breccia has a K-Ar isotopic age of 210 Ma K-Ar (Late Triassic through Early Jurassic) (Sotnikov and others, 1985a,b). Younger K-Ar isotopic ages for three porphyrytic stages are 250 to 240 Ma for the deposit-hosting stage. K-Ar and Rb-Sr ages are 220 Ma for a younger stage with less extensive deposits. A K-Ar isotopic age is 185 Ma for a post-ore stage (Sotnikov and others, 1984). A $^{40}Ar/^{39}Ar$ isochron age of 207±2 Ma is reported for white mica from the highest grade part of the Erdenet mine (Lamb and Cox, 1998). The major deposit is at Erdenetiin Ovoo, which consists of the north-eastern or the Erdenetiin Ovoo, the central, and the Zavsryn and the Qyut parts. The small Shand deposit occurs south of the Erdenetiin Ovoo. Besides the Shand deposit, most porphyry Cu-Mo (±Au, Ag) occurrences in this belt constitute potential for concealed deposits at depths of 200 to 300 m.

Erdenetiin Ovoo Porphyry Cu-Mo (±Au, Ag) Mine

This deposit (Sotnikov and others, 1985; Koval and Gerel, 1986; Gerel, 1989; Dejidmaa, 1996; Gerel and Munkhtsengel, 2005) consists of stockwork veinlets and veins of quartz, chalcopyrite, and molybdenite in or near the granodiorite porphyry of the Selenge Complex. The size of the stockwork at the surface is 2,800 m by 300 to 1300 m and the primimary ore dimensions are 1,000 by 600 m. The deposit is related to intensive hydrothermal alteration of host rocks. A quartz-sericite zone is strongly developed in the center of the stockwork and grades outward into sericite-chlorite and carbonate-epidote-chlorite zones. In the upper part of the stockwork argillite alteration occurs, and K-feldspar alteration, locally with hydrothermal biotite and tourmaline, occurs. Altered quartz-sericite rock is called a secondary quartzite. In the eastern part of the deposit, the porphyritic rock and alteration zone is cut by a central meridian fault. This mine contains numerous supergenic halos. The northwest trending fault zone is important for the ore location process. The host rocks for the deposit are Precambrian basement composed of amphibolite, schist, and volcanic and edimentary rocks.

Five stages of mineralization correspond to five phases of porphyry intrusion. The stages are (1) magnetite, quartz-pyrite, (2) molybdenite-quartz, (3) chalcopyrite-pyrite-quartz, (4) pyrite metacrystals, (5) pyrrotite (cubanite)-chalcopyrite, (6) chalcocite-bornite, (7) galena-sphalerite-tennantite, and (8) zeolite-gypsum-carbonate in both primary and secondary enrichment zones. The main minerals in the oxide zone are malachite, azurite, cuprite, iron oxides, and native copper. A vertical zonation consists of (1) oxidized and leached ore (from 10 to 90 m thick); (2) secondary sulphide-enrichment zone (from 60 to 300 m thick); and (3) primary ore (to a depth 1,000 m). Cu grade varies from 0.8 percent to 7.6 percent Cu in secondary sulphide zone in the central part of the deposit and decreases to the periphery. Mo grade varies from 0.001 to 0.76 percent Mo in the econdary sulphide zone. Cu grade in primary ore decreases from the centre of stockwork (0.4 to 0.5 percent Cu) to 0.2 to 0.3 percent Cu at the periphery and to 0.2 to 0.25 percent Cu from 500 to 1000 m. Mo grade is variable and is somewhat antithetic to Cu grade. The secondary enrichment zone has 85 percent of the reserves. From 0.8 percent to 7.6 percent Cu and from 0.001 percent to 0.76 percent Mo occurs in the secondary enrichment zone, and 0.2 to 0.5 percent Cu and 0.025 percent Mo occurs in primary ore. The highest grade part is a chalcocite blanket composed of quartz, white mica, pyrite, and chalcopyrite with a well-developed quartz-vein stockwork. Secondary chalcocite forms coatings on both pyrite and chalcopyrite. Potassic alteration occurs mainly in the deep part of deposit. The deposit is large

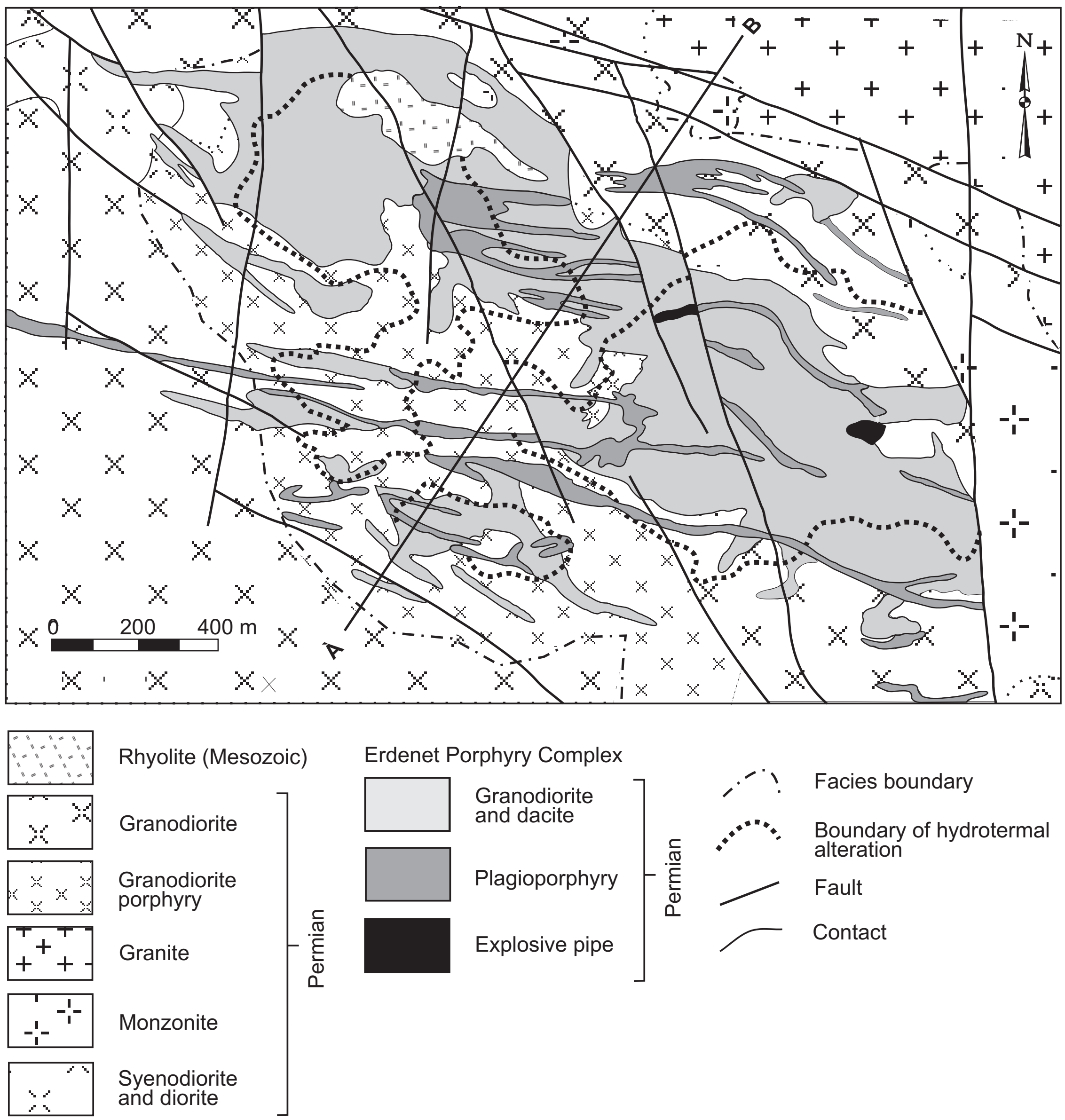


Figure 8. Geologic sketch map and cross section of Triassic Erdenet porphyry Cu-Mo deposit, Orhon-Selenge metallogenic belt. Adapted from Gavrilova and others (1989) and Gerel and Munkhtsengel (2005).

and has reserves of 10,851,000 tonnes of Cu and 167,073 tonnes of Mo.

Shand and Zuiliingol Porphyry Cu-Mo (±Au, Ag) Occurrence

This occurrence (V.P. Arsentev and others, written commun., 1985) consists of a Cu sulfide zone with surface dimensions of 350 by 1,100 m. The zone occurs along the contact of a granodiorite porphyry stock. Ore minerals are: chalcopyrite, molybdenite, sphalerite, galena, magnetite, and hematite. Grab grade from 0.1 to 1.0 percent Cu, and from 0.001 to 0.015 percent Mo, and as much as 0.001 percent Ag. Core samples grade from 0.1 to 0.4 to 0.5 percent, Cu and from 0.0001 to 0.1 percent Mo. The deposit is small with probable reserves of 500,000 tonnes of Cu and an average grade of 0.1 to 0.5 percent Cu and 0.0001 to 0.1 percent Mo. This occurrence at Shand and another at Zuiliingol have the potential for small concealed deposits at depths of 200 to 300 m.

Origin and Tectonic Control for Orhon-Selenge Metallogenic Belt

The belt is interpreted interpreted as having formed along the Selenga transform continental margin arc along the northern margin of the Mongol-Okhotsk Ocean. The transform margin consisted of oblique subduction of oceanic crust of the Mongol-Okhotsk Ocean plate under the southern margin of the Siberian continent. The Late Permian through Early Jurassic plutonic rocks of the Orhon-Selenge metallogenic belt are part of the mainly Permian Selenga sedimentary-volcanic plutonic belt (Tomurtogoo and others, 1999). Remnants of this ocean are preserved in a narrow band that extends 3000 km from central Mongolia to the Okhotsk Sea (Obolenskiy and others, 1999).

Shanxi Metallogenic Belt of Sedimentary Bauxite and Evaporate Sedimentary Gypsum Deposits (Belt SX) (North China)

This Pennsylvanian metallogenic belt is related to stratiform units in the upper part of the sedimentary platform cover for the Sino-Korean craton. The belt is hosted in Pennsylvanian sedimentary assemblages overlapping the West Liaoning-Hebei-Shanxi Archean terrane. The belt occurs along the Fanhe River and the middle reaches of the Yellow River in West Shanxi Province. The bauxite deposits occur in the lower part of the Pennsylvanian Benxi Formation. The belt trends north-south, is 300 km long, and ranges from 30 to 50 km wide. The belt contains 55 bauxite deposits of moderate or large size, with a reserve (1997) of 941 million tones that comprise 50 percent of China’s bauxite reserve (Chen and others, 1997). The most significant deposit is at Keer. A minor evaporate sedimentary gypsum deposit occurs at Lingshi.

The main references on the geology and metallogenesis of the belt are Wang (1985), Jiang and others (1987), and Chen and others (1997).

Ke’er Sedimentary Bauxite Deposit

This deposit (Editorial Committee, Discovery History of Mineral Deposits of China, Shanxi volume, 1996; Chen and others, 1997) consists of stratiform and lenticular layers that are as much as 1800 m long and 400 m wide. Individual bauxite layers range from 0.5 to 11.7 m thick. From bottom to the top, the host rocks consists of a volcanogenic-sedimentary Fe deposit (hematite), allite, bauxite, refractory clay, shale, carbonaceous shale, and coal seams. The sequence is 8 to 20 m thick and occurs in the lower member of the Benxi Formation. The underlying strata are Middle Ordovician limestone. The lower boundary of the bauxite layer is 2 to 5 m above an ancient weathering-surface of the Ordovician limestone. In the mine, the strata are monoclinal and dip gently at 3 to 5 degrees. Oblique bedding occurs in the ores that are massive, rough, and oolitic. The ore minerals are mainly diaspore (98 percent) and local gibbsite (5 to 7 percent). Minor minerals are kaolinite, dickite, and hydromica and rare zircon, oysanite, tourmaline, quartz, and barite. Below the bauxite layer is hematite claystone and hematite shale, and local abundant intercalated limonite lenses. The bauxite probably formed during allochthonous surface accumulation on a weathering crust of carbonate and not by mechanical sedimentation. The Carbonaceous and Permian units of the North China Platform contain seven bauxite layers. The layer in the Late Carboniferous Benxi Formation is the most extensive. The deposit is large and has reserves of 62,656 thousand tonnes grading 64.43 percent Al_2O_3.

Origin and Tectonic Controls for Shanxi Metallogenic Belt

The belt is interpreted as having formed during weathering of metamorphic rock of the Northern China Platform. The bauxite deposits were deposited in karst and lagoonal basins in a littoral-shallow sea. The entire North China Platform, including the bauxite metallogenic belt, was uplifted, weathered, and eroded during the Middle Ordovician. During the Pennsylvanian, the platform subsided with formation of a littoral shallow sea (Wang, 1985). Bauxite deposits formed in local favorable karst and lagoon basins. The bauxite was derived from weathered metamorphic rock of the North China Platform and not from weathered Ordovician limestone that underlies the bauxite sequence (Chen and others, 1997). However, some authors advocate derivation of bauxite deposits from the weathering of the underlying limestone (Jiang and others, 1987).

Major Late Triassic through Early Early Jurassic (230 to 175 Ma) Metallogenic Belts and Host Units

Central Hentii Metalogenic Belt of Sn-W Greisen, Stockwork, and Quartz Vein, REE-Li Pegmatite, Ta-Li Ongonite, Ta-Nb-REE Alkaline Metasomatite, Peralkaline Granitoid-Related Nb-Zr-REE, W-Mo-Be Greisen, Stockwork, and Quartz Vein, and W±Mo±Be Skarn Deposits (Belt CHE) (Mongolia)

This Late Triassic through Early Jurassic metallogenic belt is related to replacements and granitoids in the Mongol-Transbaikal volcanic-plutonic belt that intrudes and overlaps Hangay-Dauria terrane and adjacent units. The Sn-W deposits and occurrences are hosted in a Late Triassic and Early Jurassic granodiorite and granite belt that forms the Hentii megadome that is 600 km long, as much as 200 to 220 km wide, and trends northeast. This dome is the Mongolian part of the Hentii-Daurian megadome that has been uplifted from the early Mesozoic through the Recent. The Hentii megadome contains Devonian and Carboniferous turbidite intruded by Paleozoic and Mesozoic granitoids. The major deposits are at Modot, Tsagaan dabaa, Gorkhi, Zuunbayan, Janchivlan, and Avdrant.

Various Sn-W greisen, stockwork, and quartz-vein deposits, at at Tsagaan Davaa, Modot, and Janchivlan, occur mainly in the upper part of evolved granite and rarely in host rocks. The host granite has a K-Ar isotopic age of 190.49±4.7 Ma and a Rb-Sr isotopic age of 225 to 188 Ma, and consists of three types: (1) coarse-grained porphyritic biotite granite and rare amphibole-biotite granite, (2) medium-grained two-mica granite, and (3) K-feldspar biotite granite (alaskite) and Li-F granite including microcline-albite, amazonite-albite, lepidolite-albite granite. Many granites are S-type granite higher alkalinity than typical. Li-F granite is A2 type (after Eby, 1992) and formed in post-collisional setting (Gerel, 1995; Gerel and others, 1999). First granite type contains many unique miarolic pegmatites (as at Gorkhi, Zuunbayan, and Janchivlan) with piezoelectrical quartz. The second granite type contains W-Sn veins (as at Modot, Bayan Mod, and Khujihan) and rare scheelite-skarn. The third granite type contains Ta-bearing granite deposits (as at Urt Gozgor, Buural Khangai, Borkhujir) and W-Sn vein and Be greisen deposits (as at Tsagaan Davaa). Numerous Sn placers, including the very large Tsenkher Mandal Sn placer deposit, occur nearby. Greisen bears biotite and contains topaz-quartz, tourmaline-quartz, and muscovite-quartz zones.

The main references on the geology and metallogenesis of the belt are Gerel (1995, 1998), Koval (1998), Gerel and others (1999), Gerel and others (1999), and Tomurtogoo (2001).

Modot Sn-W Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Khasin, 1977; Jargalsaihan and others, 1996) consists of Sn-W quartz veins related to Mesozoic granite pluton with a K-Ar isotopic age of 199 to 175 Ma. The pluton intrudes Vendian and Early Cambrian metamorphic rock, Paleozoic granitoids and Permian molasse. The deposit occurs along the pluton margin in the pluton, or in adjacent hornfels. The veins dip gently and strike northwest to north. Some veins dip steeply. The ore minerals are cassiterite, wolframite, arsenopyrite, pyrite, galena, sphalerite, and chalcopyrite. Greisen alteration occurs. The deposit is small and has produced 300 tonnes of WO_3.

Tsagaan dabaa W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (fig. 9) (Khasin, 1977; Jargalsaihan and others, 1996) consists of quartz-wolframite veins and zones that occur in a multistage Late Triassic-Early Jurassic granite pluton. Veins mainly occur in the central elevated part of pluton that consists of fine- to medium-grained biotite and leucocratic granite. The veins are 2 km long, 200 to 500 m wide, and occur at different hypsometric levels. The veins form subhorizontal bodies dip gently south, southeast, and southwest, parallel with pluton roof. Ore minerals are wolframite, cassiterite, molybdenite, and beryl, and rare chalcopyrite and pyrite. Gangue minerals are garnet, fluorite, and biotite. Associated greisen and silica alteration is common. Assemblage of biotite and fluorite is characteristic of the deposit. The deposit is medium size and has a resource of 3,497 tonnes. Grade ranges from 0.1 to 12.6 percent WO_3.

Janchivlan Ta-Nb-REE Alkaline Metasomatite Deposit

This deposit (Kovalenko and others, 1971; Ivanov and others, 1996) is hosted in albite-lepidolite and amazonite-albite granite that occurs along the southwest contact of a Mesozoic Janchivlan pluton that occurs along the northwest trending Ulaandavaa fault. Associated with the granite and deposit are microcline alteration, quartz-lepidolite greisen, albite metasomatite, and quartz-muscovite greisen, and quartz veins. Granites are composed of albite, quartz, lepidolite, amazonite and microcline, and topaz. Accessory minerals are fluorite, columbite, monazite, Pb-pyrochlore, zircon, and cassiterite. Grade from surface to depth of 100 m is 60 g/t Ta (Ta/Nb= 1.2), 600 g/t Li, 800 g/t Rb, and 50 g/t Sn. The average grade is 0.001 to 0.011 percent Ta.

Avdrant Peralkaline Peralkaline Granitoid-Related Nb-Zr-REE Deposit

This deposit (Kovalenko and others, 1971) is hosted in an albite amazonite granite that occurs in the upper part of a

Mesozoic granite pluton with a K-Ar isotopic age of 222 to 172 Ma and in dikes in adjacent host rock. The albite-amazonite granite occurs in a rim of alaskiteor in the core of the pluton, is medium-grained, and composed of amazonite, albite, quartz and zinnwaldite. The amazonite-albite granite contains 330 to 1400 g/t Li, 6 to 75 g/t Ta, and 76 to 350 g/t Nb. The average grade is 0.007 percent Ta and 0.008 percent Nb.

Origin and Tectonic Controls for Central Hentii Metallogenic Belt

The Sn-W greisen, stockwork, and quartz vein in the belt are interpreted as having formed during generation of collisional granitoids of the Mongol-Transbaikal volcanic-plutonic belt during final closure of the Mongol-Okhotsk Ocean (Zonenshain and others, 1990; Kovalenko and others; 1995; Koval, 1998). The REE deposits are related to small plutons that are interpreted as having formed during a continental post-collisional event. The margins of this metallogenic belt are northeast-trending faults that may also be favorable for epithermal Au deposits and intrusion-related sedimentary-hosted deposits (Gerel and others, 1999).

Delgerhaan Metallogenic Belt of Porphyry Cu (±Au) (Au, Ag) and Granitoid-Related Au Vein Deposits (Belt DE) (Central Mongolia)

This Late Triassic metallogenic belt is related to granitoids in the Mongol-Transbaikalia volcanic-plutonic belt that intrudes Hangay-Dauria terrane, Ononsky terrane, and the Gobi-Khankaisk-Daxinganling volcanic-plutonic belt. $^{40}Ar/^{39}Ar$ isochron ages for two samples of plagioclase-biotite porphyry and for one sample of biotite granodiorite from Bayan Uul ore-field are 220 to 223 Ma (Lamb and Cox, 1998). The major deposits are the Bayan Uul district with porphyry Cu (±Au) vein and Au-Ag-Cu and explosive pipe occurrences, and the Unegt district with Au-Ag-Cu vein and Cu vein and explosive pipe occurrences. Porphyry Cu (±Au), granitoid-related Au and Cu occurrences occur at the junction of the Ovorhangai, Tov, and Dundgovi provinces. The main deposit is at Bayan uul 2.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Gerel and others (1984), Dolgov and others (1984), Sotnikov and others (1984, 1985a,b), Koval and Gerel (1986), Gerel (1990), and Lamb and Cox (1998).

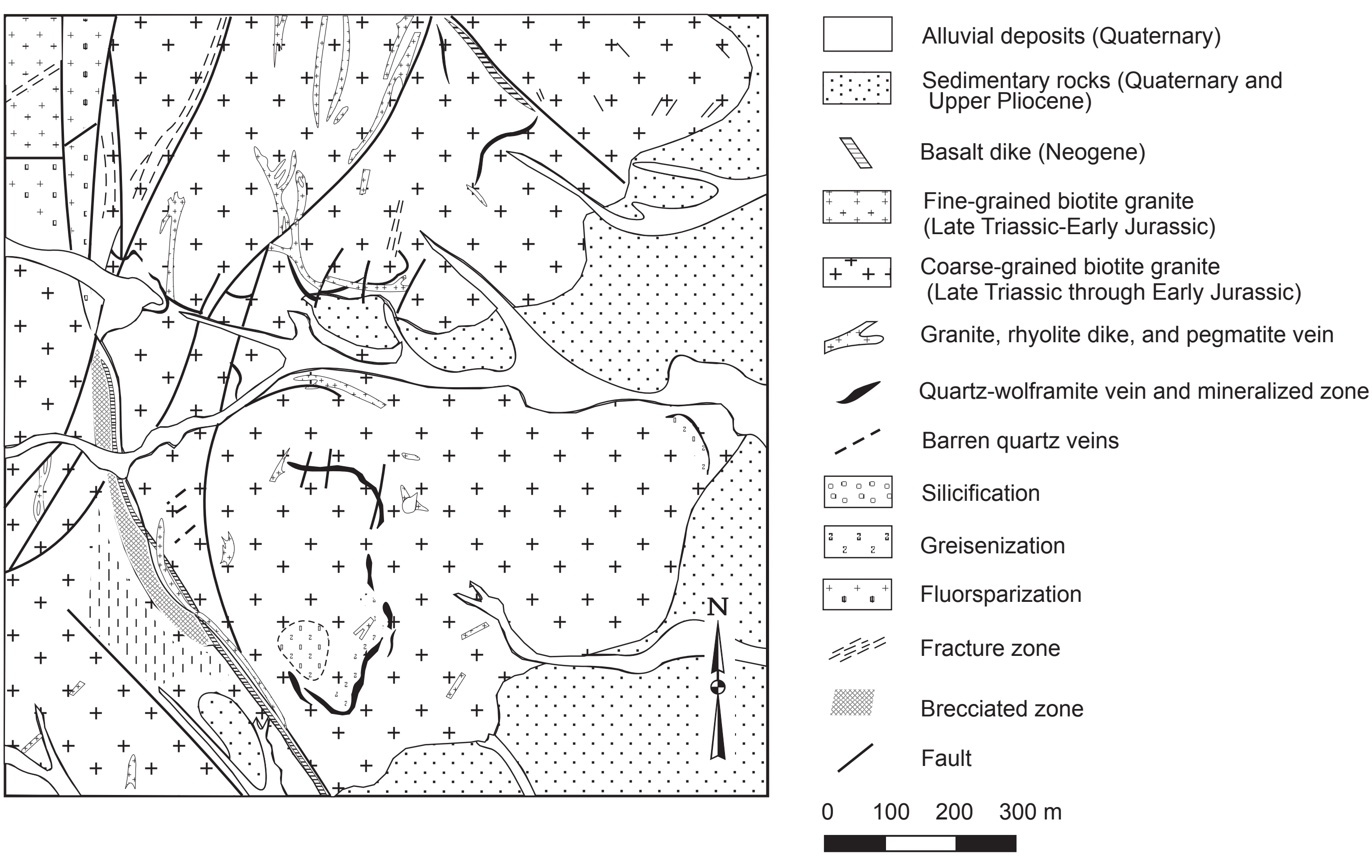


Figure 9. Geologic sketch map of Late Triassic through Early Jurassic Tsagaan dabaa W-Mo-Be greisen, stockwork, and quartz-vein deposit, Central Hentii metallogenic belt. Adapted from Marinov and others (1977).

Bayan Uul District

This district (Koval and others, 1989, G.A. Dolgov written commun., 1984; Ariunbileg and Khosbayar, 1998) occurs in the southeastern Delgerhaan area, and is related to tourmaline explosive breccia and subvolcanic granodiorite porphyry, granite porphyry, and syenite porphyry stocks and dikes that occur along a 2 by 2 km ring structure. The ring structure is in an intensely-developed caldera that exhibits advanced argillic and quartz-sericitic metasomatite with extensive pyrite. Cu deposits extend 150 m downdip in explosive breccia. Cu grade is not high on the surface. Average Cu grade is 0.2 percent for a width of 600 m and includes 8 to 10 linear zones with a total thickness of 100 to 120 m. The ratio of Cu:Mo is 16:1. Au and Ag deposits occur mostly in the margin of the district. Au grade ranges up to 2 g/t, with an average of 0.2 g/t, for a thickness of 47.5 m in a drill hole. Ag grade ranges from 4.3 g/t for a thickness 15.6 m, to 15 g/t for a thickness 1.0 m. Au grade is as much as 10 g/t in tourmaline-pyrite veins and breccia. Some tourmaline explosive breccia pipes in margin of the Delgerhaan district contains Cu high grade. The Unegt district occurs north-northwest of the Bayan Uul district and contains Au-bearing pyrite-quartz-tourmaline, pyrite-magnetite-hematite-quartz-tourmaline veins and breccia, and Cu-bearing tourmaline explosive breccia.

Bayan Uul 2 Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (G.A. Dolgov written commun., 1984; Koval and others, 1989, Ariunbileg and Khosbayar, 1998) consists of quartz-tourmaline-chalcopyrite veins in an area of pervasive sericite and argillic alteration. The deposit is hosted in an early Mesozoic volcanic-plutonic system that includes small porphyritic intrusions of diorite to granite. The alteration zone is nearly oval, is 3 km wide and extends northeast for 5 km. Major ore minerals are pyrite, chalcopyrite, bornite and peripheral sphalerite, galena, and Ag minerals. The deposit consists of stockwork veinlets and veins of quartz, pyrite, chalcopyrite, and molybdenite that occur in or near porphyritic intrusions. The veins contain mainly quartz and carbonate minerals. The high-level intrusive porphyry is contemporaneous with abundant dikes, faults, and breccia pipes, and hydrothermal alteration zonation is centered on the porphyry intrusion. The central part of alteration zone consists of K-feldspar and biotite alteration and is surrounded by phylitic, and peripheral propylitic alteration zones. The deposit at the surface contains greater than 0.1 percent Cu, greater than 0.002 percent Mo, and greater than 0.1 ppm Au across an area of 0.6k by 2.3 km. A zone 300 by 900 m contains >0.3 percent Cu, and 0.005 percent Mo. The deposit occurs in the center of a biotite and potassic alteration. Grades correlate positively with quartz-veinlet intensity. In the southeastern area, a 40-m-thick leached cap occurs with As, Sb, Bi, Pb minerals and minor secondary Cu. The dominance of sericite and advanced argillic and silica alterations at the surface suggests a relatively shallow porphyry Cu system. The deposit contains-contact zone reserves of 300,000 tonnes of Cu.

Origin and Tectonic Controls for Delgerhaan Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during the final closure of the Mongol-Okhotsk Ocean and formation of the Mongol-Transbaikal arc. The age and origin of the Bayan Uul ore-field is similar to that of the Erdenetiin Ovoo ore-field in the Orhon-Selenge metallogenic belt. The Delgerhaan metallogenic belt may be a direct continuation of the Orhon-Selenge metallogenic belt. The Oyuthonhor porphyry Cu-Mo (±Au, Ag) occurrence and the Out Ovoo Cu tourmaline breccia occurrences are hosted in the Avzaga Basin that contains Middle and Late Triassic rock, and Late Triassic through Early Jurassic trachyandesite.

Govi-Ugtaal-Baruun-Urt Metallogenic Belt of Fe-Zn Skarn, Cu-Zn-Pb (±Ag, Cu) Skarn, Zn-Pb (±Ag, Cu) Skarn, Sn-Skarn, Fe-Skarn, and Porphyry Mo Deposits (Belt GB) (Central and Eastern Mongolia)

This Late Triassic through Early Jurassic metallogenic belt is related to replacements in the Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlies Idermeg terane and Gobi-Khankaisk-Daxinganling volcanic-plutonic belt. The major deposits are the Tomortiin Ovoo Fe-Zn skarn deposit and the Oortsog Sn-skarn deposit.

The two major Govi-Ugtaal-Bayanjargalan and Salhit districts are at the southwestern and northeastern ends of the belt, respectively. A few Fe-skarn deposits and occurrences are between these two major districts in Borondor area. Major three types of skarn occur (1) Fe-skarn at Mandalyn Hiid, Sainshand hudag,; (2) Fe-Zn skarn at Tomortei; and (3) Fe-Sn skarn at Oortsog in the Goviugtaal-Bayanjargalan district. These skarns are closely related to Late Triassic and Early Jurassic alkaline alaskite and granite stocks (Dorjgotov, 1996). Fe-skarn consists mostly of pyroxene, phlogopite, garnet, magnetite, and hematite, and Fe-Zn skarn consists mostly of andradite, pyroxene, epidote, quartz, magnetite, sphalerite, galena, and pyrite. Fe-Sn skarn consists mostly of pyroxene, andradite, vesuvianite, actinolite, epidote, magnetite, molybdenite, and cassiterite. Hematite, sphalerite, molybdenite, and pyrite occur in all three types, but in varying amounts. Fe-skarn and Fe-Zn skarn occur mostly in the Salhit district near Baruunurt city. Salhit and Tomortein Ovoo deposits are Fe-Zn skarn deposits, however, sphalerite is dominate. The deposits are hosted in Devonian carbonate and sedimentary rock along the contact of subalkaline biotitic granite (Podlessky and others, 1988). Ore assemblages are: magnetitic-hematite, sphalerite-magnetite, and sphalerite. Sphalerite is major ore mineral in magnetite-sphalerite and sphalerite skarn, and ranges from 45 to 90 percent. Other sulfides are minor molybdenite, chalcopyrite, and pyritec and galena, and compriseless than 5 to

10 percent ore. Above mentioned three skarns are overprinted on clinopyroxene, clinopyroxene-garnet, and garnet skarn (Podlessky and others, 1998).

The main references on the geology and metallogenesis of the belt are Fillippova and Vydrin (1977), Batjargal and others (1997), Yakovlev (1977), Podlessky and others (1988), and Tomurtogoo and others (1999).

Tumurtiin-Ovoo Fe-Zn Skarn Deposit

This deposit (Yakovlev, 1977; Podlessky and others, 1998; D. Dorjgotov, written commun., 1990) consists of a calcic skarn that occurs along the contact between Devonian limestone and a Mesozoic subalkaline granite. The skarn is elongated to the northwest and dips concordantly with host rock to the southwest. The skarn extends for about 800 m along strike, 480 m downdip in the central part, and 200 to 230 m downdip on the eastern and western flanks. Average thickness is 14 m. The major minerals are andradite, hedenbergite, grossular, epidote, quartz, and wollastonite. The deposit is zoned, and the major ore minerals are sphalerite and magnetite. The deposit is large with resources of 750,000 tonnes Zn and 1,770 tonnes Cd. The average grades are 17 percent Fe, 9.9 to 13.1 percent Zn.

Oortsog ovoo Sn-Skarn Deposit

This deposit (Podlessky and others, 1998, Jargalsaihan and others, 1996) consists of a steeply dipping skarn that forms sheets like along the contact between a late Paleozoic granite pluton and marble with beds of calc-silicate schist. The skarn sheets range from 200 to 1500 m long, 5 to 80 m wide, comprise as much as 25 lenticular bodies composed of garnet, pyroxene, and magnetite, and Sn and base metal minerals. Three stages are: (1) an early stage of pyroxene-garnet and magnetite; (2) cassiterite, stannite, lollingite, Zn sulfide, Pb sulfide, Cu sulfide, and Fe sulfide, and (3) less common fahlore, enargite, bismuthite, and scheelite. Also occurring are hypergene cerussite, smithsonite, anglesite, greenockite, martite, montmorillonite, kaolinite, and gypsum. Grades are 0.02-1.28 percent Sn, 0.001 to 0.06 percent W, 0.02 to 1.28 percent Zn, and 0.01 to 0.9 percent Cu. Reserves are 39,200 tonnes Sn, 11,500 tonnes Zn, and 1.500 tonnes Cu.

Origin and Tectonic Controls for Govi-Ugtaal-Baruun-Urt Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc. The belt is hosted in Late Triassic through Early Jurassic age alaskite, granite, and alkaline granite of the Mongol-Transbaikalia volcanic-plutonic belt. The deposits ae hosted in an alaskite granite and alkaline granite plutons (Dorjgotov, 1996).

Harmorit-Hanbogd-Lugiingol Metallogenic Belt of Sn-W Greisen, Stockwork, and Quartz Vein, REE (±Ta, Nb, Fe) Carbonatite, Peralkaline Granitoid-related Nb-Zr-REE, and REE-Li Pegmatite Deposits (Belt HL) (Mongolia)

This Middle Triassic through Early Jurassic metallogenic belt is related to replacements and granitoids in the South Mongolian volcanic-plutonic belt that intrudes and overlaps the Hutaguul-Xilinhot and Gurvansayhan terranes and Lugyngol overlap volcanic and sedimentary basin. The carbonatite related REE deposit at Lugiin gol, the REE – Nb-Zr alkaline granite and pegmatite deposit at Khanbogd, and Sn-occurrences at Kharmorit are related to high alkaline potassic granitoid and Li-F facies leucogranite. The deposits are related to the Khalzan uul Complex with a Rb-Sr isotoic age of 194±9.06. The major deposits are at Khar morit, Lugiin gol, and Khanbogd. Also occurring are associated Sn placer deposits.

The main references on the geology and metallogenesis of the belt are Kovalenko and others (1974), Koval and others (1982), Luchitsky (1983), Ruzhentsev and others (1992), Amory and others (1994), Batbold (1998), and Munkhtsengel and Iizumi (1999).

Lugiin Gol REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (Jargalsaihan and others, 1996; Batbold, 1998) consists of bastneasite carbonatite dikes that occur mainly along the contact zone of the Lugingol alkaline nepheline syenite pluton that intrudes Permian sedimentary rock of the Lugin gol Formation (Batbold, 1998). For the Lugiin gol nepheline syenite pluton a Rb-Sr whole rock isochron age is 244±22.4 Ma and a Rb-Sr whole rock-mineral isochron ages are 222±3.2 and 199 to 180 Ma (Kovalenko and others, 1974; Munkhtsengel and Iizumi, 1999). K-Ar isotopic ages range from 242 to 228 Ma. A linear to oval eruptive breccia, cemented by carbonatite, crops out in the western part of the pluton. Carbonatite veins occur in the pluton, host rock, and along the contact. Pluton is altered fluorite, feldspar, sericite, hematite, and Fe sulfides. The veins trend north or east, are as much as 430 m long, and are 0.1 to 0.8 m thick. Synchysite is predominant ore mineral and gangue minerals are fluorite and calcite. The deposit is small and has reserves of 14,000 tonnes grading 0.5-3.5 percent TR_2O_3, 50.7 percent Ce, 33.0 percent La, 5.0 percent Nd, 2.85 percent Sr, 1 to 5 percent Ba, 0.03 to 0.3 Y, and 5 to 20 percent CaF_2.

Khan Bogd Ta-Nb-REE Alkaline Metasomatite Deposit

This deposit (Vladykin and others, 1981; Jargalsaihan and others, 1996) is hosted in an alkaline granite pluton composed of medium-grained arfvedsonite-aegirine granites with dikes of eckerites, pantellerites, grorudits, and alkaline pegmatite with REE. Pegmatite is composed of microcline, quartz, arfvedsonite, and elpidite, and local aegirine. The metasomatic zone contain aegirine and elpidite. The uppermost part of the pluton contains elpidite and Ti-silicate, and accessory polilitionite, synchisite, monazite, sphene, and other REE minerals. Grades are as much as 2 to 3 percent, REE, 1 percent Nb, 0.07 percent Th, and 7 to 8 percent Zr. REE are concentrated in synchizite, monazite, and sphene. Zr is concentrated in elpidite and armstrongite. The average grades are 620 g/t Nb_2O_3, 0.8 percent TR_2O_3, and 0.04 percent Hf.

Khar morit Sn-W Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Amory and others, 1994; Armory, 1996, Batbold, 1998) consists of zones of greisen and veins in the apical part of a Li-F granite porphyry stock and in adjacent host rocks. The granite has a Rb-Sr isochron age of 194± 9.06 Ma. The zones extend from 100 to 500 m long and as much as 3 m wide. The deposit has two parts: cassiterite-wolframite-quartz vein, and cassiterite-wolframite-zinwaldite-quartz greisen; and (2) cassiterite-sulfide with Sn, Cu, Pb, and Zn. The ore minerals are cassiterite, pyrite, arsenopyrite, galena, sphalerite, and chalcopyrite, and rare scheelite and wolframite. Gangue minerals are quartz, muscovite, zinnwaldite, beryl, tourmaline, sericite, and chlorite. The most common minerals are topaz and fluorite. A well developed oxidized zone contains relics of sulfides and secondary minerals. Sn is very irrregular and sometimes very high. The deposit exhibits a complex mineralization and includes Sn-sulfide, Zn-Pb and Be, Sn-W greisen, and Sn-W vein stages. The various stages are zoned and occur in the altered cupola of the stock with wolframite and cassiterite, in the contact hornfels with cassiterite and sulfides, and with cassiterite in host sandstone and shale. Associated Sn placer deposits also occur. The deposit is small and has resources of 780 tonnes of Sn and 65 tonnes of WO_3.

Origin and Tectonic Controls for Harmorit-Hanbogd-Lugiingol Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc.

Kalgutinsk Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz Vein, Ta-Nb-REE Alkaline Metasomatite Deposits (Belt KG) (West Siberia, Gorny Altai Mountains, Russia)

This Early Jurassic metallogenic belt is related to granitoids and replacements related to the Belokurikha plutonic belt (too small to show at 10 M scale) that intrudes the Altai and West Sayan terranes. The belt occurs in the southern part of Gorny Altai region in southern Eastern Siberia and Mongolia, extends along a sublatitudinal trend for 300 km, and ranges from 80 to 100 km wide. The belt belt is hosted in early Mesozoic REE plumasite granite plutons that are composed of porphyritic biotite granite, leucogranite, and muscovite-tourmaline pegmatite. Also occurring are local Li-Cs ongonite and spodumene granite porphyry (Dergachev, 1989; Vladimirov and others, 1996, 1997; Dovgal and others, 1997). REE deposits occur in granite plutons and along exocontact zones in contact metamorphosed host rock that is mainly Cambrian and Ordovician flysch. Local associated scheelite deposits also occur (Urzarsaiskoye deposit). The major deposit is the large Kalgutinskoye W-Mo-Be greisen, stockwork, and quartz-vein deposit that is being mined. Another prospective, medium-size deposit is the Akalakhinskoye Li-Ta-Nb-REE deposit that is hosted in an alkali metasomatite.

The main references on the geology and metallogenesis of the belt are Sotnikov and Nikitina (1977), Dergachev (1989), Il'in and others (1994), Shokalskiy and others (1996), Vladimirov and others (1996, 1997), and Dovgal and others (1997).

Kalgutinskoye 1 W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Sotnikov and Nikitina, 1977; Sharov and others, 1998) consists of quartz veins that occur in Kalguta granite pluton and in adjacent country Devonian extrusive rock. The deposit consists of more than 300 veins that occur in a northeastern-striking band that is about 2 km long and as much as 500 m wide. Single veins range from a few meters to 330 m long. The quartz veins are divided into W, W-Mo, and Mo types. Major minerals are wolframite, molybdenite, chalcopyrite, pyrite, beril, muscovite, fluospar, scheelite, feldspar, and topaz. Veins are associated with greisen that contains dissiminations and nests of ore minerals. A pipe of muscovite and quartz greisen occurs in porphyry granite and consists of breccia with granite fragments and matrix intensely altered to greisen. The ore minerals occur in the altered matrix and are disseminated molybdenite, chalcopyrite, pyrite, and rare wolframite. The deposit is large and has reserves of 12,000 tonnes of WO_3, 5,500 tonnes of Mo; 235 tonnes of Bi_2O_3; and 48 tonnes of BeO. The average grades are 1.9 percent WO_3; 0.36 percent Mo; 0.11 percent Bi_2O_3; 0.35 percent Be.

Urzarsaiskoye W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Obolenskiy, 1960; Sotnikov and Nikitina, 1977; Kuznetsov and others, 1978) consists of a stockwork of scheelite-bearing veinlets hosted in contact metamorphosed and locally in weakly metasomatized Cambrian and Early Ordovician sandy shale. The stockwork is 600 m long, 400 m wide, and extends as much as 500 m at depth. The stockwork consists of a dense network of quartz, quartz-feldspar, and quartz-feldspar-carbonate veinlets with scheelite, fluorite, beryl, chalcopyrite, and pyrite. Increased W occurs in quartz-feldspar veinlets. Mo increases downward. Wall rocks are silicified and altered to greisen and sericite. The thickness of the veinlets varies from 0.2 to 15 cm and averages 0.5 to 4 cm. Veinlets comprise from 10 to 30 percent of the host rocks. The deposit is large and has reserves of 100,000 tonnes. The average grade is 0.11 percent WO_3, with as much as 0.3 percent WO_3.

Akalakhinskoye (Alakha) Ta-Nb-REE alkaline MetasomatiteDeposit

The deposit (Vladimirov and others, 1997) consists of a stock (with dimensions of 1 by 1.5 km) of spodumene-granite porphyry and biotite porphyry granite in the main phase of the Chindagatui pluton. The spodumene granite porphyry is white with a fine-grained groundmass of albite, quartz, and muscovite. Phenocrysts range as much as 1 cm and are composed of quartz and spodumene (10 to 30 percent) and local microcline and muscovite. Accessory minerals are columbite, tantalite, magnetite, and garnet. Grades range from 50 to 150 ppm Ta, 120 to 264 ppm Nb, 3700 to 5100 ppm Li, 1200 ppm Rb, and 260 ppm Cs. Spodumene aplite and muscovite aplite dikes also occur. Muscovite aplite and spodumene granite porphyries are interpreted as having formed in the late stage of crystallization of the pluton, significantly after intrusion of the early stage granite that comprises the major part of the pluton.The Ta-bearing spodumene granite porphyry and aplite are the analogues of spodumene and REE pegmatite and contain high Ta, Nb, Li, Rb, Cs, Sn, and Be. The deposit is medium size and has reserves of 128 million tonnes. The average grades are 0.8 percent Li_2O, 0.01 percent Ta_2O_5, 0.01 percent Cs, and 0.08 percent Rb.

Baliktigkhem W-Sn-W Greisen, Stockwork, and Quartz Vein Deposit

The deposit (Matrosov and Shaposhnikov, 1988) consists of cassiterite-quartz veins and greisen zones in the apical part of a Devonian granite pluton. The greisen contains tourmaline, topaz, cassiterite, pyrite, arsenopyrite, and beryl. The ore minerals are more abundant in veins and lenses of quartz, muscovite-quartz, and siderophyllite-quartz. Cassiterite is irregularly disseminated and also occurs in nests in veins. The deposit is small.

Origin and Tectonic Controls for Kalgutinsk Metallogenic Belt

The belt is interpreted as having formed during generation of REE granitoids along transpression zones (Hovd regional fault zone and companion faults) that formed during final closure of the Mongol-Okhotsk Ocean. The REE deposits are genetically related to early Mesozoic REE plumasite granite in the Belokurikha plutonic belt. The age of hosting granite is Late Triassic and Early Jurassic. Rb-Sr isotopic ages are 201.0±1.5 Ma for the Chindagatui pluton, and 204.0±1.6 Ma for the Kalguta pluton-(Vladimirov and others, 1997). The initial $^{87}Sr/^{86}Sr$ ratio is 0.7069 to 0.7103 indicating an incorporation of significant crustal rock. The U-Pb ages of Ta spodumene granite in the Alakha stock are 188 and 183 Ma, whereas the Rb-Sr age is 195±3 Ma (Il'in and others, 1994). The Rb-Sr age of Li-F granite porphyry in the Dzulaly stock is 188.0±6.4 Ma (Dovgal and others, 1997). The belt of REE granite intrudes a middle Paleozoic continental-margin arcs consisting of a calc-alkalic volcanic-plutonic belts (Shokalskiy and others, 1996).

Mino-Tamba-Chugoku Metallogenic Belt of Volcanogenic-sedimentary Mn, Podiform Chromite, and Besshi Cu-Zn-Ag Massive Sulfide Deposits (Belt MTC) (Japan)

This Permian (or older) to Jurassic metallogenic belt is hosted in structural units in the Mino-Tamba-Chichibu and Akiyoshi-Maizuru subduction-zone terranes. The belt occurs in the western part of Honshu Island in the Inner Zone of southwestern Japan, trends east-northeast to west-southwest for more than 900 km, and is as much as 150 km wide. The eastern margin of the belt is the Tanakura tectonic line. Tsuboya and others (1956) named the belt the Chichibu geosyncline Fe-Mn metallogenic province. The North Kitakami metallogenic belt is interpreted as an eastern extension of this belt. The Mino-Tamba belt contains a large number of various types of deposits. Mn deposits are hosted in the Mino-Tamba-Chichibu terrane, and podiform chromite and Besshi Cu-Zn-Ag massive sulfide deposits are hosted in in the Akiyoshi-Maizuru terrane. The Mino-Tamba-Chichibu terrane is a Jurassic accretionary complex, and Mn deposits are associated with Triassic and Jurassic chert. Podiform Cr deposits occur in ophiolite in the pre-Permian Sangun metamorphic complex. Massive sulfide deposits occur in the Permian forearc Maizuru group. The significant deposit is at Awano.

The main reference on the geology and metallogenesis of the belt is Tsuboya and others (1956).

Wakamatsu Podiform Chromite Mine

This deposit (H. Miyake and others, written commun., 1997) occurs in serpentinite derived from dunite of the Tari-Misaka ultramafic body in the Sangun belt. The ultramafic body is mostly composed of massive harzburgite and dunite. The ultramafic rocks are contact metamorphosed by a Cretaceous granite. The mine contains three main ore bodies. Main number 7 body is 190 m long, 60 m wide, and 30 m thick and yielded 1 million tonnes of ore. The ore mineral is refractory grade chromite. Serpentine and olivine occur in the ore. The deposit was discovered in 1899, and the mine closed in 1994. The deposit is medium size and it produced 780,000 tonnes of ore grading 32 percent Cr_2O_3.

Yanahara Besshi Cu-Zn-Ag Massive Sulfide Mine

This mine (Mining and Metallurgical Institute of Japan, 1965; Dowa Mining Corporation, 1981) consists of the main Yanahara ore body and nine smaller ore bodies. The ore bodies are stratiform and lenticular and occur in a 4.5 by 2 km area. The Yanahara deplsit consists of the upper, lower, and lowest ore bodies. The upper body is 350 m long along strike, extends 1,000 m down dip, and is as much as 100 m wide. The lower ore body is similar. The main ore mineral is pyrite; minor ore minerals are pyrrhotite, magnetite, chalcopyrite, and sphalerite. Gangue minerals are quartz, sericite, and chlorite. The deposit is hosted in rhyolite pyroclastic rock and mudstone of the Paleozoic Maizuru Group. The deposit occurs immediately above the basalt of the Yakuno Group. The mine started in 1916 and closed in 1991. The mine is medium size and has reserves of 3.7 million tonnes grading 44 percent Fe, 47 percent S, 0.2 percent Cu, and 0.3 percent Zn.

Hamayokokawa Volcanogenic-Sedimentary Mn Mine

This mine (Mining and Metallurgical Institute of Japan, 1968; Uemura and Yamada, 1988) is located in the Yokokawa (Shiojiri) Mn deposit district that contains 17 deposits. The Hamayokokawa deposit contains six main ore bodies. The main ore body is 50 m long, 8 m thick, and extends 120 m down dip. The ore bodies occur in Paleozoic and Mesozoic chert and slate of the Mino belt. The ore minerals are rhodochrosite, hausmannite, manganosite, rhodonite, tephroite, and braunite. The mine closed in 1984. The mine is medium size, and produced 260,000 of tonnes ore grading 33 to 42 percent Mn.

Origin and Tectonic Controls for Mino-Tamba-Chugoku Metallogenic Belt

The belt is hosted in a subduction-zone complex composed of marine sedimentary and volcanic rock and fragments of oceanic crust with ultramafic rock. The Besshi deposits are interpreted as having formed along a spreading ridge. In the oceanic crustal fragments are podiform chromite deposits hosted in ultramafic rocks and chert-hosted Mn deposits. The deposits and host rocks were subsequently incorporated into an accretionary wedge of the Mino-Tamba-Chichibu subduction-zone terrane.

Mongol Altai Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposits (Belt MA) (Western Mongolia)

This Late Triassic(?) to Early Jurassic(?) metallogenic belt is related to small bodies of leucogranite that intrude the Altai and Hovd Hovd terranes. The belt extends northeast to east (Kovalenko and others, 1988) and subsequently defined the late Paleozoic east-west-trending North Hangai-Selenge metallogenic belt of REE deposits (Kovalenko and others, 1990). Three major mineral districts occur along the northwest-striking Hovd regional fault zone (Borisenko and others, 1992). Herein, we interpret the northwest-striking, early Jurassic Mongol Altai metallogenic belt that occurs along the major Hovd fault zone. The major deposits are at Ulaan Uul and Tsunkheg.

The main references on the geology and metallogenesis of the belt are Luchitsky (1983), Kovalenko and others (1988, 1990), Borisenko and others (1992), and Dandar and others (1999).

Ulaan uul W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Amitan, 1993; A.N. Demin and others, written commun., 1990; S. Dandar and others, written commun., 1999) consists of about 40 northeast-trending quartz-wolframite veins that occur in the western part of the Jurassic Ulaanuul leucocratic granite pluton. The veins are as much as 1000 m long and from 0.1 to 1.5 m wide and contain beryl, molybdenite, Y-bearing fluorite and sulfides. The Ulaanuul pluton is 10 by 2.5 km in size and is elongated northwest along the major Khovd fault. K-Ar isotopic ages range from 200 to 180 Ma, and Rb-Sr isochron ages are 180 to 170 and 196 ± 20 Ma. Granite pluton consists of porphyritic coarse-grained biotite granite, medium-grained microcline granite, and microcline-albite leucogranite. The deposit is small and has reserves of 2,280 tonnes WO_3 and resources of 5,870 tonnes of WO_3, 8.4 tonnes of Nb, and 500 kg of Y.

Tsunkheg W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Jargalsaihan and others, 1996) consists of complex vein and W stockwork that are hosted in a northeast-trending zone of Ordovician-Silurian sandstone, siltstones, tuffstone, and tuffaceous siltstone. Host rock is altered to sulfides, contact metamorphosed, and intruded by minor bodies of gabbro and diabase. Three steeply-dipping quartz-wolframite veins extend for 200 to 300 m along strike, more than 100 m downdip, and range from 0.3 to 0.45 m thick. The northeast-trending zone extends for 950 m and is as much as 270 m wide, and extends to a depth of 300 m. The ore mineral assemblages are scheelite-quartz-feldspar-molybdenite, wolframite-quartz-pyrite-pyrrhotite-scheelte-chalcopyrite, and sporadic quartz-carbonate. The deposit is large with resources of 8,000 tonnes of WO_3 grading 0.1 to 40 percent WO_3 and average grade of 2.39 percent WO_3; 50,000 tonnes of WO_3 grading 0.12 to 0.2 percent WO_3, 100 g/t Ag, 0.5 to 1.0 percent Cu, 1 percent Sb, 0.5 to 1.0 percent Zn, and 2 percent As.

Origin and Tectonic Controls for Mongol Altai Metallogenic Belt

The belt is interpreted as having formed during Mesozoic intraplate rifting related to magmatism along transextension zones. The belt is hosted in granitoids that intrude along the major Early Jurassic Hovd fault zone. In this region various REE deposits are related to Middle Devonian collisional, Carboniferous postcollisional, and Permian and Early Jurassic late-stage and post-orogenic granitoids (Dandar and others, 1999). For the Mongol Altai metallogenic belt, the W-Mo-Be deposits and occurrences in the Ulaan Uul ore-field are related to Early Jurassic granite. The major deposits are the Ulaan Uul and Tsunheg W-Mo-Be deposits; the Tsunheg II, Buraat and Mo stockwork; and W-Mo occurrences in the Ulaan Uul district. The Maraagiin (W, Sn, Mo) and Bodonchiin (W-Sn) districts are similar to the Ulaan Uul district. This belt is interpreted as having formed during Mesozoic continental interplate rifting associated with a mantle plume.

North Hentii Metallogenic Belt of Granitoid-Related Au Vein and Au in Shear Zone and Quartz Vein Deposits (Belt NH) (North Mongolia)

This Middle Triassic through Middle Jurassic metallogenic belt is related to granitoids in the Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlaps Zag-Haraa turbidite basin. The granitoids that host granitoid-related Au deposits consist of small intrusive stocks and dikes and are part of the Yoroogol gabbro and granite sequence (Koval and Tsypukov, 1977; Koval and others, 1982) that consists of small hypabyssal stocks and dikes in the margin of a calc-alkaline granitoid baholith in northeast-striking zone bounded by the Bayangol fault to the northwest and the Yoroogol fault to the southeast. These early Mesozoic intrusive stocks consist of simple gabbro, and (or) multiphase plutons composed of gabbro, diorite, and granite, and single granite plutons with abundant gabbro schlieren. The Au deposits occur throughout and the Sn deposits occur in simple granite stocks (Tsypukov, 1977). The Yorogol sequence contains abundant variable composition dikes and hydrothermal-metasomatitic alterations. The K-Ar isotopic age of the Yoroogol sequence ranges from 235 to 166 Ma (Koval and others, 1982). REE granite in the Yorogol sequence is mostly Jurassic.

The north and northwestern marginal part of the Central Hentei REE belt of Sn and Sn-W greisen, stockwork, and quartz-vein deposits, described below, is overprinted on the eastern and southeastern margin of the North Hentii 2 metallogenic belt. This North Hentii metallogenic belt was previously defined as a multiple age Au metallogenic belt containing early Paleozoic and early Mesozoic age hard rock Au, Late Cretaceous Au-bearing conglomerate, and placer Au deposits and occurrences (Blagonaravov and Shabalovskii, 1977; Blagonravov and Tsypukov, 1978; Poznyak and Dejidmaa, 1977; Blagonravov and others, 1984; Tcherbakov and Dejidmaa, 1984).

From northeast to southwest, the granitoid-related Au vein deposits and occurrences are at Yorogol, Boroo-Zuunmod, and Zaamar-Ugtaaltsaidam (Dejidmaa, 1996). Only early Mesozoic granitoid-related Au deposits occur in the Boroo-Zuunmod district, Yorogol district, in the Ugtaaltsaidam-Argalynnuruu group in the Zaamar-Ugtaaltsaidam district, and in the Zaamar group of the Zaamar-Ugtaaltsaidam district. Also occurring are a few early Mesozoic Au quartz deposits or disseminated Au-sulfide and quartz-vein deposits that are hosted in a metasomatitic zone (Dejidmaa, 1985). The Narantolgoi, Boroo 7, Tsagaanchuluut, Ereen, Urt and Baabgait deposits in the Boroo-Zuunmod district are typical Au-quartz-vein deposits. The Boroo and Sujigt deposits contain both large disseminated Au-sulfide deposits and high-grade Au-quartz veins. These deposits are hosted in early Paleozoic clastic rock, Devonian granite, Late Devonian through early Carboniferous subvolcanic rhyolite, and early Mesozoic granodiorite. The Au deposits in the North Khenti belt are interpreted as having formed during multistage hydrothermal activity related to multistage dikes. For example, gabbro and diabase dikes formed before the deposits, while diorite dikes intruded between the early disseminated Au-pyrite-arsenopyrite and the middle disseminated Au-pyrite-beresite stages of mineralization in the large Boroo deposit (Dejidmaa, 1985).

The main references on the geology and metallogenesis of the belt are Gottesman (1978), Blagonravov and others (1984), Tcherbakov and Dejidmaa (1984), and Dejidmaa (1985).

Boroo Granitoid-Related Au Vein Deposit

This deposit (fig. 10) (R. Barsbold and others, written commun.,1960; R. Khenel and others, written commun., 1968, 1970; G. Choren and others, written commun., 1986, 1988; Cluer and others, 2005) occurs along a major sublatitudinal fault zone that dips gently north and cuts sedimentary rock in the early Paleozoic Khara Group of the early Paleozoic Borogol granitoid complex. These rocks are intruded by early Mesozoic gabbro, diabase, and diorite dikes that are altered and host the deposit. The deposit extends approximately 2.0 km along strike and ranges from 3 to 34 m thick. The ore mineral assemblages, from older to younger, are preore epidote-chlorite; quartz-sericite-albite-chlorite; gold-pyrite-arsenopyrite-K-feldspar-quartz; gold-beresite; quartz; gold-sulphide-quartz vein; and postore calcite. Gold is fine-grained and occurs in pyrite and arsenopyrite and as free gold in quartz veins. Fineness of gold varies from 700 to 940. Main ore minerals are pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, tetrahedrite, and gold. Main gangue minerals are quartz, sericite, iron-carbonates, calcite, albite and muscovite. Sulphides comprise 5 to 25 percent in replacements and 1 to 2 percent in quartz veins. The average grade is 3.0 g/t Au in the replacement zone and 10 to 20 g/t Au in quartz veins in the replacement zone. The deposit was mined through openpit and underground workings from 1948 to 1955. The deposit contains reserves of 40.0 tonnes grading 3.0 g/t Au.

Sujigt Granitoid-Related Au Vein Deposit

This deposit (R. Kruse and others, written commun., 1970; Jargalsaihan and others, 1996) consists of quartz veins and stockwork that occurs along a northeast-striking minor fault-altered zone that cuts early Paleozoic granite and granodiorite of the Boroogol Complex. The fault zone is a part of the Sujigtgol regional fault and occurs between a middle Paleozoic rhyolite subvolcanic body and early Paleozoic granodiorite-granite massif. The deposit includes five main quartz veins that range from 110 to 250 m long, 0.27 to 0.48 m wide, and dip southeast to northeast. Grades range from 10 to 25 g/t Au. A lower grade stockwork occurs between the veins. Primary ore minerals are pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, tetrahedrite, burnonite, altite, and gold. Ore minerals in the oxidized zone are limonite, covellite, chalcocite, malachite, azurite, and cerussite. Sulphides comprise from 2 to 10 percent veins. The deposit extends to 275 m below the surface with downward decrease in Au grade and thickness of the Main vein. The deposit deposit was discovered by Mongolor joint venture in 1913 and mined from 1914 to 1916. The deposit is medium size with resources of 2,918.2 kg Au, and 975.1 kg Ag.

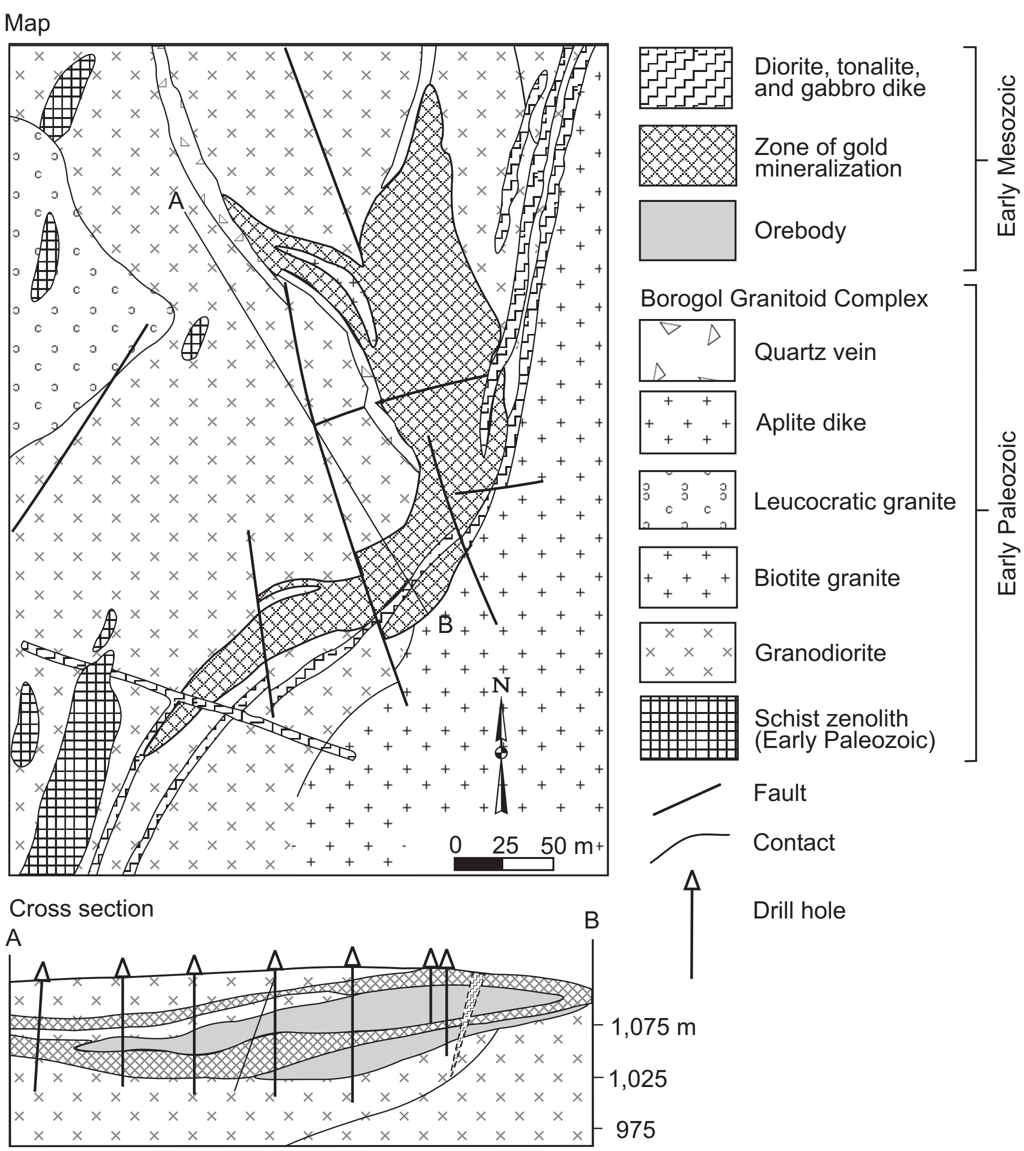


Figure 10. Geologic sketch map of Boroo granitoid-related Au vein deposit, North Hentii metallogenic belt. Adapted from Jargalsaihan and others (1996) and Cluer and others (2005).

Origin and Tectonic Controls for North Hentii Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc. The metallogenic belt is overprinted on the Orodovician Zaamar-Bugant Au quartz vein belt. The granitoid-related Au-vein deposits of the North Hentii belt are clearly distinguished by intrusives, mineralogy, and deposit morphology.

North Kitakami Metallogenic Belt of Volcanogenic-Sedimentary Mn and Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposits (Belt NK) (Japan)

This Triassic through Early Cretaceous metallogenic belt is related to stratiform units in the Mino Tamba Chichibu subduction-zone terrane. The belt occurs in the northern Kitakami Mountains, trends approximately north-south for more than 150 km, ranges up to 75 km wide, and occurs north of the Hayachine tectonic line. The metallogenic belt may extend further northwest onto southwestern Hokkaido Island. In the northern Kitakami mountains, two tectonic units are defined, the Kuzumaki-Kamaishi and Akka-Tanohata belts (Okami and Ehiro, 1988) that are separated by the Iwaizumi tectonic line. The Kuzumaki-Kamaishi belt consists of chert, limestone, and clastic rock. The chert and limestone form olistoliths in the clastic rocks. The olistolith ages range from Permian through Early Jurassic, and the age of clastic rock is Middle Jurassic through Late Cretaceous. The units form a typical Jurassic accretionary complex. The Akka-Tanohata belt consists of Middle Jurassic through Early Cretaceous shale, sandstone, mafic pyroclastic rock, limestone, and abundant Triassic through Jurassic chert. Early Cretaceous siliceous tuff, black shale, and andesitie occur in the eastern Akka-Tanohata belt and host the Kuroko Taro deposit. Manganese deposits occur in or adjacent to the chert. The belt contains a large number of stratiform Mn deposits, and one Kuroko massive sulfide deposit occurs in the belt. Tsuboya and others (1956) defined the Chichibu geosyncline Fe-Mn metallogenic province that contains the Mn deposits of the North Kitakami metallogenic belt. The significant deposits are at Nodatamagawa and Taro.

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956) and Okami and Ehiro (1988).

Nodatamagawa Volcanogenic-Sedimentary Mn Mine

This mine (fig. 11) (Mining and Metallurgical Institute of Japan, 1968) consists of three major stratiform ore bodies hosted in Jurassic chert. The ore bodies are stratiform or lenticular and are controlled by folding in the host chert. Cretaceous granite occurs near, and have contact metamorphosed the deposit with formation of biotite and cordierite in the slate around the deposit. The ore bodies are 600 m long and 1m thick. The ore minerals are rhodonite, tephroite, pyrochroite, hausmannite, rhodochrosite, and brounite. The gangue mineral is quartz. The ores are typically zoned with a central pyrochroite-haumannite, medial tephroite, and the outermost rhodonite that is adjacent to wall rock chert. The deposit is medium size and has produced 311,600 tonnes of Mn grading 30 to 35 percent Mn.

Taro Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type) MIne

This mine (Mining and Metallurgical Institute of Japan, 1965) consists of seven main bodies that strike in a northwest direction and dip southwest at 60 to 70 degrees. The main body extends 500 m along strike and ranges as much as 12 m thick. The main ore minerals are chalcopyrite, pyrite, galena, sphalerite, pyrrhotite, magnetite, and chalcocite. Gangue minerals are chlorite, calcite, and quartz. Host rocks are Mesozoic shale and sandstone. Mining started in 1854. The deposit is smalland has produced 36,857 tonnes of Cu, 18,942 tonnes of Zn, 5,825 tonnes of Pb grading 0.8 percent Cu.

Origin and Tectonic Controls for North Kitakami Metallogenic Belt

The Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor. The Kuroko deposits are interpreted as having formed in an island arc. The deposits and host rocks were subsequently incorporated into an accretionary wedge.

North Taimyr Metallogenic Belt of Granitoid-Related W-Mo-Be Greisen, Stockwork, and Quartz Vein, W±Mo±Be Skarn, and Porphyry Cu-Mo (±Au, Ag) Deposits (Belt NT) (Taimyr Peninsula, Russia)

This Middle and Late Triassic metallogenic belt is related to replacements and granitoids (too small to show on 5 million-scale map) intruding the Permian and Triassic volcanic and sedimentary rock of the Lenivaya-Chelyuskin sedimentary assemblage, Central Taimyr superterrane, and Kara terrane. The belt occurs in the Gorny Taimyr region, extends east-northeast for more than 600 km, and contains small early Mesozoic granitoid intrusions and numerous small W-Mo occurrences (Ravich, 1959; Ravich and Markov, 1959). The small intrusions occur in tectonic blocks bounded by postorogenic faults and consist of stocks and tabular bodies of granosyenite, syenite, granodiorite, and rare quartz monzonite with dimensions of 1 to 2 to 70 to 75 km^2. Granite porphyry dikes are common. Granitoids intrude Permian and Triassic volcanic and sedimentary rock, a Precambrian metamorphic sequence, and older granitoid plutons. The deposits occur mainly along the exocontacts. The metallogenic belt is still poorly studied and is prospective for undiscovered porphyry Cu-Mo (±Au, Ag) deposits. The significant deposits are at Kolomeitseva River, Morzhovoye, and Mamont River.

The main references on the geology and metallogenesis of the belt are Ravich (1959), Ravich and Markov (1959), and Vernikovsky (1996).

Kolomeitseva River W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Ravich, 1959; Ravich and Markov, 1959) consists of quartz veins with disseminated molybdenite. The veins cut Precambrian granitoid and Paleozoic clastic rock and exocontacts of small Permian and Triassic syenite intrusions. Molybdenite occurs also in the exocontact of an augite syenite intrusion in an older granitoid pluton. Scheelite occurs in heavy concentrates. The deposit is small and poorly studied.

Morzhovoye W±Mo±Be Skarn Deposit

This deposit (Ravich, 1959) consists of a grossular-diopside-calcite skarn with disseminated molybdenite in a roof pendant in a Triassic(?) syenite intrusive. The ore minerals are fine-grained molybdenite and disseminated pyrrhotite, pyrite, pentlandite, and marcasite. A stockwork of thin garnet-epidote-calcite veins with coarse molybdenite occurs in the northern part of the roof pendant. Altered rock along vein walls contains disseminated pyrite, chalcopyrite, and magnetite. Scheelite occurs in heavy concentrate. The deposit is small.

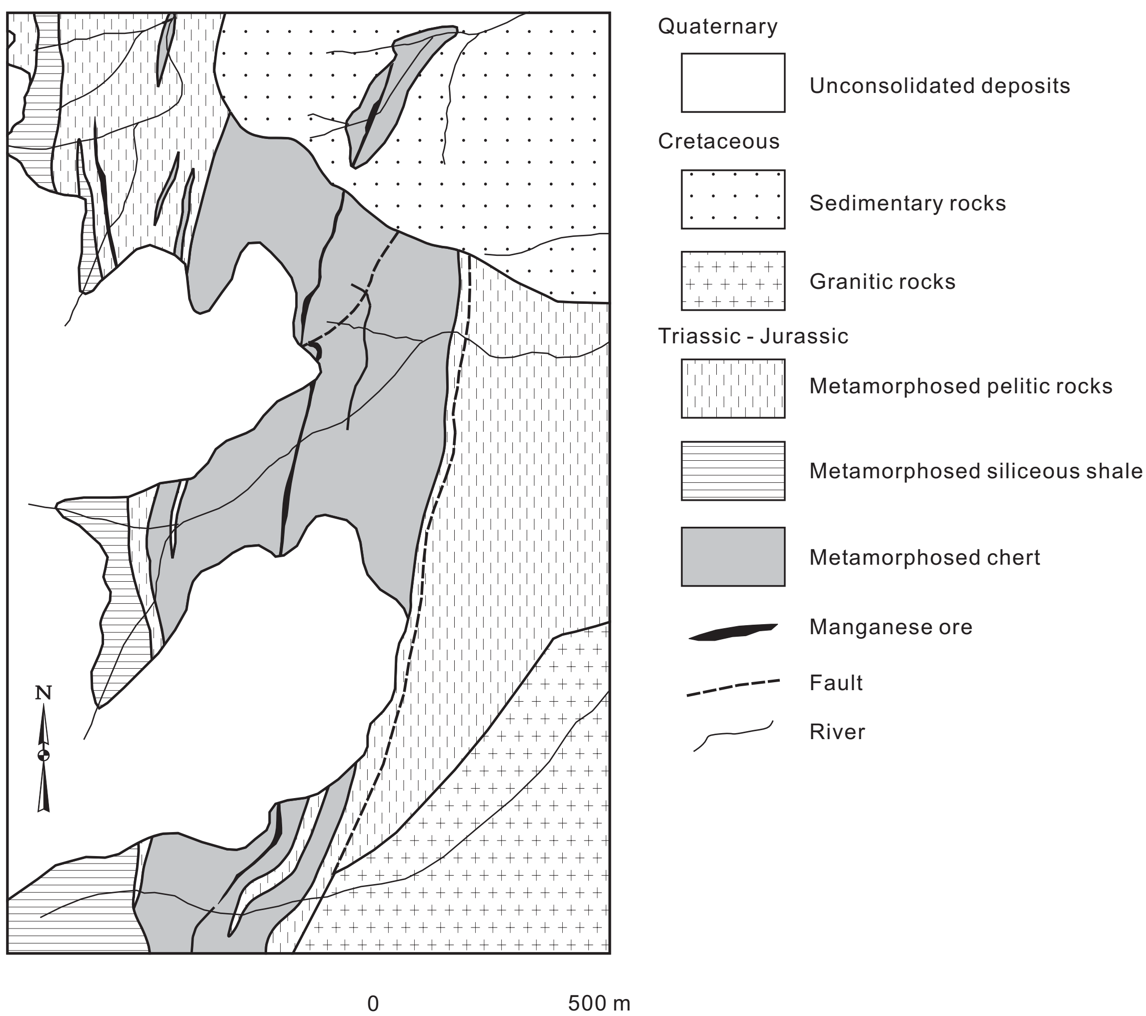


Figure 11. Geologic sketch map of Triassic through Early Cretaceous Nodatamagawa volcanogenic-sedimentary Mn deposit, North Kitakami metallogenic belt. Adapted from Sato and others (1957).

Mamont River 2 Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Ravich, 1959; Ravich and Markov, 1959) consists of quartz veins with disseminations and nests of molybdenite. The veins occur in small Permian and Triassic syenite intrusions that cut large Precambrian granitoid plutons. Quartz veins are accompanied by silica and sericite alteration. Along with molybdenite, the quartz veins contain pyrite, scheelite, sericite, and feldspar. The deposit is small and poorly studied.

Origin and Tectonic Controls for North Taimyr Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids during and after collision between the North Asian craton and Kara superterrane. The belt is hosted in intrusions in tectonic blocks bounded by post-orogenic faults. The host granitoids intrude Permian and Triassic tuff and lava sequence of the age. Granitoid pebbles occur in Early Cretaceous conglomerate (Ravich, 1959). The isotopic age of granitoid is about 233 to 223 Ma (Vernikovsky, 1996).

Sambagawa-Chichibu-Shimanto Metallogenic Belt of Besshi Cu-Zn-Ag Massive Sulfide (Cu, Zn, Ag), Volcanogenic-sedimentary Mn, and Cyprus Cu-Zn Massive Sulfide Deposits (Belt SCS) (Japan)

This Early Jurassic through Albian metallogenic belt is related to stratiform units in the Shimanto and Mino Tamba Chichibu accretionary-wedge terranes and the Sambagawa metamorphic terrane. The belt occurs in the outer zone of Southwestern Japan, trends approximately northeast-southwest for about 800 km, ranges as much as 70 km wide, and occurs in the Chubu district and Kii Peninsula on Honshu, Shikoku, and Kyushu Islands. The belt contains a large number of Besshi and Cyprus Cu-Zn massive sulfide deposits, and stratabound Mn deposits. Most of the Besshi deposits occur in the Sambagawa terrane in the northern part of the belt. The Besshi deposit occurs on Shikoku Island. The Besshi deposits and host rocks in the Sambagawa terrane are generally metamorphosed to epidote-amphibolite facies, high-pressure greenschist facies, or pumpellyite-actinolite facies metamorphism (Watanabe and others, 1998). The age of peak metamorphism is interpreted at about 110 Ma, and the age of submarine basalt volcanism and formation of related Besshi deposits is interpreted as being between 200 and 140 Ma (Watanabe and others, 1998). Geochemical characteristics of basalt associated with the deposits suggest submarine volcanism occurred in an oceanic intraplate setting or in a constructive plate margin (Watanabe and others, 1998). Several Besshi deposits occur in the Chichibu terrane south of the Sambagawa terrane, but most of them are small and not of economic value. The Shimanto terrane, south of the Chichibu terrane, hosts several Besshi deposits, including the Makimine deposit that occurs in the Mikabu greenstone zone of the Chichibu terrane. Manganese deposits in the metallogenic belt occur mainly in the Chichibu terrane, with fewer occurring in the Sambagawa and Shimanto terranes. The deposits are stratiform volcanic and sedimentary deposits and occur in or adjacent to chert. Three metallogenic provinces, a Besshi metallogenic province, the Chichibu Fe-Mn metallogenic province, and the outer zone of Southwest Japan pyrite and Fe-Mn metallogenic province, were defined by Tsuboya and others (1956) for the area of the Sambagawa-Chichibu-Shimanto metallogenic belt in this study. The significant deposits in the belt are at Besshi, Ananai, and Okuki.

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956) and Watanabe and others (1998).

Besshi Cu-Zn-Ag Massive Sulfide (Cu, Zn, Ag) Mine

This Mine (Mining and Metallurgical Institute of Japan, 1965; Suyari and others, 1991; Watanabe and others, 1998) consists of four srtratiform ore bodies. The Main Motoyama body extends 1,600 m along strike, 2,000 m down dip, and has dimensions of 3,000 by 11,000 m. Average thickness is 2.4 m with a maximum thickness of 15 m. The main ore minerals are pyrite, chalcopyrite, bornite, and magnetite. Gangue minerals are chlorite, hornblende, glaucophane, and quartz. The deposit is hosted in pelitic schist of Cretaceous Sambagawa Metamorphic Rocks. Mafic schist and piedmontite schist occur in the ore zone. Geochemistry indicates mafic schist derived from basalt that formed in an oceanic intraplate or constructive plate margins. Age of peak of metamorphism is 110 Ma according to Rb-Sr and K-Ar isotopic studies. Possible age for submarine basaltic volcanism and deposit formation is 200 (Late Triassic) to 140 Ma (Jurassic). The deposit was discovered in 1690. The deposit is large with production of 706,000 tonnes of Cu, reserves of 8 million tonnes of Cu, and average grades of 1.0 to 1.8 percent Cu, 0.1 to 1.4 percent Zn, 11.9 to 40 percent S, 0.3 to 0.7 g/t Au, and 7 to 20 g/t Ag.

Ananai Volcanogenic-Sedimentary Mn District

This district (Yoshimura, 1969; Suyari and others, 1991) contains more than eleven small ore bodies and is also named the Amatubo district. The ore bodies are hosted in Paleozoic and Mesozoic greenstone and sandstone of the Chichibu belt. The main Ananai deposit produced about 300,000 tonnes ore and consists of seven ore bodies that trend east-west for 4 km. Thickness of the deposit is typically 2 to 12 m. Ore minerals are rhodochrosite, braunnite, and bementite. The deposit is medium size with production of 300,000 tonnes of Mn ore.

Okuki Cyprus Cu-Zn Massive Sulfide Mine

This mine (Mining and Metallurgical Institute of Japan, 1965; Watanabe and others, 1970; Suyari and others, 1991) consists of Cu sulfide and pyrite massive sulfide that occurs conformably in metamorphosed mafic volcanic and pyroclastic rock associated with a gabbro body and thin chert beds in the Mikabu ophiolite. The deposit consists of the Honko and Otoko ore zones. Each ore zone contains several small ore bodies, which typically occur at hinges of anticlines. The hanging wall of the deposits is mafic volcanic rock and red chert, and the foot wall is phyllite. The red chert marks the ore horizon. The Honko ore zone is 1,500 by 400 m. The main ore minerals are pyrite, chalcopyrite, sphalerite, and native gold, and minor bornite, tetrahedrite, and cobaltite. Gangue minerals are chlorite, quartz, and calcite. The deposit is medium size with production of 50,000 tonnes of Cu, 2 tonnes of Au, and 7 tonnes of Ag grading 2.14 percent Cu, 4 g/t Au, and 60 g/t Ag.

Origin and Tectonic Controls for Sambagawa-Chichibu-Shimanto Metallogenic Belt

The Mn deposits in the belt are interpreted as having formed in a syngenetic, ocean floor setting. The Besshi and Cyprus deposits are interpreted as having formed during submarine volcanism along a spreading ridge. The deposits were subsequently incorporated into an accretionary wedge.

Wulashan-Zhangbei Metallogenic Belt of Alkaline Complex Hosted Au, Au Potassium Metasomatite, and Granitoid-Related Au Vein Deposits (Belt WZh) (North-Central China)

This Middle Jurassic metallogenic belt is related to granitoids in the Alashan-Yinshan Triassic plutonic belt (too small to show at 10 million scale) that intrudes the Sino-Korean craton, the Erduosi and Solon terranes, and adjacent units. The belt extends from the Wulashan Mountain of the western Inner Mongolia to the Zhangbei area in the Northwest Hebei Province. The belt is related to a Late Triassic through Early Jurassic alkaline complex and alkaline to subalkaline granite. The belt trends east-west, is about 600 km long, and ranges from 20 to 50 km wide. The discontinuous plutons related to Au deposits form a belt that is 40 to 50 km long and as much as 5 to 8 km wide. The significant deposits are at Dongping and Hadamen.

The main references on the geology and metallogenesis of the belt are Nie and others (1989), Zhou (1995), Song and Zhao (1996), and Shi and Xie (1998).

Dongping Alkaline Complex Hosted Au Deposit

This deposit (Song and Zhao, 1996), that was discovered in 1985 and was explored as a large Au deposit in 1992, consists of several tens of clusters of veins that trend northeast to north to northwest. Each vein cluster contains numerous parallel and oblique veins. The main deposit varies from a Au-pyrite-quartz vein to Au-sulphide-quartz vein to Au sulphides in veinlets-stockworks altered rock. Most of the numerous parts of the deposit are 1 to 4 m thick, 200 to 500 m long, and 200 to 500 m downdip. Sulphides comprise mostly less than 3 percent and consist mainly of pyrite and lesser chalcopyrite, galena, and sphalerite. Gold occurs mainly as native Au, and to a lesser amount in calaverite. Gangue minerals are mainly quartz and K-feldspar. Alteration consists of K-feldspar, silica, sericite, and carbonate. The deposit and alteration is strongly controlled by faults and related fissures. The host rock is the Shuiquan alkaline complex that is 5 to 8 km wide, 55 km long, trends east-west, and intrudes Archean granulite facies metamorphic rock. The intrusion exhibits strong petrologic zoning. The main rock types are alkali feldspar syenite, quartz-alkali feldspar syenite, pyroxene-amphibole-alkali feldspar syenite, pyroxene syenite, and amphibole monozite. The $^{40}Ar/^{39}Ar$ isotopic ages are 327.4±9 Ma and 177 to 157 Ma for the intrusion and K-feldspar in the deposit, respectively. The deposit is controlled by the east-west striking major Chicheng-Chengde fault at the northern margin of the Sino-Korean craton. Numerous similar deposits in the area are also related to alkaline intrusions. The deposit is large, and has reserves of 16.06 tonnes of Au grading 5 to 20 g/t Au.

Hadamen Au Potassium Metasomatite Deposit

This deposit (Zhou, 1995) occurs in veins in the middle and upper Archean Wulashan Group, mainly in garnet gneiss, granulite, magnetite quartzite, cordierite-, sillimanite-, garnet and graphite-biotite schist, quartzite, and marble. The Dahuabei potassic granite intrusion is 3 km to the west. The veins occur in clusters and swarms in large vein groups or plates. Three types of veins occur (1) Au quartz vein with gold, quartz, pyrite, chalcopyrite, galena, and sphalerite; (2) Au-K-feldspar and quartz-K-feldspar veins with Au, K-feldspar, quartz, pyrite, sericite, chlorite, and speculaite; and (3) Au potassic and silica-altered rock with gold, quartz, K-feldspar, albite, sericite, chlorite, calcite, and pyrite, and minor biotite, magnetite, muscovite, and garnet. Alterations include K-feldspar, silica, sericite, and carbonate alteration. Temperature of the formation of the deposit varied from an early high temperature of about 400 to 450°C to a later, low temperature of about 172°C. Pressure is estimated at 425 to 461±105 Pa. The deposit is interpreted as having formed during magmatic-related hydrothermal alteration related to the Dahuabei granite. The deposit is large, and has reserves of 20.86 tonnes grading Au 5.21 g/t Au.

Origin and Tectonic Controls for Wulashan-Zhangbei Metallogenic Belt

The belt is interpreted as having formed during intrusion of granitoids generated above a mantle plume in an extensional tectonic setting. The host intrusions are alkaline syenite, alkaline monzonite, subalkaline granite, and lesser calc-alkaline granite. The Au deposits are assocated with potassium metasomatism. The intrusions in the belt are controlled by major east-west-trending faults. These intrusions may have formed from the remelting deep crust (Zhou Kun, 1995), or from mantle-derived magma (Song and Zhao, 1996). Shi and Xie (1998) interpret the magmatism and deposits as being related to a mantle plume that formed in a tensile tectonic setting. There are many ages in the mineralization. Reliable isotopic data suggest a Late Triassic and Early Jurassic age (Shi and Xie, 1998; Nie and others, 1989).

Late Carboniferous (Pennsylvanian) to Early Triassic Tectonic and Metallogenic Model

Major Metallogenic and Tectonic Events

For the Late Carboniferous (Pennsylvanian) to Early Triassic (320 to 240 Ma), the major metallogenic-tectonic events were (fig. 12; tables 1, 2) (1) in the northern North Asian craton, formation of the Tungus Plateau igneous province and associated metallogenic belts with widespread intrusive traps consisting of extensive belts of sills and rare dikes that intruded major fault zones; (2) accretion of the Argun-Idermeg superterrane(Amur microcontinent composed of Agun and Idermeg passive continental margin terranes); (3) formation of the Gobi-Khankaisk-Daxing'anling continental-margin arc and associated metallogenic belts along the outboard edge of the accreted South Mongolia-Khingan collage and Argun-Idermeg superterrane (Amur microcontinent composed of Agun and Idermeg passive continental margin terranes); (4) formation of the North Margin continental-margin arc and associated metallogenic belts along the edge of the Sino-Korean craton; (5) formation of the transform-continental-margin Hangay arc and associated metallogenic belts along the southern margin of the North Asian craton and accreted terranes; (6) beginning of closure of the Mongol-Okhotsk Ocean and inception of an extensive, mainly right-lateral series of transform faults; (7) formation of the Jihei continental-margin arc and associated metallogenic belts along the margin of the Bureya-Jiamusi superterrane; and (8) inception of the Alazeya island arc.

The major Late Carboniferous through Early Triassic metallogenic belts in Northeast Asia are summarized in appendix C and portrayed on figure 3. The tectonic setting of each metallogenic belt is portrayed on figure 12.

Metallogenic Belts and Tectonic Origins

Metallogenic Belts Related to Selenga Arc

Four major metallogenic belts are hosted in the Selenga transform continental-margin arc along the margin of the Mongol-Okhotsk Ocean (figs. 3, 12). This arc is preserved manily in the Selenga sedimentary-volcanic plutonic belt (fig. 2).

The Battsengel-Uyanga-Erdenedalai belt (BUE, figs. 3, 12; appendix C) contains granitoid-related Au vein deposits that are hosted in small Late Carboniferous through Permian stitching plutons that formed during an early stage of intrusion of the Hangay plutonic belt that intrudes Hangay-Dauria and Onon subduction-zone terranes, part of the Mongol-Okhotsk collage. The plutonic rocks are part of Selenga sedimentary-volcanic plutonic belt.

The Buteeliin nuruu belt (BU, figs. 3, 12; appendix C) contains peralkaline granitoid-related, Nb-Zr-REE, REE-Li pegmatite, and W-Mo-Be greisen, stockwork, and quartz-vein deposits that are hosted in Permian granitoids related to the Selenga sedimentary-volcanic plutonic belt that intrudes the West Stanovoy terrane. The belt is part of a Permian core complex that contains granitoids that intrude granite-gneiss and mylonite.

The Central Mongolia belt (CM, figs. 3, 12; appendix C) contains Fe-Zn skarn, Sn-skarn, Zn-Pb (±Ag, Cu) skarn, W±Mo±Be skarn, Cu (±Fe, Au, Ag, Mo) skarn, porphyry Cu-Mo (±Au, Ag), porphyry Mo (±W, Bi); Au-skarn, granitoid related Au vein, and W-Mo-Be greisen, stockwork, and quartz-vein deposits that are hosted in Early to Late Permian that are part of the Selenga sedimentary-volcanic plutonic belt.

The Orhon-Selenge belt (OS, figs. 3, 12; appendix C) contains porphyry Cu-Mo (±Au, Ag) deposits that are hosted in Triassic granitoids in the Selenga sedimentary-volcanic plutonic belt.

Metallogenic Belts Related to South-Mongolia Continental-Margin Arc

The Harmagtai-Hongoot-Oyut belt (HH, figs. 3, 12; appendix C) contains porphyry Cu-Mo (±Au, Ag), porphyry Au, granitoid-related Au vein, and Au-Ag epithermal-vein deposits that are hosted in Middle Carboniferous through Early Permian granitoids that are part of the South-Mongolian volcanic-plutonic belt that formed the South Mongolian continental-margin arc.

Metallogenic Belts Related to South-Mongolia-Khingan Island Arc

The Duobaoshan belt (DB, figs. 3, 12; appendix C) contains porphyry Cu-Mo (±Au, Ag) deposits that are hosted in Pennsylvanian granitoids related to the Nora-Sukhotin-Duobaoshan island-arc terrane that is part of South Mongolia-Khingan collage. The belt is interpreted as having formed in the late stage of the South-Mongolia-Khingan subduction-related island arc.

The Kalatongke belt (KL, figs. 3, 12; appendix C) contains mafic-ultramafic related Cu-Ni-PGE and granitoid-related Au-vein deposits that are hosted in the Pennsylvanian Waizunger-Baaran island-arc terrane, part of Atasbogd collage. The belt is interpreted as having formed in the South Mongolia-Khingan subduction-related island arc.

Metallogenic Belts Related to Tungus Plateau Igneous Province

Four major metallogenic belts are hosted in the Tungus Plateau Igneous Province (figs. 3, 11; appendix C). The belts are interpreted as being related to Late Permian and Early Triassic mantle superplume magmatism that resulted in widespread development of trapp magmatism on the North Asian craton.

The Angara-Ilim belt (AI, figs. 3, 12; appendix C) contains Fe-skarn, REE (±Ta, Nb, Fe) carbonatite, and weathering crust carbonatite REE-Zr-Nb-Li deposits and is hosted in replacements related to Tungus plateau basalt, sills, dikes, and intrusions that intrude North Asian craton. The REE-Ta-Nb carbonatite deposits are associated with alkali-ultramafic intrusions.

The Kureisko-Tungsk belt (KT, figs. 3, 12; appendix C) contains Fe-skarn, mafic-ultramafic related Cu-Ni-PGE, and metamorphic graphite deposits that are hosted in Permian through Triassic replacements and plutons. The belt ocurs along the long-lived West-Siberian rift system and Yenisei sublongitudinal major fault.

The Maimecha-Kotuisk belt (MK, figs. 3, 12; appendix C) contains Fe-Ti (±Ta, Nb, Fe, Cu, apatite), carbonatite, REE (±Ta, Nb, Fe), carbonatite, and phlogopite-carbonatite deposits that are hosted in Late Permian through Early Triassic alkali-ultramafic-carbonatite intrusions. The magmatic rocks include tholeiite, diabase, trachybasalt, melanonephelinite volcanic rocks and intrusive rocks, and ijolite-carbonatite and kimberlite complexes.

The Norilsk belt (NR, figs. 3, 12; appendix C) contains mafic-ultramafic related Cu-Ni-PGE, basaltic native Cu (Lake Superior type) and porphyry Cu-Mo (±Au, Ag) deposits that are hosted in Early Triassic intrusions.

Miscellaneous Metallogenic Belts

The Altay belt (AT, figs. 3, 12; appendix C) contains REE-Li pegmatite and muscovite pegmatite depsoits that are hosted in veins, dikes, and replacements related to Late Carboniferrous granitoids in Altai volcanic-plutonic belt that intrudes Altai continental margin turbidite terrane. The belt formed during intrusion of collisional granite that formed during collision of the Kazakhstan and North Asian cratons. The belt formed during high-grade metamorphism associated with with crustal melting and generation of anatectic granite.

The Hitachi belt (HT, figs. 3, 12; appendix C) contains Permian volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) deposits that are hosted in the South Kitakami island-arc terrane that probably formed on the margin of the Sino-Korean craton.

The Shanxi belt (SX, figs. 3, 12; appendix C) contains Pennsylvanian sedimentary bauxite deposits that occur in stratiform units in the upper part of Sino-Korean platform units overlapping the Sino-Korean craton. The belt is interpreted as having formed during weathering of metamorphic rocks of the Northern China Platform.

Middle Triassic through Early Jurassic Tectonic and Metallogenic Model

Major Metallogenic and Tectonic Events

For the Middle Triassic through Early Jurassic (240 to 175 Ma), the major metallogenic-tectonic events were (fig. 13; tables 1, 2): (1) accretion of the Argun-Idermeg superterrane (Amur microcontinent composed of Agun and Idermeg passive continental-margin terranes), Bureya-Jiamusi supterterrane, and Sino-Korean craton, and formation of associated metallogenic belts; (2) continuation of closure of the Mongol-Okhotsk Ocean and continuation of an extensive, mainly right-lateral series of transform faults along the western, closed part of the ocean and formation of associated metallogenic belts; (3) inception of the Uda-Murgal continental-margin and island-arc system and associated metallogenic belts; (4) continuation of the Alazeya island arc; and (5) collision between the North Asian craton and Kara superterrane with formation of postcollisional granitoid intrusions (with isotopic ages of about 233 to 223 Ma) and associated metallogenic belts.

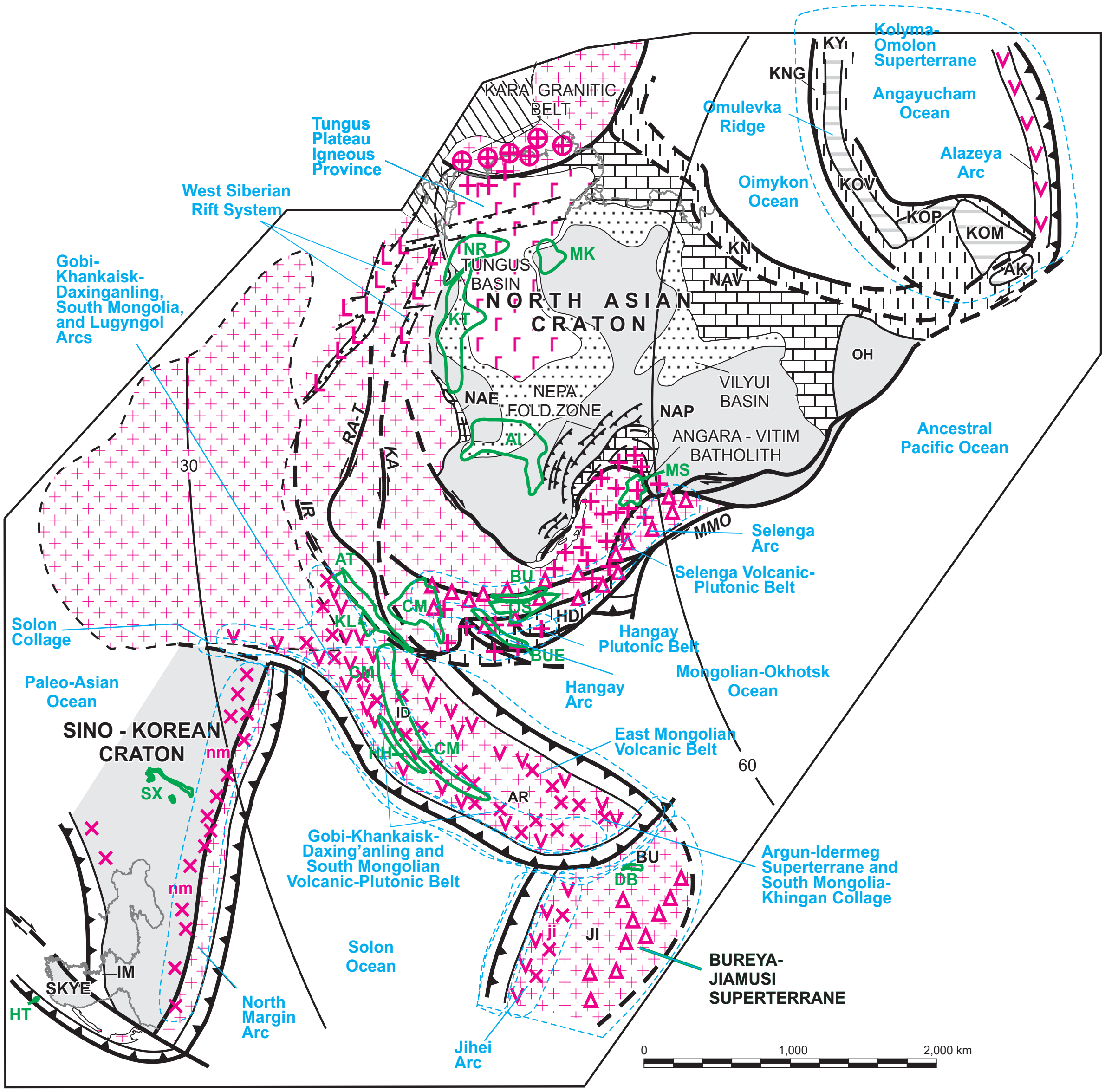
The major Middle Triassic through Early Jurassic metallogenic belts in Northeast Asia are summarized in appendix C and portrayed on figure 4. The tectonic setting of each metallogenic belt is portrayed on figure 13.

Metallogenic Belts and Tectonic Origins

Metallogenic Belts Related to Mongol-Transbaikalia Volcanic-Plutonic Belt

Several metallogenic belts are hosted in the Mongol-Transbaikalia volcanic-plutonic belt that is interpreted as having formed during generation of collisional granitoids and associated volcanic units during final closure of the Mongol-Okhotsk Ocean. This igneous belt is named the Mongol-Transbaikal arc (fig. 13).

The Central Hentii belt (CH, figs. 4, 13; appendix C) contains Sn-W greisen, stockwork and quartz vein, REE-Li pegmatite, Ta-Nb-REE alkaline metasomatite, W±Mo±Be skarn, and peralkaline peralkaline granitoid-related Nb-Zr-REE deposits that are hosted in Late Triassic through Early Jurassic replacements and granitoids related to the Late



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Terranes and Superterranes

AK - Avekov terrane
AR - Argunsky terrane
BU - Bureya terrane (Metamorphic)
ID - Idermeg terrane
IM - Imjingang terrane (Accretionary wedge, type B) (Devonian)
JI - Jiamusi terrane
KN - Kular-Nera terrane (Continental-margin turbidite) (Permian through Early Jurassic)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
ND - Nora-Sukhotin-Duobaoshan terrane (Island arc) (Neoproterozoic through Early Carboniferous)
OH - Okhotsk terrane
SKYE - Yeongnam terrane (Granulite-paragneiss) (Late Archean to Paleoproterozoic)

Overlap Continental-Margin Arcs and Granite Belts

ji -Jihei plutonic belt (Permian)
nm - North marginal plutonic belt Carboniferous and Permian)

Strike-Slip Fault and Shear Zone

IR - Irtysh shear zone
KA - Kuznetsk-Altai
MMO - Main Mongol-Okhotsk
RA-T - Rudny Altai - Taimyr

METALLOGENIC BELTS

AI - Angara-Ilim
AT - Altay
BU - Buteeliin nuruu
BUE - Battsengel-Uyanga-Erdenedalai
CM - Central Mongolia
DB - Duobaoshan
HH - Harmagtai-Hongoot-Oyut
HT - Hitachi
KL - Kalatongke
KT - Kureisko-Tungsk
MK - Maimecha-Kotuisk
MS - Muiskiy
NR - Norilsk
OS - Orhon-Selenge (185-240, 250)
SX - Shanxi

Figure 12. Early Permian (275 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).

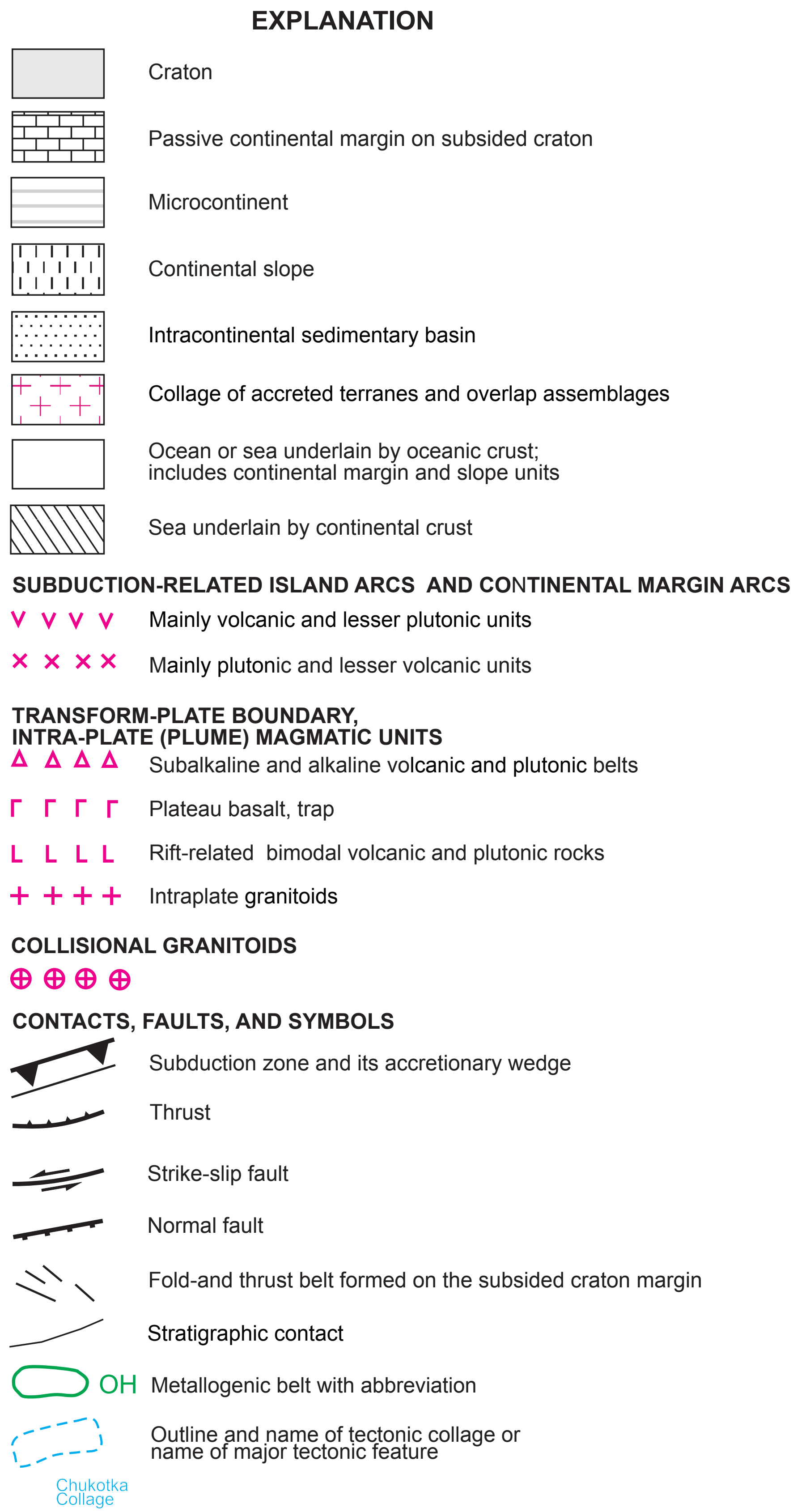
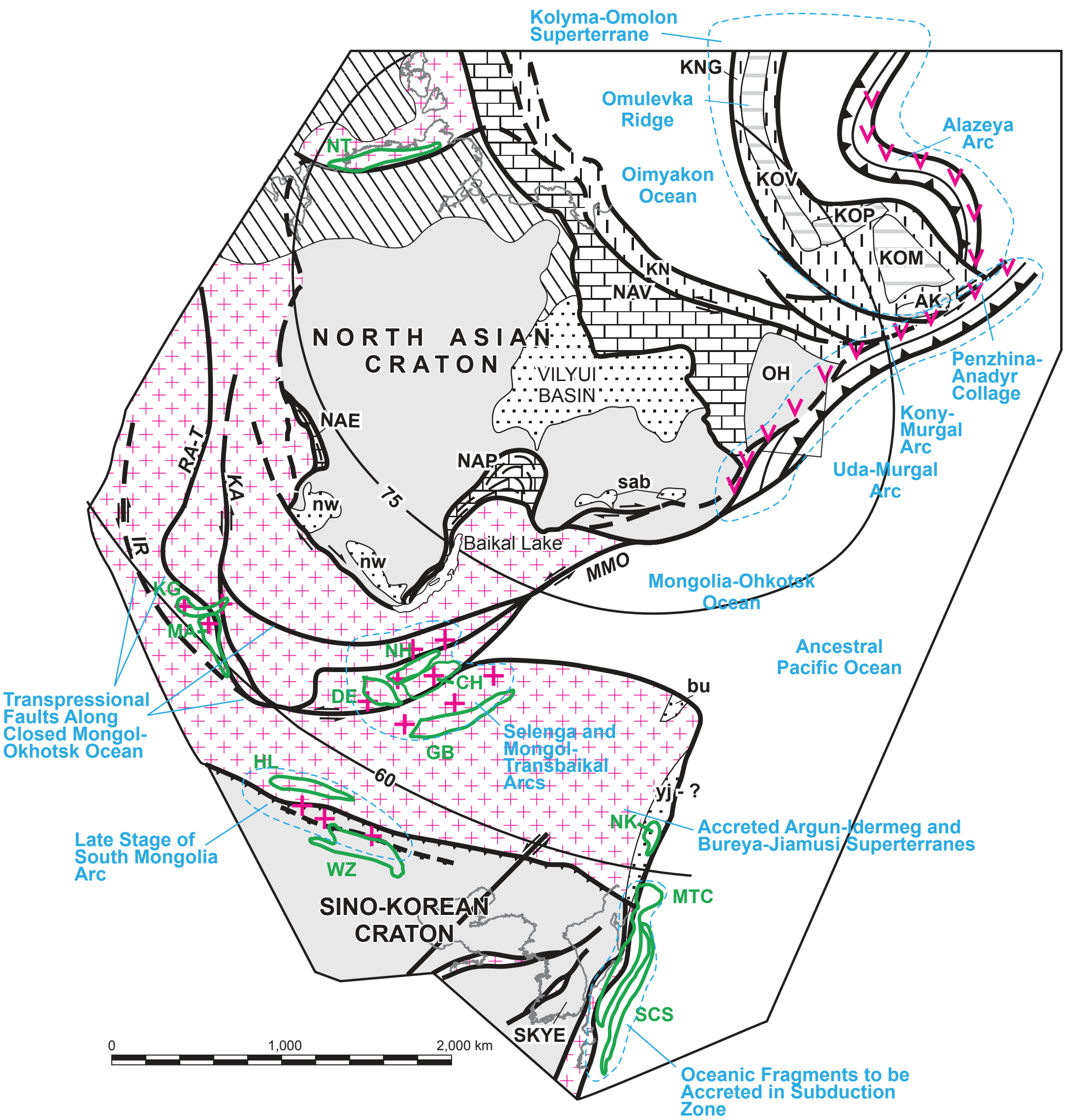


Figure 12.—Continued



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Intracontinental Sedimentary Basin

bu - Bureya sedimentary basin (Early Jurassic to Early Cretaceous)
nw - Western Siberia sedimentary basins (Mesozoic and Cenozoic)
sab - South Aldan sedimentary basin (Jurassic)
yj - Yanji-Jixi-Raohe overlap sedimentary assemblage (Mesozoic and Cenozoic)

Terranes and Superterranes

AK - Avekov terrane
KN - Kular-Nera terrane (Continental-margin turbidite) (Permian through Early Jurassic)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
OH - Okhotsk terrane
SKYE - Yeongnam terrane (Granulite-paragneiss) (Late Archean to Paleoproterozoic)

Strike-slip Fault and Shear Zone

IR - Irtysh shear zone
KA - Kuznetsk-Altai
MMO - Main Mongol-Okhotsk
RA-T - Rudny Altai - Taimyr

METALLOGENIC BELTS

CH - Central Hentii
DE - Delgerhaan
GB - Govi-Ugtaal-Baruun-Urt
HL - Harmorit-Hanbogd-Lugiingol
KG - Kalgutinsk
MTC - Mino-Tamba-Chugoku
MA - Mongol Altai
NH - North Hentii
NK - North Kitakami
NT - North Taimyr
SCS - Sambagawa-Chichibu-Shimanto
WZ - Wulashan-Zhangbei

Figure 13. Late Triassic (210 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).

Triassic through Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlaps Hangay-Dauria terrane, part of Mongol-Okhotsk collage, and adjacent units. The small plutons hosting REE deposits intruded in a continental post-collisional event.

The Delgerhaan belt (DE, figs. figs. 4, 13; appendix C) contains Late Triassic porphyry Cu (±Au) and granitoid-related Au vein deposits that are part of the Mongol-Transbaikalia volcanic-plutonic belt.

The Govi-Ugtaal-Baruun-Urt belt (GB, figs. figs.4, 13; appendix C) contains Fe-Zn skarn, Cu (±Fe, Au, Ag, Mo) skarn; Zn-Pb (±Ag, Cu) skarn, Sn-skarn, Fe-skarn, and Porphyry Mo deposits that occur as Late Triassic through Early Jurassic replacements related to the Mongol-Transbaikalia volcanic-plutonic belt.

The North Hentii belt (NH, figs. 4, 13; appendix C) contains granitoid-related Au vein and Au in shear-zone and quartz-vein deposits that are hosted in Middle Triassic through Middle Jurassic granitoids that are part of the Mongol-Transbaikalia volcanic-plutonic belt.

Metallogenic Belts Related to Closure of Mongol-Okhotsk Ocean

The Kalgutinsk belt (KG, figs. 4, 13; appendix C) contains W-Mo-Be greisen, stockwork, and quartz vein, Ta-Nb-REE alkaline metasomatite, and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in Early Jurassic granitoids and replacements in the Belokurikha plutonic belt that intrudes the Altai and West Sayan terranes, both part of Altai collage. The belt is interpreted as having formed during generation of REE granitoids along transpression zones (Hovd regional fault zone and companion faults) that formed during final closure of the Mongol-Okhotsk Ocean.

The Mongol Altai belt (MA, figs. 4, 13; appendix C) contains W-Mo-Be greisen, stockwork, and quartz-vein deposits that are hosted in small bodies of Late Triassic through Early Jurassic leucogranite that intrude Altai and Hovd Hovd terranes, both part of Altai collage. The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc.

Metallogenic Belt Related to South Mongolian Continental-Margin Arc

The Harmorit-Hanbogd-Lugiingol belt (HL, figs. 4, 13; appendix C) contains Sn-W greisen, stockwork, and quartz-vein, Ta-Nb-REE alkaline metasomatite, REE (±Ta, Nb, Fe) carbonatite, peralkaline granitoid-related Nb-Zr-REE, and REE-Li pegmatite deposits that occur as Middle Triassic through Early Jurassic replacements and granitoids related to South Mongolian volcanic-plutonic belt.

Metallogenic Belts Hosted in Tectonic Fragments in Subduction Zones

The Mino-Tamba-Chugoku belt (MTC, figs. 4, 13; appendix C) contains volcanogenic-sedimentary Mn Podiform chromite and Besshi Cu-Zn-Ag massive sulfide deposits that are hosted in tectonic fragments in the Mino Tamba Chichibu subduction-zone terrane, part of Honshu-Sikhote-Alin collage. The host rocks were incorporated into a subduction zone that formed along the margin of the Sino-Korean craton. The subduction zone contains various marine sedimentary and volcanic rocks, and fragments of oceanic crust with ultramafic rock. Besshi deposits are interpreted as having formed along a spreading ridge.

The North Kitakami belt (NK, figs. 4, 13; appendix C) contains Triassic through Early Cretaceous volcanogenic-sedimentary Mn and volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) deposits that are hosted in the Mino Tamba Chichibu subduction-zone terrane, part of Honshu-Sikhote-Alin collage. The Mn deposits formed in syngenetic setting on the ocean floor, and the Kuroko deposits formed in an island arc. The deposits were subsequently incorporated into a subduction zone.

The Sambagawa-Chichibu-Shimanto belt (SCS, figs. 4, 13; appendix C) contains Besshi Cu-Zn-Ag massive sulfide (Besshi), volcanogenic-sedimentary Mn, and Cyprus Cu-Zn massive sulfide deposits that are hosted in Early Jurassic and to Campanian fragments in the Shimanto subduction-zone terrane (part of Sakhalin-Hokkaido collage), the Mino Tamba Chichibu subduction-zone terrane (part of Honshu-Sikhote-Alin collage), and the Sambagawa metamorphic terrane (part of Honshu-Sikhote-Alin collage). The Mn deposits formed in a syngenetic setting on the ocean floor. The Besshi and Cyprus deposits formed during submarine volcanism related to a spreading ridge. All the deposits were subsequently incorporated into a subduction zone.

Miscellaneous Metallogenic Belts

The North Taimyr belt (NT, figs. 4, 13; appendix C) contains W-Mo-Be greisen, stockwork, and quartz vein, W±Mo±Be skarn, and porphyry Cu-Mo (±Au, Ag) deposits that are associated with Middle and Late Triassic replacements and granitoids intruding Permian-Triassic volcanic and sedimentary rocks of Lenivaya-Chelyuskin sedimentary assemblage, Central Taimyr superterrane, Kara superterrane. The belt is interpreted as having formed during generation of granitoids during and after collision between the North Asian craton and Kara superterrane. The belt hosted in intrusions in tectonic blocks bounded by postorogenic faults.

The Wulashan-Zhangbei belt (WZ, figs. 4, 13; appendix C) contains alkaline complex-hosted Au, Au potassium metasomatite, and granitoid-related Au vein deposits that are hosted in the Middle Jurassic granitoids related to the Alashan-Yinshan Triassic plutonic belt that intrudes the Sino-Korean craton - Erduosi terrane. The belt is interpreted as having formed in Late Triassic through Early Jurassic alkaline to subalkaline granitoids above a mantle plume in an extensional tectonic setting.

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Chapter 8

Middle Jurassic through Quaternary Metallogenesis and Tectonics of Northeast Asia

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Introduction

This article presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia for the Middle Jurassic through Quaternary (154 to 0 Ma). The major purposes are to provide a detailed summary of these features for readers who are unfamiliar with Northeast Asia. Several parts of this book on Northeast Asia provide background information. An overview of the regional geology, metallogenesis, tectonics of the region, and other materials, such as an employed geologic time scale and standard geologic definitions, are provided in Chapter 1. The methodology for the metallogenic and tectonic analysis of this region is provided Chapter 2. Descriptions of mineral-deposit models are provided in Chapter 3. Additional information on project publications, descriptions of major geologic units, and summaries of metallogenic belts are provided in appendixes A through C.

Compilations Employed for Synthesis, Project Area, and Previous Study

The compilation of regional geology and metallogenesis in this introduction is based on publications of the major international collaborative studies of the metallogenesis and tectonics of Northeast Asia that were led by the U.S. Geological Survey (USGS). These studies have produced two broad types of publications. One type is a series of regional geologic, mineral deposit, and metallogenic-belt maps and companion descriptions for the regions. Examples of major publications of this type are Obolenskiy and others (2003, 2004), Parfenov and others (2003, 2004a, b), Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006). The other type of publication is a suite of metallogenic and tectonic analyses of these same regions. Examples of major publications of this type are Rodionov and others (2004), Nokleberg and others (2000, 2004, 2005), and Naumova and others (2006). Detailed descriptions of lode deposits are available in Ariunbileg and others (2003). For more detail. refer to the detailed descriptions of geologic units and metallogenic belts in the publications listed above.

The Northeast Asia project area consists of eastern Russia (most of Siberia and most of the Russian Far East), Mongolia, Northern China, South Korea, Japan, and adjacent offshore areas (fig. 1). This area is approximately bounded by 30 to 82° N. latitude and 75 to 144° E. longitude. The major participating agencies are the Russian Academy of Sciences; Academy of Sciences of the Sakha Republic (Yakutia); VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation; Mongolian Academy of Sciences; Mongolian University of Science and Technology; Mongolian National University; Jilin University, Changchun, China; the China Geological Survey; the Korea Institute of Geosciences and Mineral Resources; the Geological Survey of Japan/AIST; University of Texas Arlington; and the USGS.

The Northeast Asia project extends and builds on data and interpretations from a previous project on the *Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera* that was done by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada. A summary of the major products of this project are available online at http://pubs.usgs.gov/of/2006/1150/PROJMAT/ and in appendix A.

[1]Russian Academy of Sciences, Khabarovsk.
[2]Russian Academy of Sciences, Vladivostok.
[3]Russian Academy of Sciences, Novosibirsk.
[4]Geological Survery of Japan/AIST, Tsukuba.
[5]Irkutsk State Technical University, Irkutsk.
[6]Russian Academy of Sciences, Yakutsk.
[7]U.S. Geological Survey, Menlo Park, Calif.

Major Geologic Units

The major Middle Jurassic through Quaternary geologic and tectonic units of Northeast Asia are cratons, craton-margins, tectonic collages, superterranes (microcontinents) and terranes, and overlap sedimentary basins and intrusive belts (fig. 2, table 1). Short descriptions of map units are given in appendix B. Summary descriptions of the major units are provided in descriptions of metallogenic belts (below), and detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004), and Parfenov and others (2004b).

Major Cratons, Cratonal Margins, and Cratonal Margin Terranes

The backstop or core units for the region of Northeast Asia are the Archean and Proterozoic North Asian craton and Sino-Korean craton and their cratonal margins (Baikal-Patom, East Angara, South Taimyr, and Verkhoyansk (North Asian).

The North Asian craton (NAC) consists of Archean and Proterozoic metamorphic basement, and nondeformed, flat-laying platform cover consisting of late Precambrian, Paleozoic, and Mesozoic sedimentary and volcanic rock.

Figure 1. Regional summary geographic map for Northeast Asia showing major regions and countries.

The Sino-Korean craton (SKC) consists of several major Archean and Proterozoic metamorphic basement terranes and younger Paleozoic through Cenozoic overlap units.

The Baikal-Patom cratonal margin (BP) consists of a fault-bounded basin containing Riphean carbonate and fine-grained marine sedimentary rock, and younger Vendian and Cambrian sedimentary rock that discordantly overlie a fragment of the preRiphean basement of the North Asian craton.

The East Angara cratonal margin (EA) consists of late Riphean fine-grained marine sedimentary rock and carbonate sedimentary rock (interlayered dolomite and limestone) that overlie a fragment of the North Asia craton.

The South Taimyr cratonal margin (ST) consists chiefly of a thick wedge of Ordovician through Jurassic cratonal margin deposits and deep basin deposits.

The Verkhoyansk (North Asian) cratonal margin (VR) consists chiefly of a thick wedge of Devonian through Jurassic miogeoclinal deposits.

Superterrane

The major Proterozoic through Permian Bureya-Jiamusi supterterrane (BJ) occurs along the margins of the North Asian and Sino-Korean cratons (fig. 2). The superterrane consists of a collage of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island-arc terranes. The superterrane is interpreted as being a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

Tectonic Collages East of North Asian and Sino-Korean Cratons

To the east of the North Asian and Sino-Korean cratons are a series of tectonic collages that were successively accreted from west to east (older to younger) during closures of parts of the ancestral Pacific and modern Pacific Oceans and older oceans in the region. Because of successive accretions from west to east, the ages of the collages are generally young from west to east. However, this pattern is locally disrupted because some collages have been interspersed by subsequent strike-slip faulting.

Except for the Verkhoyansk-Kolyma and Chukotka collages, the other tectonic collages contain one or more island arcs or continental-margin arcs and tectonically-linked subduction zones. The tectonic collages that occur east of the North Asian and Sino-Korean cratons are as follows.

(1) The Badzhal collage (BD) (Triassic through Early Cretaceous age and accreted in Late Cretaceous) consists of the Umlekan-Ogodzhin continental-margin arc and tectonically-linked subduction-zone terranes to the east with Tethyan fauna.

(2) The Chukotka collage (CH) (Paleozoic through Triassic age and accreted in Late Jurassic through Early Cretaceous) consists of passive continental-margin terranes that formed along the long-lived Neoproterozoic through early Mesozoic North American continental margin. After subsequent rifting of the North American cratonal margin in the Late Jurassic and Early Cretaceous and translation, the collage was accreted to the northern Verkhoyansk-Kolyma collage in the Late Cretaceous.

(3) The East Kamchatka Peninsula collage (EP) (mainly Paleocene age and accreted in Pliocene) consists of the Kronotskiy island arc and associated ophiolite.

(4) The East Sakhalin collage (ES) (Late Cretaceous through early Tertiary age and accreted in early Tertiary) consists of the Late Cretaceous through middle Eocene Terpeniy-Tokoro-Nemuro-Shmidt island-arc and tectonically-linked subduction-zone terranes.

(5) Honshu-Sikhote-Alin collage (HS) (Jurassic and Early Cretaceous age and accreted in Cretaceous). Consists of fragments of island-arc, continental-margin turbidite (flysch), and subduction-zone terranes. The collage is interpreted as having formed along a transform continental margin.

(6) The Koryak collage (KOR) (Late Triassic through Cretaceous age and accreted in Late Cretaceous) consists of the Late Jurassic and Early Cretaceous Manitskiy island arc and tectonically-linked subduction-zone terranes to the east.

(7) The Olyutorka-Kamchatka collage OK) (Late Cretaceous and Paleocene age and accreted in early Cenozoic) consists of the Olyutorka island-arc and tectonically-linked subduction-zone terranes to the east.

(8) The Penzhina-Anadyr collage (PA) (Late Jurassic through Early Cretaceous age and accreted in Late Cretaceous) consists of the Murgal island-arc terrane and tectonically-linked subduction-zone terranes to the east. The collage rims the eastern Kolyma-Omolon superterrane and Verkhoyansk-Kolyma collage. The collage is also linked to the Uda continental-margin arc.

(9) The Sakhalin-Hokkaido collage (SK) (Cretaceous age and accreted in Eocene) consists of the Late Cretaceous flysch terranes of Sakhalin and Hokkaido Islands, and tectonically-linked subduction-zone terranes to the east. The collage is interpreted as being a continental-margin fore-arc basin and tectonically-linked subduction-zone terranes that are associated with the East Sikhote-Alin continental-margin arc.

(10) The South Anyui collage (SA) (Permian through Early Jurassic age and accreted in Late Cretaceous) consists of the Oloy island arc and tectonically-linked subduction-zone terranes.

(11) The West Kamchatka collage (WK) (Mid-Cretaceous through early Tertiary age and accreted in early Cenozoic) consists of late Paleozoic through Cretaceous subduction-zone terranes in the Russian Northeast. The collage was tectonically linked to Okhotsk-Chukotka continental-margin arc.

(12) The Verkhoyansk-Kolyma collage (VK) (Late Paleozoic through Early Jurassic age and accreted in Late Jurassic through early Early Cretaceous) consists of a deformed passive continental margin and accreted ophiolite and subduction-zone terranes. This collage is interpreted as having formed during accretion of the outboard Kolyma-Omolon superterrane.

Tectonic Collage Between North Asian and Sino-Korean Cratons

In the Jurassic, the Mongol-Okhotsk collage (MO) was actively forming between the North Asian and Sino-Korean cratons. The Mongol-Okhotsk collage contains units ranging from the Devonian through Late Jurassic and was completely

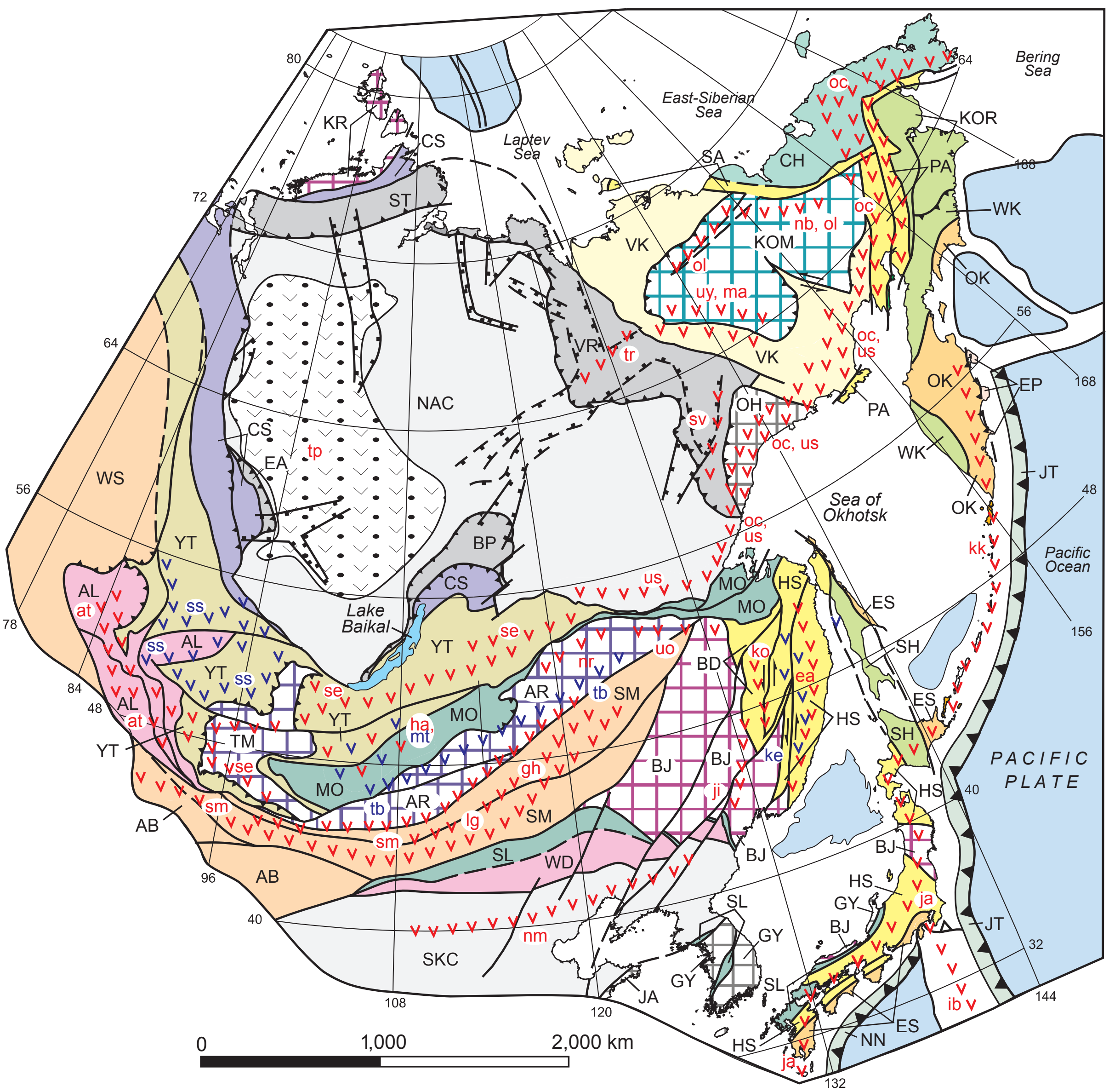


Figure 2. Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004), (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003), and (3) the western part of a Circum-North Pacific tectonostratigraphic terrane map at 10 million scale (Nokleberg and others, 1997). Map shows locations major geologic and tectonic units including cratons, and cratonal margins; cratonal terranes and superterranes; tectonic collages, overlap and transform continental-margin arcs; island arcs, and sea and ocean units. Refer to table 1 (tables 1 and 2 are found at the back of this chapter) and text for unit descriptions.

EXPLANATION

Cratons and Cratonal Margins

Cratons: NAC - North Asian (Archean and Proterozoic); SKC - Sino-Korean (Archean and Proterozoic)

Cratonal Margin: BP - Baikal-Patom (Riphean through Cambrian and older basement; EA - East Angara (Riphean and older basement; ST - South Taimyr (Ordovician through Jurassic); VR - Verkhoyansk (Devonian through Jurassic).

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

AL - Altay (Vendian to Ordovician)
WD - Wundurmiao (Riphean through Ordovician)

AB - Atasbogd (Ordovician through Permian); SM - South Mongolia-Khingan (Ordovician through Carboniferous); WS - West Siberian (Ordovician through Carboniferous)

MO - Mongol-Okhotsk (Devonian through Late Jurassic); SL - Solon (Carboniferous and Permian)

Tectonic Collages Along the Northern and Eastern Margins of North Asian and Sino-Korean Cratons

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

BD - Badzhal (Triassic through Early Cretaceous); PA - Penzhina-Anadyr (Late Jurassic and Cretaceous); HS - Honshu-Sikhote-Alin (Jurassic and Early Cretaceous); SA - South Anyui (Permian through Jurassic);

KOR - Koryak (Late Jurassic through Paleocene; SH - Sakhalin-Hokkaido (Cretaceous); WK - West Kamchatka (Mid-Cretaceous through Early Tertiary)

ES - East Sakhalin (Late Cretaceous and Early Tertiary); OK - Olyutorka-Kamchatka (Late Cretaceous to Paleocene)

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

JT- Japan Trench (including Kuril-Kamchatka trench) (Miocene through Holocene; NN - Nankai (Miocene through Holocene)

Cratonal Terranes and Superterranes

Cratonal terranes (Archean and Proterozoic): GY - Gyeonggi-Yeongnam; JA - Jiaonan; OH - Okhotsk

Late Proterozoic and Cambrian superterranes: AR - Argun-Idermeg; TM - Tuva-Mongolia

Archean through Permian superterranes: BJ - Bureya-Jiamusi; KR - Kara

Jurassic Superterrane: KOM - Kolyma-Omolon (Archean through Jurassic)

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

at - Altay arc (Devonian and early Carboniferous, 381 to 290 Ma)
ea - East Sikhote-Alin arc (Late Cretaceous through early Tertiary, 96-65 Ma)
gh - Gobi-Khankaisk-Daxing'anling arc (Permian, 295 to 250 Ma)
ha - Hangay arc (Late Carboniferous and Early Permian, 320 to 272 Ma)
ji - Jihei arc (Permian, 295 to 250 Ma)
ko - Khingan arc (Early and mid-Cretaceous)
lg - Lugyngol arc (Permian and Triassic, 295 to 250 Ma)
ma - Main granite belt (Late Jurassic, 144 to 134 Ma)
nb - Northern granite belt (Early Cretaceous, 138 to 120 Ma)
nm - North Margin (Late Carboniferous and Permian, 320 to 272 Ma)
nr - Norovlin arc (Devonian and Early Carboniferous, 410 to 255 Ma)
oc - Okhotsk-Chukotka arc (Late Cretaceous and early Tertiary, 96 to 53 Ma)
ol - Oloy arc (Late Jurassic, 154 to135 Ma)
se - Selenga arc (Permian through Jurassic, 295 to135 Ma)
sm - South Mongolian arc (Carboniferous through Triassic, 320 to 203 Ma)
ss - South Siberian arc (Devonian)
sv - South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157 to 93 Ma)
tr - Transverse granite belt (Early Cretaceous, 134 to 124 Ma)
uo - Umlekan-Ogodzhin arc (Cretaceous, 135 to 65 Ma)
us - Uda-Murgal and Stanovoy arc (Jurassic and Early Cretaceous, 203 to 96 Ma)
uy - Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154 to 120 Ma)

Plume-Related Igneous Province

tp - Tungus Plateau igneous province - (Late Permian and Early Triassic, 245 Ma)

Active Arcs

ib - Izu-Bonin (late Cenozoic, 20 to 0 Ma)
ja - Japan (late Cenozoic, 23 to 0 Ma)
kk - Kuril-Kamchatka (late Cenozoic, 11 to 0 Ma)

Transpressional Arcs

ke - Kema (Mid-Cretaceous)
mt - Mongol-Transbaikal (Late Triassic through Early Cretaceous, 230 to 96 Ma)
ss - South Siberian (Early Devonian, 415 to 400 Ma)
tb - Transbaikalian-Daxinganling (Middle Jurassic through Early Cretaceous,175 to 96 Ma)

Symbols, Faults, and Contacts

Overlap-continental-margin arc
Transform-continental-margin arc
Active subduction zone
Thrust
Strike-slip fault
Fault
Contact
Riphean aulacogen
Devonian aulacogen
Modern rift system (Gakkel Ridge)
os Metallogenic belt

Figure 2.—Continued

accreted in Late Jurassic. The collage consists mainly of the Permian through Jurassic Selenga, Late Carboniferous and Early Permian Hangay, and Uda-Murgal and Stanovoy continental-margin arcs. These arcs are composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically-linked, outboard subduction-zone terranes. The arcs overlap the southern margin of the North Asian craton and margin and previously-accreted terranes. The collage is interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean with oblique subduction of terranes beneath of southern North Asian cratonal margin and previously-accreted terranes. Closure and accretion extend from the Permian through the Late Jurassic (140 to 90 Ma). After closure of the Mongol-Okhotsk Ocean, left-lateral slip continued along the Mongol-Okhotsk fault that bounded the former ocean and resulted in formation of the Trans-Baikalian-Daxinganling bimodal igneous belt. More detailed descriptions of the terranes in each tectonic collage are provided in appendix B and in Parfenov (2003, 2004a,b).

Jurassic through Early Cretaceous Continental-Margin Arcs Occurring Along Southeastern Margin of the North Asian Craton and Adjacent Accreted Terranes

Two major continental-margin arcs occur along the southeastern margin of the North Asian craton or on adjacent accreted terranes. The arcs are interpreted as being related to subduction of the late Paleozoic and early Mesozoic Mongol-Okhotsk Ocean Plate beneath the North Asian craton and cratonal margin. This ocean occurred between the North Asian craton to the north and the Argun-Idermeg superterrane to the south (present-day coordinates).

(1) The Selenga arc (se) (Permian through Jurassic) overlies and intrudes the Yenisey-Transbaikal collage and Tuva-Mongolia superterrane. The arc is interpreted as having formed during oblique subduction of the Mongol-Okhotsk Ocean Plate under the North Asian cratonal margin and previously-accreted terranes.

(2) The Uda-Murgal and Stanovoy arcs (us) (Jurassic through Early Cretaceous) occur on the southern margin of the North Asian craton. The arcs are interpreted as having formed during the final stage of subduction of the Mongol-Okhotsk Ocean Plate.

Jurassic and Early Cretaceous Island Arcs Occurring on or Adjacent to Kolyma-Omolon Superterrane

The major island arcs occurring on the Kolyma-Omolon superterrane are the Late Jurassic through Early Cretaceous Uyandina-Yasachnaya island arc and the Late Jurassic Oloy island arc.

(1) The Oloy arc (ol) (Late Jurassic) occurs along the margin of the Kolyma-Omolon superterrane. The arc is interpreted forming on the Kolyma-Omolon superterrane during subduction of the South Anyui Ocean Plate beneath the superterrane.

(2) The Uyandina-Yasachnaya arc (uy) (Late Jurassic through Early Cretaceous) occurs along the margin of the Kolyma-Omolon superterrane. The arc is interpreted as having formed during subduction of the Oimyakon Ocean Plate between the North Asian cratonal margin and the Kolyma-Omolon superterrane. Remnants of the Oimyakon oceanic crust are preserved in small obducted ophiolites along the western margin of superterrane. This ocean occurred between the Verkhoyansk (North Asian) cratonal margin to the southwest and the Kolyma-Omolon superterrane to the northeast (present-day coordinates).

Jurassic through Early Tertiary Continental-Margin Arcs and Granite Belts Occurring along the Eastern Margin of Northern Asia

A series of Jurassic through early Tertiary continental-margin arcs and granite belts occurs along the eastern margin of the North Asian and Sino-Korean cratons and outboard accreted terranes to the east. From older to younger, the arcs and belts are as follows.

(1) The Umlekan-Ogodzhin arc (uo) (Jurassic and Cretaceous) occurs along the northern margin of the Bureya-Jiamusi superterrane. The arc is interpreted as having formed during subduction of the ancestral Pacific Ocean Plate along the margin of the superterrane.

(2) The South Verkhoyansk granite belt (sv) (Late Jurassic through mid-Cretaceous) occurs in central Russian Far East. The belt extends longitudinally along the central part of the South Verkhoyansk synclinorium in the Verkoyansk (North Asian) cratonal margin. The belt is interpreted as having formed during the accretion of the outboard Okhotsk terrane.

(3) The Main granite belt (ma) (Late Jurassic) occurs along the adjacent margins of the North Asian cratonal margin and Kolyma-Omolon superterrane. The belt is interpreted as having formed during and immediately after collision of the Kolyma-Omolon superterrane onto the North-Asian cratonal margin.

(4) The Transverse granite belt (tr) (Early Cretaceous) radiates outwards from the southwestern bend of the Kolyma-Omolon superterrane. The belt is interpreted as having formed during the late stage of accretion of the Kolyma-Omolon superterrane.

(5) The Northern granite belt (nb) (Early Cretaceous, 138 to 120 Ma) occurs along northwestern margin of the Kolyma-Omolon superterrane. The belt is interpreted as having formed during the subduction of oceanic crust that caused closure of a small oceanic basin that was associated with late stage of accretion of the Kolyma-Omolon superterrane.

(6) The Khingan-Okhotsk arc (ko) (Early and mid-Cretaceous) occurs in the Russian Southeast and consists of the Khingan-Okhotsk volcanic-plutonic belt. The arc is interpreted as having formed during subduction of the ancestral Pacific Ocean Plate. The arc was tectonically paired to the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes, part of the Honshu-Sikhote-Alin collage.

(7) The Okhotsk-Chukotka arc (oc) (Late Cretaceous through early Tertiary) occurs along the eastern margin of central and northern Russian Far East. The arc is interpreted as having formed during subduction of the ancestral Pacific Ocean Plate with formation of the West Kamchatka, Ekonay, and Yanranay subduction-zone terranes.

(8) The East Sikhote-Alin arc (ea) (Late Cretaceous through early Tertiary) occurs along the margin of southern Russian Far East. The arc is interpreted as having formed during subduction of the ancestral Pacific Ocean Plate with formation of the older part of the Hidaka subduction zone, the younger part of the Aniva subduction-zone terrane, and the Nabilsky, and Tokoro subduction-zone terranes.

Active Continental-Margin Arcs Occurring along the Eastern Margin of Northern Asia

Three active continental-margin arcs occur along the eastern margin of the North Asian and Sino-Korean cratons and outboard accreted terranes to the east.

(1) The Izu-Bonin arc (ib) (Miocene through Present) occurs south of southern Japan and consists of a volcanic arc composed chiefly of basalt to rhyolite, associated volcaniclastic rock, and intercalated hemipelagic mudstone. The arc is interpreted as having formed from subduction of the Philippine Sea Plate with creation of the Nankai subduction zone.

(2) The Japan arc (ja) (Miocene through Present) occurs along the Japan Islands and consists of extensive Quaternary volcanic and associated rock. The arc is interpreted as having formed during subduction of the Pacific Ocean and Philippine Sea Plates with formation of the Japan Trench and Nankai subduction zones.

(3) The Kuril-Kamchatka arc (kk) (Miocene through Present) occurs along Kamchatka Peninsula and the Kuril Islands and consists of the Pliocene to Quaternary Central Kamchatka volcanic belt, the central Kamchatka volcanic and sedimentary basin, and the East Kamchatka volcanic belt. The arc is interpreted as having formed during subduction of the Pacific Ocean Plate with formation of the Kuril-Kamchatka trench and subduction zone.

Transpressional Arcs (Triassic through Early Cretaceous)

Two major transpressional arcs occur along the margins of the North Asian craton and previously accreted terranes to the south. The arc formations are associated with a combination of strike-slip faulting and local compression and extension.

(1) The Mongol-Transbaikal arc (mt) (Late Triassic through Early Cretaceous) occurs in northern Mongolia and southern Siberia. The arc is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.

(2) The Transbaikal-Daxinganling arc (tb) (Middle Jurassic through Early Cretaceous) occurs in Southern Siberia, Mongolia, and Northeastern China. The arc is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.

Summary of Middle Jurassic through Quaternary (175 to 0 Ma) Metallogenesis

Major Middle Jurassic through Early Cretaceous Metallogenic Belts

The major Middle Jurassic through Early Cretaceous metallogenic belts are the Allakh-Yun, Ariadny, Bindong, Chara-Aldan, Chybagalakh, Djeltulaksky, Dzid-Selenginskiy, Daxinganling, East Mongolian-Priargunskiy-Deerbugan, Govi-Tams, Hartolgoi-Sulinheer, Jiliaolu, Kitakami, Kondyor-Feklistov, Kular, Nerchinsky, North Bureya, North Jilin, North Stanovoy, Onon-Turinskiy, Polousny, Samarka, Shilkinsko-Tukuringrskiy, Taebaegsan, Tompo, Verkhne-Ingodinsky, Verkhoyansk, Yana-Adycha, and Yanshan belts (fig. 3; appendix C).

Metallogenic Belts Related to Trans-Baikalian-Daxinganling Transpressional Arc

Eleven metallogenic belts possess geologic units favorable for a wide variety of siliceous igneous-rock related deposits, including the Daxinganling, Dzid-Selenginski, East Mongolian-Priargunskiy-Deerbugan, Govi-Tamsag, Hartolgoi-Sulinheer, Nerchinsky, Onon-Turinskiy, Shilkinsko-Tukuringrskiy, and Verkhne-Ingodinsky belts. The belts contain a wide variety of deposits. The major types of deposits are Au skarn; Zn-Pb (±Ag, Cu) skarn; W±Mo±Be skarn; Au-Ag epithermal, cassiterite-sulfide-silicate vein and stockwork; fluorspar vein;, granitoid-related Au vein; peralkaline granitoid-related Nb-Zr-REE; polymetallic metasomatite; polymetallic Pb-Zn vein and stockwork; porphyry Au; porphyry Cu-Mo, Mo, and Au; sediment-hosted U, Sn skarn; Sn-W greisen; stockwork, and quartz vein; Ta-Nb-REE alkaline metasomatite; volcanic-hosted Au-base-metal metasomatite; carbonate-hosted Ag-Pb and Hg-Sb; volcanic-hosted zeolite; W-Mo-Be greisen, stockwork, and quartz vein; W skarn; and Zn-Pb skarn. The isotopic ages of the igneous rocks that host the deposits range from 190 to 125 Ma. The belts are hosted in the major Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlaps terranes that were previously accreted to the southern of the North Asian craton and cratonal margin (present-day coordinates). The host rocks and metallogenic belts are interpreted as having formed along the major Trans-Baikalian-Daxinganling transpressional arc that formed along the major Mongol-Okhotsk suture that cuts previously-accreted terranes south of the southern margin (present-day coordinates) of the North Asian craton and cratonal margin. Displacement along the suture and arc formation occurred after the closing of the Mongol-Okhotsk Ocean.

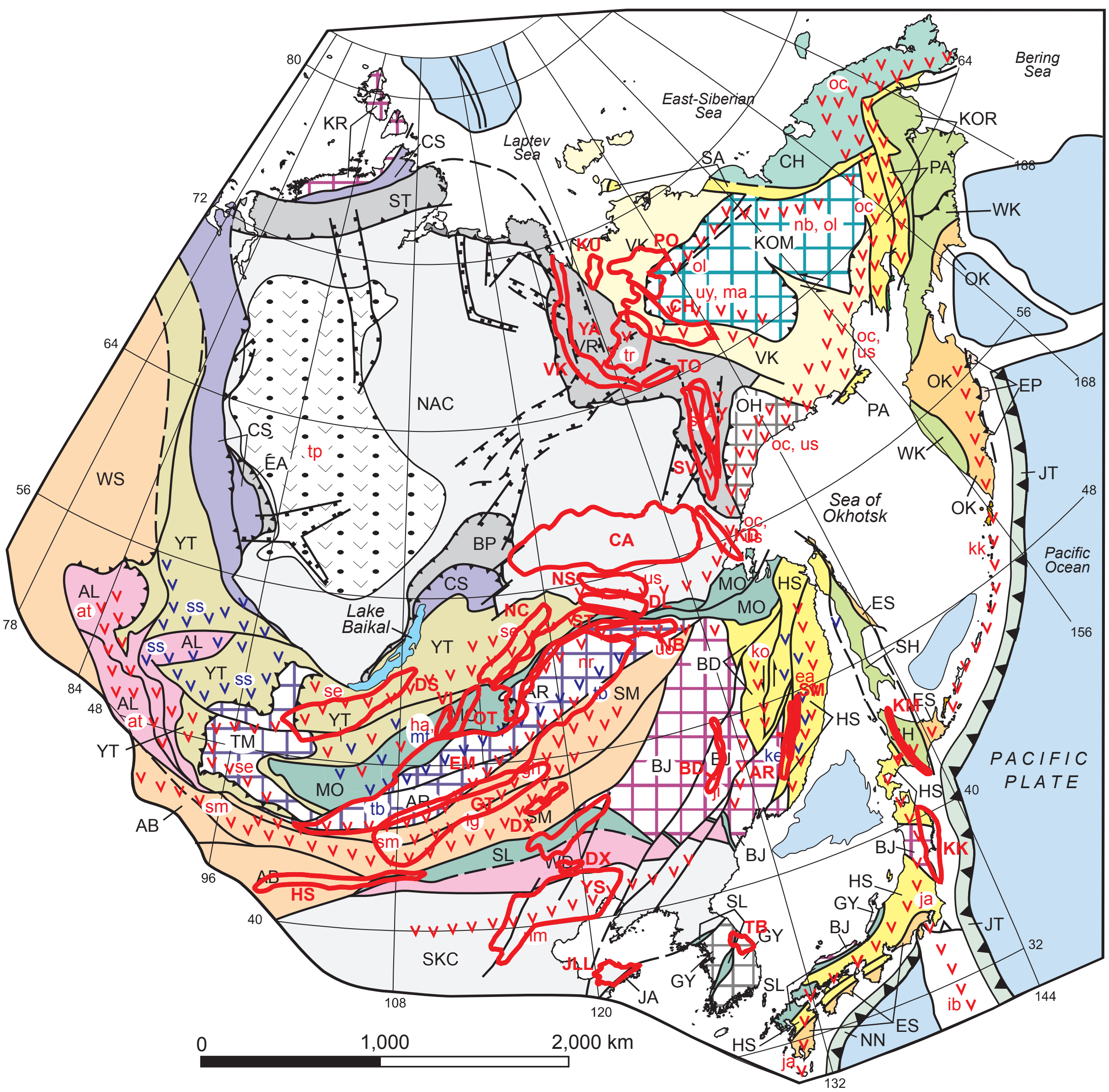


Figure 3. Generalized map of major Middle Jurassic through Early Cretaceous metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

Metallogenic Belts Related to Accretion of the Kolyma-Omolon Superterrane and Okhotsk Terrane

Eight metallogenic belts possess geologic units favorable for a wide variety of Au-vein deposits and collisional granite-related deposits, including the Allakh-Yun, Chybagalakh, Kular, Polousny, South Verkhoyansk, Tompo, Verkhoyansk, and Yana-Adycha belts (with Au in shear zone and quartz vein, granitoid-related Au vein; Cu skarn; Au in black shale; W skarn; polymetallic Pb-Zn vein and stockwork; cassiterite-sulfide-silicate vein and stockwork; Sn-W greisen, stockwork, and quartz vein; W-Mo-Be greisen, stockwork, and quartz vein; and Au-Ag epithermal-vein deposits). The ages of the veins and associated granites range from Late Jurassic through Aptian. The belts and deposits are hosted in veins and granitoids (such as the South Verkhoyansk, Main, and Northern granite belts) that intrude the Verkhoyansk (North Asian) cratonal margin and (or) the margin of the adjacent Kolyma-Omolon superterrane. The host rocks and metallogenic belts are interpreted as having formed during collision and accretion of the Kolyma-Omolon superterrane to the North Asian cratonal margin that resulted in regional metamorphism and generation of anatectic granitoids and related hydrothermal fluids. The Allakh-Yun and South Verkhoyansk metallogenic belts are interpreted as having formed immediately before the accretion of the Okhotsk terrane to the North Asian cratonal margin.

Metallogenic Belts Related to Uda-Stanovoy Continental-Margin Arc

Three metallogenic belts possess geologic units favorable for granitoid-related deposits, including the Chara-Aldan, Djeltulaksky, and North Stanovoy belts (with granitoid-related Au vein, Au-Ag epithermal vein, Au skarn, Au in shear zone and quartz vein, Au potassium metasomatite, and charoite metasomatite deposits). The isotopic ages for the granitoids hosting or related to the deposits range from Jurassic through Early Cretaceous. These metallogenic belts are interpreted as having formed during intrusion of granitoids of the Stanovoy granite belt that was part of the Uda-Stanovoy continental-margin arc. The arc is interpreted as having formed during subduction and closure of the Mongol-Okhotsk Ocean beneath the North Asian craton to the north (present-day coordinates).

Metallogenic Belts Related to Transpression

Four metallogenic belts possess geologic units favorable for a wide variety of transpressional granitoid-related deposits, including the Jiliaolu, North Jilin, Samarka, and Yanshan belts (with Au-Ag epithermal vein, Cu skarn W skarn, fluorspar vein, granitoid-related Au vein, polymetallic Pb-Zn vein and stockwork, polymetallic volcanic-hosted metasomatite, porphyry Cu and porphyry Cu-Mo, and W and Zn-Pb skarn deposits). The isotopic ages for the granitoids hosting the deposits range from 186 to 110 Ma. The granitoids and veins intrude either overlap assemblages on the Sino-Korean craton or the Samarka subduction-zone terrane (part of Honshu-Sikhote-Alin collage). The metallogenic belts are interpreted as having formed during intrusion of granitoids along transpressional zones along micro plate boundaries, underthrusting of the Kula oceanic ridge, and formation of bimodal igneous rocks along a transform continental margin, or during interplate magmatism associated with extensional tectonism related to oblique subduction of the ancestral Pacific Oceanic Plate beneath the Eurasian Plate.

Unique Metallogenic Belts

Six unique metallogenic belts formed during this time span. (1) The Kondyor-Feklistov belt with zoned mafic-ultramafic Cr-PGE deposits is hosted in mafic-ultramafic intrusions and is interpreted as having formed during intrusion of mafic-ultramafic plutons along a deep-seated fault that formed along the North Asian cratonal margin during collision and accretion of outboard terranes. (2) The North Bureya belt with Au-Ag epithermal vein and granitoid-related Au-vein deposits is hosted in the Umlekan-Ogodzhin volcanic-plutonic belt. The belt is interpreted as having formed during formation of Umlekan-Ogodzhin continental-margin arc through subduction of part of the ancestral Pacific Ocean Plate. (3) The Ariadny belt with mafic-ultramafic rock-related deposits is hosted in Middle Jurassic and Early Cretaceous plutons intruding the Samarka subduction-zone terrane, part of the Honshu-Sikhote-Alin collage. The belt is interpreted as having formed during generation of ultramafic and gabbroic plutons during underthrusting of the Kula oceanic ridge and formation of igneous rocks along a transform continental margin. (4) The Taebaegsan belt with a wide assortment of granitoid-related deposits is hosted in and related to the Late Jurassic through Early Cretaceous Daebo granite. The granitioid are interpreted as being part of a continental-margin arc that was linked to subduction of the ancestral Pacific Ocean Plate. (5) The Kitakami belt with Cu skarn and granitoid-related Au deposits is hosted in the Early Cretaceous Hiroshima granite belt (with isotopic ages of 120 to 110 Ma) and is interpreted as having formed during intrusion of granitoids associated with a continental-margin arc and siliceous magmatism. (6) The Bindong belt with Zn-Pb (±Ag, Cu) skarn and W±Mo±Be skarn deposits is hosted in small granitoids in the Mesozoic Jihei volcanic and plutonic belt and is interpreted as having formed during interplate extensional tectonism and generation of subalkaline to alkaline volcanism and related sedimentation along northeast and east-west regional faults.

Major Cenomanian through Campanian Metallogenic Belts

The major Cenomanian through Campanian metallogenic belts are the Badzhal-Komsomolsk, Central Polousny, Chelasin, Chokhchur-Chekurdakh, Eckyuchu-Billyakh, Gyeongnam, Gyeongpuk, Hidaka, Inner Zone Southwest Japan, Khandyga, Kukhtuy-Uliya, Luzhkinsky, Malo-Khingan, Pilda-Limuri, Preddzhugdzhursky, Selennyakh, Sergeevka-Taukha, South Verkhoyansk, Tumnin-Anyui, and Upper Uydoma belts (fig. 4, appendix C).

Metallogenic Belts Related to Okhotsk-Chukotka and East Sikhote-Alin Continental-Margin Arcs

Seven metallogenic belts possess geologic units favorable for a wide variety of granitoid-related deposits, including the Chelasin, Kukhtuy-Uliya, Luzhkinsky, Preddzhugdzhursky, Sergeevka-Taukha, Tumnin-Anyui, and Upper Uydoma belts (with Au-Ag epithermal vein; boron (datolite) skarn; cassiterite-sulfide-silicate vein and stockwork; granitoid-related Au vein; polymetallic Pb-Zn vein and stockwork; polymetallic volcanic-hosted metasomatite;, porphyry Cu, Cu-Mo; and Mo, Cu skarn; porphyry Sn; Sn-W greisen, stockwork, and quartz vein; Sn-B skarn; W-Mo-Be greisen, stockwork, and quartz vein; and Zn-Pb skarn deposits). The ages of the associated granites range from mid-Cretaceous through Paleocene. The belts and deposits are hosted in granitoids in the Okhotsk-Chukotka volcanic-plutonic belt or the East Sikhote-Alin volcanic-plutonic belt. Both units are major overlap assemblages in the Russian Far East and are interpreted as being part of the extensive, nearly coeval, and colinear continental-margin Okhotsk-Chukotka and East Sikhote-Alin arcs that overlie the North Asian craton and cratonal margin and previously-accreted terranes to the east (present-day coordinates).

Metallogenic Belts Related to Opening of Eurasia Basin

Four metallogenic belts possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits, including the Central Polousny, Chokhchur-Chekurdakh, Eckyuchu-Billyakh, Khandyga, and Selennyakh belts (with Ag-Sb vein; Au-Ag epithermal vein; carbonate-hosted As-Au metasomatite; cassiterite-sulfide-silicate vein and stockwork; clastic sediment-hosted Hg±Sb and Sb-Au, Hg-Sb-W vein and stockwork; polymetallic Pb-Zn vein and stockwork; carbonate-hosted Hg-Sb; volcanic-hosted Hg;, and Sn-W greisen, stockwork, and quartz-vein deposits). The isotopic ages for the-vein deposits range from 120 to 97 Ma, and the interpreted ages for the deposits range from Aptian through Late Cretaceous. The belts and deposits are hosted in units that intrude the Northern and Transverse granite belts, the Svyatoi Nos volcanic belt, and the Uyandina-Yasachnaya volcanic belt that intrude or overlie the Verkhoyansk (North Asian) cratonal margin and outboard accreted terranes. The belts are interpreted as having formed during extension related to the formation of the Eurasia Basin during initial opening of the Arctic Ocean.

Metallogenic Belts Related to Khingan Continental-Margin Arc

Four metallogenic belts possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits, including the Badzhal-Komsomolsk, Ezop-Yam-Alin, Malo-Khingan, and Pilda-Limuri belts (with Cu skarn; porphyry Mo; granitoid-related Au vein; polymetallic Pb-Zn; porphyry Sn; rhyolite-hosted Sn; Sn-W greisen, stockwork, and quartz vein; cassiterite-sulfide-silicate vein and stockwork; and W-Mo-Be greisen, stockwork, and quartz-vein deposits). The isotopic ages for the granitoids hosting or associated with the deposits range from 100 to 75 Ma. The belts and deposits are hosted in granitoids related to the Khingan-Okhotsk volcanic-plutonic belt that is interpreted as having formed during the generation of granitoids along the Khingan continental-margin arc. The arc is related to oblique subduction of the ancestral Pacific Ocean Plate and formation of the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes, part of the Honshu-Sikhote-Alin collage.

Unique Metallogenic Belts

Three unique metallogenic belts formed during the Cenomanian through Campanian.

(1) The Gyeongpuk and Gyeongnam belts (with granitoid-related deposits) have isotopic ages of Cenomanian through Campanian and are hosted in the Cretaceous Bulgugsa granite that intrudes the Sino-Korean craton.

(2) The Hidaka belt with Cyprus Cu-Zn massive sulfide deposits is hosted in Middle Cretaceous through Eocene stratiform units that occur in tectonic fragments in the Shimanto subduction-zone terrane, part of the East Sakhalin collage.

(3) The Inner Zone Southwest Japan belt, with a wide variety of vein and replacement and granitoid-related deposits, is hosted in the Nohi rhyolite volcanic belt and coeval Hiroshima granitic belt that intrude and overlie previously-accreted terranes. The host rocks and deposits have isotopic ages of Cretaceous through Paleogene.

Major Maastrichtian through Oligocene Metallogenic Belts

The major Maastrichtian through Oligocene metallogenic belts are the Kema, Lower Amur, and Popigay belts (fig. 5; appendix C).

Two metallogenic belts possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits, including the Kema and Lower Amur belts (with Ag-Au epithermal vein; porphyry Cu-Mo; porphyry Cu; porphyry Au; porphyry Mo; Au-Ag epithermal vein; epithermal quartz-alunite; and Sn-W greisen, stockwork, and quartz-vein deposits). The isotopic ages for the granitoids hosting or associated with the deposits range from Late Cretaceous through Paleocene. The belts and deposits are hosted in granitoids in the East Sikhote-Alin volcanic-plutonic belt that is a major overlap assemblage in the Russian Far East. The belt is interpreted to be part of an extensive continental-margin arc that formed along the eastern margin (present-day coordinates) of the North Asian craton and cratonal margin and previously-accreted terranes to the east. The arc is interpreted as having formed during subduction of the ancestral Pacific Ocean Plate.

The unique Popigay metallogenic belt contains impact diamond deposits. Isotopic age from tagamite (impact melt rock) and impact glasses is 35.7 Ma. The belt is hosted in

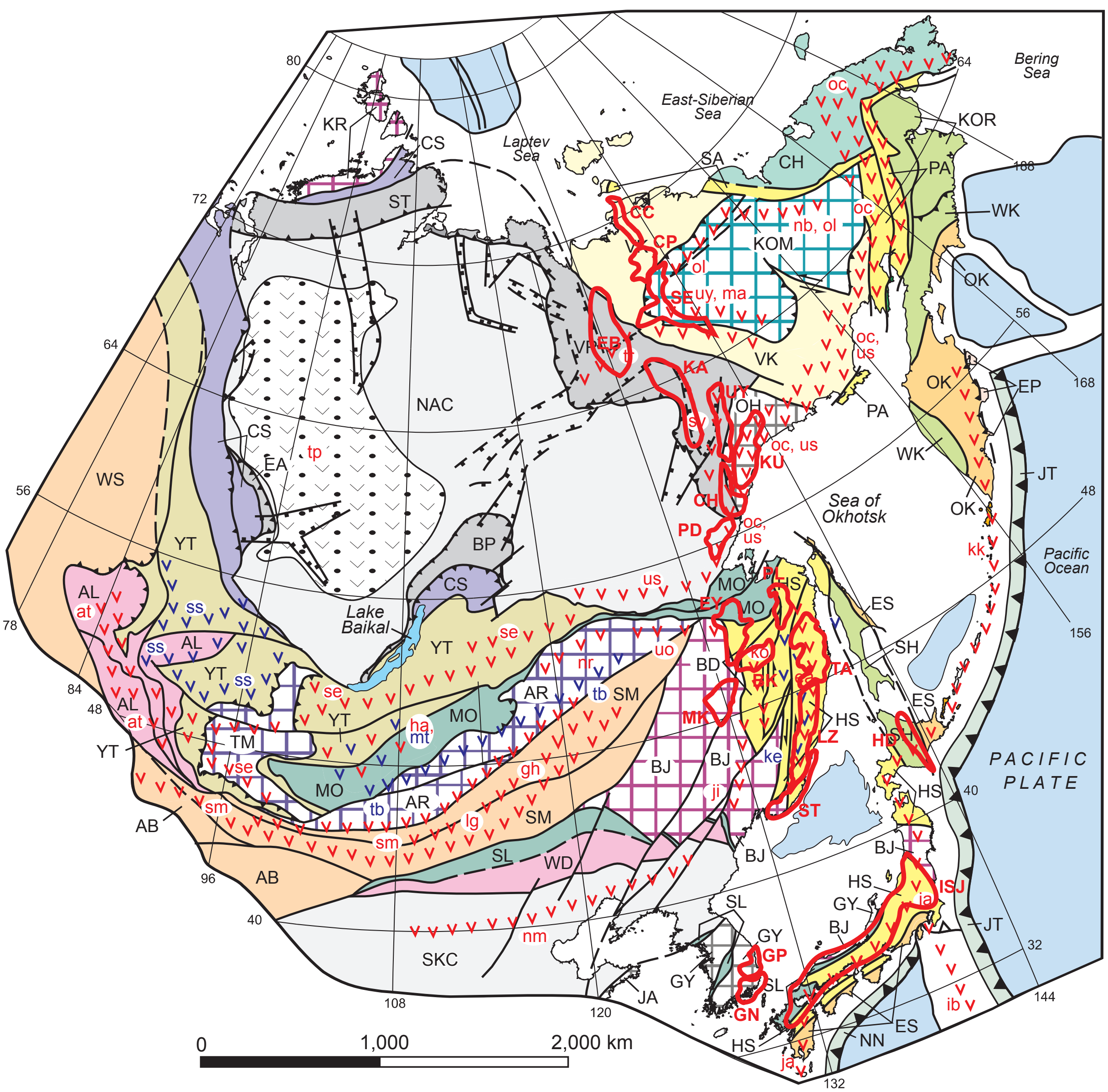


Figure 4. Generalized map of major Cenomanian through Campanian metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

the Popigay ring structure and is interpreted as resulting from meteoritic impact with formation of pseudotachylite, diamond, high-grade shock metamorphic minerals, and allogenic breccia.

Major Miocene through Quaternary Metallogenic Belts

The major Miocene through Quaternary metallogenic belts are the Kyushu, Northeast Hokkaido, Hokuriku-Sanin, Northeast Japan, and Outer Zone Southwest Japan belts (fig. 5; appendix C).

All five major metallogenic belts possess geologic units favorable for a wide variety of volcanic-rock-related deposits. These belts contain a wide variety of deposits, including Au-Ag epithermal vein; cassiterite-sulfide-silicate vein and stockwork; chemical-sedimentary Fe-Mn; clastic sediment-hosted Hg±Sb; clastic-sediment-hosted Sb-Au;Ag-Sb and Hg-Sb-W vein and stockwork; limonite from spring water; Mn vein; polymetallic Pb-Zn vein and stockwork; polymetallic volcanic-hosted metasomatite; Sn skarn; Sn-W greisen, stockwork, and quartz vein; sulfur-sulfide; volcanic-hosted Hg; Ag-Sb vein; volcanogenic Zn-Pb-Cu massive sulfide; volcanogenic-sedimentary Mn; W-Mo-Be greisen, stockwork, and quartz vein; and Zn-Pb skarn deposits. The isotopic ages of the igneous rocks hosting the deposits range from 15 to 0.3 Ma. The belts and deposits are hosted in the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that are interpreted as being part of the modern-day Japan continental-margin arc. This arc is tectonically related to subduction of the Pacific Ocean and Philippine Sea plates beneath the East Asia continental margin.

Late Middle Jurassic through Early Cretaceous (154 to 96 Ma) Metallogenic Belts

Allakh-Yun' Metallogenic Belt of Au in Shear Zone and Quartz-Vein, Cu (±Fe, Au, Ag, Mo) Skarn, and Au in Black Shale Deposits (Belt AY) (Russia, Verkhoyansk-Kolyma Region)

This Late Jurassic through Early Cretaceous metallogenic belt is related to veins that cut the southern Verkhoyansk fold and thrust belt in the North Asian cratonal margin. The belt extends longitudinally for 300 km in the Minorsk-Kiderikinsk zone of highly deformed Late Carboniferous and Permian sedimentary rock in the western South Verkhoyansk synclinorium. The Au in shear zone and quartz-vein deposits that are characteristic in the belt, is relatively older than the large anatectic granitic plutons of the South Verkhoyansk synclinorium that have a $^{40}Ar/^{39}Ar$ isotopic age of 123 to 120 Ma. The main deposits are concordant and crosscutting veins that occur in hinges and limbs of minor folds. The concordant-vein deposits thin outward into concordant stockworks. Also occurring are tabular deposits along tension fractures. The major deposits are at Yur, Muromets, and Svetly.

The main references on the geology and metallogensis of the belt are Konstantinov and others (1988), Fridovsky (1998), and Parfenov and others (1999).

Yur Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Strona, 1960; Kobtseva, written commun., 1988) consists of four interbedded quartz veins that occur along a zone of meridional faults in Middle Carboniferous sandstone and shale. Veins range from 0.3 to 0.4 meters thick and are 100 to 500 meters long. The main ore minerals are gold, arsenopyrite, galena, pyrite, and sphalerite and comprise as much as 2 percent veins. Gangue minerals are quartz, ankerite, and albite. Wallrock alteration is insignificant and consists of sericite, silica minerals, and arsenopyrite. The deposit is small and has an average grade of 3.5 to 5.7 g/t Au.

Muromets Cu (±Fe, Au, Ag, Mo) Skarn Deposit

This deposit (Krasny and Rasskazov, 1975; Nikitin and Rasskazov, 1979) is hosted in Middle Cambrian dolomite along the contact with an Early Cretaceous quartz monzodiorite. The deposit consists of a band of skarn bodies that are 1 km long and dip gently (20 to 40°) under the intrusion. The bodies range from 6 to 12 meters thick and occur in disseminations, stringers, and rare masses. Minor magnesian skarn consists of spinel, forsterite, phlogopite, tremolite, diopside, and serpentine. Predominant limestone skarn consists of salite, diopside, scapolite, grossular, and andradite. Ore minerals are magnetite, chalcopyrite, molybdenite, scheelite, pyrrhotite, bornite, pyrite, galena, and sphalerite. The skarn formed three stages (1) magnesian skarn with magnetite; (2) calcareous pyroxene-garnet skarn with magnetite and scheelite; and (3) metasomatic quartz-feldspar rock with molybdenite and Cu sulfides. Disseminated Cu sulfides also occur in adjacent altered quartz monzodiorite is a skarn-related porphyry Cu deposit. The deposit is medium size and the average grades are as much as 10 percent Cu, 0.92 percent WO_3, and 0.3 percent Mo.

Origin and Tectonic Controls for Allakh-Yun' Metallogenic Belt

The belt is interpreted as having formed during accretion of the Okhotsk terrane to the North Asian craton. The belt occurs in the Minorsk-Kiderikinsk zone of highly deformed Late Carboniferous and Permian sedimentary rock in the western South Verkhoyansk synclinorium. The deformation associated with formation of the Allakh-Yun' belt occurred in the Late Jurassic through Early Cretaceous and is interpreted as having formed during accretion of the Okhotsk terrane to the North Asia craton.

Ariadny Metallogenic Belt of Mafic-Ultramafic Related Ti-Fe (±V) and Zoned Mafic-Ultramafic Cr-PGE Deposits (Belt AR) (Russia, Far East)

This Middle Jurassic and Early Cretaceous metallogenic belt is related to mafic-ultramafic plutons intruding the Samarka subduction-zone terrane. The zoned intrusions that host the Ariadny metallogenic belt consist of Late Jurassic ultramafic and gabbroic plutons with K-Ar isotopic ages of about 160 Ma. The complexes are interpreted as being synvolcanic intrusives that intruded the turbidite deposits of the Samarka subduction-zone terrane immediately before accretion of the terrane in the Early Cretaceous.

The major deposits are at Katenskoe, Ariadnoe, and Koksharovskoe. The deposits consist mainly of disseminated to massive ilmenite that is hosted in layers in gabbro and pyroxenite. Titanium-magnetite and apatite are rare. The deposits also contain sparse PGE minerals, and sparse PGE minerals

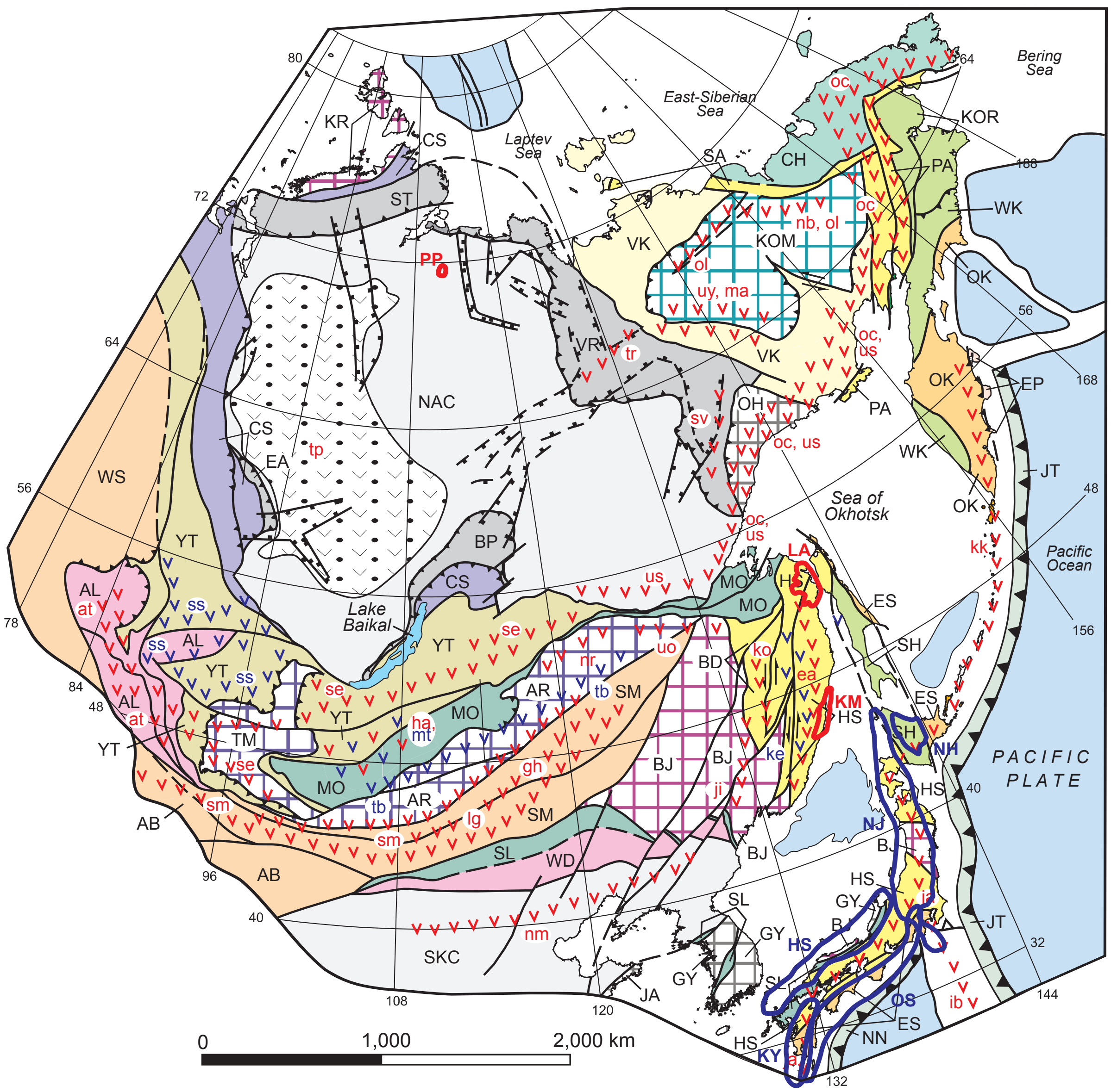


Figure 5. Generalized map of major Maastrichtian through Quaternary metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

also occur in stream-sediment samples. The host plutonic bodies are several tens of meters thick and several hundred meters long. K-Ar isotopic ages are 170 to 160 Ma. The petrochemical features and mineral composition of the gabbro and pyroxenite intrusions hosting the mafic-ultramafic related Ti-Fe (+V) deposits are similar to those hosting the Kondyor PGE deposit.

The main references on the geology and metallogenesis of the belt are Shcheka and Vrzhosek (1985), Philippov (1990), A.I. Khanchuk, written commun. (1992), Nechaev and others (1996, 1997), and Nokleberg and others (1997, 1998, 2003).

Katenskoe Zoned Mafic-Ultramafic Cr-PGE Deposit

This deposit (Shcheka and others, 1991) consists of disseminated ilmenite in Early Cretaceous pyroxene-hornblende gabbro and olivine gabbro. The deposit consists of lenticular bodies that are several tens of meters thick and at least 1 km long. The deposit is large.

Ariadnoe Mafic-Ultramafic Related Ti-Fe (+V) Deposit

The deposit (Shcheka and Vrzhosek, 1985) consists of abundant disseminated ilmenite that occurs in layers in pyroxene-hornblende gabbro and pyroxenite in layered intrusions. The ilmenite layers are several tens of meters thick and several hundred meters long. A K-Ar isotopic age for the host intrusion is 170 to 160 Ma. Ilmenite contains rare PGE inclusions. The deposit is large, and the average grades are 1.0 to 11.8 percent TiO_2 and 0.086 percent V_2O_5.

Koksharovskoe Mafic-Ultramafic Related Ti-Fe (+V) Deposit

This Koksharovskoe deposit (Shcheka and others, 1991) consists of disseminated ilmenite, magnetite, and apatite that occur in a hornblende and biotite pyroxenite with a K-Ar isotopic age of 160 Ma. Minor PGE minerals also occur. Intrusive rocks are weathered and weathered pyroxenite may have economic concentrations of vermiculite. The deposit is large, and the average grades are 1.0 to 10 percent P_2O_5, and 3.3 to 4.5 percent TiO_2.

Origin and Tectonic Controls for Ariadny Metallogenic Belt

The belt is interpreted as having formed during generation of ultramafic and gabbroic plutons during underthrusting of the Kula oceanic ridge and formation of igneous rocks along a transform continental margin that consisted of intensive strike-slip faulting and magmatism close to the Khingan arc. The Middle and Late Jurassic clastic matrix of the Samarka terrane consists of parautochthonous turbidite and olistostrome with fragments of mainly Middle and late Paleozoic ophiolitic rock and greenstone, Middle Triassic chert, Early Jurassic schist and shale, and Triassic through Jurassic clastic rock. Olistostromes, particularly in the northern terrane, contain large fragments of Carboniferous through Early Permian limestone. A fragment of the terrane occurs near the town of Bikin, where meimechite and picrite flows occur in a Late Jurassic(?) matrix. The Samarka subduction-zone terrane and correlative subduction zone units in Japan are tectonically linked to Jurassic granitoids in Korea. These subduction-related units are interpreted as being offset from their tectonically-linked igneous arcs by left-lateral movement during the Cretaceous and Cenozoic.

Bindong Metallogenic Belt of Zn-Pb (±Ag, Cu) Skarn W±Mo±Be Skarn, Cu (±Fe, Au, Ag, Mo) Skarn, and Fe-Zn Skarn Deposits (Belt BD) (Northeastern China)

This metallogenic belt is related to Late Jurassic through Early Cretaeous granitoids intruding the Jihei volcanic and plutonic belt of mainly Permian age that intrudes and overlies the Zhangguangcailing superterrane, the Zhangguangcailing sedimentary overlap assemblage, and adjacent units. The belt occurs in the Zhangguangcailing Mountains in the East Heilongjiang Province, and is hosted in a Late Jurassic and Early Cretaceous plutonic belt that intrudes various units of the Paleoproterozoic Zhangguangcailing continental-margin arc superterrane and younger overlap sedimentary assemblages (Shi Lindao, 1994). The skarn deposits occur at contacts between the Devonian and Permian limestone strata and granitoid intrusions. The significant deposits are at Erguxishan, Chuihongshan, Goupengzi, and Wudaling.

The main reference on the geology and metallogenesis of the belt is Shi (1994).

Ergu-Xishan Zn-Pb (±Ag, Cu) Skarn Deposit

This deposit occurs (Xu, Enshou and others, 1994) in the axial part of the Ergu-Xujiugou anticline in the Zhangguangcailing fold belt that contains Early Permian siltstone and marble that in xenoliths in Hercynian medium-grained biotite plagiogranite, porphyritic biotite granite, and granodiorite. The deposit is controlled by the east-west-trending, north-dipping fractures and the contacts. The main wallrock alteration is skarn. The deposit is small and has reserves of 129,800 tonnes Pb and 221,300 tonnes Zn; the average grades are 2.55 to 3.37 percent Pb and 3.23 percent Zn.

Chuihongshan Fe Skarn Deposit

This deposit (Cao, Jingxian, 1993a,b) consists of several skarn lenses that occur concordant to the bedding of host rocks and trend northwest along the contact between the alaskite granite and dolomite. The skarns occur mainly in masses, layers, stockworks, and veinlets. The ore minerals are magnetite, cassiterite, molybdenite, scheelite, galena, sphalerite, chalcopyrite, and pyrrhotite. The gangue minerals are diopside, phlogopite, garnet, actinolite, wollastonite, clino-humite, and fluorite. Horizontal zoning in the main deposit occurs and consists from inward to outward of Mo W-Fe, Mo-W-Fe, Fe-Zn-Cu, and Pb-Zn ore minerals. At the contact zone are contact metasomatic scheelite, cassiterite, and magnetite, and younger hydrothermal deposits of molybdenite and Cu-Pb-Zn sulphides. The host strata are Middle to Late Carboniferous slate, marble, and metamophosed sandstone and dolomite. Late Permian tuffeous pebble sandstone and intermediate to siliceous volcanic rock occur but do not contain skarn. Both sequences are intruded by granite. The deposit is medium size and has reserves of 531,000 tonnes Cu, 121,600 tonnes WO_3, 194,300 tonnes Pb, and 478,600 tonnes Zn. The average grades are 40 to 50 percent Fe, 0.45 percent Cu, 0.32 percent WO_3, 3.30 percent Pb, and 2.43 percent Zn.

Wudaoling W±Mo±Be Skarn Deposit

This deposit (Hwang and others, 1994) consists of irregular masses at a contact zone between quartz porphyry and intermediate and siliceous volcanic rock of Late Permian Wudaoling Formation. The quartz porphyry is silica-rich with more than 75 percent SiO_2, 7.97 to 8.04 percent K_2O+Na_2O, 1.21 to 1.31 percent K_2O/Na_2O; it has a whole rock K-Ar isotopic age of 157.8 Ma. Both the porphyry and W±Mo±Be skarn bodies are controlled by an east-west striking fault. Ore minerals are mainly molybdenite, pyrite, and magnetite, with lesser hematite, specularite, chalcopyrite, galena, sphalerite, bornite, chalcocite, tetrahedrite, and bismuthinite. Mo bodies occur in disseminations and minor veins. The wallrocks are altered to skarn, silica, beresite, and carbonates. The deposit occurs at the southeast part of Yuquan-Sandaogang anticlinorium in the Variscan Jilin-Heilongjiang orogenic belt. The deposit is medium size.

Origin and Tectonic Controls for Bindong Metallogenic Belt

The belt is interpreted as having formed during interplate extensional tectonism and subalkaline to alkaline volcanism and related sedimentation. The belt occurs along northeast and east-west-trending regional faults, consists of various skarn zones and deposits that occur at contacts between some small intrusions of granodiorite, biotite granite, granite porphyry, quartz porphyry and Devonian limestone and clastic rock, Early Permian marble, sandstone, shale, and the Late Permian felsic volcanic rock. Previously, the belt was interpreted as having formed during the Triassic (Indosinian Orogeny); however, new isotope data indicate the belt is the Middle Jurassic and Early Cretaceous (Shi, Lindao, 1994). The skarns contain numerous metals, including Fe, Cu, Pb, Zn, W, Sn, and Mo. Like other Middle Jurassic and Early Cretaceous metallogenic belts in Northeastern China, the magmatism and deposits in this belt are interpreted as having formed in a tensile tectonic setting along north-northeast-trending regional faults (Tanlu fault system or fracture zone). The origin of the Mesozoic magmatic and related deposits in Northeastern China is a controversial topic. Some authors relate the magmatism and deposits to the subduction of the ancestral Pacific Oceanic Plate under the Eurasian Plate; however, this interpretation may be too simple.

Chara-Aldan Metallogenic Belt of Au Potassium Metasomatite, U-Au, Au in Shear-Zone and Quartz-Vein, Au-Ag Epithermal-Vein, Au-Skarn, Charoite Metasomatite, and Felsic Plutonic U-REE Deposits (Belt CA) (Russia, Aldan-Stanovoy Shield)

This Jurassic through Early Cretaceous metallogenic belt is related to replacements and granitoids in the South Yakutian subalkaline and alkaline igneous belt that intrudes the North Asian craton and Central Aldan superterrane in the southeastern part of North Asian craton. The belt consists of Au sheets, veins, crush zones and U-Au zones that are related to the Jurassic and Early Cretaceous subalkaline and alkaline granitoids. The belt contains several districts of Mesozoic subalkaline and alkaline plutons, stocks, and sills of alkali syenite, monzonite, granosyenite, alkali gabbro, and associated volcanic rocks. These magmatic rocks intrude the Early Precambrian crystalline basement and Vendian and Early Cambrian sedimentary cover of the Aldan-Stanovoy shield. The belt is promising for undiscovered REE and U deposits. The major deposits are at Kuranakh, Klin, Krutoy, and Murunskoye.

The main references on the geology and metallogenesis of the belt are Naumov and Shumilin (1994), Konev and others (1996), Vetluzhskikh and Kim (1997), Miguta (1997), Boitsov and Pilipenko (1998), Parfenov and others (1999), and Fredericksen and others (1999).

Kuranakh Au Potassium Metasomatite (Kuranakh type) Mine

This mine (Benevolskiy, 1995; Fredericksen, 1998; Fredericksen and others, 1999) consists of Au-bearing potassium metasomatite that occurs along horizontal Cambrian calcareous rock and Jurassic sandstone where intruded by lamprophyre dikes emplaced along high-angle fault and especially bedding. Host rocks are Jurassic arkose, Early Cambrian limestone and dolomite, underlying Precambrian metamorphic basement, and abundant Mesozoic plutonic rock. The deposit occurs in subhorizontal sheets that range from a few meters to a few tens of meters thick and extend for several kilometers along sublongitudinal faults and Mesozoic dikes. The deposit formed during Jurassic and Early Cretaceous intrusion of dike swarms and (or) small plugs and sills of bostonite, microgabbro, and minette. Gold deposits are spatially related to dikes that range from premineral to postmineral in relative age. Several subhorizontal deposits occur in blankets or ribbons, are as much as a few dozen meters thick, and are located mainly along and (or) above or under the contact between the Cambrian calcareous footwall and the overlying Jurassic clastic rock in a long narrow zone that is bounded by several north-south-trending faults. The two types of metasomatite are quartz-adularia and quartz-replacing adularia.

The main metasomatite minerals are quartz, pyrite, marcasite, gold, Ag, bismuth, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite, carbonate, and barite. The main part of the Au deposits contains pyrite, arsenopyrite, sphalerite, and galena with sulfide comprising only a few percent of rock volume. The deposit is thoroughly oxidized and only a few traces of arsenopyrite and pyrite occur. The Au occurs primarily as grains less than 5 microns in size and usually contains friable porous goethite. Fluid inclusion homogenization temperatures range from 80°C to 220°C but generally average 110 to 160°C. Metasomatite is controlled by interplate rift structures. Local areas are complicated by formation of karst cavities with deposition of secondary rubble ore, and by surficial weathering of ore minerals and replacement of Au. The Kuranakh deposit was discovered in 1947 and modest production began in 1955. Large scale open pit mining began in 1965 and continues to the present. The Kuranakh mine is one of the largest lode gold mines in Russia. Gold recovery averages 83 percent using resin columns. The deposit is large and it produced 7.1 million ounces of gold through 1997 from 74.1 million tonnes of ore. The average grade is 3.57 g/t Au.

El'kon Group of Au in Shear-Zone and Quartz-Vein deposits

The El'kon group of Au in shear-zone and quartz-vein deposits (Naumov and Shumilin, 1994; Boitsov and Pilipenko, 1998) occurs on the eastern margin of the Central Aldan ore district that contains several hydrothermal deposits that occur along northwestern striking Mesozoic faults that cut the crystalline basement of the Aldan-Stanovoy shield. These deposits contain the largest U reserves in Russia. Three types of deposits occur, Au-brannerite, Au-uraninite, and Au-Ag brannerite. Au-brannerite deposits consist of metasomatite zones that extend as much as 20 km long, range from 1.0 to 40 meters thick, and formed from replacement of host gneiss, schist, metadiorite, and blastomylonite. The sequence of mineral assemblages is (1) pyrite, ankerite, and K-feldspar; (2) pyrite, dolomite, K-feldspar; and (3) calcite and adularia. Au grade in pyrite of the first assemblage is 60 to 90 g/t. The third assemblage contains native gold and ranges from 40 to 100 g/t. Brannerite is the only U mineral in the metasomatite and occurs in a matrix of microbreccia and veinlets. Typical U-ore shoots extend for 20 km and form distinct deposits (Druzhnoye, Kurung, El'kon Plato, El'kon). Au-uraninite deposits occur in the northwestern part of the belt (Nadezhnoye and Interesnoye deposits) and consist of auriferous pyrite-carbonate-K-feldspar metasomatite with superposed U. In the southern part of the area, Brannerite-Au-Ag deposits are characteristic of the Fedorovskoye deposit which contains U minerals and consisits of a metasomatite zone that ranges from 8 to 30 km thick and is 10 km long. The metasomatite and brannerite deposits are overprinted by a late-stage mineral assemblage of quartz, carbonate, native gold, native silver, and acanthite. Grades range from 3 to 10 g/t Au, 15 to 200 g/t (as much as 1,400 g/t) Ag, and 0.02 to 0.5 percent U.

Murunskoe-Tokski Group of Charoite Metasomatite Deposits

The Murun-Tokski group (Konev and others, 1996) occurs in western Northern Transbaikalia along the margin of the West-Aldan cratonal terrane, and is related to magmatic complexes of the overlap Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt. The major deposit is at Murunskoye. The group of deposits occurs in the extreme northeastern of Baikal-Patom highland, extends northeast for 200 km, and si as much as 75 km wide. The Middle to Late Jurassic igneous rocks of the Transbaikalian sedimentary and volcanic-plutonic belt consist of minor ultrapotassic and alkaline intrusions (stocks and laccolith), and subvolcanic rock of the Aldan Complex. The igneous rocks occur at intersections of large faults that trend northeast, northwest and submeridional (Atbastakh-Torgoy and others) and cut the periphery of the Archean Chara block. The main igneous rock types are K-Na nepheline syenite, alkaline syenite, quartz syenite, alkaline granite, biotite pyroxenite, lamproite, ijolite, leucite fergusite, and shonkinite. Zones of alkaline metasomatite occur along margins of alkaline intrusions. The deposit-hosting Murun laccolith is a zoned intrusive complex composed of syenite, alkaline syenite, and fenite, and is surrounded by alkaline ring dikes (Konev and others, 1996). Comagmatic trachyte lavas occurs in separate volcanic structures that are mostly eroded. This laccolith contains a wide spectrum of high- and medium-temperature hydrothermal deposits (Th-Ti, Th-U, U) and metasomate that contain charoite as the major useful mineral. This deposit is the only global occurrence of charoite. The charoite bodies occur in veins and irregular shapes in metasomatite.

Origin and Tectonic Controls for Chara-Aldan Metallogenic Belt

The belt is interpreted as having formed in a back-arc region of an Andean-type continental-margin arc that formed along the Early Cretaceous margin of the North Asian craton. The belt is hosted in subalkaline and alkaline plutons, stocks, and sills of syenite, monzonite, granosyenite, and alkali gabbro, and related volcanic rocks.

Chybagalakh Metallogenic Belt of Sn-W Greisen, Stockwork, and Quartz Vein, Sn-B (Fe) Skarn (ludwigite), and Granitoid-Related Au-Vein Deposits (Belt CH) (Russia, Verkhoyansk-Kolyma Region)

This Late Jurassic through Early Neocomian metallogenic belt is related to veins and replacements in the Main granite belt. The belt extends for 250 km, is as much as 75 km wide, and coincides spatially with the Main batholithic belt (Trunilina, 1992). The northwestern part of the belt contains the Burgavli-Chalba Sn-W and Upper Tirekhtyakh B-Sn districts. The Burgavli-Chalba Sn-W district extends sublatitudinally for 70 km, is as much as about 10 km wide (Flerov and others, 1979), and contains complexly-deformed Jurassic flysch in the Inyaly-Debin synclinorium that is intruded by Early Neocomian granitoid. In the subsurface, contact-metamorphic zones occur adjacent to granitoid plutons. The deposits are related to granite and leucogranite and contain cassiterite-quartz and cassiterite-wolframite-quartz veins and stockwork. The Upper Tirekhtyakh B-Sn district occurs to the northeast of the Burgavli-Chalba district and is hosted in a homogeneous granodiorite and granite pluton (Trunilina, 1992). The district extends to the northwest for 40 km and is as much as 10 to 15 km wide. B-Sn and magnetite skarn deposits occur along the margins of the granodiorite in Paleozoic carbonate rock. Granitoid-related Au-REE deposits also occur in the belt. The major deposits are the Kere-Yuryakh Sn-W greisen, stockwork, and quartz-vein deposit, the Titovskoe Sn-B (Fe) skarn (ludwigite) deposit, and the Chuguluk and Nenneli granitoid-related Au-vein deposits.

The main references on the geology and metallogenesis of the belt are Shoshin and Vishnevsky (1984), Trunilina (1992), and Parfenov and others (1999).

Kere-Yuryak Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Flerov and others, 1979) occurs in the apical portion of a granite pluton that intrudes an anticline formed in Middle Jurassic sandstone. The deposit consists of stockwork veins and stringers that occur along the upper contact of the pluton. The veins and stringers are 0.1 to 2 meters thick and are as much as 100 meters long. Outcrops of vein and stringer zones vary from 50 to 150 meters wide. Major minerals are quartz, tourmaline, muscovite, arsenopyrite, cassiterite, and wolframite. Rare minerals are topaz, apatite, scheelite, tetrahedrite, pyrite, molybdenite, and bismuthine. The deposit exhibits intense greisen alteration. The average grades are 0.6 percent Sn, 0.487 percent As, and 0.62 percent W.

Titovskoe Sn-B (Fe) Skarn (ludwigite) Deposit

This deposit (Dorofeev, 1979) consists of 40 bodies of Mg skarn that occur along the contact between the quartz monzonite phase of an Early Cretaceous granitoid intrusion and Silurian and Devonian dolomite and limestone. The skarn ranges from 5 cm to 20 meters thick and ranges from 50 to 1,000 meters long. The main ore mineral is ludwigite and it forms as much as 70 to 80 percent some deposits. The skarn also contains ascharite, kotoite, datolite, harkerite, monticellite, fluoborite, clinohumite, calcite, periclase, forsterite, diopside, vesuvianite, brucite, garnet, axinite, tourmaline, biotite, phlogopite, serpentine, spinel, hornblende, pyroxene, feldspar, quartz, and magnetite. Sn occurs as an isomorphous admixture in ludwigite. Ludwigite is often replaced by sulfides, including pyrrhotite, sphalerite, pyrite, arsenopyrite, and chalcopyrite. Kotoite ore veins occur along margins of ludwigite bodies. Contact between the intrusion and carbonate is highly irregular. Most skarn bodies occur in embayments into the intrusion. The deposit occurs in an area 3 by 6 km, is medium to large in size and has average grades of 9.5 percent B_2O_3 and 0.3 percent Sn.

Origin and Tectonic Controls for Chybagalakh Metallogenic Belt

The belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and generation of anatectic high-alumina granitoids. The collision was accompanied by deformation, metamorphism, and formation of the high-alumina granitoid Main batholithic belt.

Djeltulaksky Metallogenic Belt of Granitoid-Related Au-Vein Deposits (Belt DL) (Russia, Far East)

This Early Cretaceous metallogenic belt is related to granitoids in the Stanovoy granite belt that intrude the Tynda terrane and the Dzugdzur anorthositic belt. The deposits generally consist of quartz and quartz-carbonate veins that are spatially related to Jurassic through Early Cretaceous granite and granodiorite that are generally interpreted as having formed in a collisional setting. Also occurring in the area are numerous placer Au mines and local, large placer Au mines in the west-central part of the Russian Far East. The major deposit is at Zolotaya Gora.

The main references on the geology and metallogenesis of the belt are Mel'nikov (1984) and Nokleberg and others (2000, 2003).

Zolotaya Gora Granitoid-Related Au-Vein Deposit

This deposit (Mel'nikov, 1984) consists of quartz veins and zones of hydrothermally altered metamorphic rock that are conformable to host rock layering. Alteration assemblages are predominantly sericite and quartz, and chlorite, amphibole, and quartz. The main mineral assemblages are sulfide, biotite, and quartz; sulfide, sericite, and quartz; and biotite, quartz, amphibole, and chlorite. Less common is an assemblage of amphibole, quartz, and feldspar. Four successive stages of deposition are identified (1) magnetite, chalcopyrite, pyrrhotite, and quartz; (2) gold, carbonate, and sulfide; (3) zeolite; and (4) supergene. Gold occurs both in early and late quartz and in hydrothermally-altered rock. Gold generally occurs in films and fine plates in fractures and is concentrated in selvages of quartz and quartz-pyrite veins. Gold fineness is high (985). The deposit is hosted in gneissic granite, granulite, calcareous shale, and quartzite of the Tynda terrane. The deposit is small, and the average grade is about 52 g/t Au. The deposit was intermittently mined from 1917 to 1948; it has produced 2.5 tonnes gold.

Origin and Tectonic Controls for Djeltulaksky Metallogenic Belt

The belt is interpreted as having formed during late-stage accretion of the Bureya superterrane to the south with the North Asian craton to the north, during final closure of the Mongol-Okhotsk Ocean. The Paleozoic rocks contain beds of Au-bearing, pyrite-bearing graphitic shale.

Daxinganling Metallogenic Belt of Zn-Pb (±Ag, Cu) Skarn, Sn-Skarn, Cassiterite-Sulfide-Silicate Vein and Stockwork, Polymetallic Pb-Zn, Cu (Au, Ag) Veins and Stockwork, Peralkaline Granitoid-Related Nb-Zr-REE, and Au-Ag Epithermal-Vein Deposits (Belt DX) (Northeastern China)

This Late Jurassic and Early Cretaceous metallogenic belt is related to veins, replacements, and granitoids in the Daxinganling part of the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt. The belt overlies and intrudes the Gobi-Khankaisk-Daxinganling volcanic-plutonic belt. The belt occurs in the central and southern Daxingaling region (Great Khingan Mountains), southeastern Inner Mongolia. The belt consists of three northeast-trending, subparallel zones. The middle zone is the largest, and is 500 km long and 100 km wide. The Daxinganling volcanic-plutonic belt contains very thick, multiple stages of volcanic rock that are as much as 2,000 to 3,000 meters thick, and it consists mainly of basalt, andesite, trachyandesite, trachyte, and dacite. Felsic volcanic rock is dominant. The volcanic rocks are calc-alkalic with slightly high alkaline content. The associated plutonic rocks occur in a batholith, stocks, and dikes, and consist mainly of granodiorite, granite, tonalite diorite porphyry, granite porphyry and quartz monzonite, orthoclase granite and alkaline granite. The plutonic rocks intrude Permian oceanic volcanic and sedimentary rocks that are interpreted as having formed in an island arc in a residual oceanic basin (Xu, Zhigang, 1993). The island arc assemblage forms an overlap assemblage that formed after accretion of the Xilinhot, Solon, and Hegenshan terranes. The metallogenic belt includes a variety of deposits and metals. The major cassiterite-sulfide-silicate vein and stockwork deposit is at Maodeng, the major polymetallic Pb-Zn, Cu (Au, Ag) veins and stockwork deposits are at Meng'entaolegai and Aonaodaba; the major peralkaline granitoid-related Nb-Zr-REE deposit is at Baerzhe, and the major Au-Ag epithermal-vein deposit is at Guandi.

The main references on the geology and metallogenesis of the belt are Li (1993), Xu (1993), and Zhang, and others (1994).

Baiyinnuoer Zn-Pb (±Ag, Cu) Skarn Deposit

This deposit (Li and others, 1993) occurs in the central part of Huanggangliang-Wulanhaote polymetallic belt. The deposit occurs in a secondary anticline of the Sifangcheng-Baiyinwula anticlinorium. Northeast-striking faults control the formation and distribution of igneous intrusions in the deposit. The strata consist of Early Permian low-grade metamorphic rock and late Jurassic siliceous and intermediate volcanic rock. The Early Permian strata host most of the deposit. The strata are composed of sandy slate, carbonate, and pelitic slate and occur in the central and southeast parts of the associated district. The Yanshannian granitoids consists of granodiorite, granodioritic porphyry, quartz syenite porphyry, and granite porphyry. The deposit occurs mainly in skarn along a contact zone between granodioritic porphyry and country rock. The main ore minerals are sphalerite and garnet, and the minor ore minerals are chalcopyrite, pyrite, pyrrhotite, and stannite, and Ag minerals. The main gangue minerals are hedenbergite, epidote, andradite, actinolite, diopside, wallstonite, quartz, and calcite. The deposit is large and has reserves of 2.4 million tonnes of Pb+Zn grading 3.24 percent Pb and 5.46 percent Zn.

Maodeng Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (Liu, 1996) occurs in the western contact zone of the Alubaogeshan granite porphyry with a Rb-Sr isotopic age of 149 Ma. The deposit is hosted in a Jurassic bimodal volcanic sequence, including a lower basalt and upper rhyolite unit, in the Maoding volcanic basin. The deposit occurs in veins controlled by a northwest-trending fault system. The major ore minerals are cassiterite, chalcopyrite, arsenopyrite, sphalerite, and molybdenite. The minor ore minerals are pyrite, galena, magnetite, hematite, wolframite, bornite, scheelite, and bismuthine. Nonmetallic minerals are quartz, fluorite, K feldspar, biotite, calcite, tourmaline, topaz, and muscovite. The ore minerals are idiomorphic to hypidiomorphic granular texture and occur in metasomatic fillings, disseminations, masses, veins, veinlets, stockwork, and breccia. In the magnetite, cassiterite, and sulphide deposits–potassic silicates, greisen, and silica, respectively. The deposit is interpreted as having formed during hydrothermal conditions at a moderate depth of 1.6 to 2 km and moderate temperature of 450 to 200°C. The deposit is medium size.

Meng’entaolegai Polymetallic Pb-Zn, Cu (Au, Ag) Vein and Stockwork Deposit

This deposit (Li and others, 1993) occurs along the west junction between the Daxinganling orogenic belt and the Songliao Basin. The main part of the deposit is controlled by east-west-and northeast-trending faults. The deposit is hosted in Permian and Jurassic tuffaceous sandstone, slate, tuffaceous clastic rock, marble, arkose, pelitic siltstone, lava, and bioclastic limestone. Both Hercynian and Yanshannian-age granitoids occur. The Mengentaolegai granite covers an area of 240 km^2, has a K-Ar isotopic age of 286 Ma, and a U-Pb isotopic age of 235 Ma. The Duerji granite complex consists of coarse-grained biotite-plagioclase granite, granodiorite, moyite, alaskite, and fine-grained biotite granite. The complex covers an area of 150 km^2 and has a U-Pb zircon age of 150 Ma. Forty-four sizes of veins occur. The main wall-rock alterations are sericite, Mn siderite, silica, and chlorite. The main ore minerals are sphalerite, galena, and Ag minerals, and the minor minerals are chalcopyrite, pyrite, pyrrhotite, arsenopyrite, chalcocite, and cassiterite. The deposit formed at temperatures of 140 to 340°C, and the deposit is closely related to the Yanshannian Duerji granite. The deposit is large and has reserves of 84,300 tonnes Pb and 2,300 tonnes Zn. The average grades are 84 g/t Ag, 1.02 percent Pb, and 2.30 percent Zn.

Baerzhe Peralkaline Granitoid-Related Nb-Zr-REE Deposit

The deposit (Lin, Chuanxian and others, 1994) is hosted in a riebeckite granite that intrudes Middle Jurassic volcanic rock and occurs in two areas. The western part of the intrusion covers an area of 0.11 km^2, the eastern part covers an area of 0.24 km^2, and at the depth, the two parts merge. A Rb-Sr isotopic age is 125 Ma. The main minerals are barbierite, quartz, and riebeckite, the minor minerals are aegrite and albiteoligoclase, and accessory minerals are zircon, monazite, bunsite, fluorite, calcite, galena, sphalerite, pyrrhite, and ferrothorite. In the eastern intrusion, from the surface to depth, successive zones of pegmatitic granite, albite-altered granite, and porphyritic riebeckite granite occur. Weak alterations are silica, chlorite, carbonate, aegrute, and sulphides. The ratio of K+Na/Al is greater than 1, and SiO_2 content is high. REE distribution patterns slope slightly to the right. The rocks are rich in REE, and Eu is intensely depleted. The main economic minerals are bunsite (500 to 800 g/t), monazite (79 to 2,000 g/t), pyrrhite (80 g/t), titano euxenite (20 to 80 g/t), xinganite (600 to 7000 g/t) and niobite (94 to 5000 g/t). The initial $^{87}Sr/^{86}Sr$ is 0.689±1. The deposit is large and has it has an average grade of 0.051 percent BeO and 0.258 percent Nb_2O_5 .

Ag-Sn Deposits

Various Ag-Sn deposits (Meng’entaolegai, Aonaodaba, and others), mainly polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork deposits (Li Henian and others, 1994) occur in the middle Hercynian Daxinganling orogenic belt. The main structures are a north-northeast-trending syncline and northeast-striking faults. The host rocks are Early Permian low-grade metamorphosed sandstone, graywacke, sericite slate, and knotted slate. The igneous intrusion is mainly the Yanshannian granite porphyry that occurs at the core of the syncline and is intruded by slightly younger granodioritic porphyry and quartz syenite porphyry. The granite porphyry has a Rb-Sr whole-rock isochron age of 148.3 Ma. The main alterations are silica, topaz beresite, K-feldspar and chlorite. The deposits occur in veins and, locally, in lenses. The main ore minerals are pyrite, chalcopyrite, arsenopyrite, sphalerite, and pyrrhotite, and the minor ore minerals are loelingite, garnet, and tetrahedrite. Rare argentite, molybdenite, and marcasite also occur. The deposit-forming temperatures are 160 to 426°C.

Aonaodaba Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (Li and others, 1993; Zhang and others, 1994) occurs in the southeastern part of the Daxinganling Hercynian orogenic belt that is hosted in Early Permian, low-grade metamorphosed sandstone, graywacke, sericite slate, and knotted slate. The Yanshannian granite porphyry, that intrudes the core of a syncline, is intruded by slightly younger granodiorite porphyry and quartz syenite porphyry. The granite porphyry has a Rb-Sr whole-rock isochron age of 148.3 Ma and is altered to silica, topaz-beresite, K-feldspar, and chlorite. The dposit occurs in veins and rare lenses. The main ore minerals are pyrite, chalcopyrite, arsenopyrite, sphalerite, and pyrrhotite, and minor loelingite, garnet, and tetrahedrite, along with very minor argentite, molybdenite, and marcasite. The deposit formed at temperatures of 160 to 426 C. The deposit is large.

Guandi Au-Ag Epithermal-Vein Deposit

This deposit (Zhang and others, 1994) consists of several Ag veins in a volcanic rock belt. The ore mineral textures range from hypidiomorphic to xenomorphic to varied metasomatic. The ore minerals occur in disseminations, masses, veins and stockwork. Ag minerals are freibergite, Ag tetrahedrite, vitreous Ag, stromeyerite, and electrum. Other metallic minerals are sphalerite, galena, pyrite, chalcopyrite, tetrahedrite, cerusite, and magnetite. Gangue minerals are quartz, rhodochrosite, calcite, dolomite, sericite, chlorite, siderite, and fluorite. The deposit is large and grades 60 to 1500 g/t Ag (locally as much as 2,400 g/t Ag), and Au ranges from 0.68 to 4.4 g/t.

Origin and Tectonic Controls for Daxinganling Metallogenic Belt

The belt is interpreted as having formed during Middle Jurassic through Early Cretaceous extensional tectonism associated with generation of the Trans-Baikalian-Daxinganling volcanic-plutonic belt that was related to the back arc of a continental-margin arc. The metallogenic belt is controlled by major, regional northeast-and northwest-trending faults. The basins and granitoids are controlled by northeast-north-northeast and east-west striking regional faults that to certain degree reflect the preMesozoic structures (Xu, 1993, Zhang and others, 1994). The granitoids related to W and Sn deposits are mainly K feldspar granite, whereas the granitoids related to Pb, Zn and Cu deposits are granodiorite and quartz syenite. The two types of granite differ greatly in petrochemical and geochemical features (Zhang and others, 1994). The Permian volcanic and sedimentary rock may be the main source for Sn, Pb, Zn and Ag (Li Henian, 1993; Zhang and others, 1994).

Dzhid-Selenginskiy Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz-Vein, Granitoid-Related Au Vein, Au Skarn, Porphyry Mo (±W, Bi) (+W, Sn, Bi), Fluorspar-Vein; and Magmatic, and Metasomatic Apatite Deposits (Belt DS) (Russia, West Transbaikalia, Mongolia)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to veins, replacements, and plutons related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Dzhida, Hamar-Davaa, and Orhon-Ikatsky terranes, the Selenga sedimentary-volcanic plutonic belt, the Barguzin-Vitim granitoid belt, and adjacent units. The belt occurs in the Selenga and Dzhida River Basins and extends from Mongolia northeast to southern Lake Baikal in Russa. The belt is 725 km long and 85 to 175 km wide. The Transbaikalian sedimentary and volcanic-plutonic belt occurs in numerous rift basins in two sequences (1) Middle and Late Jurassic shoshonite and latite; and (2) Late Jurassic and Early Cretaceous trachybasalt. Plutonic rocks occur in several intrusive Jurassic complexes: (1) the Kyrinsky complex with large plutons of calc-alkaline biotite, biotite-amphibole diorite, granodiorite, granite, and leucogranite; (2) the Sokhondinsky complex with subvolcanic dacite and rhyolite bodies; (3) the Asakan-Shumilovsky complex of biotite and biotite-amphibole granite, granite, and leucogranite; (4) the Kharalginsky complex of high alkaline biotite leucogranite, syenite porphyry, leucogranite, and alaskite; and (5) gabbro and syenite and local carbonatite. Deposits and occurrences are located in various districts. The most widespread are W and Mo deposits of different model types (Reif and Bazheev, 1982; Petrovskaya and Spiridonov, 1977; Dzhida ore region, 1984, Khodanovich, 1995). The major deposits are in the Dzidinskoye district, and at Malo-Oinogorskoye, Arsentievskoye, Naranskoye, and Oshurkovskoye. The belt may contain undiscovered deposits.

The main references on the geology and metallogenesis of the belt are Tsyba (1990), Bulnaev (1995), Khodanovich (1995), Litvinovsky and others (1999), and Dondovyn (1999).

Dzhidinskoe District of W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposits

This district (fig. 6) (Gordienko, 1987; Khodanovich, 1995; Skursky, 1996) occurs in three areas in the apical part of a small Triassic granite massif.

The Pervomayskoye stockwork Mo deposit (with dimensions of 620 by 540 meters) is mushroom-shaped, and extends to a depth of 240 to 250 meters. Ore consists of molybdenite, pyrite, sphalerite, chalcopyrite, bismuthine, fluorite, aud beryllium. Gangue minerals are quartz, K-feldspar, and muscovite. Ore contains 0.1-0.15 percent Mo, 0.018 percent BeO, and 0.031 percent W_20_5.

The Kholtosonkoye vein W deposit consists of economic hubnerite-sulfide-quartz veins (500-2,000 by 0.8 by 500 to 600 meters). Ore consists of hubnerite (10.4 to 4.5 percent), scheelite (0.1 to 3.5 percent), galena (0.1 to 11.9 percent), sphalerite (0.1 to 3.5 percent), pyrite (0.2 to 7.6 percent), chalcopyrite (0.001 to 0.8 percent), fluorite (0.2 to 7.6 percent). The grade of WO_3 varies from 1.10 to 0.42 percent.

The Inkurskoye stockwork W deposit (with dimensions of 1700 by 400-600 by 300-400 meters) consists a network of quartz, quartz-feldspar, quartz-muscovite and quartz-sulfide veinlets with hubnerite and scheelite. The major minerals are hubnerite and scheelite. Less widespread minerals are pyrite, galena, sphalerite, chalcopyrite, and gray ore. The average grade in stockwork is 0.147 percent WO_3; 0.019 percent Pb; 0.045 percent Zn; 0.0035 percent Cu; 0.046 percent BeO; 0.7 ppm Au, and 6 ppm Ag. Many veins occur along the dike belt with diorite porphyry, microdiorite, aplite, syenite porphyry, and lamprophyre. The early and middle Paleozoic host granitoid rock is altered to berisite, sericite, and greisen. The deposit is large and has a a grade in stockwork ores of 0.16 to 0.18 percent WO_3 and a grade in vein bodies 0.5 to 1.0 percent WO_3. The average grades are 0.1 to 0.15 percent Mo, 0.3 to 0.5 percent Pb, 0.3 percent Cu, and as much as 2.8 ppm Au, and as much as 315 ppm Ag. The deposit is explored to 700 meters depth.

In northern Mongolia, the district is related to granitoids intruding the Vendian through early Paleozoic Dzida island-arc terrane. The district contains W-Mo-Be greisen, stockwork, and quartz vein; W-Mo-W±Mo±Be skarn; granitoid-related Au vein; and Au-skarn deposits. The major deposits are the Bulagtai vein and stockwork W-Mo deposit, Sohatinh W-Mo skarn occurrence, the Baruunhujirt granitoid-related vein Au occurrence, Tavt granitoid-related vein Au (Cu, Ag) deposit, and Teshig group Cu, Au, Fe skarn deposit and occurrences. The granitoid-related deposits are closely related to Late Jurassic leucogranite stocks of the Gudjir Complex that also contains REE granite stocks. Isotopic ages for granitoids in the Gudjir complex are 180 to 170 Ma and 145 to 140 Ma. The related granitoids in the district consist of small stocks of granite porphyry and leucogranite, and dikes of aplite, aplite porphyry, fine-grained granite, syenite, syenite porphyry, and granite porphyry.

Tavt (Ereen) Granitoid-Related Au-Vein Deposit

This deposit (Tsyba, 1990; Jargalsaihan and others, 1996) is hosted mainly in early Paleozoic gabbro and granitoids with xenoliths of Vendian through Lower Cambrian limestone that are intruded by Late Permian granitoids of the Selenge complex, and by early Mesozoic granitoid stocks and dikes of the Orkhon intrusive complex. Abundant quartz veins occur and contain gold and sulphides, mostly in the early Paleozoic gabbro and gabbro-diorite, and in the first phase granitoids of the Selenge complex. About 100 gold-sulfide-quartz veins occur in mainly 10 zones that range from 2.0 to 7.5 km long and 50.0 to 800.0 meters wide, and strike northwest, and dip steeply southwest. The length of individual veins ranges from 100 to 250 meters and rarely as much as 800 meters, and range from 6.0 to 8.0 meters wide with an average thickness of 0.5 to 1.5 meters. Ore minerals are native gold and silver, pyrite, chalcopyrite, galena, molybdenite, and sphalerite. Sulphides are replaced by carbonates and hydroxides in an oxidized zone. Grade ranges from 0.1 to 230.0 g/t Au, and rarely as much as 1.5 kg/t Au. The average grade is 21.2 g/t Au in 0.7 meters average thickness of vein. The high grade of Cu and Ag also occurs with an average grade of 61.2 g/t Ag, and 1.94 percent Cu. Drilling shows the deposit extends 300.0 meters below land surface and decreases in grades and thickness. The deposit is large and has resources of 12 million tonnes of ore.

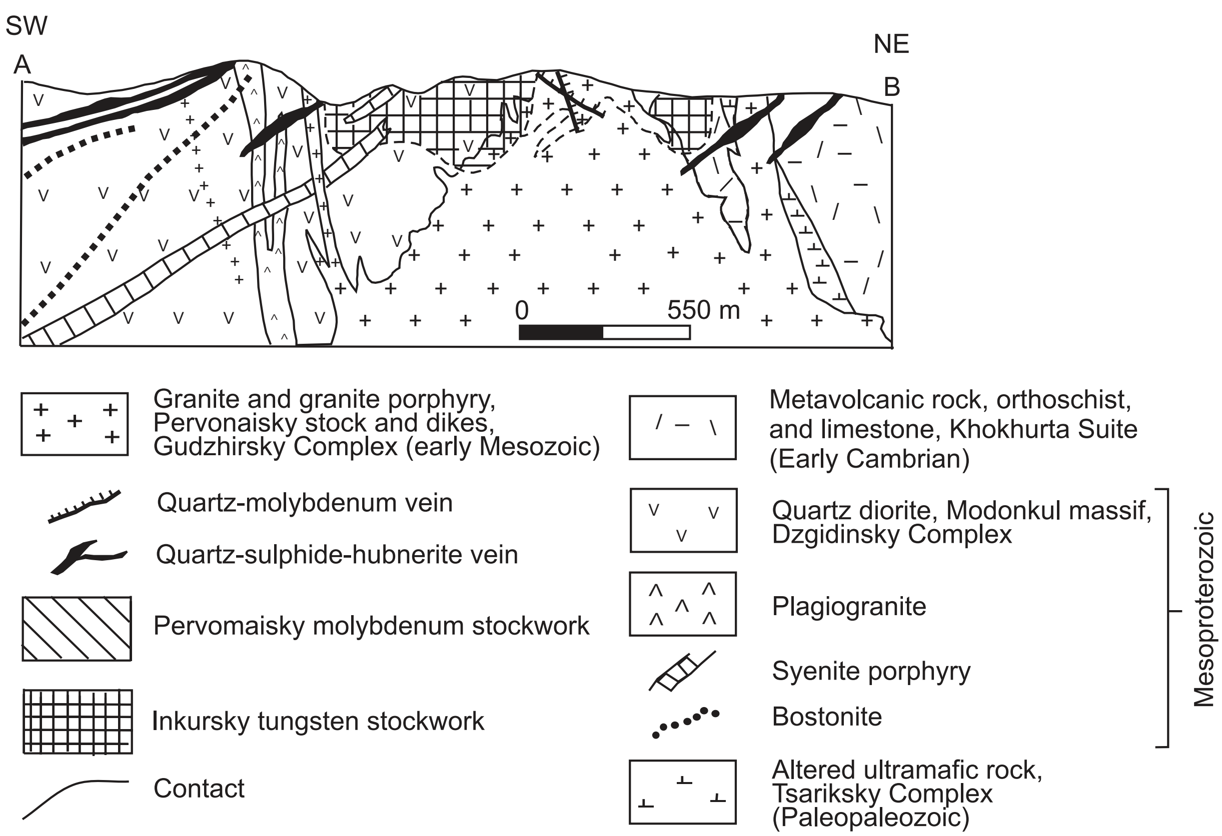


Figure 6. Schematic cross section of Dzhidinskoe W-Mo-Be greisen, stockwork, and quartz-vein deposit, Dzid-Selenginskiy metallogenic belt, Transbaikal region. Adapted from Ignatovich (1961).

Teshig 1 Cu-Au Skarn Deposit

This deposit (Alaev and others, 1985) is hosted in Vendian through Early Cambrian volcanic and sedimentary rocks of the Buuraltai Unit that is intruded by gabbro, quartz syenite of the Late Permian Selenge Complex, and by various early Mesozoic dikes and stocks. The deposit consists of a Cu-Au magnetite-garnet-epidote skarn that occurs along the contact between the Vendian through Lower Cambrian limestone and the early Mesozoic diorite-granite intrusive stock. The contact is cut by a northwest-trending fault zone that contains vein magnetite Cu and Au, and postdeposit intermediate dikes. The magnetite bodies dip steeply northeast and are intensely altered to limonite and Fe hydroxides. The skarn is 1,500.0 meters long and varies from 25.0 meters to 80.0 meters wide. The same Cu and Au minerals occur in skarn, magnetite, and limonite-magnetite bodies. The ore minerals are mainly malachite, rare azurite, chalcopyrite, pyrite, bornite, covellite, and gold. Au grains vary from 0.001 to 0.7 mm and have an average size 0.05 to 0.2 mm. The deposit is divided into three parts. The skarn contains 0.1 to 1.0 g/t Au with average grade of 0.5 g/t Au. Magnetite bodies average 0.3 percent Cu, as much as 0.5 g/t Au (average 0.1 g/t Au). The average grade is 0.12 percent Cu in skarn without magnetite.

Naranskoye Fluorspar Vein Deposit

This deposit (Kozhemyachenko and others, 1971; Bulnaev, 1995) consists of 17 steeply-dipping veins. The nine largest are 600 to 1200 by 1.0 to 6 by 170 to 300 meters). The deposit occurs in both veins and crush zones with major quartz and fluorite in variable proportions (10 to 85 percent CaF_2 with an average of 31 percent) and lesser kaolinite, montomorillonite, hydromuscovite, pyrite, and very rare galena and sphalerite. The minerals occur in breccia and masses. S, P, Fe are as much as about 0.01 percent. The host rocks are diverse and include mainly Middle Triassic granosyenite and lesser Mesoproterozoic sedimentary-metamorphic, Early Triassic through Early Jurassic volcanic and sedimentary, and Middle Triassic through Middle Jurassic granitoids. Peripheral alterations are weak to absent. The deposit occurs in a highly-deformed tectonic block (about 8 km^2) that occurs along a local fault. The deposit is large and has an average grade of 31 percent CaF_2.

Oshurkovskoye Magmatic and Metasomatic Apatite Deposit

This deposit (Litvinovsky and others, 1999) consists of apatite in a plutonic sheeted complex and occurs in concordant, lenses, plates and dikes of coarse- and medium-grained alkaline gabbro and syenite. Apatite is disseminated in alkaline gabbro with average grade of 4 percent P_2O_5. Locally are sites that range from 100 to 400 meters wide, 300-600 meters long and contains 5 to 6 percent P_2O_5 and locally 10 to 20 percent P_2O_5. Apatite forms tabular, short prismatic, and rare spicular crystals in cumulates. Poikilitic apatite inclusions occur in pyroxene and amphibole, in phenocrysts in microgabbro dikes, and in variably-trending lenses and nests with dimensions of 0.2 to 2.0 meters. The includins are composed of 80 to 90 percent tabular apatite grains with minor hornblende and titanic magnetite. Gabbro also has numerous apatite inclusions. The deposit includes fracture and hydrothermal alteration zones that range from 5 to 20 meters thick and 50 to 80 meters long that are enriched in carbonate, chlorite, local apatite (about 35 percent), and zeolite. The host rock is granite and gneiss. This large deposit formed in during Early Cretaceous rifting and has an average grade of 4.1 percent P_2O_5.

Origin and Tectonic Controls for Dzhid-Selenginskiy Metallogenic Belt

The belt is interpreted as having formed during subalkaline and alkaline granitoid magmatism associated with transform-continental margin faulting (Mongok-Okhotsk and related faults) and magmatism during and following late-stage closing of the Mongol-Okhotsk Ocean. The metallogenic belt is hosted in the Transbaikalia sedimentary-volcanic-plutonic belt. The main characteristics of the granitoid-related Au vein and Au skarn deposits and occurrences in the Tseshig district are (1) complex major metals of Au, Ag, and Cu; (2) a close relation to a high alkaline syenite-diorite and monzonite-granite sequence; (3) a close relation of W, Mo vein, greisen and skarn, granitoid-related Au-vein deposits and occurrences with siliceous and leucocratic granite; and (4) a relation of Au-Ag-Cu vein and skarn deposits to intermediate intrusives and melanocratic granitoid sequences that intruded during continental rifting.

East Mongolian-Priargunskiy-Deerbugan Metallogenic Belt of Polymetallic Metasomatic Carbonate and Volcanic Hosted, Zn-Pb (Ag, Cu, W) Skarn, Au Skarn, Au-Base-Metal Metasomatic Volcanic Hosted, W-Mo-Be Greisen, Stockwork, and Quartz-Vein, Porphyry Cu-Mo (±Au, Ag), Porphyry Mo (±W, Bi) (W, Sn, Bi), Granitoid-Related Au Vein, Carbonate-Hosted As-Au Metasomatite, Au-Ag Epithermal-Vein, Sedimentary Siderite Fe, Sn-W Greisen, Stockwork, and Quartz-Vein, Carbonate-Hosted Hg-Sb, Sb, Fluorspar Vein, and Volcanic-Hosted U Deposits (Belt EM) (Russia, Eastern Transbaikalia; Central and Eastern Mongolia, Northeastern China)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to Middle Jurassic through Early

Cretaceous veins, volcanic complexes, replacements, and granitoids in the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Argunsky terrane, Idermeg terrane, Gazimur sedimentary basin, Gobi-Khankaisk-Daxinganling volcanic-plutonic belt, Lower Borzja fore-arc basin, Upper Borzja marine molasse basin. The belt extends from central Mongolia to northeastern Mongolia, and into Russia and China. This metallogenic belt is one of the largest in Northeast Asia and contains about 80 mines, deposits, or occurrences.

The Russian part of the belt occurs in the Priargunsky passive continental-margin terrane that is overlapped by the Gazimur sedimentary basin, Lower Borzja fore-arc basin, Upper Borzja Basin, and Transbaikalian sedimentary and volcanic-plutonic belt. The Mongolian part the belt is related to granitic and volcanic units on the Paleoproterozoic Ereendavaa and Idermeg terranes. In Russia, the belt extends nearly for 500 km, ranges from 100 to 150 km wide, and occurs along the Gazimur, Urov, Uryumkan, and Argun Rivers. The belt is the largest and richest in Central Asia.

In Mongolia, the belt extends approximately 2,000 km and varies in width from 100 km in southwestern part to 550 km in northeastern part. The eastern Mongolian part of the metallogenic belt is overprinted on the Hangay-Dauria subuction zone, Onon subuction zone, Ereendavaa passive continental margin, Herlen ophiolite, Idermeg passive continental margin, Govi-Altay turbidite, and Mandal Ovoo island-arc terranes (Tomurtogoo and others, 1999).

In Northeastern China the belt contains the Deerbugan group of porphyry Cu-Mo (±Au, Ag), granitoid-related Au vein, and Au-Ag epithermal vein occur in the western side of the Daxinganling Mountain ranges in Northeast Inner Mongolia of Northeastern China. The tectonic setting and metallogenic features of the group are similar to those in Russia and Mongolia (Hu and others, 1998).

In China, the metallogenic belt is locally named the Deerbugan metallogenic belt, and it is controlled by the northeast-trending Deerbugan fault. The belt extends for 800 km, ranges from 50 to 100 km wide, and is related to the Middle Jurassic through Early Cretaceous Daxinganling volcanic-plutonic belt that formed after accretion of the Argun terrane. The multiple units of continental volcanic rock in the Daxinganling belt consist mainly of calc-alkalic felsic volcanic rock, including basalt, andesite, trachyandesite, dacite, and rhyolite. The associated plutonic rocks are diorite, granodiorite, biotite granite, granite porphyry, quartz monzonite, monzonite, and quartz monzonite porphyry. The metlalogenic belt contains several Cu, Mo, Au, and Ag deposits with great economic potential. The significant deposits are at Wunugetushan, Jiawula, and Erentalegai.

The main references on the geology and metallogenesis of the belt are Mironov and Solovyev (1993), Sotnikov and others (1995), Mironov and Trofimov (1993), Bat-Ulzii (1996, 1999), Batjargal and others (1997), Deng and others (1996), Dejidmaa (1996, 1998), Hu and others (1998), and Lin and others (1998).

Akatuevsky and Blagodatskoye District–Transbaikalia

The Akatuevsky and Blagodatskoye districts contain widespread polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposits (Ekaterino-Blagodatskoye, Vozdvizhenskoye). The sphalerite-galena deposits contain significant Ag, Cd, and local Au.

Au Deposits and Occurrences–Mongolia

Various Au deposits and occurrences (Dejidmaa, 1996) are at Dochiin gol, Turgen gol, Narsyn hondlon, Onon-Berh, Herlen, Dornot, Tsav, and Bulgan (Dejidmaa, 1996). Au deposits and occurrences in Dochiin gol, Dornot and Tsav districts (Mironov and Solovyev, 1993) are subdivided into various age groups. Many deposits are related to diorite, granodiorite, monzonite, and granite that occur in hypabyssal stocks and have K-Ar isotopic ages of 190 to 180 Ma and 175 to 165 Ma. Other deposits are closely related to a Late Jurassic through Late Cretaceous basalt and rhyolite bimodal sequence.

The major deposit types are granitoid-related Au deposit and granitoid-related Au-Ag-Sb-As and Au-Ag-Cu deposits. The granitoid-related vein and replacement Au (Tsagaanchuluut and others) occurrences are related to multiphase stocks of gabbro, diorite, granodiorite and granite that are cut by abundant granodiorite and granite porphyry and diorite dikes. Granitoid-related-vein and replacement Au-Ag-Sb-As occurrences (Borondor, Ovorhooloi and others) occur mostly in the northeastern Mongolian part of the belt in the exocontacts of granodiorite stocks in the Middle and Late Jurassic Yamalh complex that intrudes clastic rock. Granitoid-related vein and replacement Au-Te (Dagai, Harguit and Urliin ovoo and others) deposits and occurrences are closely related to microsyenite, lamprophyre, and diabase dikes with K-Ar isotopic ages of 220 to 190 Ma (Mironov and Solovyev, 1993; Mironov and Trofimov, 1993). The granitoid-related vein and stockwork and replacement Au-Ag-Cu occurrences at Nomint and Soyo Ondor are related to the Avdar tolgoi porphyry Cu-Mo (±Au, Ag) (W, Au, Ag) deposit that is located at the intersection of the Ulz gol and Doch gol Rivers. The Avdar porphyry Cu-Mo (±Au, Ag) tolgoi deposit is small and is Mo dominated. The granitoid-related Au (Il turuut) and Ag-Pb-Zn (Lutaagiin) occurrences are closely related to the Avdar tolgoi deposit.

Au-Ag Epithermal Vein Occurrences–Mongolia

Various poorly-studied Au-Ag epithermal vein occurrences are located mostly along the Onon and Ulz faults in the northern part of the metallogenic belt and along the major Mongolian and Nariin-hiid faults in the southeastern part of the Mongolian part of the belt. The Au-Ag epithermal vein occurrences in the Turgen gol, Dornot, and Onon-Berh Au districts (Dejidmaa, 1996), located in the northern part of the belt, consist of vein and linear stockworks composed mostly of chalcedony and quartz in breccia with minor fluorite. The major occurrences are at Tsagaanchuluut khudag II in the Turgen gol district, the Ugtam occurrence in the Dornot district, and the Tenuun gol, Tsagaan, Bayanzurh, and others in the Onon-Berh district. The Au-Ag epithermal-vein occurrences are located mostly along the southeastern margin of the belt and are mainly related to a large hydrothermal-metasomatite that exhibits mainly argillic alteration. Potential deposits of this type occur between the Ma lineament in Mongolia and the Nariinhiid fault in China.

Baga Gazar Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposit

This deposit (Polyakova, 1963; Sanin and Zorina, 1980) consists of a series of veins and stockworks. The large Kadainsly vein is characterized by varying thickness, presence of gentle bends over strike, and dipping branches and pinches. The deposit occurs in carbonate rock along the contact with a thick, extensive dike of lamprophyre. The vein extends more than 360 to 560 meters, downdip to 180 meters, and varies in thickness from 0.4 to 6 meters (average 1.7 meters). The deposit occurs in breccia, veinlets, and disseminations and consists of rare massive sphalerite, pyrite, and galena. The deposit is intensely oxidized to a depth of 150 meters. The large Osinovsky stock is wedge-shaped. The upper horizon has a 3000 m^2 area and the lower one has a 100 m^2 area. The inner structure of the stock is complicated by non-metalliferous limestone and abundant, intricately branching bodies of lamprophyre. The stock contains rich galena and sphalerite. The ore minerals occur in veinlets and disseminations. Gangue minerals are quartz, ankerite, calcite, dolomite, sericite, and rare tourmaline. Depth of zone of oxidation is 20 to 25 meters. At the predeposit stage, the host limestone was altered to skarn, dolomite, serpentinite, and silica, and shale to pyrite. A predeposit stage consisted of Fe-Mn metasomatite. The syndeposit stage consists of quartz-dolomite-ankerite metasomatite. Dikes of lamprophyre and granite porphyry are altered to beresite. The deposit is small and has an average grade of 3.5 percent Pb and 5.6 percent Zn.

Bayan uul 1 Granitoid-Related Au-Vein Deposit

This deposit (Yu.B. Mironov and others, written commun., 1993; Jargalsaihan and others, 1996) is high grade (as much as 250 g/t Au). The deposit consists of a few quartz veins, measuringt as much as 5.0 by 1500 meters that occur in a weak fault zone that ranges from 7.7 to 15.95 meters wide. The deposit contains 9.36 to 123.0 g/t Ag, 0.11 to 1.46 percent Pb, 0.05 to 1.06 percent Zn, and 0.01 to 0.1 percent Cu. Heavy mineral concentrates grade as much as 30.0 to -50.0 g/t Au in pyrite, as much as 10.0 to 30.0 g/t Au in sphalerite and chalcopyrite, and 0.4 to 2.0 g/t Au in galena. Also occurring is lower fineness gold that ranges from 1 micron to 0.1 to 0.2 mm. High grade Au associated with rich polymetallic mineral concentrations. Also occurring are zones of berisite alteration that range from 1.0 to 2.0 meters thick, having abundant pyrite and that contain from 8.0 to 20.0 g/t Au. Quartz occurs in stringers, from 0.1 to 5.0 mm thick and along with pyrite, galena, sphalerite, and chalcopyrite, and grades as much as 100.0 g/t Au. Microprobe analyse of gold grains shows compositions of 28.7 to 66.65 percent Au, 32.0 to 67.35 percent Ag, 0.2 to 2.5 percent Bi, and 0.3 to 3.8 percent Cu. The deposit is medium size and has reserves of 7 tonnes Au and has an average grade of 9.36 to 123.0 g/t Ag, 0.11 to 1.46 percent Pb, 0.05 to 1.06 percent Zn, and 0.01 to 0.1 percent Cu.

Bayandun Fe-Zn Skarn Deposit

This deposit (D. Dorjgotov, written commun., 1990; Jargalsaihan and others, 1996) consists of numerous, steeply-dipping lenticular bodies of Fe- Zn skarn that occurs along the contact between Devonian limestone and early Mesozoic subalkaline granite. The size of skarn bodies ranges from 40 by 100 to 100 by 800 meter. The bodies extend 100 meters downdip. The sulfide-bearing skarn ranges from 100 to 300 meters wide and extends for several hundred meters. The major ore minerals are sphalerite and magnetite. Gangue minerals are garnet, pyroxene, amphibole, quartz, and calcite. The deposit is medium size and has reserves of 240,000 tonnes of ore grading 25 percent Fe and 4 to 7.1 percent Zn.

Erentaolegai Au-Ag Epithermal-Vein Deposit–China

This deposit (Li and others, 1993) consists of layers, veins, and pods hosted in Late Jurassic volcanic rock, mainly Mesozoic Yanshanian adamellite and rhyolite porphyry. The deposits are strongly controlled by fractures. Two ore mineral assemblages are recognized, Mn-Ag and Ag quartz-vein minerals. The Mn-Ag assemblage consists of chlorargyrite and psilomelane with minor argentite, iodargyrite, cryptomelane, coronadite, pyrolusite, manganite, and limonite. The Ag quartz-vein assemblage consists of argentite and freibergite with minor polybasite, miargyrite, and jalpaite. Alterations are sericite, chlorite, silica, adularia, and carbonate. The deposit occurs in a Variscan orogenic belt between the Siberian and North China Platforms. The deposit is large.

Fluorspar-Vein Deposits–Transbaikalia and Mongolia

In Transbaikalia, widespread development fluorspar-vein deposits occur at Abagaituiskoye and Solonechnoye and in nearby areas. The richer deposits occur in the southwestern end of the belt. The deposits consist of quartz-fluorite veins hosted in variable rocks in the southern (Abagaituiskoye) and central (Solonechnoye, Shakhmatnoye) parts of the belt. In Mongolia, the fluorite-vein deposits occur in northern and southern fluorite zones (Khrapov, 1977) that were first named the North Herlen, South Herlen, and Har Airag-Buyant fluorite zones (Kandinov and Dobrolyubov, 1984).

Jiawula Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit, China

This deposit (Pan and Sun, 1992; Li and others, 1993) consists of more than 40 vein-like bodies that occur along northwest-striking fractures. The wallrocks are a complicated sequence of Late Permian volcaniclastic rock of the Laolongto Formation, intermediate to mafic volcanic rock of the Late Jurassic Tamulangou Formation, intermediate to siliceous volcanic rock of Late Jurassic Shangkuli Formation, Variscan granite and Mesozoic diorite porphyry, feldsparphyre, quartz porphyry, and beschtauite. The main ore minerals are galena, sphalerite, pyrite, marcasite, pyrrhotite, and chalcopyrite. The minor ore minerals are magnetite, hemalite, bornite, and arsenopyrite. Alterations are silica, chlorite, carbonate, sericite, fluoritie, epidote, and hydromica. The deposit occurs in a Variscan orogenic belt between the Siberian and North China Platforms. The deposit is large and has reserves of 236,300 tonnes Pb and 379,000 tonnes Zn grading 130 to 173 g/t Ag, 3.16 percent Pb, and 5.24 percent Zn.

Kadainskoye Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposit

This deposit (fig. 7) (Polyakova, 1963; Sanin and Zorina, 1980) consists of a series of veins and stockworks. The largest vein is characterized by varying thickness, presence of gentle bends over strike, and dipping branches and pinches. The deposit occurs in carbonate rock along the contact with a thick, extensive dike of lamprophyre. The vein extends more than 360 to 560 meters, downdip to 180 meters, and thickness varies from 0.4 to 6 meters (average 1.7 meters). The deposit occurs in breccia, veinlets, and disseminations, and consists of rare massive sphalerite, pyrite, and galena. The deposit is intensely oxidized to a depth of 150 meters. The large Osinovsky stock is wedge -shaped. The upper horizon has a 3000m^2 area, the lower one has a 100 m^2 area. The inner structure of the stock is complicated by non-metalliferous limestone and abundant, intricately branching bodies of lamprophyre. The stock contains rich galena and sphalerite. The ore minerals occur in veinlets and disseminations. Gangue minerals are quartz, ankerite, calcite, dolomite, sericite, and rare tourmaline. Depth of zone of oxidation is 20 to 25 meters. At the predeposit stage, the host limestone was altered to skarn, dolomite, serpentinite, and silica, and shale to pyrite. A predeposit stage consisted of Fe-Mn metasomatism. The syn-deposit stage consists of quartz-dolomite-ankerite metasomatite. Dikes of lamprophyre and granite porphyry are altered to beresite. The deposit is small and has an average grade of 3.5 percent Pb and 5.6 percent Zn.

Klichkinskoye District (Transbaikal)

The Klichkinskoye district contains polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite (Klichkinskoye) and Zn-Pb (Ag, Cu, W) skarn (Savinskoye-5) deposits. The deposits are hosted in early Paleozoic dolomite, carbonaceous shale, and shale with interbedded limestone, sandstone, and conglomerate. These sedimentary rocks are intruded by late Mesozoic stocks and dikes of diorite, leucocratic granite and porphyry. The host rocks and deposits are cut by faults and deformed into folds that control the location of bed, vein, and pipe-shaped deposits.

Klichkinskoye Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposit

This deposit (Arkhangelskaya, 1963; Sanin and Zorina, 1980) consists of a series of thin and discontinuous plates, veins, and pipes with sphalerite and galena in dolomite having thin beds of shale. The deposit occurs in the same tectonic zone as the Savinsky-5 deposit to the south. The bodies strike for a few hundred meters, extend downdip for tens of meters, and range from 0.1 to 1.1 meters thick with an average thickness of 0.2 to 0.3 meters. The major ore minerals are pyrite, galena, sphalerite, and arsenopyrite; minor pyrrhotite, chalcopyrite, and tetrahedrite, and rare bulanzherite, cassiterite, and scheelite. Major gangue minerals are quartz and calcite. The main ores assemblages are pyrite-arsenopyrite, sphalerite-galena, and pyrite-arsenopyrite-sphalerite-galena. Sulfide bodies are cut by the quartz-fluorite (and local barite) veins and streaks. Oxidized ore minerals are limonite, cerussite, smithonite, kalamine, anglesite, skorodite, jarosite, galena, and quartz. The host dolomite is intruded by Late Jurassic granite, diorite stock, and rare granite porphyry dikes. The deposit and host rocks are altered to dolomite, serpentinite, silica, skarn, greisen, and beresite. The deposit is small with grade ranging from tens of fractions to 50 percent Pb (average 12 percent), as much as 17 percent Zn, and about 400 ppm Ag.

Novo-Shirokinskoye Volcanic-Hosted Au-Base-Metal Metasomatite Deposit

This deposit (fig. 8) (Kormilitsyn and Ivanova, 1968; Sanin and Zorina, 1980; Tauson and others, 1987) consists of a thick metasomatic zone of listvenite-beresite and sulfides that occurs in en-echelon branching bodies. The zone is hosted in trachyandesite latite volcanic rock that is intruded by small stocks and dikes of diorite porphyry, granodiorite porphyry and lamprophyre. The host rock is propiliticaly-altered to quartz, chlorite and dolomite. The zone extends for more than 6 km, varies from 20 to 300 meters thick and has no clear outlines. The sulfide bodies occur in pipes, nests, lenses and veins, extend along strike for 1500 meters and range from 1.5 to 30 meters thick. The sulfides occur in layers, streaks, and disseminations. Sulfide bodies consist of 60 to 80 percent pyrite, galena and sphalerite with local sulphosalt, quartz, and dolomite. The sulfide body structures are massive, banded, dense disseminations, spots and coliform. Streaks and disseminations form haloes around massive sulfides, but commonly form independent bodies with irregular distribution of sulfides. Several assemblages occur (1) tourmaline; (2) pyrite with Au (pyrite, rare areson-pyrite and chalcopyrite); (3) polymetallic with Au (pyrite, galena, sphalerite, quartz, carbonates); (4) sulphosalt with Au (gray ore, tetrahedrite, shwartzite, tennatite, cleiophane, dolomite); and (5) realgar-antimonite with Au and Hg-barite-antimonite. Gold is fine-grained and occurs in sulfides. The oxidation zone occurs to a depth of 16 meters. The deposit is medium size and has an average grade of 3.53 percent Pb, 1.35 percent Zn, 3.11 ppm Au, 62 ppm Ag, 0.25 percent Cu, 3.47 ppm Cd, 9.77 ppm In, 3.75 ppm Se, and 6.44 ppm Te.

Savinskoye-5 Zn-Pb (Ag, Cu, W) Skarn Deposit

This deposit (Sanin and Zorina, 1980) consists of lenses, veins, nests, and pipes that occur in a thick (150 to 200 meters) and extensive (more than 2 km) zone. The zone contains skarn, propylite, relict of host limestones, schist, diorite, rare dolerite dikes, and fluorite and zeolite veins and nests. The deposit occurs in a tectonic zone and is bounded by the western and eastern bodies of quartz diorite of the Paleozoic Savinsky stock. The skarn bodies extend for 80 to 500 meters and, locally, as much as 960 meters, extend downdip for 100 to 500 meters, and range from 0.7 to 17 meters thick. The major ore minerals are pyrite, pyrrhotite, galena, and sphalerite, and lesser arsenopyrite, chalcopyrite, bulanzherite, markasite, and melnikovite. The major gangue minerals are quartz and calcite. Pyrite-galena in aksinite and diopside skarn occur in the upper and middle layers, and pyrrhotite-sphalerite occur in garnet skarns in lower layers. Oxidation zone extends to 80 meters depth. Oxidized minerals include limonite, cerussite, smithsonite, kalamine, anglesite, skorodite, jarosite, residual galena, and quartz. The deposit age is interpreted as being Late Jurassic. The deposit is medium size and has an average grade of 2.45 percent Pb and 4.5 percent Zn.

Sediment-Hosted Hg and Sb Occurrences–Mongolia

Sediment-hosted Hg (Obolenskiy, 1985) and sediment-hosted Sb occurrences are located in the northeastern part of the metallogenic belt and are hosted in Late Permian and Triassic marine sedimentary rock in central part of the Doch gol district. The major occurrences are at Harzat Hg, Tagiinburd Sb, Gorhit bulag Sb, Baruun bulag Sb, and Huts Ondor Sb. These and other occurrences are located along a northeast-striking fault zone. Vocanic-rock-hosted Hg occurrences, such as at Dalai Am gol and Hotol and others, occur in the northeast-striking Ulz fault that occurs between Cretaceous grabens and preCretaceous horsts. The Hg deposits consist of Hg-quartz-carbonate and barite vein and stockworks and curt early Paleozoic and Permian granite. The occurrence of barite-vein deposits is similar to volcanic-hosted Hg occurrences.

Shakhtaminskoye Porphyry Mo (±W, Sn, Bi) Deposit

This deposit (Kormilitsyn, 1973; Sidorenko, 1961; Sotnikov and others, 1995) consists of more than 300 steeply-dipping veins (30 to 800 by 0.2 to 0.5 meters) having low-grade stockwork inbetween. Three types deposit mineral assemblages occur (1) early-quartz-tourmaline with rare disseminations of large-scaly molybdenite; (2) average-fine-grained quartz with small-scaly molybdenite and rare pyrite; and (3) sphalerite, chalcopyrite, galena, tetrahedrite, bismuthite, pyrarhyrite, gray ore, antimonite, and native gold. Assemblages are zonally combined in the veins of complex composition. Stock-and veins formed in a predeposit explosive breccia have dimensions of 500 by 600 meters. The deposit minerals contain impurities (ppm)—10 to 70 Re; 10 to 30 Se and Te; 0.1 to 1.6 Au; and 17.0 Ag; as well as Cd, In, Ga, Ge. The deposit occurs in the southern part of the multiphase Shakhtaminsky massif (135 sq. km) of biotite-hornblende granite and granodiorite (Middle and Late Jurassic) cut by late Mesozoic dikes producing the zone of 40 by 7 km. Granitoids are altered to K-feldspar, sericite, beresite and argillite. The deposit is medium size with a grade of 0.03-1 to 2 percent (average 1 percent) MoS_2, 0.5 to 0.7 percent Cu, 0.8 percent Pb, and about 0.9 percent Zn.

Solonechnoye Fluospar-Vein Deposit

This deposit (Ivanova, 1974) consists of an intricate zone that extends ENE for 1.5 km along strike and dips steeply northwest. The zone contains two bodies. The main body is a linear stockwork (with dimensions of 350 by 25 to 30 by 200 meters) that contains a series of closely-spaced, subparallel feathering veins that are cut by a network of small and variably-oriented veinlets. The eastern vein (with dimensions of 300 by 1.5 to 3.0 meters) is a gash vein. All veins and veinlets display a symmetrically-zoned structure and consist of quartz and fluorite (90 percent), minor adularia and hydromicas, and sporadically disseminations of calcite, pyrite, and arsenopyrite. Fluorite is mainly green and rarely violet. Structures are massive and rare bands, and texture is coarse-crystalline. The hosting middle Paleozoic biotite-hornblende granite (PZ2) is altered to silicified and chlorite adjacent to the deposit. The deposit is small and has an average grade of 67 percent CaF_2. The surrounding area contains a resource of 2.8 million tonnes CaF_2.

Tsagaanchuluut khudag II Au-Ag Epithermal-Vein Deposit

This deposit (Dejidmaa and others, 1993) occurs along a sublatitudinal weak fault zone that occurs between

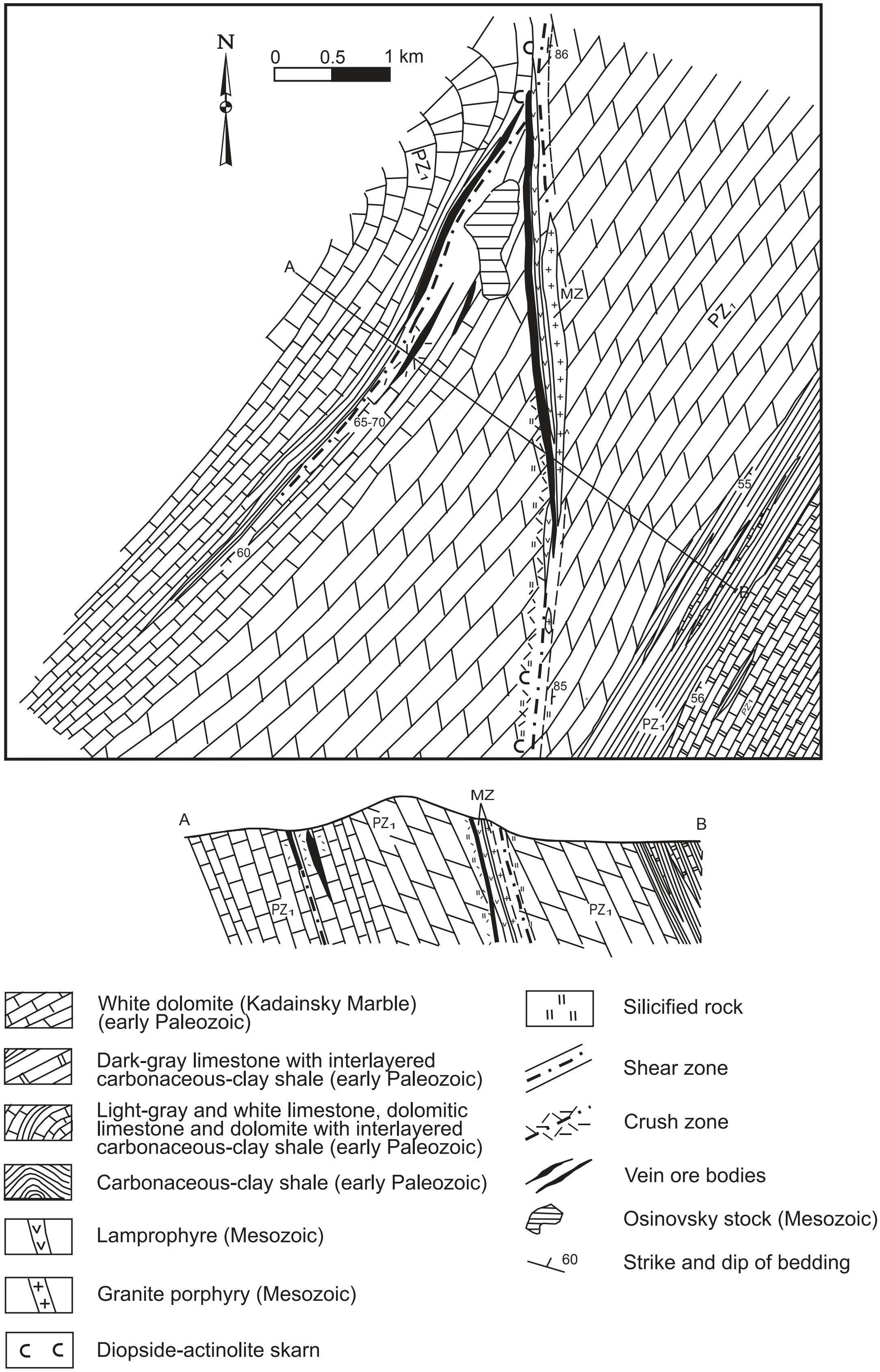


Figure 7. Generalized geologic map and schematic cross section of Kadainskoye polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposit, East Mongolian-Priargunskiy-Deerbugan metallogenic belt, Transbaikal region. Adapted from Polyakova (1963).

Proterozoic basement and a late Mesozoic graben. The deposit consists of a zone of quartz breccia, veinlets, and crystalline and porcelain quartz veins. The veins and breccia are variably oriented, and are extensively developed in early Paleozoic cataclastic granite and form a stockwork. The zone ranges from 0.1 to 3.0 meters wide and 10 toa few hundreds meters long. The average grades are as much as 0.1 as 0.5 g/t Au and altered zones are as much as 10.0 to 30.0 g/t Au. The altered zones consist of limonite and are intensely deformed. Samples with high-grade Au contain high grade of Pb, Zn, Mo, As, and Ag.

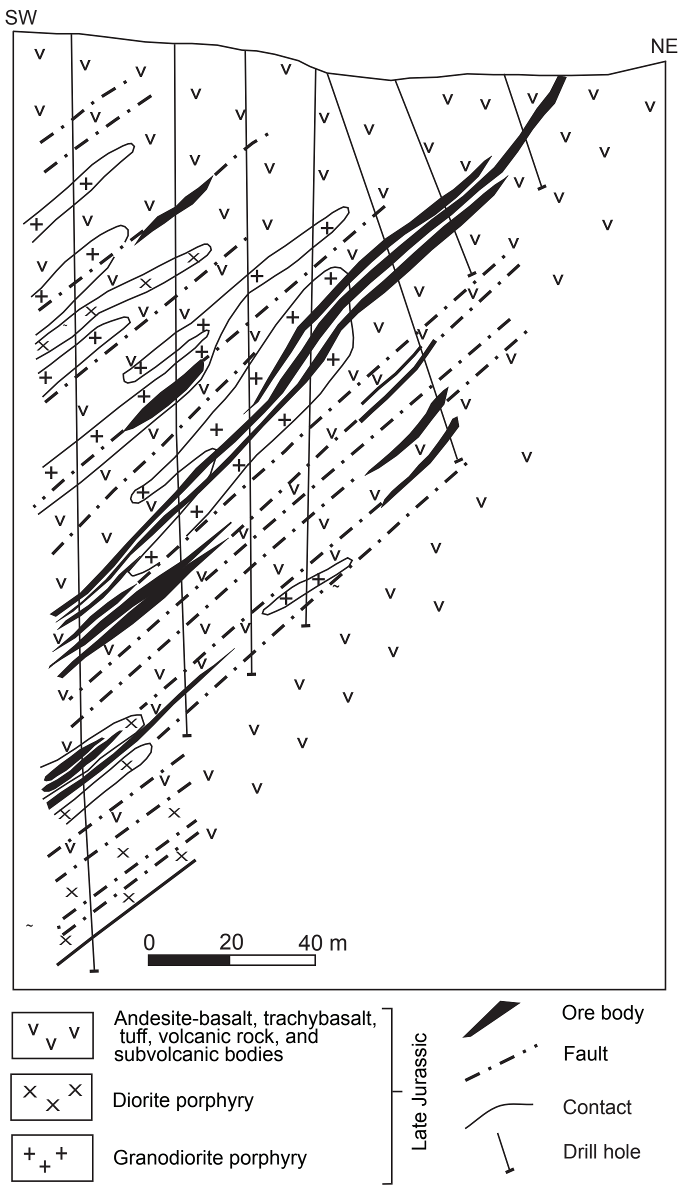


Figure 8. Schematic cross section of Novo-Shirokinskoye volcanic-hosted Au-base-metal metasomatite deposit, East Mongolian-Priargunskiy-Deerbugan metallogenic belt, Transbaikal region. Adapted from Kormilotsun and Ivanova (1968).

Tsav and Bayan Uul Granitoid-Related Au Vein Deposits–Mongolia

Various granitoid-related Au vein (Bayan uul 1 deposit) and Ag-Pb-Zn vein (Tsav deposit) deposits and occurrences occur extensively in the Tsav-Delgermonh and Dochiin gol districts and are closely related to Late Jurassic monzodiorite, granodiorite, and granite stocks (Batjargal and others, 1997; Bat-Ulzii, 1996 and 1999). Similar deposits occur to the southeast in China (Ke-Zhang and others, 1995).

Tsav Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (fig. 9) (D. Dorjgotov, written commun., 1990; Jargalsaihan and others, 1996) consists of quartz-sulfide and quartz-carbonate-sulfide veins in NW-trending, steeply-dipping altered zones hosted in Jurassic diorite, granodiorite and granite porphyry intruding Proterozoic metamorphic rock. The alteration consists of beresite (quartz-sericite-pyrite metasomatite). The alteration zone is 10 to 20 meters wide. Metasomatic alteration has a zonal structure, with a central part that contains an assemblage of quartz-sericite-pyrite and a peripheral zone with less pyrite, sericite, chlorite, and carbonate. Bodies are 700 to 1900 meters long, 0.5 to 1.2 meters thick, and 125 to 500 meters down dip. The deposit minerals are sphalerite, galena, pyrite, magnetite, chalcopyrite, pyrrhotite, arsenopyrite, and Ag minerals. Major gangue minerals are quartz, sericite, muscovite, eligonite, rhodochrosite, chlorite and calcite. Numerous occurrences of polymetallic-vein deposits are also in the area. The deposit is medium size, has grades grade of 6.48 percent Pb, and 3.53 percent Zn, and has a resource of 420,000 tonnes.

Tumentsogt W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Khasin, 1977; Kovalenko and others, 1985) consists of wolframite and molybdenite related to a Mesozoic granite pluton that consists of coarse-grained porphyritic granites and fine- and medium-grained leucocratic granite. The deposit occurs in granite porphyry and fine-grained granite that intrude porphyritic granites. Greisen formed during alteration of coarse-grained porphyritic granites, and, rarely, in fine-grained granite. Greisen bodies are irregular and extend to a depth of 150 meters. Quartz-muscovite and muscovite form the core of greisen bodies along with assemblages of muscovite, fluorite-muscovite, molybdenite-muscovite, and rare beryl-muscovite. Pyrite and scheelte also occur. Muscovite contains anomalous Li, Rb, and Cs. Also occurring are pegmatite, veins, and albitite. The deposit is small and has resources of 1,043 tonnes WO_3 in the main deposit. The West Tumentsogt deposit has resources of 2,302 tonnes WO_3.

Urliin Ovoo Granitoid-Related Au Vein Deposit

This deposit is hosted in Proterozoic gneiss intruded by early Paleozoic granite and by Mesozoic microdiorite, microsyenite, and lamprophyry dikes. The deposit contains three zones with more than 20 quartz veins. The zone occurs in a northwest-trending area with dimensions of 10.0 km by 3.0 km. Veins are 80 to 160 meters long and 0.1 to 1.0 meters thick. Quartz veins extend for 100-200 meters in four areas. Grade ranges from 0.5 g/t to 30.0 g/t Au in quartz veins and from 0.5 g/t to 20.0 g/t Au in altered host rock. The three mineral associations are (1) medium-grained, white quartz, rare pyrite, chalcopyrite (3 to 5 percent) with a grade of 1.0 to 3.0 g/t Au; (2) chalcopyrite, rare galena, sphalerite, tellurides (gessite, veissite, silvanite, crennerite, and rikkardite), bornite, rare tetrahedrite in quartz-carbonate viens with as much as 0.1 percent Te and 10 to 30 g/t Au; and (3) postdeposit carbonate veinlets with as much as 4.2 percent Ag, 0.11 percent Cu, and 0.09 percent Hg, and trace of Te. The deposit is medium size and has an average grade of 0.5 to 30.0 g/t Au, 4.2 percent Ag, 0.11 percent Hg, and 0.09 percent Cu.

Vozdvizhenskoye Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposit

This deposit (Kulagashev, 1963; Sanin and Zorina, 1980) consists of sulfide bodies that occur in two parallel pseudo-layers spaced 10 to 40 meters apart. The layers extend for over 600 meters along the strike and 400 meters downdip. Individual sulfide bodies occur in flattened pipes, nests, and layers. The dimensions along strike vary from 80 to 200 meters, downdip from 20 to 200 meters, and from 0.97 to 6.2 meters thick. The main ore minerals are pyrite, galena, and sphalerite, and localy arsenopyrite, bulanzherite, burnonite, chalcopyrite, grey ore, and geokronite. Vein minerals are dolomite, quartz, and calcite. Sulfides occur in masses and disseminations. An oxidation zone extends to a depth 160 meters and consists of Fe oxides, cerussite, smithsonite, anglesite, calamine, plumbojarosite, skorodite, and psilomelane, and local malachite and azurite. Host rocks are carbonaceous limestone and dolomite with local coal shale and dikes of felsite-porphyry, quartz porphyry, and lamprophyre. The main sulfide bodies occur in dolomite, locally close to or along the contact with lamprophyre and shale. Host rocks are altered to dolomite, silica, serpentine, sericite, sericite, chlorite, and argillite. Sulfide bodies formed along with quartz-dolomite-ankerite metasomatite. The deposit is medium size and has an average grade of 6.3 percent Pb, 8.5 percent Zn, and 106 ppm Ag.

W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposits–Mongolia

This type of deposit occurs mainly in small outcrops of bedrock that are intruded by granitoids and (or) overlain by a Late Jurassic through Early Cretaceous basalt and rhyolite bimodal sequence. Major W-Mo deposits are related to Late Jurassic leucogranite, granite porphyry stocks in the Chuluunhoroot REE complex in northeastern Mongolia. These deposits occur in veins and stockworks in the Chuluunhoroot, Ondor-tsagaan, Tumentsogt, Burentsogt, and Ikh Nartynhiid deposits. Most deposits were exhausted before 1970, but the Ondortsagaan W-Mo and Tsagaanchuluut Mo stockwork and greisen deposits are new discoveries.

Wunugetushan Porphyry Cu-Mo (±Au, Ag) Deposit–China

This deposit (Wei and Lu, 1994) occurs at the intersection between the northeast-trending Manzhouli-Dalaidong thrust and strike-slip fault with a secondary northwest-striking Hanigou normal fault that is a secondary structure of the northeast-striking Deerbugan major fault zone. The deposit is hosted in the Yanshannian granodiorite porphyry that is exposed over an area of 0.12 km^2. A K-Ar age for the porphyry is 164 Ma. The wallrock alteration forms a circular-zoned pattern that has an inner quartz-K-feldspar zone, a middle quartz-sericite-hydromica zone, and an outer illite-hydromica zone. There are 33 Cu and 13 Mo bodies in the deposit that are controlled by the porphyry body and the contact zone. From the center of the porphyry outward, the zonation pattern is a pyrite-molybdenite zone, apyrite-chalcopyrite zone, and a pyrite-galena-sphalerite zone. Cu and Mo minerals occur mainly in disseminations and networks. The temperatures of formation of the porphyry intrusion and deposits are 1003 to 1205°, and 140 to 500° C, respectively. The ore-forming fluids exhibit high salinity (51 percent NaCl) and high density (1.12 g/cm^3). The deposit is large and has resources of 2.232 million tonnes grading 0.4 percent Cu, and resources of 0.412 million tonnes grading 0.05 percent Mo.

Zapokrovskoye District–Transbaikalia

The Zapokrovskoye district contains carbonate-hosted As-Au metasomatite deposits (Gurulevskoye, Oktyabrskoye, Zapokrovskoye) that occur in veins, pillars, nests and lenses. The deposits are hosted in faulted carbonate rock that is intruded by dikes and stocks of granite, diorite, and monzonite porphyry (Volfson, 1963). The Shakhtaminskoye porphyry Mo (±W, Sn, Bi) deposit occurs in the Shakhtaminskoye granodiorite and granite pluton (Sotnikov and others, 1995). The deposits consist of typical quartz-Mo veins that occur in the southeastern margin of an eroded subvolcanic structure (Seminsky, 1980).

Zapokrovskoye Carbonate-Hosted As-Au Metasomatite Deposit

This deposit (Zavorotnykh and Titov, 1963) consists of various bodies of As-Au minerals that occur in fractured veins, pillars, pipes, nests, and lenses that are hosted in carbonate rock, primarily along the contacts between marble and schists and other sedimentary rock. The bodies occur along faults and have sharp and folded contacts. The bodies extend along strike for about 20 to 250 meters, and 300 meters down dip. The main gangue minerals are quartz, calcite, and dolomite. In swells, the bodies are banded with alternating bands of grey quartz with rare disseminations of arsenopyrite and bands with massive arsenopyrite that contains nests of quartz and inclusions of host rock. Along faults that bound the veins is local serpentine. An oxidation zone occurs from 5 to 20 meters depth. Oxidized ore minerals are scorodite and red-brown ochres. Limestone in the southern part of the deposit is intruded by the Zapokrovsky monzonite intrusion that also contains metasomatic hybride quartz syenite with local skarn along contacts. The deposit is cut by numerous dikes of quartz porphyry, granodiorite porphyry, granodiorite porphyry, and lamprophyre. Alterations consist of zones of dolomite, serpentine, silica, ankerite, chlorite, sericite, and kaolinite. The deposit is medium size and has an average grade of 6.93 percent As in primary ore and 2.2 to 9.65 percent As in oxidized ore.

Zn-Pb (±Ag, Cu) Skarn Deposits–Mongolia

Various Zn-Pb (±Ag, Cu) skarn deposits and occurrences are in the Bayandun district and are hosted in Proterozoic gneiss and carbonate rock, Devonian carbonate and clastic rock, and in Permian volcanic and sedimentary rock. The deposits and occurrences are closely related to Middle and Late Jurassic granodiorite and granite stocks.

Origin and Tectonic Controls for East Mongolian-Priargunskiy Metallogenic Belt

The belt is interpreted as having formed during Middle Jurassic through Early Cretaceous extensional tectonism

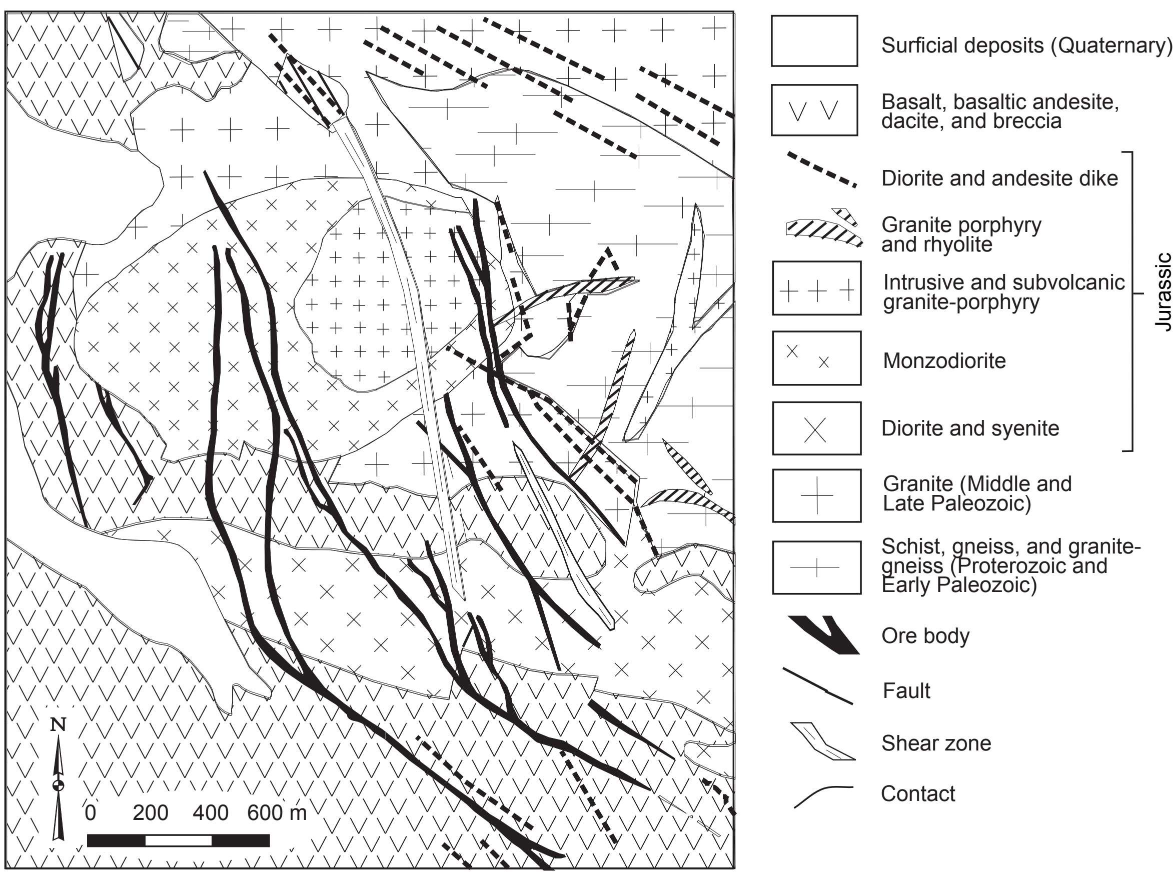


Figure 9. Generalized geologic map of Tsav and Bayan Uul granitoid-related Au-vein deposits, Mongolia. Adapted from Jargalsaihan and others (1996).

associated with generation of the Trans-Baikalian-Daxinganling volcanic-plutonic belt that was related to the back arc of a continental-margin arc. The metallogenic belt is controlled by major, regional northeast- and northwest-trending faults. The northeast-striking faults (Byrkinsky-Urovsky, Gazimur-Urjumkan, Argunsky) control the magmatic and hydrothermal activity and internal structure of the belt.

In Russia, the related major volcanic units are basalt, rhyolite, and andesite (Shadoronsky, Berjozovsky, Ust-Kara, and Argunsky Suites) and comagmatic hypabyssal and subvolcanic units (Shakhtaminsky, Samudzhikan and Akatuevsky complexes). The volcanic units occur in grabens, paleocalderas, volcanic comes, plutonic domes, and volcanic basins. Cassiterite-silicate-sulfide vein and stockwork occurrences (Shalz and Narsyn khondlon) and granitoid-related Au-magnetite vein and stockwork occurrences (Delberhei bulag and Salhit) are related to Middle Jurassic diorite stocks in the Narsynhondlon district. Cassiterite-silicate-sulfide vein occurrences are mainly in the central part of the belt, and granitoid-related Au-magnetite-hematite vein and stockwork occurrences are in the north-northwest and in southeastern marginal parts of the belt.

In Mongolia, the metallogenic belt contains the Early Cretaceous Onon graben that is interpreted as an extensional feature superimposed on the Hentii megadome. The Onon graben contains Early Cretaceous basalt and arkose (Enkhtuvshin, 1995) that are down-faulted against postcollisional Mesozoic intrusions (Gerel, 1998). The Au deposits in the Onon graben are interpreted as having formed during early Mesozoic, postorogenic back-arc volcanism-plutonism that occurred along a late Paleozoic suture zone between the North China Plate and the North Asian craton. During collision, some terranes were consumed in a subduction zone that dipped toward the North Asian craton prior to transpressional tectonism and continental magmatism. Various Au hydrothermal systems formed during the transpression and were subsequently downdropped into the Onon graben (Cluer and others, 2000). An alternative interpretation is that the Onon graben is related to the Mongol-Okhotsk system of northeast-trending, Late Jurassic and Early Cretaceous grabens that formed after collision between the North Asian craton with microcontinents (Zonenshain and others, 1975).

In China, several different interpretations exist for the origin of the metallogenic belt. (1) Some studies discuss the effect of Argun terrane during the closing of the Mongolia-Okhotsk Ocean (Hu and others, 1998). (2) Some studies suggest that the distance between the Late Mesozoic volcanic belts and the subduction zone of the ProtoPacific Plate would be more than 1000 km and a plate subduction model is regarded as difficult. Instead, the Late Jurassic through Creaceous Daxinganling volcanic belt is interpreted in some studies as being a ring-shaped volcanic belt related to uprising of deep, hot mantle plumes in the ancient Asian Ocean (Lin, Qiang and others, 1998). (3) Continental plume tectonics are also employed in some studies to interpret the region (Deng and others, 1996). During the Jurassic, to the east was the Zianagi Ocean, and to the north was the Mongolia-Okotsk Ocean that was subducted under east China with de-rooting and thinning of lithosphere and upwelling of asthesnosphere. The upwelling is interpreted as the cause of intense Jurassic magmatism and formation of large and superlarge deposits from mantle plumes (Hu and others, 1998). (4) In this study, the Nariinhiid fault is interpreted as the direct continuation of northeast-striking Ergun-Hulun fault that controlled the distribution of Middle Jurassic through Late Cretaceous volcanic and plutonic rocks and related porphyry Cu-Mo (±Au, Ag), Ag-Au-Pb-Zn-vein deposits, epithermal Ag(Au) deposits, hot spring Au-Ag occurrences (Ke-Zhang Qin and others, 1995), and the new intrusion-related Zalaa Uul sediment hosted Au+(As ± Sb) Au occurrence (Cluer and others, 2000).

Govi-Tamsag Metallogenic Belt of Sediment-Hosted U, Evaporate Sedimentary Gypsum, Sedimentary Celestite, and Volcanic-Hosted Zeolite Deposits (Belt GT) (Southern Mongolia)

This Late Jurassic through Early Cretaceous metallogenic belt is related to stratiform units in the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Dzhida, Govi Altai, and Mandalovoo-Onor terranes. The major sediment-hosted U deposits are at Haraat and Narsyn, and the major evaporate sedimentary gypsum deposits are at Taragt, Unegt, and Modonus.

The main references on the geology and metallogenesis of the belt are Goldenberg and others (1978), Ochirbat (1998), and Ganbaatar (1999).

Sediment-Hosted U Deposits

The sediment-hosted U deposits at Haraat and Narst, and various occurrences are hosted in an Early Cretaceous sedimentary graben and a Late Cretaceous sedimentary basin in the Late Mesozoic Eastern Mongolian continental rift. Some deposits are interlayered with coal deposits that contain high-grade U. The U deposits and occurrences consist of U-bearing sandstone beds and lenses (Ochirbat, 1998).

Haraat Sediment-Hosted U Deposit

The deposit (Jargalsaihan and others, 1996; Ochirbat, 1998; Wetz and others, 1999) is hosted in the Early Cretaceous Choir graben. The deposit surface area is more than 100 km^2. The host rocks are intercalated sandstone and siltstone and range from 0.2 to 20.0 meters thick. The deposit bed is approximately horizontal, 20 km long, 0.5 to 2.0 km wide, ranges from 1.0 to 30.0 meters thick, and is covered by 0.5 meters to 45 meters of barren rocks. Two explored bodies are 400 meters and 2500 meters long, range from 50-300 meters wide, and from 1.0 to 12.0 meters thick. Ore minerals are nasturan (pitchblende), autunite, and torbernite. The average grade ranges from 0.01 to 0.04 percent U to 0.05-0.2 percent U, partly 1.2 to 4.0 percent U. Uranium ore contains 0.02 to 0.3 percent Ce, 0.017 to 0.17 percent La, 0.7 to 60 g/t Sc, 25 to 30 g/t Y, 2 to 12 g/t Yb, 0.1 to 8 g/t Re, 10 to 90 g/t Ge, and as much as 0.03 percent Mo, as much as 0.01 percent Se, and as much as 3.0 g/t Ag. An in-place leach-mining method has been successfully tested. The deposit is medium size and has an average grade of 0.01 to 0.2 percent U and reserves of 22,700 tonnes U.

Evaporate Sedimentary Gypsum Occurrences

Evaporate sedimentary gypsum deposits are extensive and occur mainly in sandstone and shale in a Late Cretaceous and local Paleogene basin (Ganbaatar, 1999). The occurrences are related to continental evaporate basins. The Unegt and Shiree Uul (Taragt-2) deposits are in operation at the present.

Shiree Uul (Taragt-2) Evaporate Sedimentary Gypsum Mine

This mine (D. Begzsuren, written commun., 1999; Ganbaatar, 1999) consists of gypsum and calcite concretions that occur in Tertiary sedimentary rock. The gypsum thickness is 1 meters. The gypsum concretions range from 30 to 40 cm in size. The deposit age is interpreted as middle and late Oligocene. The deposit is small and has production and reserves of 4.5 million tones grading 83 to 84 percent gypsum.

Sedimentary Celestite Occurrences

Sedimentary celestite occurrences are hosted in Early Cretaceous sandstone, siltstone and mudstone. Sandstone beds contain thin (1 to 5 cm) layers or roses of celestite (Goldenberg and others, 1978). Sedimentary celestite is poorly studied, and occurrences are mainly in southern part of metallogenic belt.

Horgo Uul Sedimentary Celestite Deposit

This deposit (V.I. Goldenberg and others, written commun., 1978) consists of 1.0 to 5.0 cm thick layers of celestite in Early Cretaceous sandstone. Celestite also occurs as isometric black concretions with a diameter of 0.3 to 0.4 cm, and as celestite roses. These concretions contain as much as 6.56 percent Sr. The thickness of celestite-bearing beds with concretions ranges from 10 to 50 meters. The beds are intercalated with barren sandstone (as much as 0.07 percent Sr) beds that range from 50 to 100 meters thick. The average grade is 45.59 percent Sr.

Tsagaantsav Volcanic-Hosted Zeolite Deposit

This deposit (P.Shaandar and others, written commun., 1992; Petrova and Amarjargal, 1996) consists of zeolite beds and layers in siliceous tuff, tuffaceous sandstone, and argillite of the Early Cretaceous Tsagaantsav Formation. The deposit has a surface area of 1.5 by 3 km and is 200 meters thick. The zeolite beds are elongate and strike east-southeast and dip gently. The maximum zeolite content (60 to 90 percent) occurs adjacent to an underlying siliceous vitreous tuff. The main zeolite mineral is clinoptilolite. The deposit is large and has resources of 179.0 million tonnes grading 10 to 80 percent zeolite.

Origin and Tectonic Controls for Govi-Tamsag Metallogenic Belt

The belt is related to Aptian-Albian (Early Cretaceous) sedimentary rocks deposited in grabens and depressions that overlap the Mesozoic Eastern-Mongolian-Preargune continental-rift belt that developed on the Idermeg passive continental margin, Govi-Altai turbidite, and Mandal-Ovoo island-arc terranes. The sedimentary U deposits and occurrences formed duringt the latest stage of a late Mesozoic continental rift. The gypsum deposits and occurrences formed in continental evaporite basins.

Hartolgoi-Sulinheer Metallogenic Belt of Au-Ag Epithermal Vein, Ag-Pb Epithermal Vein, Porphyry Mo, W±Mo±Be Skarn, Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Carbonate-Hosted Hg-Sb, and Silica-Carbonate (Listvenite) Hg Deposits (Belt HS) (Southern Mongolia, Northwestern China)

This Late Jurassic through Early Cretaceous metallogenic belt is related to veins and replacements in latite and lamporphyre dikes in the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that intrudes and overlies the Tsagaan Uul-Guoershan and Solon terranes and the Lugyngol volcanic and sedimentary basin. The belt extends approximately 1,200 km along the southern and southeastern border of Mongolia's border with China. The major deposits are the Hartolgoi carbonate-hosted Ag-Pb, Biluut Ag-Pb vein-replacement deposits, and the Zuuntogoo Uul, Baruuntogoo Uul carbonate and hosted Sb (Au, Ag, As) occurrences, the Hotoltolgod, Barjin uul Au-Ag epithermal vein occurrences, and the Hangi Ovoo silica-carbonate Hg occurrence. The Ag-Pb vein and replacement and carbonate and hosted Ag-Pb deposits and occurrences in the Biluutiin and Ulaan Uul districts are located in the western part of the belt and were first assigned to the South Govi-Nuhetdavaa metallogenic belt (Yakovlev, 1977; Batjargal and others, 1997). Various carbonate-hosted Sb (Au, Ag, As), Au-Ag epithermal vein, and listvenite Hg occurrences are located along an east-west-trending thrust fault in the Sulinheer subuction-zone terrane and were discovered as the result of detailed geological mapping and prospecting in the last 10 years. The significant deposits are at Biluut, Harmorit, Hartolgoi, Khartolgoi, Khoit Barjin, Qiyishan, Ulaan Uul, and Zuun Togoo.

The metallogenic belt displays the following features. (1) The vein and replacement Ag-Pb, carbonate-hosted Ag-Pb, and carbonate-hosted Sb (As, Au, Ag), epithermal Au-Ag and silica-carbonate Hg deposits and occurrences all occur in the southern, border part of Mongolia, and are controlled by east-west trending thrust faults. (2) The deposits are closely related to monzonite, quartz porphyry ,and diabase stocks and dikes that intrude Late Triassic through Early Jurassic granite porphyry and granite stocks with local REE deposits. (3) The thrust fault is a part of the east-west trending Yenshan thrust zone. The western part of this metallogenic belt of Qiyishan W-Mo-W±Mo±Be skarn occurs in the western part of Inner Mongolia (Northwestern China) It trends east-west and is about 170 km long and 30 km wide. (4) The Tsagaantolgoi fault in Mongolia, which controls the Buluutiin and Ulaan Uul districts, is the western continuation of the Sulinheer thrust fault that may be a part of the Yenshan thrust zone in China (Geological and Mineral Resources Maps of China). These east-west trending thrust faults closely control the Late Mesozoic vein and replacement deposits and occurrences in the belt. The post-accretionary Late Jurassic granite that is related to the deposits in the metallogenic belt, intruded the volcanic and sedimentary units of the Archean Alashan terrane.

The main references on the geology and metallogenesis of the belt are Batjargal and others (1997), Mineral Resources (Metals) Map of China (1992), Editorial Committee of the Discovery History of Mineral deposits of China, Inner Mongolia (1996a), and Tomurtogoo and others (1999).

Khartolgoi Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (fig. 10) (Khasin, 1977; Jargalsaihan and others, 1996; D. Dorjgotov, written commun., 1990) consists of Pb-Ag veins and lenticular bodies in Proterozoic metamorphic rock intruded by Triassic granitoid. Bodies have dimensions of 100 by 400 to 2 to 29 by120 meters. Wallrock hydrothermal alteration consists of carbonate and silica alteration. Ore minerals are galena, pyrite, stibnite, arsenopyrite, and Ag minerals. Major gangue minerals are chalchedony, siderite, quartz, and calcite. The deposit is large and has an average grade of 1.8 to 13.4 percent Pb and 2.6 percent Sb. The deposit has a resource of 60,000 tonnes Pb, 30,000 tonnes Sb, and 138 tonnes Ag.

Biluut Ag-Pb Epithermal-Vein Deposit

This deposit (Yakovlev, 1977) and other occurrences in the Biluutiin district are located in the western margin of the belt in a zone with quartz veins containing galena, pyrite, and chalcopyrite. The zone occurs along a east-northeast-striking fault that cuts Silurian sandstone and is closely spatially related to quartz porphyry dikes that also contain ore minerals. Some occurrences also contain anglesite and cerussite and are hosted in Proterozoic carbonate and Silurian sedimentary rocks, and in Devonian granitoid.

Ulaan Uul District

This district (Yakovlev, 1977) occurs in south of Dalanzadgad city and contains Hartolgoi and Hormorit carbonate-hosted Ag-Pb deposits and related occurrences. The bedrock is Proterozoic marble, Carboniferous granodiorite and granite, Permian sandstone and shale, Late Triassic through Early Jurassic granite stocks, and Late Cretaceous basalt (Yakovlev, 1977). The deposits and occurrences are controlled by the east-northeast-striking Tsagaantolgoi fault that bounds the Hashaat Tsagaan Uul and Sulinheer terranes.

Hartolgoi Carbonate-Hosted Ag-Pb Deposit

The deposit (Yakovlev, 1977) is hosted in Proteozoic marble that is thrust over a Carboniferous granitoid pluton composed of gabbro, diorite, granodiorite, granosyenite, and granite. Also occurring close to the deposit are extensive Late Triassic and Early Jurassic(?) stocks and dikes of monzonite, quartz monzonite, and quartz-porphyry (Yakovlev, 1977). The deposit is mainly hosted in marble and, to a lesser degree, in monzonite and quartz porphyry. Individual bodies occur along a major north-northwest-striking, north-dipping thrust and parallel faults, and also in northwest-striking, steeply-dipping faults associated with the major thrust. Ore minerals occur mainly in thrust faults and veins in steep-dipping faults. Ore mineral assemblagess are siderite-sulfide, massive sulfide, and sulfide-magnetite. Main sulfides are pyrite, galena, and arsenopyrite. In addition to high Pb are high contents of Ag, Sb, As, Cd, Cu, and Zn. The deposit is intensely oxidized and leached on the surface. In addition to the Hartolgoi deposit, extensive Fe-oxides zones occur along the Tsagaantolgoi fault and branches.

Harmorit Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This polymetallic deposit (Khasin, 1977; Yakovlev, 1977) is hosted along a fault in Permian sandstone and shale that are intruded by a Late Triassic through Early Jurassic granite porphyry stock that also hosts a Sn vein and greisen deposit. Diabase and diabase porphyry dikes are extensive and are closely related to the polymetallic veins. Cassiterite-quartz veins and cassiterite-topoz-fluorite greisens occur in the granite porphyry stock and in adjacent, contact-metamorphosed Permian sandstone and shale. Polymetallic veins are altered to sericite, chlorite, and limonite, and contain pyrite, arsenopyrite, galena, and chalcopyrite. The veins occur in Permian shale, mostly to the southwest of the granite porphyry stock. Gangue minerals are quartz, feldspar, and calcite. The polymetallic veins, diabase, and diabase porphyry dikes intrude the granite porphyry stock and related Sn vein and greisen. Pb grade ranges from 0.1 to 11 percent at the surface. Khasin (1977) and Yakovlev (1977) interpret that the polymetallic veins are closely related to the granite-porphyry stock and related Sn vein and greisen deposits, but formed in separate stages. This study interprets that polymetallic veins are closely related to diabase and diabase porphyry dikes, and are younger than granite porphyry stock and associated Sn deposits.

Carbonate-Hosted Hg-Sb Deposits

Various carbonate-hosted Sb (Au, Ag, As) deposits and occurrences, as at Zuun Togoo Uul and Baruuntogoo Uul, are hosted in Carboniferous limestone that is thrust over Permian sedimentary rock. The major ore mineral is stibnite. The deposits consist of thin veins with stibnite, quartz, and carbonate that are as much as 10 cm wide and form a stockwork in limestone. The occurrences contain high Au, Ag, and As. Diabase dikes are widespread.

Zuun Togoo Uul Carbonate-Hosted Hg-Sb Deposit

This deposit (A. Gotovsuren and others, written commun., 1995) has a surface area of 7 km^2 and is hosted in Carboniferous limestone thrusted over Permian volcanic and sedimentary rock and serpentenitized ultramafic rock that occur along a sub-latitudinal fault zone. The rocks are intensively altered to stibnite and are cut by a quartz vein stockwork with stibnite and other sulfides. NEE-trending quartz veins and veinlets are also abundant. Limestone is intensively altered to silica. Soil samples show a complex anomaly of Sb, W, Ni, As, Cr, Ba, Ag, Mo, and Au. Grab rock and chip samples contain 0.01 to 1.0 percent and more Sb, 0.01 to 1.0 percent As, 0.001 to 0.01 percent W, 0.005 to 0.02 percent Ni, 0.07 to 0.3 percent Cr, 0.002 to 0.02 percent Co, 0.0005 to 0.001 percent Mo, 0.007 to 1.0 g/t Au and 0.3 to 1.0 g/t Ag. A complex hard rock geochemical anomaly occurs in a 1.2 km^2 area with average grade of 0.12 percent Sb, 0.19 percent As, 0.06 percent Ni, 0.14 percent Cr, and 0.94 to 1.41 percent Sb. The anomaly coincides with the Zuun Togoo uul peak. Ore minerals are stibnite, marcasite, pyrite, chromite, nickeline, native silver, native gold, and Fe oxides and various secondary minerals. The deposit is small and has a resource of 15,000 tonnes Sb and grades as much as 1.41 percent Sb.

Au-Ag Epithermal-Vein Occurrences

Various Au-Ag epithermal vein occurrences are closely related to an Early Cretaceous basalt and rhyolite sequence. The Barjin Uul occurrence occurs along the Sulinheer thrust zone and consists of silicified and brecciated andesite and chalcedony-like quartz veins that are hosted in Cretaceous andesite.

Khoit Barjin Au-Ag Epithermal-Vein Deposit

This occurrence (N. Aizawa and others, written commun., 1996) occurs in the eastern part of an Early Cretaceous siliceous, en-echelon, subvolcanic bodies that arealigned along a sublatitudinal fault zone. The Khoit Barjin hill subvolcanic body is cut by northeast-trending and sublatitudinal quartz veins that are as much as 1.0 meters thick and as much as 50 meters long. A northeast-trending quartz-vein zone contains parallel veins and contains coarse-bladed quartz that is partly fractured, brecciated, and is altered to limonite. A northnortheast-trending breccia zone occurs in siliceous volcanic rock and contains abundant disseminated fine-grained pyrite. Rock chip samples contain as much as 1.0 to -3.0 g/t Au. The average grade is as much as 3.0 g/t Au.

Qiyishan W±Mo±Be Skarn Deposit

This deposit (Editorial Committee of the Discovery History of Mineral Deposits, 1996a) consists of 71 small lensoid bodies that strike east-west and dip 50 to 65^o. The largest body is 700 meters long, extends 300 to 500 meters downdip, and ranges from 80 to 150 meters wide. The bodies occur predominately in the contact-metamorphosed tuffaceous sandstone and andesite in the exocontact zone and partly in the granite intrusion. The bodies consist of veinlets and disseminations and are complicated. The main ore minerals are wolframite, scheelite, colloform Sn-minerals, molybdenite, cassiterite, lepidolite, and quartz. Rb lepidolite occurs. The deposit is closely related to a Jurassic biotite granite and granitic porphyry that was previously interpreted as a Rb-Li granite deposit. The deposit is not mined because of difficulty in ore dressing. The deposit is medium size.

Origin and Tectonic Controls for Hartolgoi-Sulinheer Metallogenic Belt

The part of the belt located in northwestern China is interpreted as having formed during generation of postaccretionary granite during subduction of Pacific Plate under the Eurasian Plate. The part of the belt in southern Mongolia is interpreted as having formed as a result of back arc extension of a late Mesozoic continental-margin arc.

Jiliaolu Metallogenic Belt of Zn-Pb (±Ag, Cu) Skarn, Cu (±Fe, Au, Ag, Mo) Skarn, Granitoid-related Au Vein, Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, and Volcanic-Hosted Au-Base Metal Metasomatite Deposits (Belt JLL) (Northeastern China)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to replacements and granitoids of the Jilin-Liaoning-East Shandong volcanic-plutonic belt that overlies and intrudes the Sino-Korean craton, Jilin-Liaoning-East Shandong terrane. The belt extends northeast from East Jilin Province to the Liaodong and Shandong Peninsulas, and is 600 km long and 100 to 200 km wide. Nearly 20 relatively large volcanic basins overlap the Jilin-Liaoning-East Shandong Archean terrane and Proterozoic-Paleozoic overlap assemblages. The host volcanic rock for the belt include calc-alkalic andesite, dacite, and rhyolite. Plutonic rocks associated with volcanic rock are mainly multiple stages of granite. The belt contains several types of large deposits. The

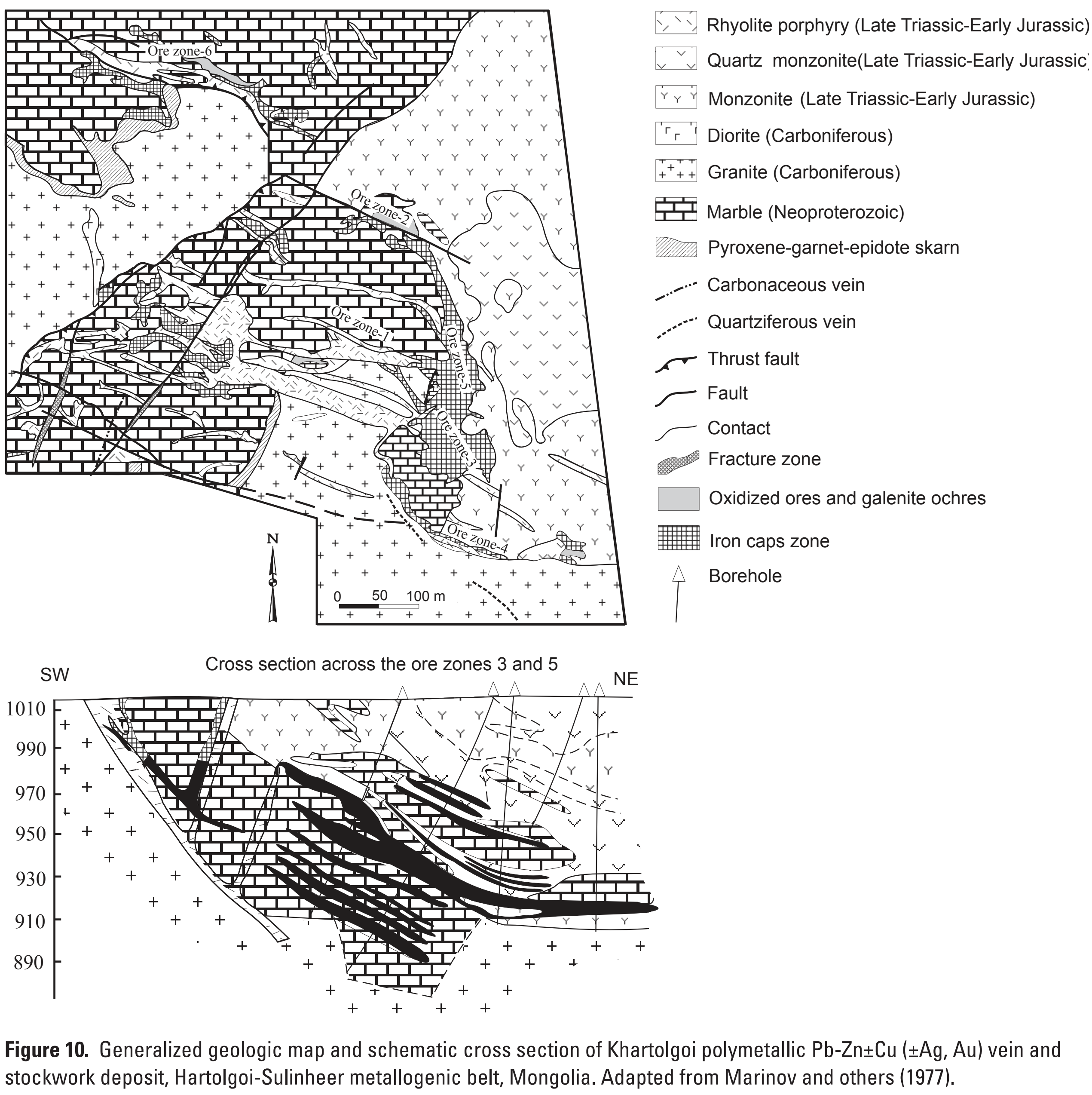


Figure 10. Generalized geologic map and schematic cross section of Khartolgoi polymetallic Pb-Zn±Cu (±Ag, Au) vein and stockwork deposit, Hartolgoi-Sulinheer metallogenic belt, Mongolia. Adapted from Marinov and others (1977).

belt is the important economic resource for Cu, Pb, Zn and Au in China. The significant deposits are at Huanren, Huatong, Ermi, Jiaojia, Liudaojiang, and Xianluwanzhi.

The main references on the geology and metallogenesis of the belt are Yao and others (1990), Rui (1994), and Lin and others (1998).

Huanren Zn-Pb (±Ag, Cu) Skarn Deposit

This deposit (Tu Guangzhi and others, 1989) occurs at the contact zone between limestone and diorite. The skarn occurs in a belt that ranges from 30 to 60 meters wide and 600 to 800 meters long in an external contact zone. The skarn forms several complicated-shaped lenses. The skarn belt and alteration is as much as 200 meters wide. The skarn extends more than 300 meters downdip. Apparent lateral and vertical zoning occurs. The lateral zonation is diorite altered to K feldspar-altered diorite, epidote-altered diorite, epidote skarn, garnet skarn, garnet-diopside skarn, Pb Zn sulfides, marble, and limestone. The vertical zonation is an upper Pb-Zn sulfide zone, a middle Cu and Zn sulfide zone,; and a lower are Fe sulfide zone. The ore minerals occur in masses and disseminations, and are mainly magnetite, hematite, pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, garnet, diopside, calcite, quartz, epidote, and actinolite. The exposed area of the diorite intrusion is 12 km^2. The intrusion consists of diorite, granodiorite, and quartz diorite and is intruded by numerous mafic, intermediate, and siliceous dikes. The diorite is Cretaceous and intrudes Precambrian strata and Jurassic volcanic rock. The deposit is large and has reserves of 495,900 tonnes Zn grading 0.40 percent Zn.

Huatong Cu (±Fe, Au, Ag, Mo) Skarn Deposit

This deposit (Deng and others, 1994) occurs at the contact zone between the marble in the Paleoproterozoic Dashiqiao Formation and a giant phenocryst granite. Both magnesian and calcic skarn occurs. Sulphides occur mainly in calcic skarn but overprint both skarn types. Ore minerals are chalcopyrite, magnetite, pyrrhopyrite, and pyrite. Minor and trace minerals are ludwigite, molybdenite, scheelite, chalcocite, bornite, galena, gold, and arsenopyrite. Gangue minerals are skarn minerals, talc, wollastonite. The deposit shape is very complicated and is controlled by the shape of the intrusion, lithology of host rocks, and fissures in the host rocks. Gold occurs in both skarn types and may comprise a separate resource. The deposit is medium size.

Ermi Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (Feng, 1998) is hosted in a Late Jurassic sedimentary and volcanic sequence, and occurs in the eastern part of a quartz diorite intrusion that formed in a Mesozoic volcanic basin during the Yanshan orogeny. The deposit mainly occurs in the inner and outer contact zone of a granite porphyry intrusion, partly in the contact zone of quartz diorite intrusion, and in andesite. About 8,000 veins are recognized and are concentrated around quartz diorite and granite porphyry in an arc. The economic deposits are divided into gently-dipping and steeply dipping arcuate fractures with massive ore minerals, and steeply-dipping lenses. The ore minerals are chalcopyrite, pyrrhotite, sphalerite, marcasite, pyrite, galena, chalcocite, magnetit, and bismuthine. Gangue minerals are quartz and calcite along with minor sericite, kaolinite, and chlorite. Cu mainly occurs in chalcopyrite. The ore minerals display idiomorphic-hypidiomorphic, porphyritic, and metasomatic textures. The ore minerals occur in masses, bands, disseminations, breccia, veins, stockworks, and colloidal masses. The main ore assemblages are chalcopyrite-marcasite, Cu-bearing magnetite, tourmaline, and chalcopyrite-pyrrhotite-arsenopyrite. Main alteration minerals are silica, tourmalinie, chlorite, carbonate, pyrite, chalcopyrite, kaolinite, and sericite. Vertical and horizontal zoning occurs in the deposit. The deposit is medium size.

Jiaojia Granitoid-Related Vein Au Deposit

This deposit (Wei and Lu, 1994; Sun and others, 1995) consists of tabular zones in the Mesozoic Yanshanian Linglong granite that intrudes gneiss and amphibolite of the Archean Jiaodong group. Pyrite is the dominant ore mineral with lesser chalcopyrite, sphalerite, galena, gold, and electrum. Gold occurs in altered and fractured rock in networks and disseminations. Extensive alterations are K-feldspar, sericite, silica, beresite, and carbonate alterations. The deposit is controlled by the Jiaojia-Xincheng fracture zone and the main deposits parallels the fracture. The largest part of the deposit is as much as 800 meters long and 70 meters wide, and extends downdip more than 1,000 meters. Four mineralizing stages are recognized. The mineralizing temperatures range from 150 to 450°C and pressures range from 60 to 120 MPa. The deposit occurs in the western part of the Jiaodong Peninsula. The deposit is large and has reserves of 60 tonnes of ore grading: 5 to 8 g/t Au.

Liujiapuzhi Volcanic-Hosted Au-Base Metal Metasomatite Deposit

This deposit (Wu, 1995) is hosted in the limestone in the Neoproterozoic, Cambrian, and Ordovician Wanlong and Badaojiang Formations. The deposit occurs in various branches, dikes and veins of granite, diorite, diorite porphyry, quartz diorite porphyry, and syenite porphyry. The deposits are controlled by faults in a steeply-dipping, quartz diorite porphyry intrusion. Sulphide minerals comprise more than 50 percent deposit minerals. The ore minerals occur in masses and disseminations. The main ore minerals are pyrite, galena, sphalerite, and chalcopyrite, and minor hessite and gold. Gangue minerals are quartz and calcite. Alterations are silica, sericite, pyrite, carbonate, epidote, and zeolite. The deposit is medium size.

Origin and Tectonic Controls for Jiliaolu Metallogenic Belt

The belt is interpreted as having formed during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic Plate beneath Eurasian Plate. The metallogenic belt occurs in about twenty relatively large volcanic basins and east of the famous Tanlu fault zone along a series of northeast-trending regional faults. The volcanic and plutonic rocks hosting the belt are interpreted as having formed during back-arc extension (Rui, 1994). The alkalinity, REE, and lithophyle content of volcanic rock in the belt are slightly lower than those of the Daxinganling volcanic belt, but are slightly higher than those of interplate continental volcanic rock. The north-northeast-trending, strike-slip faults, such as the Tanlu fault zone that occurs along the coast, are an important control (Lin Qiang and others, 1998). The metallogenic belt contains several very important districts. The belt contains more than 200 granitoid-related vein Au deposits in a district of 23,000 km^2, some large and superlarge, that comprise one quarter of proven Au reserve in China. In addition, the belt contains Zn-Pb (±Ag, Cu) skarn and volcanic rock related polymetallic-vein deposits in the Shandong Peninsula. Debate continues about why so much Au was concentrated in a limited area (Yao and others, 1990).

Kitakami Metallogenic Belt of Cu (± Fe, Au, Mo) Skarn and Granitoid-Related Au-Vein Deposits (Belt Kit) (Japan)

This Early Cretaceous (Aptian through Albian) metallogenic belt is related to replacements in the Cretaceous and Paleogene Hiroshima granitic belt (too small to show on the summary geodynamics map) that intrudes the South Kitakami and Mino-Tamba-Chichibu terranes. The belt occurs in the Kitakami Mountains and eastern Abukuma Mountains in the eastern part of northeast Japan, trends north-south for more than 350 km, and has a maximum width of 70 km. The rocks units in the Kitakami Mountains are divided into the North Kitakami and South Kitakami provinces. The North Kitakami province consists of a Jurassic accretionary complex and is a part of the Mino-Tamba-Chichibu terrane. The South Kitakami province consists of Paleozoic granite, sedimentary rock, and andesite. These units are intruded by a Cretaceous granitoid, part of the Hiroshima granite belt. K-Ar isotopic ages of the granitoid in the Kitakami Mountains range from 120 to 110 Ma, and the granitoid forms about 25 percent of the surface exposure. The granitoids consist mainly of I-type tonalite, granodiorite, and granite. The major deposit types in the Kitakami metallogenic belt are Cu skarn and Au-Ag-vein deposits, and the major deposit is the Kamaishi Cu-Fe skarn deposit that formed during intrusion of Cretaceous granite along with the Au-Ag-vein deposits that frequently contain scheelite. Mo skarn and-vein deposits occur in the eastern margin of the North Kitakami province, although those deposits are not described in the database. Tsuboya and others (1956) previously defined the Kitakami metallogenic province and Abukuma metallogenic province; however, this study limits the Kitakami metallogenic belt to the eastern margin of the Abukuma province. The Kitakmi metallogenic belt is interpreted as the eastern extension of the Outer Zone. The major mines are at Kamaishi and Oya.

The main references on the geology and metallogenesis of the belt are Ishihara (1978), and Ishihara and others (1992).

Kamaishi Cu (±Fe, Au, Ag, Mo) Skarn Mine

This mine (fig. 11) (Ishihara and others, 1992) consists of 12 skarns bodies that occur in irregular masses. The main ore body is 660 meters long, 100 meters wide, and 450 meters deep. The main ore minerals are magnetite and chalcopyrite. Minor minerals are cubanite, pentlandite, pyrrhotite, pyrite, sphlerite, hematite, arsenopyrite, scheelite, and molybdenite. Skarn minerals are hedenbergite, actinolite, diopside, garnet, and epidote. Host rocks are Paleozoic limestone, slate, and sandstone, and Cretaceous granodiorite. The mine is related to a Cretaceous granodiorite with a K-Ar isotopic age 119 Ma. The deposit was discovered in 1727. Mining was started by the government 1874 and completed in 1993. The mine is medium size with production of 200,000 tonnes Cu and 14,000,000 tonnes Fe grading 30.9 percent Fe, and 0.63 percent Cu for copper-iron ore.

Oya Granitoid-Related Au-Vein Mine

This mine (Geological Survey of Japan, 1955; Mining and Metallurgical Institute of Japan, 1968) consists of north-south striking veins with eight main vein systems. Veins occur in an area 3 km by 1.5 km. The main vein is 700 meters long and has an average thickness of 0.3 meters. The main ore minerals are arsenopyrite, pyrrhotite, pyrite, sphalerite, chalcopyrite, native gold, galena, argentite, tetradymite, and molybdenite. Gangue minerals are mainly quartz, calcite, hedenbergite, actinolite, epidote, and sericite. Wallrocks are alteted to quartz and calcite. Host rocks are Jurassic sandstone, slate, and granodiorite. Veins are contact metamorphosed. Veins are interpreted as having formed during intrusion of Cretaceous granodiorite. The deposit is small and has prodeuced 15.6 tonnes Au and 2.8 tonnes Ag. The average grades are 20 to 30 g/t Au and 2 to 8 g/t Ag.

Origin and Tectonic Controls for Kitakami Metallogenic Belt

The belt is interpreted as having formed during intrusion of granitoids that were part of a continental-margin arc with abundant siliceous magmatism. Ishihara (1978) defined the western W-Cu province and eastern Mo-Pb-Zn province in the Kitakami Mountains. The Mo-Pb-Zn province included the Taro Kuroko-type Pb-Zn deposit that is excluded from the Kitakami belt in this study. Granitoids in the Kitakami metallogenic belt are characteristically magnetite-series (Ishihara and others, 1992).

Kondyor-Feklistov Metallogenic Belt of Zoned Mafic-Ultramafic Cr-PGE Deposits (Belt KD) (Russia, Far East)

This Early Cretaceous metallogenic belt is related to several zoned mafic-ultramafic intrusions that occur along a northwest-trending, major, buried fault that cuts the southeastern Stanovoy block of the North Asian craton and the northeastern part of Galam terrane. The belt contains the large zoned mafic-ultramafic Kondyor Cr-PGE deposit and the Chad (Mokhovoy) and Feklistov (Shantar Islands) deposit. The major deposit is at Kondyor.

The main references on the geology and metallogenesis of the belt are Marakushev and others (1990), A.I. Khanchuk, written commun (1994), and Dalrymple and others (1995).

Kondyor Zoned Mafic-Ultramafic Cr-PGE Deposit

This deposit (fig. 12) (Marakushev and others, 1990; Bakulin and others, 1999) is hosted in the Kondyor pluton and consists of two types: (1) short lenses, veins, and disseminations that are about 2 to 50 meters long, range up to a few meters thick, and occur in the central part of a dunite stock; and (2) oval-shaped, roughly equidimensional metasomatite with dimensions of about 200 by 300 meters. The first type contains PGE minerals in intergrowths with chromite and olivine, and in small inclusions. Isoferro Pt is the major PGE mineral. The second type consists of PGE minerals that form intergrowths with magnetite, pyroxene, and rarely with metasomatic phlogopite, chrome diopside, and magnetite. This type of deposit is intruded by alkalic igneous veins and dikes including nepheline syenite, lujavrite, ijolite, and urtite. In addition to isoferro Pt and tetraferro Pt, the deposit contains as much as 5 to 8 percent sulfide and As minerals. Controversy exists about the age and tectonic environment for the host mafic and ultramafic rock. The host rocks were originally interpreted as an integral part of the Neoproterozoic and older cratonal rock of the Stanovoy block of the North Asian craton. However, A.I. Khanchuk (written commun, 1994) interprets the mafic and ultramafic rock as Jurassic because the intrusions are similar in composition to other Jurassic plutons of the Ariadny igneous belt. This igneous belt is interpreted as having formed possibly immediately before Late Jurassic accretion in the region, or possibly in the mid-Cretaceous. Unpublished K-Ar isotopic ages for the zoned mafic-ultramafic intrusions in the Kondyor metallogenic belt range from 110 to 160 Ma (A.M. Lennikov, written commun., 1993). An Ar-Ar isotopic age of 127 Ma (Early Cretaceous) was recently obtained for the alkalic mafic and ultramafic igneous rocks at Ingagli (Dalrymple and others, 1995) that may be part of the same igneous belt that hosts the Kondyor metallogenic belt. The deposit is medium size and has about 13.5 tonnes PGE produced from 1984 to 1993. Annual production of about 2.5 to 3.0 tonnes PGE has occurred since 1993. In 1999, approximately 2.9 tonnes PGE were produced.

Origin and Tectonic Controls for Kondyor-Feklistov Metallogenic Belt

The belt is interpreted as having formed during interplate intrusion of mafic-ultramafic plutons along a major fault that formed along the North Asian cratonal margin during collision and accretion of outboard terranes during the Early Cretaceous.

Kular Metallogenic Belt of Au in Shear-Zone and Quartz-Vein, Granitoid-Related Au-Vein, and Sn-W Greisen, Stockwork, and Quartz-Vein Deposits (Belt KU) (Russia, Verkhoyansk-Kolyma Region)

This Late Jurassic and Early Neocomian metallogenic belt is related to veins and replacements in the Kular-Nera terrane. The belt occurs on the northwestern flank of the Kular-Nera (slate belt) terrane, extends northeastward for 150 km, and ranges from 30 to 40 km wide. The belt is hosted in Permian through Triasssic deep-marine black slate that is intruded by granite with a $^{40}Ar/^{39}Ar$ of 103 Ma. Early studies interpreted the belt as forming in an uplifted fault-fold complex with simple box folds. Subsequent, detailed structural studies revealed a complex fold and thrust zone with numerous refolded, recumbent isoclines. The host rocks are metamorphosed to greenschist facies (muscovite-chlorite and biotite subfacies). The metamorphic Au in shear zone and quartz-vein deposits in the Solur, Ulakhan-Sis, and Magyl-Khayata districts occur along crests of antiforms formed in Permian slate. The mineral assemblage is quartz, carbonate (ankerite and calcite), chlorite, muscovite, and albite. An early pyrite-arsenopyrite assemblage is succeeded by a productive Au pyrrhotite-chalcopyrite-sphalerite-galena assemblage. The major deposits are at Emelyanovskoye, Novoe, and the Tirekhtyak district (Nagornoe, Podgornoe, and Poputnoe).

The main references on the geology and metallogenesis of the belt are Fridovsky (1996) and Parfenov and others (1999).

Emelyanovskoye Au in Shear Zone and Quartz-Vein Deposit

This deposit (Parfenov and others, 1999) consists of concordant, stratabound saddle, lenticular, and sheet veins. High density veins and veinlets form concordant stockworks. Most of the veins and veinlets exhibit parallel cleavage and some occur in S-shaped shears and fractures. Up and down-dip, the veinlets grade into concordant veins or are truncated by decollement faults. The deposits extend as much as a few hundreds of meters long, are as much as 1.5 meters thick, and consist mainly of quartz and carbonate, along with subordinate pyrite, galena, sphalerite, Au, pyrrhotite, arsenopyrite, fahl, and chalcopyrite. Gold grains are 3 to 4 mm long.

Novoe Granitoid-Related Au-Vein Deposit

This deposit (Ivensen and others, 1975) consists of steeply-dipping, cross-cutting shear zones and lenticular veins that occur in tension gashes. The shear zones strike northeast and dip northwest or southeast at 15-60°, commonly are as much as several meters thick, locally to 10 to 12 meters thick, and as much as 1.5 km long. The lenticular veins range from 0.1 to 2 meters thick and as much as 50 to 100 meters long. Major minerals are quartz, wolframite, arsenopyrite, carbonate, cassiterite, and gold. The deposit hosted in Late Permian sandstone and shale near the dome of the Central-Kular anticline. The deposit is small with as much as 0.2 to 6.8 percent $W0_3$, 0.03 to 0.16 percent Sn, and 0.5 to 5 percent As.

Tirekhtyak District (Nagornoe, Podgornoe, Poputnoe) Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Ivensen and others, 1975) consists of veins of tourmaline-quartz and cassiterite-scheelite-quartz; and cassiterite stringers. The major minerals are beryl, pyrrhotite, arsenopyrite, muscovite, sphalerite, and galena. Veins and stringers range from 0.01-1.2 meters thick and as much as 100 meters long. Veins and stringers strike northeast and occur near the contact of the Early Cretaceous Tirekhtyak granite

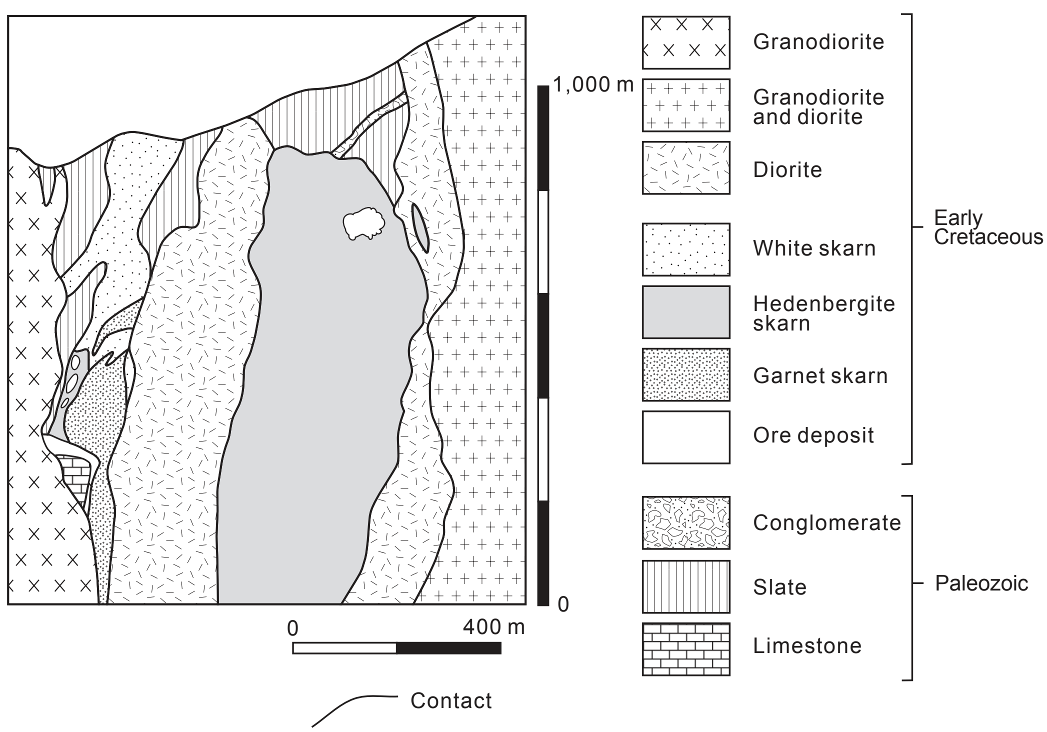


Figure 11. Schematic cross section of Kamaishi Cu (±Fe, Au, Ag, Mo) Skarn Mine, Kitakami metallogenic belt, Japan. Adapted from Kaneda and others (1978) and Nittetsu Mining Co. (1981).

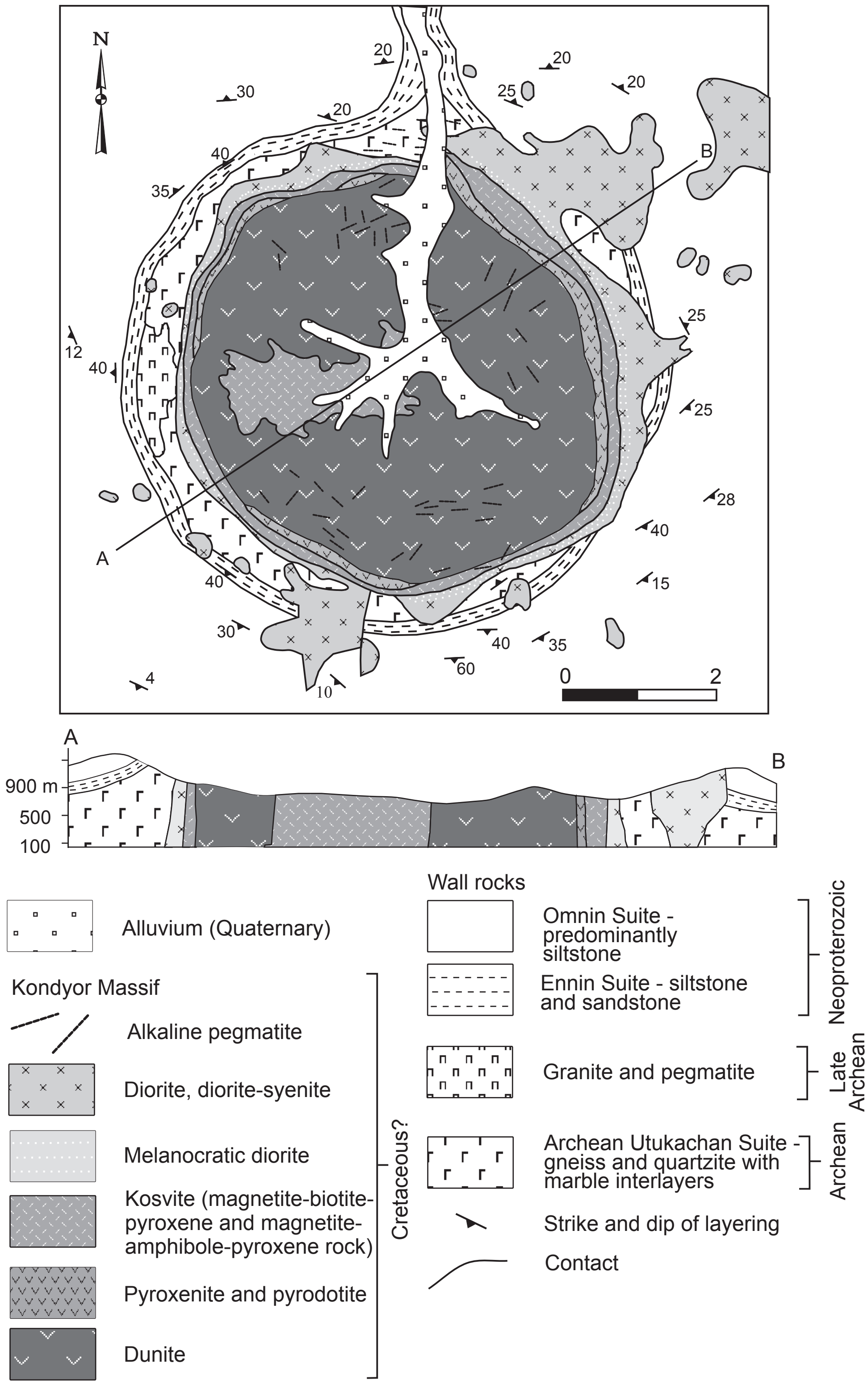


Figure 12. Generalized geologic map and schematic cross section of Kondyor zoned-mafic-ultramafic Cr-PGE deposit, Kondyor-Feklistov metallogenic belt, Russian Southeast. Adapted from G.V. Andreev, A.A. El'yanov, and A.N. Mil'to, written commun. (1974).

pluton. Veins and stringers intrude aplite dikes and granites and adjacent Triassic clastic rock that is contact metamorphosed. The deposit is small with as much as 5 percent S, 1 percent $W0_3$, 0.6 percent Pb, and 1 percent As.

Origin and Tectonic Controls for Kular Metallogenic Belt

The belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane to the North Asia craton and associated regional metamorphism in Late Jurassic through early Neocomian. The belt occurs on the northwestern flank of the Kular-Nera slate belt.

Nerchinsky Metallogenic Belt of Granitoid-Related Au-Vein, W-Mo-Be Greisen, Stockwork, and Quartz-Vein, and Fluorspar-Vein Deposits (Belt NC) (Russia, Eastern Transbaikalia)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to granitoids and volcanic complexes related to Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that intrudes and overlaps the Western Stanovoy terrane, Barguzin-Vitim granitoid belt, and the Selenga and Transbaikalia sedimentary and volcanic-plutonic belts. The northeast-to east-trending belt occurs in the Chersky Range in the watershed of the Uruljunguy and Nercha Rivers and the upper Olekma River. The belt is 1,025 km long and 85 km wide. The host Mesozoic intrusions consist of coarse-, medium-, and fine-grained biotitic granite porphyry in the Amanan and Amudzhikan complexes that are intruded by numerous granite porphyry, andesite, diabase, microdiorite, pegmatite, and fine-grained granite dikes. The major deposits are at Darasun, Teremkinskoye, Talatuyskoye, Muoklokanskoye, and Usuglinskoye.

The major deposits in the belt are (1) major granitoid-related Au vein type deposits at Darasun, Teremkinskoye, and Talatuyskoye, and numerous small deposits); (2) W-Mo-Be greisen, stockwork, and quartz-vein deposits at Muoklokan W and elsewhere; and (3) fluorspar-vein deposits at Usuglinskoye, Uluntuy, and elsewhere. All deposits contain numerous components formed in multiple stages. The Au deposits occur in zoned volcanic-tectonic structures (Seminsky and others, 1987; Zorina, 1993; Zorina and others, 1989), and are related to Mesozoic subvolcanic bodies of mainly granodiorite porphyry and rare granite and diorite porphyry (Tauson and others, 1987). The vein form of deposits and a distinct relationship to local extrusive domes and volcanic basins structures is common. Also occurring in the belt are Wo-Mo hydrothermal deposits and W hubnerite-sulfide deposits in quartz veins, vein zones, and stockworks that are related to Mesozoic granitoid plutons. The fluorite deposits occur in basins filled with Late Jurassic and Early Cretaceous sedimentary and volcanic rock and occur near margins of widespread Late Jurassic granodiorite and granosyenite porphyry plutons that contain numerous Paleoproterozoic metamorphic-rock xenoliths with granitic gneiss, schist, and migmatite. The deposits consist of quartz-fluorite veins (Yakzhin, 1962; Kotov, 1995). The belt is prospective for undiscovered Au,W, fluorite, and associated deposits.

The main references on the geology and metallogenesis of the belt are Seminsky and others (1987), Zorina and others (1989), Zorina (1993), and Kotov (1995).

Darasunskoye Granitoid-Related Au-Vein Deposit

This deposit (Zvyagin and Sizikov, 1971) consists of more thanb 120 steeply-dipping quartz-sulfide veins that extend along strike for 1.0-1.2 km. The zone of veins ranges from 100 to 1,000 meters thick, and individual veins vary from 5 to 20 cm thick. A zone of wallrock marginal to the veins is about 0.6 to 1.5 meters thick and contains disseminated sulfides. The ore minerals comprise the complex Darasun sulfide-sulfosalt type with as much as 40 to 60 percent sulfides. The main ore minerals are pyrite, arsenopyrite, chalcopyrite, pyrrhotite, galena, sphalerite, Pb, Cu, Ag, Bi, As, and Sb sulfosalts, tellurides, native gold, quartz, carbonates, and tourmaline. The principal economic gold-bearing mineral assemblages are chalcopyrite-gray ore, chalcopyrite-pyrrhotite, pyrite-arsenopyrite, and sphalerite-galena. Gold occurs in arsenopyrite, pyrite, chalcopyrite, pyrrhotite, and gray ore, and is finely dispersed. The deposit ocurs along the Mongol-Okhotsk suture and is hosted in a middle and Late Cretacous granodiorite-porphyry that intrudes a volcanic dome. The porphyry is accompanied by dikes of diorite and granodiorite porphyry, and explosive breccia. The deposit occurs both in the intrusion and in the enclosing early Paleozoic gabbro, middle Paleozoic granodiorite, and in late Paleozoic and Triassic granite. Host rocks are altered to propylite. The deposit is large with grades up to 300 ppm Au and averages 6.5 ppm Au.

Muoklakanskoye W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Sizykh and others, 1985; Skursky, 1996) consists of two subparallel zones that host 30 steeply dipping quartz-hubnerite-sulfide veins (with dimensions of 300 to 600 by 0.5 by 2.0 meters). The first zone contains a series veinlets with about 1.0 percent WO_3, as much as 1,400 ppm Ag and to 3.4 ppm Au. The second zone contains three large quartz veins and several small ones and grades 0.45 percent WO_3. The ore minerals are quartz, hubnerite, muscovite, native gold, molybdenite, sphalerite, galena, chalcopyrite, and calcite. Host rocks are altered to K-feldspar, beresite, and silica. The deposit is hosted in Archean granitic gneiss, plagiogneiss, amphibolite, and diopside quartzite along the exocontact of the Middle and Late Jurassic Dzhekdachinsky granite massif that intrudes the Archean Muoklakan block. The deposit is small and has an average grade of 0.8 percent WO_3.

Usuglinskoye Fluorspar-Vein Deposit

This deposit (Yakzhin, 1962; Kotov, 1995) is hosted in seven fault zones that strike northwest and occur in an area from 1-3 km wide. The zones contain extensive, steeply-dipping veins that extend from 800 to 3000 meters, range from 0.3-1.8 meters thick, and extend to a depth of 100 to -400 meters. The deposits occur in pillars that range from 8 to 45 meters thick. The ore minerals are fluorite and quartz (90 percent), minor kaolinite, and rare dikkite, narkite, hydromicas, barite, calcite, pyrite, apatite, rutile, sphene, calcite, and sericite. The deposits occur in masses, layers, breccia, and veinlets. The vein texture is symmetrically banded with a variable color for fluorite. The main mineral assemblage is quartz-fluorite. Sulfur grade is about about 0.12 percent with 0.01 to 0.16 percent P_2O_5. The deposit is hosted in Neoproterozoic and early Paleozoic granite and granodiorite along the northern edge of a late Mesozoic basin filled with Middle Jurassic through Early Cretaceous terrigenous, volcanic, and sedimentary rock. The deposit is medium size and has resources of 2.9 million tonnes CaF_2 grading 64 percent CaF_2.

Origin and Tectonic Controls for Nerchinsky Metallogenic Belt

The belt is interpreted as being related to magmatism along transtensional zones along transform microplate boundaries and within plate (plume) environment. The belt is related to granitoids in the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt.

North Bureya Metallogenic Belt of Au-Ag Epithermal-Vein and Granitoid-Related Au-Vein Deposits (Belt NB) (Russia, Far East)

This Early Cretaceous metallogenic belt is related to veins and granitoids in Early Cretaceous felsic and intermediate volcanic rock in the Umlekam-Ogodzhin volcanic-plutonic belt that intrudes and overlaps the Malokhingansk terrane, Turan terrane of the Bureya superterrane, Gonzha terrane, Nora-Sukhotin-Duobaoshan terrane, and Tukuringra-Dzhagdy terrane. The host volcanic rock extends along the boundary between the Tukuringra-Dzhagdi terrane and the North Asia craton. Several poorly-explored Carlin type deposits that consist of layers of disseminated gold in jasper beds, occur in the area, but are unexplored. Numerous related placer Au mines occur in the metallogenic belt. The Au in the placer mines is interpreted as being mainly derived from Au-bearing quartz veins in Late Jurassic through Early Cretaceous sedimentary and volcanic rock. The major Au-Ag epithermal-vein deposit is Pokrovskoe and granitoid-related Au-vein deposit is at Pioneer.

The main references on the geology and metallogenesis of the belt are Mel'nikov (1984), Khomich (1990), V.D. Mel'nikov, written commun. (1993), and Khanchuk and others (1996).\

Pokrovskoe Au-Ag Epithermal-Vein Deposit

This deposit (fig. 13) (Mel'nikov, 1984; Khomich, 1990; V.D. Mel'nikov, written commun., 1993) is hosted in a sequence of Early Cretaceous andesite, dacite andesite, and tuff that overlies a Jurassic coal-bearing sequence of sandstone, siltstone, and argillite. The deposits consist of gently-dipping quartz veins and zones of hydrothermal alteration. The main alterations are propylitic (albite, sericite, calcite, chlorite, and pyrite), berezite (quartz, sericite, and hydromica), and argillite (kaolinite, montmorillonite, hydromica, carbonate, quartz, and pyrite). The largest part of the deposit is a gently-dipping zone of altered rock that occurs near the lower contact of an andesite sequence with a granodiorite porphyry sill. Hydrothermally altered rock consists of quartz (25 to 85 percent), carbonate (2 to 5 percent), hydromica (5 to 12 percent), adularia (as much as 5 percent), kaolinite (5 to 7 percent), and sulfides (less than 1 percent, mostly pyrite). Gold is fine-grained (0.0005 to 0.032 mm), is associated with quartz, and is rarely or not associated with sulfides. Silver grains (0.002 to 0.016 mm) occur in Fe-hydroxide alteration. The deposit is interpreted as having formed in the Early Cretaceous. The deposit is medium size and has reserves of 15 million tonnes grading 4.4 g/t Au and 15 g/t Ag.

Pioneer Granitoid-Related Au-Vein Deposit

This deposit (N.E. Malyamin and V.E. Bochkareva, written commun., 1990; V.N. Akatkin, written commun., 1991) occurs near the margin of an Early Cretaceous granodiorite intrusion and in adjacent country rock that consists of contact-metamorphosed Jurassic sandstone and siltstone. The deposit consists of veins of quartz, quartz-feldspar, quartz-tourmaline, and quartz-carbonate, and altered zones of quartz, K-feldspar, sericite, and albite. The veins and zones vary from 1 to 50 meters thick. The deposit is large, low grade, and has no visible boundaries. The extent of deposit is determined by geochemical sampling. Both gold and Au-sulfide ores occur. The Au ore consists of quartz-adularia-carbonate veins, and the Au-sulfide ore consists of quartz veins with pyrite, galena, stibinite, and Ag-sulfosalts. The deposit is small and has reserves of 17.1 tonnes Au and 20.1 tonnes Ag, and an average grade of 2.7 g/t Au and 5.2 g/t Ag.

Origin and Tectonic Controls for North Bureya Metallogenic Belt

The belt is interpreted as having formed during formation of Umlekan-Ogodzhin continental-margin arc that formed during subduction of part of ancestral the Pacific Ocean Plate. The arc is now preserved on the Bureya-Jiamusi superterrane and Badzhal collage (Khabarovsk, and Samarka terranes). This tectonic pairing is based on (1) occurrence of the subduction-zone terranes outboard (oceanward) of the Umlekan-Ogodzhin arc; (2) formation of melange structures during the Jurassic and Early Cretaceous; and (3) where not disrupted by extensive Cretaceous and Early Cenozpic movement along the Central Sihote-Aline strike-slip fault, dipping of melange structures and bounding faults toward and beneath the igneous units of the arc. Subduction is generally interpreted as ending in the Early Cretaceous when extensive sinsitral faulting occurred along the subduction zone.

North Jilin Metallogenic Belt of Zn-Pb (±Ag, Cu) Skarn, Granitoid-Related Au-Vein, Porphyry Au, Porphyry Cu (±Au), Porphyry Mo (±W, Bi), Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite, Au-Ag Epithermal-Vein, and Fluorspar-Vein Deposits (Belt NJ) (Northeastern China)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to replacements and granitoids that intrude the Late Carboniferous through Permian North Margin plutonic belt of North China Platform that in turn intrudes the Laoling terrane and Zhangguangcailing superterrane in the Sino-Korea craton in the North Jilin Province. The deposit-related igneous rocks formed during multiple stages of volcanism and plutonism mainly in the Late Jurassic and Cretaceous during central and pipe-like eruptions of intermediate volcanic rock. The major Mesozoic granite intrusions in the area are Early Jurassic granite (I type) and Late Jurassic granite (A type) (Rui, 1994). The metallogenic belt is controlled by the structures along the northern margin of the Sino-Korea craton, and by northeast-, northwest-, and east-west-trending faults. Though irregular, the belt generally trends east-west, and is 500 km long and 50 km wide. The significant deposits are at Tianbaoshan, Haigou, Sanwen, Daheishan, Xiaoxinancha, and Ciweigou.

The main references on the geology and metallogenesis of the belt are Rui (1994) and Lin and others (1998).

Xiaoxinancha Porphyry Cu (±Au) Deposit

This deposit (fig. 14) (Rui, 1994) is located at the intersection of Tianshan-Jilin (Heilongjiang) east-west-trending Paleozioc accretion zone and Circum Pacific Mesozoic tectono-magmatic zone.The oldest exposed strata are the early Paleozoic Qinglong Group, that often occur as xenoliths in late Hercynian granite and diorite and consist of amphibolite, amphibolitic gneiss, biotite schist, graphite schist, andalusite state, sillimanite slate and sandy slate. Early and Late Permian strata are distributed in the adjacent region amd are composed of intermediate-siliceous tuff, volcanic breccia, lava and sandy slate. Jurassic volcanic rock can be seen in the fault basins south and northwest of the deposit. Ingneous intrusives account for more than 60 percent the deposit area, including Hercynian, Indosinian, Yanshannian and Himalayan igneous bodies. The dominant Hercynian intrusives consist of plagioclase granite, biotite-plagioclase granite, gneissic biotite granite, and diorite. The main host rock is Hercynian diorite. During early Yanshannian stage, many kinds of intrusives formed, including diorite, quartz diorite, granite, diorite porphyry, moyite, admallite and granitic porphyry. The intrusives occur as small igneous stocks or dikes of Hercynian granite and Jurassic volcanic rock. Intermediate porphyry, especially diorite porphyry (130.1 Ma) also contains Cu and Au minerals. The deposit is controlled by the intersection of northwest-and north-northeast-striking faults. There are 34 bodies in a north-northwest-trending belt with an area of 2.4 to 1.8 km^2. The bodies are composite vein type, single vein type, network type and veinlets and disseminations. Main deposit minerals are chalcopyrite, pyrite, pyrrhotite, native gold and electrum. Quartz, calcite, sericite, chlorite, epidote, actinolite, and zeolite are gangue minerals. Wallrock alterations include K-feldspar alteration, biotitization, beresite alteration, propylitic alteration and carbonate alteration. The deposit-forming temperatures are 200 to 450ºC. The deposit is large.

Tianbaoshan Zn-Pb (±Ag, Cu) Skarn Deposit

This deposit (Rui, 1994) occurs at the intersection of the the east-west-trending Tianbaoshan-Madida fault and the major northeast-striking Liang Jiang-Tianqiaoling fault. The host rocks are Cambrian and Ordovician amphibolite, chlorite schist interlayered with siliceous marble, Late Carboniferous marble interlayered with biotite slate, chert, and limestone, Late Trisssic rhyolite, andesite, and Late Jurassic mafic and intermediate volcanic rock. Several periods of igneous intrusives occur in the area: (1) early Hercynian gneissoid granite with a U-Pb zircon isochron age of 326.4 Ma; (2) late Hercynian granodiorite with a U-Pb zircon isotopic age of 245.2 Ma; (3) Indosinian porphyritic adamellite and dacite porphyry with a U-Pb zircon isotopic age of 205 Ma; and (4) Yanshannian andesitic porphyry and granite porphyry. The deposit is related to Yanshannian igneous rocks and is controlled by the intersections of northwest-, northeast-, and north-south-trending faults. The skarn occurs in the contact zone of Indosinian and Yanshanian granodioritic porphyries and marble in metavolcanic rock. The main ore minerals are magnetite, galena, sphalerite, and chalcopyrite. Explosive breccia pipe deposits occur in the western part of the Mesozoic Tianbaoshan volcanic basin. Galena, sphalerite, chalcopyrite, and pyrite are the main ore minerals, and alteration minerals are quartz, calcite,

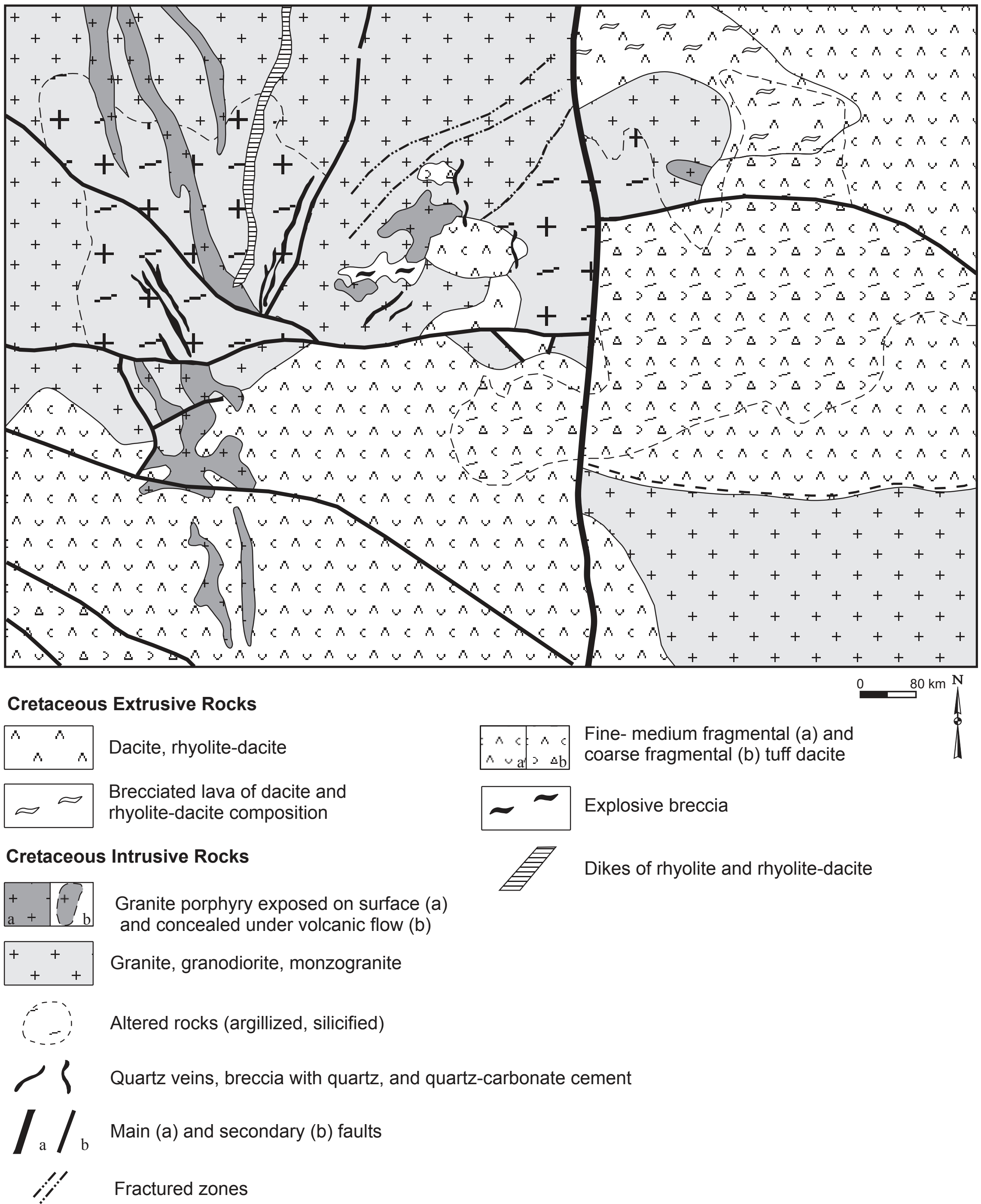


Figure 13. Generalized geologic map of Pokrovskoe Au-Ag epithermal-vein deposit, North Bureya metallogenic belt, Russian Southeast. Adapted from N.I. Novikov and others, written commun., 1987.

epidote, hydromica, and chlorite. The main sulfide depositional temperatures are 210 to 300ºC. The deposit is medium size and has reserves of 123,300 tonnes Pb and 193,900 tonnes Zn. The average grades are 0.52 percent Pb and 1.76 percent Zn.

Sanmen Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (Tian and Shao, 1992) consists of veins, lenses, and stockwork. The main part of the deposit is 1800 meters long. The ore minerals occur in masses, veinlets, and disseminations and consist of native silver, pyrite, galena, sphalerite, argentite, Cu and Sn sulfides, and quartz. Intense host-rock alteration consists of silica, pyrite, and beresite. The host rocks are Cambrian and Ordovician intermediate and siliceous volcanic rock, sedimentary clastic and carbonate rock that is intruded by Jurassic and Cretaceous granitoids. The deposit is controlled by north-northeast-trending faults and fracture zones. The deposit is large and has an average grade of 180 g/t Ag.

Daheishan Porphyry Mo (±W, Bi) Deposit

This deposit (Huan others, 1994) consists of veinlets and disseminations in the Yanshanian plagiogranite that intrudes the highly metamorphosed Variscan granite of the Devonian Hulan group with a K-Ar biotite isotopic age of 354 Ma. The plagiogranite forms an ellipse with a surface area of 8 km^2. Ore mineral is mainly molybdenite with minor pyrite, chalcopyrite, galena, and sphalerite. From central to outward, the important proximal alterations are silica, sericite, kaolinite alterations. The deposit occurs at the intersection between north-northeast-trending Panshi and the east-west-trending Huadian-Shuanghe structural zones that occur in the southeastern part of the Jilin Variscan fold belt near the north margin of Sino-Korean Plate. The deposit is large and has reserves of 1.09 million tonnes of ore grading 0.066 percent Mo.

Ciweigou Au-Ag Epithermal-Vein Deposit

This deposit (Xu and others, 1994; Rui, 1994) occurs along the Yanshannian intracontinental volcanic basin along the southeastern Inner Mongolia-Xinganling Hercynian fold belt. The host rocks are Late Jurassic siliceous, intermediate, and mafic volcanic rock with a Rb-Sr isochron age of 147.5 Ma. The deposit is controlled by circular and radial faults around a maar volcano that occurs at the intersection between east-west-trending major faults and northwest-trending faults. The deposit occurs in veins. Wallrocks display silica, carbonate, sericite, and propylitic alterations. The depositional temperatures range from 180 to 240°C, and pressures from 20 to 1.48 MPa. Ore minerals are pyrite, chalcopyrite, tetrahedrite, sphalerite, galena, electrum, argentite, gold, calaverite, and sylvanite. The deposit is medium size.

Origin and Tectonic Controls for North Jilin Metallogenic Belt

The belt is interpreted as being related to magmatism along transpression zones along transform microplate boundaries and within plate (plume) environment. The volcanic rocks that host part of the deposits are interpreted as having formed during lithosphere extension and are controlled at least partially by the major, north-northeast-trending Tanlu strike-slip fault system. The belt occurs in (1) the northern margin of the Archean Jilin-Liaoning-East Shandong terrane of the Sino-Korea craton; (2) plutonic rocks related to early and late Paleozoic accretions; and (3) postaccretionary Early Triassic, Late Jurassic, and Cretaceous volcanic and plutonic rocks. The deposits in the belt may have formed in multiple stages. Various authors cite different isotopic ages for the same deposit and, therefore, some deposit ages are uncertain. Some deposits probably formed during the Early Jurassic and Late Triassic (Rui, 1994), but most surely formed in the Middle Jurassic and Early Cretaceous. Lin and others (1998) suggested that the volcanism in the area continued from the Late Triassic through post Early Cretaceous with most intense activity in the Middle Jurassic and Early Cretaceous.

North Stanovoy Metallogenic Belt of Granitoid-Related Au-Vein and Au-Ag Epithermal-Vein Deposits (Belt NS) (Russia, Far East)

This Early Cretaceous metallogenic belt is related to granitoids in the Stanovoy granite belt that intrude the Tynda terrane. The deposits generally consist of quartz and quartz-carbonate veins that are spatially related to Jurassic through Early Cretaceous granite and granodiorite that are generally interpreted as having formed in a collisional setting. The one large Au-Ag epithermal-vein deposit is at Bamskoe. Also occurring in the area are numerous related placer Au mines that are some of the largest placer Au mines in the west-central part of the Russian Far East.

The main references on the geology and metallogenesis of the belt are Parfenov (1995) and Sukhov and others (2000).

Bamskoe Granitoid-Related Au-Vein Deposit

This deposit (A.V. Lozhnikov and others, written commun., 1989; Kurnik, 1992) consists of thirty-five zones of listwenite and beresite hydrothermal alteration that occur in granite and gneiss. The altered zones contain eight Au prospects with abundant veins, pods, and small quartz and quartz-carbonate veinlets. Prospects range from 140 to 960 meters long and have an average thickness of about 3 meters. The deposits are related to, and occur around the periphery of an Early Cretaceous subvolcanic rhyolite and rhyodacite stock that intrudes Neoproterozoic granite and biotite-amphibolite gneiss of the Tynda terrane.

Burindinskoe Au-Ag Epithermal-Vein Deposit

This deposit (fig. 15) (V.A. Taranenko, written commun., 1991; G.P. Kovtonyuk, written commun., 1993) occurs in steeply-dipping quartz and quartz-carbonate gold-bearing veins. The veins are as much as 200 meters long and have an average thickness of about 10 meters. The veins are hosted in an Early Cretaceous volcanic sequence overlying the Gonzhinsky terrane of the Burea-Khanka superterrane. The deposit is medium size and has reserves of 6,230 kg gold and 38,200 kg silver grading 9.5 g/t Au and 42.6 g/t Ag.

Origin and Tectonic Controls for North-Stanovoy Metallogenic Belt

The belt is interpreted as having formed during late-stage accretion of the Bureya superterrane to the south with the North Asian craton to the north, during final closure of the Mongol-Okhotsk Ocean. The lode Au and related large placer deposits occur in the southern part of the metallogenic belt, near a major fault between Precambrian gneiss of the Tynda terrane to the north and the Paleozoic rocks of the Tukuringra-Dzhagdi subduction-zone terrane to the

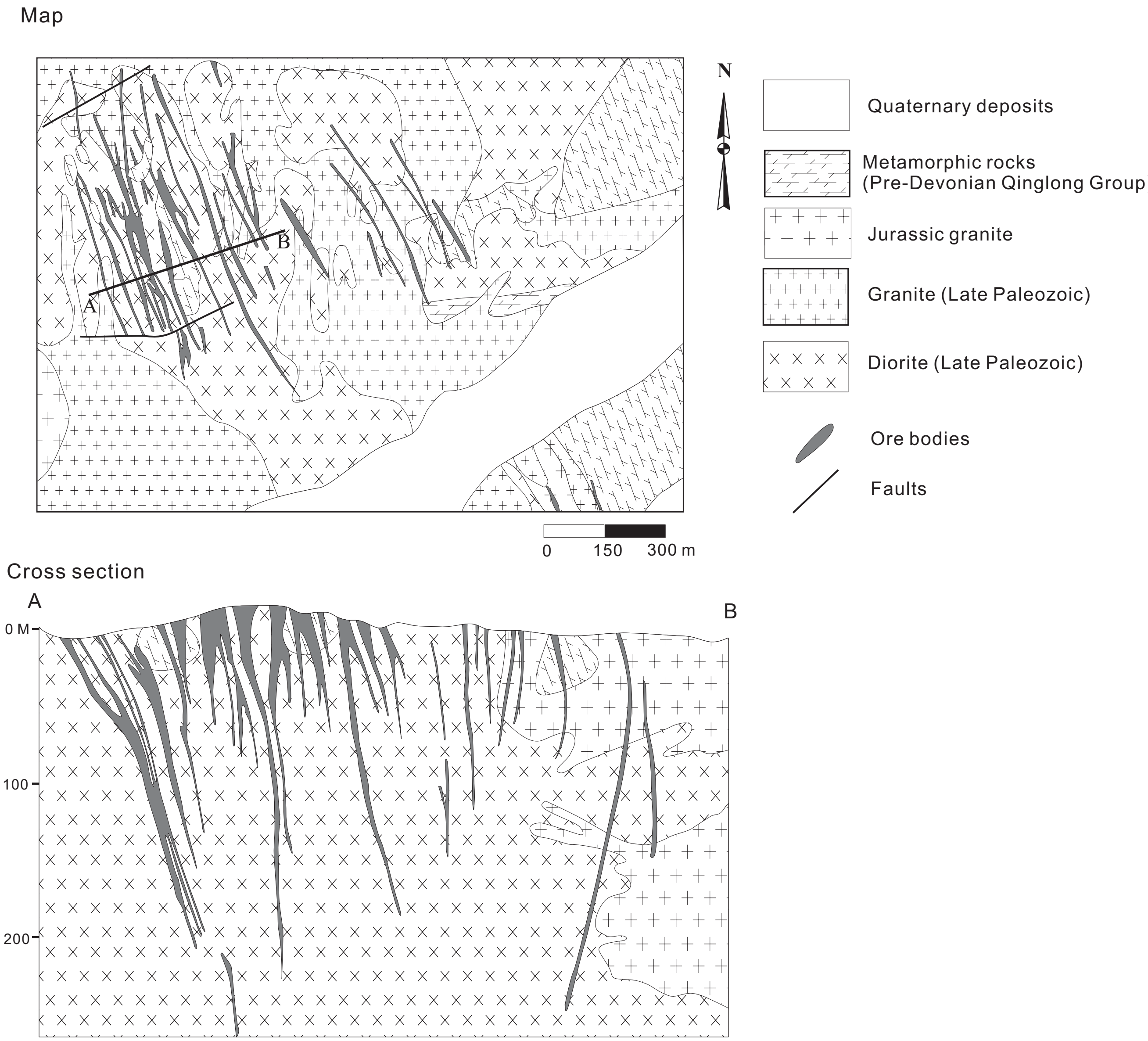


Figure 14. Generalized geologic map and schematic cross section of Xiaoxinancha porphyry Cu (±Au) deposit, North Jilin metallogenic belt, northern China. Adapted from Rui (1994).

south. The latter is metamorphosed to greenschist facies. The Paleozoic rocks contain beds of Au-bearing, pyrite-bearing graphitic shale.

Onon-Turinskiy Metallogenic Belt of Porphyry Au, Granitoid-Related Au-Vein, and Cassiterite-Sulfide-Silicate Vein and Stockwork Deposits (Belt OT) (Russia, Central Transbaikalia and Mongolia)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to veins, volcanic complexes, and replacements related to Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Selenga sedimentary-volcanic plutonic belt, and Ononsky terrane. The belt occurs along the Onon and Ingoda Rivers, trends east-northeast along the western boundary of the Argunsky terrane for 300 km, and ranges from 50 to 70 km wide. The Late Mesozoic Transbaikalia sedimentary-volcanic-plutonic belt consists of calc-alkaline and subalkaline volcanic rock of the Sokhondinsky and Dzhargalantuy Suites, calc-alkaline and subalkaline granitoid of the Sokhondinsky, Kyrinsky, Asakan-Shumilovsky Kharalginsky Complex, diorite and granodiorite of the Shakhtaminsky Complex, and REE granite of the Kukulbey Complex. The volcanic rock units are lava, pyroclastic, extrusive, and subvolcanic varieties that occur in volcanic domes, pluton-related domes, and basins that are controlled by longitudinal and transverse faults (Seminsky, 1980). The Mongolian part of the belt occurs in the Hentii subterrane of the Hangay-Dauria terrane adjacent to Russia, and consists of Sn-W greisen, stockwork, and quartz vein, and stockwork deposits. The belt contains a few cassiterite-wolframite-quartz and wolframite-cassiterite-beryl-quartz veins that are related to small plutons composed of biotite, two-mica, and muscovite fluorite leucogranite that is intensely altered to greisen with a K-Ar isotopic age of 146 Ma (Koval, 1998). The major deposits are at Ara-Ilinskoye, Khapcheranga, Lubavinskoye, and Tarbaldzhiskoye.

The major deposits in the Onon-Turinskiy belt occur in two districts that strike northeast and are controlled by crossing northwest-striking faults. The deposits are related to Jurassic and Cretaceous magmatism and faults that define the districts. The largest district is at Lubavinsky-Tarbaldzhey and contains the Lubavinsky granitoid-related Au-vein deposit. This deposit contains simple and saddle-like Au-quartz veins (Shubin, 1984). The Tarbaldzhey deposit with cassiterite-sulfide-silicate veins and stockwork contains feldspar-fluorite-quartz veins with cassiterite and sulfides (Ontoev, 1960). The Ara-Ilinsky porphyry Au deposit occurs in a cryptovolcanic diatreme and consists of an Au stockwork (Fogelman, 1964).

The main references on the geology and metallogenesis of the belt are Zonenshain and others (1990), Kovalenko and others (1995), Koval (1998), Gerel and others (1999), Cluer and others (2000), and Tomurtogoo (2001).

Khapcheranga Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (fig. 16) (Gongalsky and and others, 1995; Skursky, 1996) consists of 20 extensive (to 1,100 meters) veins with thicknesses of 0.4 to 0.5 meters, in swells 1.5 to 2.0 meters in steeply-dipping shears with a northnorthwest strike, and 50 small, variably-trending veins on the southern flank of the deposit. Major minerals are cassiterite, arsenopyrite, sphalerite, pyrrhotite, and galena; less common are chalcopyrite, pyrite, stannite, ferebrite, and marcasite; minor molybdenite, lellingite, magnetite, bismutine, gray ore, and argentite; and very rare hydrothermal kavalerite, tantalite, hematite, and monazite. Nonmetalliferous minerals are quartz, muscovite, topaz, chlorite, microcline, albite, biotite, fluorite, calcite, tourmaline, and epidote. The vein occurs along southern exocontact of a stock (2 km^2 area) of Middle Jurassic granite porphyry with greisen in apical part. The veins are multistaged, and have a mineral zonation defined by the distance from the contact of the granite stock. Zone 1 has apical Sn-W greisen; zone 2 contains quartz-feldspar with arsenopyrite, pyrite, pyrrhotite, cassiterite, and sphalerite; zone 3 contains sulfate-cassiterite-chlorite with pyrrhotite and sphalerite, an economic assemblage; and zone 4 has carbonate-sphalerite-galena with cinnabar and antimonite. The enclosing rock consists of quartz-altered and chlorite-altered sandstone and shale of Early and Middle Triassic age that is sheared in a sublatitudinal anticlinal fold. The deposit is medium size and has a grade of 0.75 percent Sn, 0.3 to 25 percent Pb, 1 to 25 percent Zn, 0.01 to 0.17 percent Cd, and 11 to -600 ppm Ag. More than 10,000 tonnes of metal has been produced. The deposit is prospected to a depth of 475 meters, and it is developed to 400 meters depth.

Lubavinskoye Granitoid-Related Au-Vein Deposit

This deposit (Kitaev, 1977; Shubin, 1984) consists of saddle-shaped gold-quartz veins, mineralized dikes, and local stockworks. The veins are subdivided into extensive veins that extend some hundred meters and dip steeply, and short brecciated veins that extend tens of meters and dip gently. The former occur in shears often parallel to layering of hosting rock, whereas the latter occurs in fractures. The thickness of both types of veings ranges from a few centimeters to 1 to 5.2 meters in swells. The deposit is hosted in weakly metamorphosed sandstone and shale that is intruded by intermediate and siliceous granitoids dikes and stocks. The highest concentration of veins occurs adjacent to small granitoid stock. Gold occurs in veins in columns. The veins consist of quartz with minor (0.5 to 4.0 percent) sulphides with lesser ankerite, siderite, and barite. The primary ore minerals are gold, arsenopyrite, and pyrite with lesser galenite, sphalerite, chalcopyrite, grey ore, Pb and Sb sulfosalts, pyrrhotite, Pb, Bi, and Bi meneginite and sulfoantimonite, and local scheelite, cassiterite, molybdenite, and cinnabar. Gold occurs as free gold in quartz (70 percent), in intergrowths with sulfides, and dispersed. The ore minerals occur in breccia, layeres, and disseminations. Main alterations are beresite and silica. The deposit is located along the Mongolo-Okhotsk suture. The deposit is medium size and grades to several hundred ppm Au.

Ara-Ilinskoe Porphyry Au Deposit

This deposit (Fogelman, 1964; Shubin, 1984) consists veinlets and stockwork that are hosted in a cryptovolcanic diatreme that contains extrusive units (trachyliparites), subvolcanic bodies (dikes of quartz porphyries, diorite porphyry, and diorite stock), and explosive units (breccia with clasts of fragmented granite). All units in diatreme are altered to beresite. Gold occurs in cement of breccias as phenocrysts and in veinlets along with quartz, carbonate, and minor sulfides (3 percent). The sulfides are arsenopyrite and pyrite with lesser chalcopyrite, sphalerite, galenite, and tetrahedrite. The granite contains tourmaline. Gold is distributed irregularly; 80 percent occurs as native gold, and 20 percent occurs in sulfides. Fineness of gold is 784 to 880. The deposit occurs along the Mongolo-Okhotsk suture. The deposit is small.

Tarbaldzheiskoe Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (Radkevich, 1947; Ontoev, 1960) consists of three stockworks and a series of veins. The largest stockwork is 350 to -400 meters wide and 400 to 800 meters long. The stockworks consists of thin subparallel veinlets with quartz, cassiterite, and arsenopyrite, and rare fluorite, topaz, muscovite, pyrite, wolframite, beryl; and bodies of explosive breccias with quartz, orthoclase, and fluorite, rare wolframite. The deposit is interpreted as being a complicated cassiterite-sulfide body that is overprinted by Sn greisen. The veins have dimensions of 50 by 600 by 0.1 to 0.5 meters, and contain assemblages of feldspar-fluorite-quartz (quartz, orthoclase, fluorite, galenite, sphalerite, arsenopyrite, and cassiterite), polymetallic (quartz, chlorite, galenite, sphalerite, chalcopyrite, cassiterite, stannine, pyrite, pyrrhotite, and arsenopyrite), and quartz (quartz, fluorite, galenite, sphalerite, native gold) composition. The veins occur in the superdomal part of a hidden Mesozoic granitoid stock that occurs along a regional fault. The host rocks are metamorphosed Middle Permian through Early Tertiary sandstone and shale on the southern side of the fault, and by Silurian through Early Devonian sedimentary rocks on the southern side that are altered to greisen, K-feldspar, silica, and sulfides. Middle Triassic through Late Jurassic quartz porphyry, lamprophyre, and porphyry dikes are widespread. The deposit contains anomalous Pb, Zn, As, Ag, W, Cu, Bi, Au, Be, Li, and CaF_2. The deposit is medium size and has an average grade of 0.75 percent Sn, 0.5 to 16 percent Pb, 1.6 to -24 percent Zn, and 0.05 to 0.3 percent WO_3.

Origin and Tectonic Controls for Onon-Turinskiy Metallogenic Belt

The belt is interpreted as being related to magmatism that formed alng transpression zones related to transform microplate

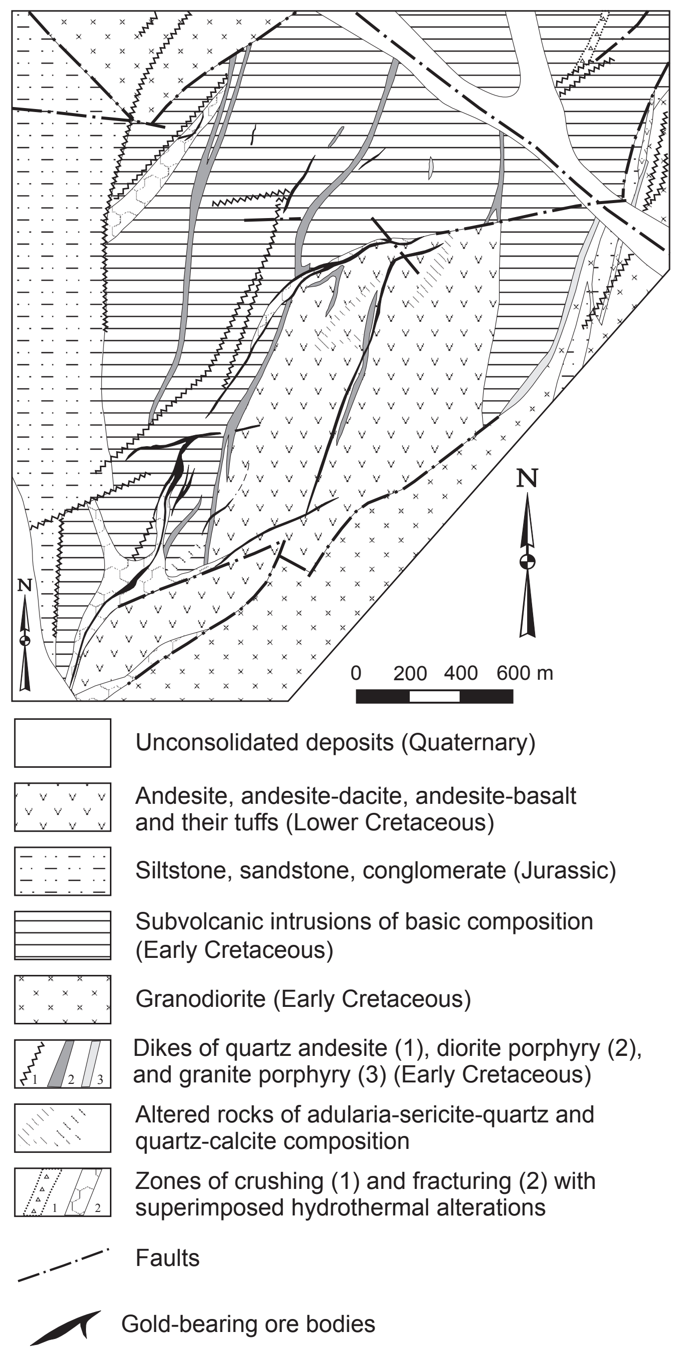


Figure 15. Generalized geologic map of Burindinskoe Au-Ag epithermal-vein deposit, North Stanovoy metallogenic belt, Russian Southeast. Adapted from N.G. Korobushkin, written commun. (1984), and V.A. Taranenko, written commun., 1991.

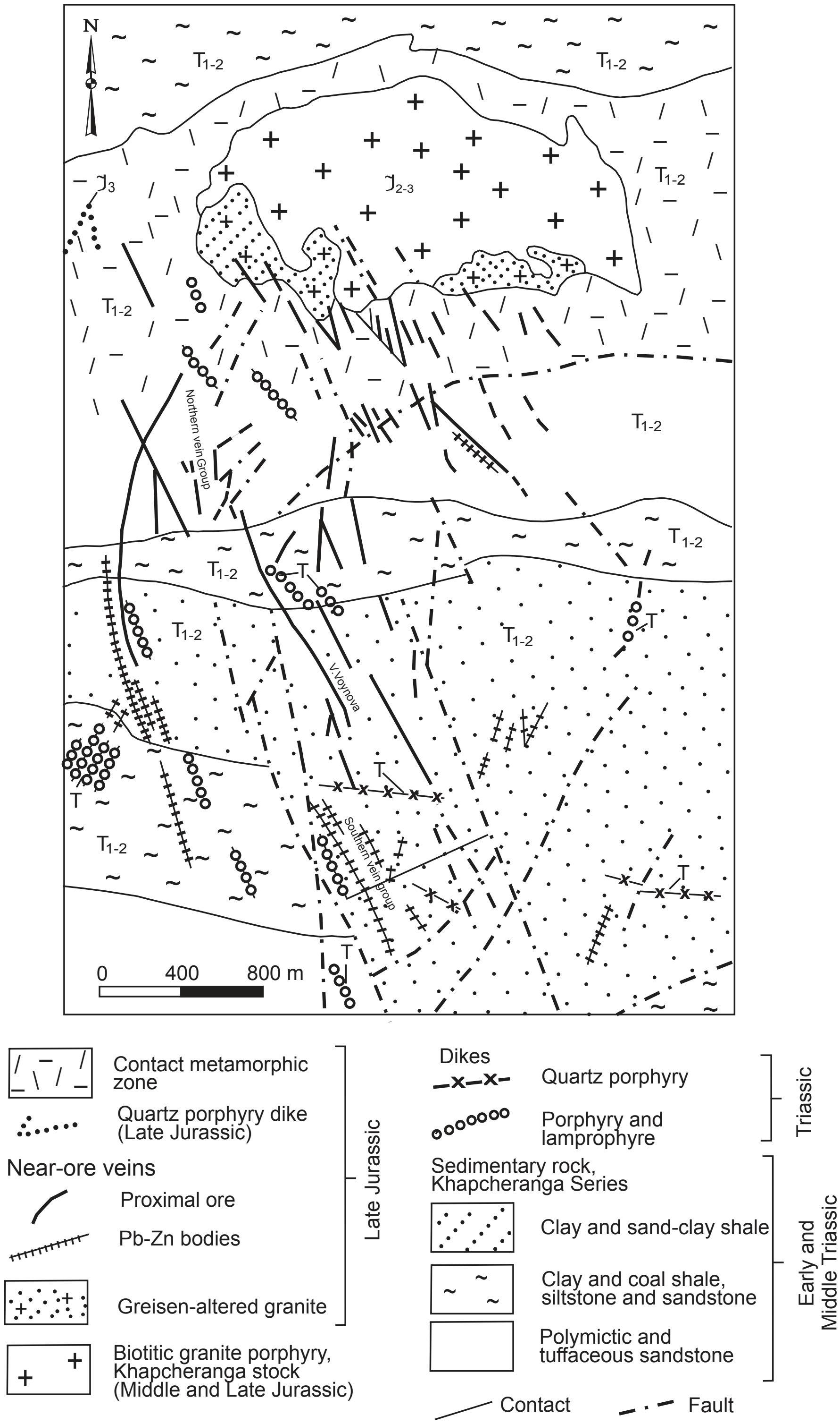


Figure 16. Generalized geologic map of Khapcheranga cassiterite-sulfide-silicate vein and stockwork deposit, Onon-Turinskiy metallogenic belt, Transbaikal, Russia. Adapted from Ontoev (1974).

boundaries and within plate (plume) environment. The belt and related host rock occurs along the submeridional Onon-Tura fault that strikes east-northeast, and companion northwest-striking faults. These major structures are associated with the tectonic origin of the intricate Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt.

Polousny Metallogenic Belt of Cassiterite-Sulfide-Silicate Vein and Stockwork, and Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposits (Belt PO) (Russia, Verkhoyansk-Kolyma Orogenic Region)

This Neocomian through Aptian (130 to 120 Ma) metallogenic belt is related to granitoids in the Northern granite belt. The metallogenic belt extends sublatitudinally for 200 km along the western margin of the Northern granite belt, is as much as 70 km wide, and crosses the northern block of the Omulevka terrane and the Polousnyy synclinorium. The Northern granite belt has $^{40}Ar/^{39}Ar$ ages of 130 to 120 Ma. In the western part of belt are the Marya-Khaya, Mamyandzhu, and Talannakh occurrences, and in the eastern part are the Egekit deposit and other occurrences. The major deposits are at Mamyandzhu, Marya-Khaya, Talannakh, and Egekit.

The main references on the geology and metallogenesis of the belt are Trunilina (1992) and Nokleberg and others (2003).

Ulakhan-Sala Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (V. Arsky and others, written commun., 1963) consists of four quartz-tourmaline and tourmaline-chlorite-quartz veins that range from 320 to 1400 meters long and 0.2 to 3.6 meters wide. Major minerals are cassiterite, pyrrhotite, arsenopyrite, sphalerite, chalcopyrite, galena, wolframite, scheelite, and calcite. Veins are brecciated. Sn decreases with depth. The wallrocks are altered to silica and sulfides. Veins hosted in Late Jurassic sandstone and shale display minor contact metamorphism. Host rocks form monocline that strikes from north to east. The deposit is small and has an average grade of 0.84 percent Sn.

Aragochan Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (V. Shpikerman in Nokleberg and others, 1997) consists of seven sheet-like veins. Veins range from 120 to 700 meters long and 0.4 to 1.13 meters thick. Major minerals are quartz, calcite, siderite, galena, sphalerite, pyrite, and rare cassiterite. Veins hosted in Upper Jurassic sandstone and shale that dip 60 to 65° N. The deposit is small and has an average grade of 5.28 percent Pb and 3.6 percent Zn.

Origin and Tectonic Controls for Polousnyy Metallogenic Belt

The belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and associated regional metamorphism and generation of anatectic granitoids.

Samarka Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag), Porphyry Mo (±W, Sn, Bi), and W±Mo±±Be Skarn Deposits (Belt SM) (Russia, Far East)

This Early to mid-Cretaceous metallogenic belt is related to replacements and S-type granitoids in the Khungari-Tatibi granitic belt that intrudes Samarka subduction-zone terrane. The belt occurs in Early to mid-Cretaceous aluminous, mainly S-type granitoids that intrude the Samarka terrane. The host granitic rocks are mainly granodiorite porphyry, granite, gabbro, and diorite. The olistostrome that host the Samarka belt consists of limestone caps of guyots that are enclosed in a matrix of highly deformed Jurassic sedimentary rock. The skarns are hosted in limestone along contacts between calcareous and alumosilicate clastic rock. The belt contains a major W±Mo±Be skarn deposit at Vostok-2, and small porphyry Cu-Mo (±Au, Ag) deposits at Khvoshchovoe, Kafen, and Malakhitovoe. The major deposits are at Malakhitovoe, Vostok-2, and Lermontovsky.

The main references on the geology and metallogenesis of the belt are Stepanov (1977), Gvozdev (1984), Rostovsky and others (1987), A.I. Khanchuk, written commun. (1997), and Nokleberg and others (1997, 2003).

Malakhitovoe Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Petrachenko and others, 1988) occurs in a circular aureole of hydrothermally altered rock with dimensions of 200 by 200 meters. The aureole occurs over an intrusive dome. Successive mineral assemblages are (1) quartz-biotite-actinolite with pyroxene and epidote; (2) quartz-biotite-actinolite; (3) quartz-biotite-sericite (± chlorite); and (4) quartz-hydromica with carbonate. A stockwork contains the first three facies and consists of a thick network of quartz-epidote-actinolite veinlets and lenses that are as much as 2 to 3 cm thick and contain chalcopyrite, bornite, and pyrite. Heavily fractured and brecciated chert and siltstone in breccia zones were prospected by rare holes to a depth of 100 meters. Ore minerals in breccia zones are chalcopyrite, bornite, molybdenite, and pyrite, rarely pyrrhotite, cubanite, arsenopyrite, galena, and sphalerite. Carbonate veinlets with chalcopyrite also occur. The deposit occurs at the northwest margin of a volcanic-tectonic depression that contains a lower structural stage of Early Cretaceous sandstone, interlayered with siltstone and shale, that grades upwards into conglomerate and sandstone overlain by Paleogene andesite and basaltic andesite lava and lava breccia. Local intrusive rocks consist of dikes of calc-alkaline andesite porphyry that is interpreted as tongues of a dome-like subvolcanic intrusion. The deposit is small and has an average grade of 0.1 to 1.6 percent Cu in stockwork, and as much as 0.5 percent Cu in the breccia zone.

Vostok-2 W±Mo±Be Skarn Deposit

This major deposit (fig. 17) (Stepanov, 1977; Rostovsky and others, 1987) consists of skarn in veins and sheets that formed in several stages. From older to younger the stages are (1) skarn composed mainly of pyroxene, plagioclase, amphibole, and garnet; (2) greisen alteration of skarn and granitoid with formation of quartz, feldspar, and muscovite, along with lesser chlorite and biotite with scheelite and apatite, and minor arsenopyrite, pyrrhotite, and chalcopyrite; (3) scheelite and quartz; and (4) low temperature scheelite and arsenopyrite. The deposit occurs along flat to steeply-dipping contacts of granitoid plutons that intrude an olistostrome consisting of Carboniferous and Permian limestone and calcareous-shale. Successive skarn and greisen alteration of limestone preceded deposition of scheelite, gold, and apatite that are as much as a few tens of percent. A plagiogranite with an approximate K-Ar isotopic age of 110 Ma is interpreted as coeval with the deposit. The deposit is large and has an average grade of 0.65 percent W_2O_3 and 1.64 percent Cu; it has been mined since the 1980s.

Lermontovsky W±Mo±Be Skarn Deposit

This deposit (Gvozdev, 1984) consists of skarn in lenses, sheets, and nests that occur at the top contact of an Early Cretaceous granitic stock that intrudes bedded limestone. Skarn ranges from 40 to 640 meters long and 1 to 78 meters thick. The deposit formed in three stages (1) skarn (diopside, hedenbergite, hornblende, wollastonite, and garnet) replacement of limestone and of biotite hornfels derived from sandstone; (2) hydrothermal alteration of granitoid, hornfels, and skarn to greisen; and (3) deposition of sulfide minerals. Two types of greisen occur (1) quartz-albite-muscovite; and (2) scheelite-muscovite-apatite-mica-quartz. Pyrrhotite is the major sulfide, and arsenopyrite, pyrite, marcasite, and scheelite are minor. Sulfide minerals are either superimposed on scheelite greisen, or occur separately in veins. The deposit also contains Ag-telluride-bismuth (polymetallic) and Au-telluride-bismuth (pyrrhotite) zones. W occurs in all parts of the deposit, although the most abundant scheelite occurs in muscovite and lesser biotite, and in phlogopite greisen, quartz veins, and a metasomatic feldspathic rock. The host Early Cretaceous granitoid is highly aluminous, contains low alkalies and Ca, and contains elevated F and P. The deposit is large and has an average grade of 0.67 to 3 percent W_2O_3.

Origin and Tectonic Controls for Samarka Metallogenic Belt

The belt is interpreted as having formed during generation of S-type grantitoid plutons during underthrusting of the Kula oceanic ridge and formation of igneous rocks along a transform continental margin. K-Ar isotopic ages for host granitoids range from 110 to 115 Ma.

Shilkinsko-Tukuringrskiy Metallogenic Belt of Granitoid-Related Au Vein, Porphyry Au, Au Skarn, Au-Ag Epithermal-Vein, Porphyry Mo (±W, Bi), W-Mo-Be Greisen, Stockwork, and Quartz Vein, Cassiterite-Sulfide-Silicate Vein and Stockwork, Ta-Nb-REE Alkaline Metasomatite, Polymetallic (Pb, Zn ± Cu, Ba, Ag, Au) Metasomatic Carbonate-Hosted, Au-Ag Epithermal-Vein, and Fluorspar-Vein Deposits (Belt ST) (Russia, Eastern Transbaikalia)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to granitoids, volcanic rocks, and replacements related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that intrudes and overlaps the West Stanovoy, Ononsky, and Argunsky terranes and adjacent units. The belt occurs in Eastern Transbaikalia along the Onon River, the Borschovochny Range, and the Shilka River. The belt extends for 1,000 km and varies from 50 to 125 km wide. The belt contains numerous major deposits at Ukonikskoye, Itakinskoye, Aleksandrovskoye, Kluchevskoye, Kariyskoye, Aprelkovskoye, Baleiskoye, Sredne-Golgotaiskoye, Fatimovskoye, Shunduinskoye, Delmachik, Andryushkinskoye, Taseyevskoye, Davendinskoye, Zhirekenskoye, Belukhinskoye, Bukukinskoye,Sherlovogorskoye; Etykinskoye, Yekaterininskoye, Kalanguyskoye, Tamenskoye, Zhetkovskoye, Kirovskoe, and Berezitovoe.

The Au, Mo, W, Sn, Pb, Ta, Nb, and F deposits are related to Middle and Late Jurassic and Early Cretaceous granitoids that occur along the Mongol-Okhotsk suture. The Au, Mo, and polymetallic deposits are related to Middle and Late Jurassic and Early Cretaceous granitoids. The Jurassic granitoids are mainly granite and granodiorite with rare granosyenite and diorite. Also occurring are granite, granodiorite, and diorite porphyry subvolcanic bodies. Associated extrusive rocks are rhyolite, dacite, latite, andesite, shoshonite, and basalt. The deposits and occurrences are commonly located in domes, dome rings, and basins and are spatially and temporally related to minor stocks, sills, and dikes of granodiorite, granite, diorite, and felsite porphyry. Vein deposits are concentrated around stocks and dikes, inside stocks, and in explosive breccias. Stocks are surrounded by zoned, decreasing temperature mineral assemblages.

Granitoid-related Au-vein deposits are dominant in the belt and consist of low-sulfide (Fatimovskoye, Shunduinskoye), medium-sulfide (Kluchevskoye, Sredne-Golgotaiskoye, Kirovskoe, Berezitovoe) and high-sulfide (Uonikskoye, Itakinskoye, Aleksandrovskoye, Karyiskoye, Aprelkovskoye) deposits. The center of the Au deposits is the intersection of the Onon fault with the main Mongol-Okhotsk suture. This area also contains low- and medium-sulfide (Sredne-Golgotaysky), Au skarn (Andryushkinskoye), porphyry Au (Delmachik), and Au-Ag epithermal-vein (Baley and Taseevsky) deposits that formed in Early Cretaceous rifting in the Baley graben. The characteristics of Au deposits evolve along the suture from the center to the northeast. Along this direction, the granitoid-related Au-vein deposits exhibit an increase of sulfides (pyrite, arsenopyrite, chalcopyrite, galena, and sphalerite), occurrence of sulfide deposits, and intense occurrence of tourmaline (Kluchevskoye) and Sb deposits (Itakinsky) to the extreme northeast. This part of belt also includes large porphyry Mo (±W, Sn, Bi) deposits (Davendinsky, Zhirekensky) and rare polymetallic (Pb, Zn±Cu, Ba, Ag, Au) metasomatic carbonate-hosted deposits (Yekaterininsky).

The belt also contains various Sn-W greisen, stockwork, and quartz vein (Belukhinsky, Bukukinsky) deposits, cassiterite-sulfide-silicate vein and stockwork deposits (Sherlovogorsky, Bolshaya Sopka, Tourmaline Otrog, Vostochny), Ta-Nb-REE alkaline metasomatite deposits (Etykinsky), and fluorine vein (Kalanguysky, Tamensky, Zhetkovsky) deposits. These deposits occur along the southwestern flank of the belt in the Onon fault that cuts the Aginsky terrane. The deposits are related to Middle and Late Jurassic granite porphyry stocks, Late Jurassic leucocratic and amazonite granite plutons, and Early Cretaceous diorite, granodiorite, and granite porphyry dikes. This area contains greisen with silica and tourmaline alteration. The belt is promising for undiscovered Au, Mo, W, Sn, Ta, Ni, and fluorite deposits.

The main references on the geology and metallogenesis of the belt are Tauson and others (1987), Zorina (1993), Spiridonov and Gnilusha (1995), Zorin and others (1998), and Zorin (1999).

Baleyskoe Au-Ag Epithermal-Vein Deposit

This deposit (fig. 18) (Petrovskaya and others, 1961; Yurgenson and Grabeklis, 1995) consists of quartz veins and zones of small veinlet and stockwork mineralization. Ore bodies are located in concentric gently-lying zones and in steeply-dipping, ruptured fractures. The former represent lenticular short and thin quartz veins, and the latter have complicated morphology. In the northern part of the deposit variably-oriented veins in granitoids form a stockwork (about 1 km^2). In places, ore pillars occur. Mineralization is penetrated by boreholes to 0.8 to 1 km depth. Ore is composed of adular, chalcedony, quartz, kaolinite, carbonate, pyrite, chalcopyrite, arsenopyrite, markasite. In places there

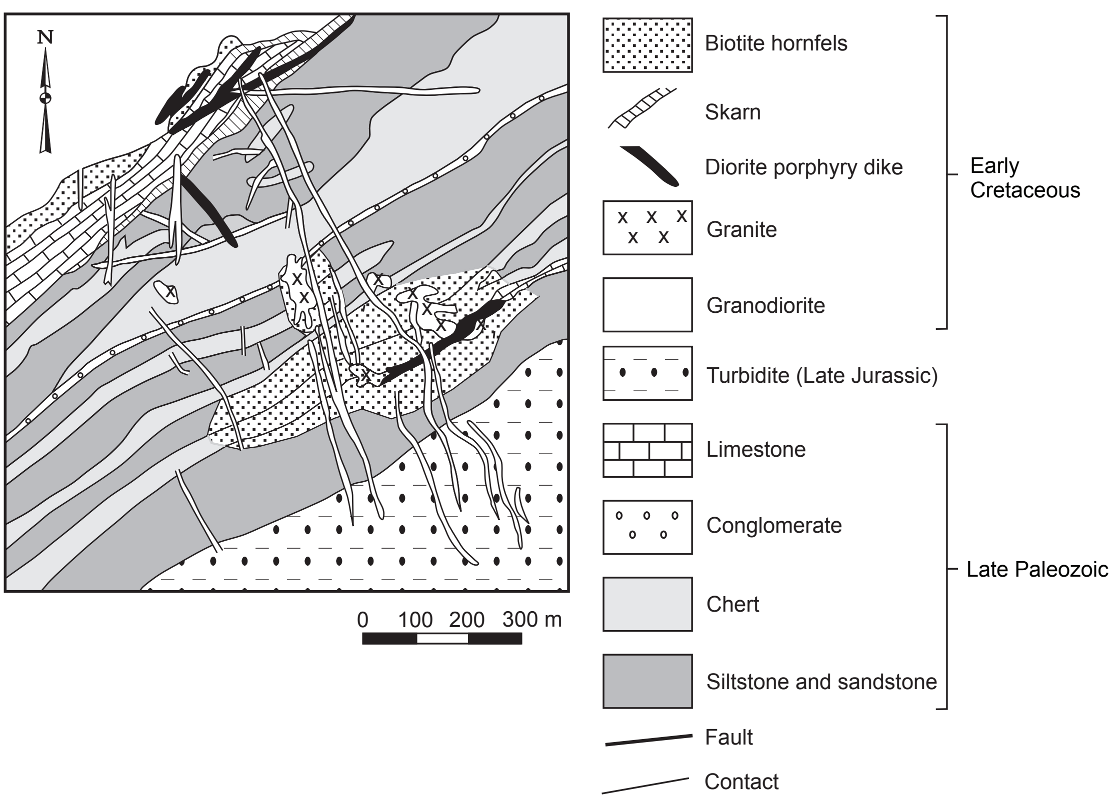


Figure 17. Generalized geologic map of Vostok-2 W±Mo±Be skarn deposit, Samarka metallogenic belt, Russian Southeast. Adapted from Stepanov (1977).

are gold-enriched stibial sulphosalts Cu, Pb, Ag, the most predominant are pyrargyrite and grey ore. Sulfides comprise 0.5 to 1.5 percent. The fineness of gold is 680 to 780, and gold contains finely dispersed silver (grading to electrum). The enclosing rocks are granodiorites, volcanics of dacite-andesite composition, conglomerate, sandstone, and aleurolite. Near-ore alterations include propilitization, beretization, and argillitization. The deposit formed during Early Cretaceous rifting and occurs in the Baley graben along the Mongol-Okhotsky suture.

Berezitovoe Polymetallic Pb-Zn±Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (A.K. Ivashchenko and A.A. Kuzin, written commun., 1982; Vakh, 1989) consists of massive Pb-Zn sulfides that occur in a lenticular, northwest-striking, steeply-dipping (75 to 85°) zone that is as much as 1,000 meters long and 100 to 160 meters thick. The deposit hosted in Early Proterozoic gneissic granite. The sulfides are metamorphosed and galena-sphalerite aggregates contain younger andradite and gahnite (zinc spinel). Host muscovite-quartz-potassium feldspar rock also contains metamorphic garnet. Adjacent Mesozoic igneous rocks are not metamorphosed, indicating preMesozoic mineralization. The deposit occurs in narrow, northeast-trending fracture zones. Gold mineralization is later than polymetallic-sulfide mineralization. Thin Au-bearing zones, associated with quartz-sericite altered rock, occur beyond the polymetallic-sulfide deposit in gneissic granite. The deposit is medium size and contains an estimated 42.3 tonnes Au, 201.0 tonnes Ag, 131.0 thousand tonnes Zn, and 80 thousand tonnes Pb. The average grade is 3.3 g/t Au, 14.3 g/t Ag, 0.93 percent Zn , 0.57 percent Pb. The deposit contains an estimated 42.3 tonnes Au, 201.0 tonnes Ag, 131,000 tonnes Zn, and 80,000 tonnes Pb.

Kalanguyskoye Fluorspar-Vein Deposit

This deposit (Kormilitsyn, 1973; Ivanov, 1974) consists of a series of fluorspar veins and zones of crushing with three commercial deposits. 80 percent resources occur in one vein with dimensions of 1300 by 0.7 to 3.6 by 600 meters. The vein contains three ore pillars with swells about 15 to 20 meters thick. The major ore minerals are fluorite, quartz, and pyrite (2 to 10 percent). Minor ore minerals are kaolinite, gearksutite, and marcasite, and rare ore minerals are galena, molybdenite, arsenopyrite, calcite, galluasite, and sphalerite. At depth sulfides increase to 15 to 25 percent and fluorite decreases from 80 to 45 percent. The upper parts of the veins exhibit a symmetric-zonal structure and are brecciated. Yellow-honey fluorite is most common, with lesser porcelaneous fluorite and violet and green fluorite. The deposit contains kidney-shaped, concretionary and boulder types of ores and is interpreted as an epithermal sulfide-quartz-fluorite deposit type. The vein occurs in a large, steeply-dipping fault zone with submeridional strike and is hosted in Late Jurassic sandstone and shale. The adjacent host rocks are altered to kaolinite or silica to a depth of 10 to 20 meters. The deposit is large and has resources of 6.3 million tonnes fluorspar grading 60 percent CaF_2.

Ukonikskoe Granitoid-Related Au-Vein Deposit

This deposit (Fedchuk and Lukin, 1995) consists of two zones that range from 300 to 1.5 km long and contain quartz-carbonate-sulfide veins, lenses, and streaks, and disseminations. The zones vary from 0.15 to 4.5 meters thick, extend 300 to 400 meters downdip, and from 40 to 220 meters along strike, with an average of 80 to 100 meters. The zones occur in gneiss and schist that altered into quartz-sericite metasomatite and beresite near the bodies. Grades range from 10 to 40 percent sulfides with an average of about 30 percent. The main ore minerals are quartz, carbonates, pyrite, arsenopyrite, galena, sphalerite, and native gold. Secondary minerals are chalcopyrite, bismuth, bismuthin, and silver. Two varieties of gold occur (1) finely dispersed gold in pyrite and arsenopyrite of quartz-pyrite and pyrite-arsenopyrite-quartz bodies; and (2) native (free) gold in polymetallic sulfides. Gold particles range from 0.5 to 200 mm, and the fraction of coarse gold is as much as 5 percent. Formation of the deposit is linked with numerous (about 45 per 1 km^2) dikes of mafic, intermediate, and siliceous porphyry granitoids. The deposit is medium size and has a range of 1 to 170 ppm Au.

Zhirekenskoye Porphyry Mo (±W, Sn, Bi) Deposit

This deposit (Pokalov, 1978; Sotnikov and others, 1995) consists of an isometric stockwork (with surface dimensions of 1,200 by 100 meters) with a central pipe-like body (120 by 60 meters) of explosive breccia that extends to a depth of 600 meters. Ore minerals occur in disseminations, veinlets, and breccia, and occur in a quartz-K-feldsparr-molybdenite assemblage with varying amounts of chalcopyrite, rare molybdenite, scheelite, magnetite, arsenopyrite, fluorite, and tourmaline. Also occurring are younger, thin veinlets of quartz, pyrite, sphalerite, galena, chalcopyrite, pyrrhotite, grey ore, bornite, and chalcocite with molybdenite, pyrite and charlcopyrite comprising about 90 to 95 percent and occurring in equal amounts. The deposit also contains as much as 5 to 20 ppm Te, 20 to 900 ppm Se, 10 to 80 ppm Re, and 380 ppb PGE. The upper part of the deposit contains as much as 0.008 to 0.4 percent WO_3. The deposit occurs adjacent to a zone of intersecting shears and late Mesozoic granite-porphyry dikes that occur along the margin of a Middle and Late Jurassic granite porphyry stock with a surface area of 8 km^2. The host rocks are intensely altered to K-feldspar, argillite, and sericite. The deposit is large and has an annual production of 2.4

million tonnes of ore grading 0.08 percent Mo, and 0.03 to 0.15 percent Cu.

Origin and Tectonic Controls for Shilkinsko-Tukuringrskiy Metallogenic Belt

The belt is interpreted as being related to magmatism along transextension zones along transform microplate boundaries and within plate (plume) environment. The belt occurs in basins with continental sedimentary rocks and alkaline magmatic plutonic and volcanic rocks that occur along the Mongol-Okhotsk suture that separates various terranes and the North Asian and the Sino-Korean cratons.

South Verkhoyansk Metallogenic Belt of Au in Shear-Zone and Quartz-Vein, Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein, Stockwork, Granitoid-Related Au Vein, Cu (±Fe, Au, Ag, Mo) Skarn W-Mo-Be Greisen, Stockwork, and Quartz Vein, and Au-Ag Epithermal-Vein Deposits (Belt SV) (Russia, Verkhoyansk-Kolyma Region)

This Aptian through Late Cretaceous metallogenic belt is related to veins related to Early Cretaceous granitoids in the South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous) that intrude the Verkhoyansk fold and thrust

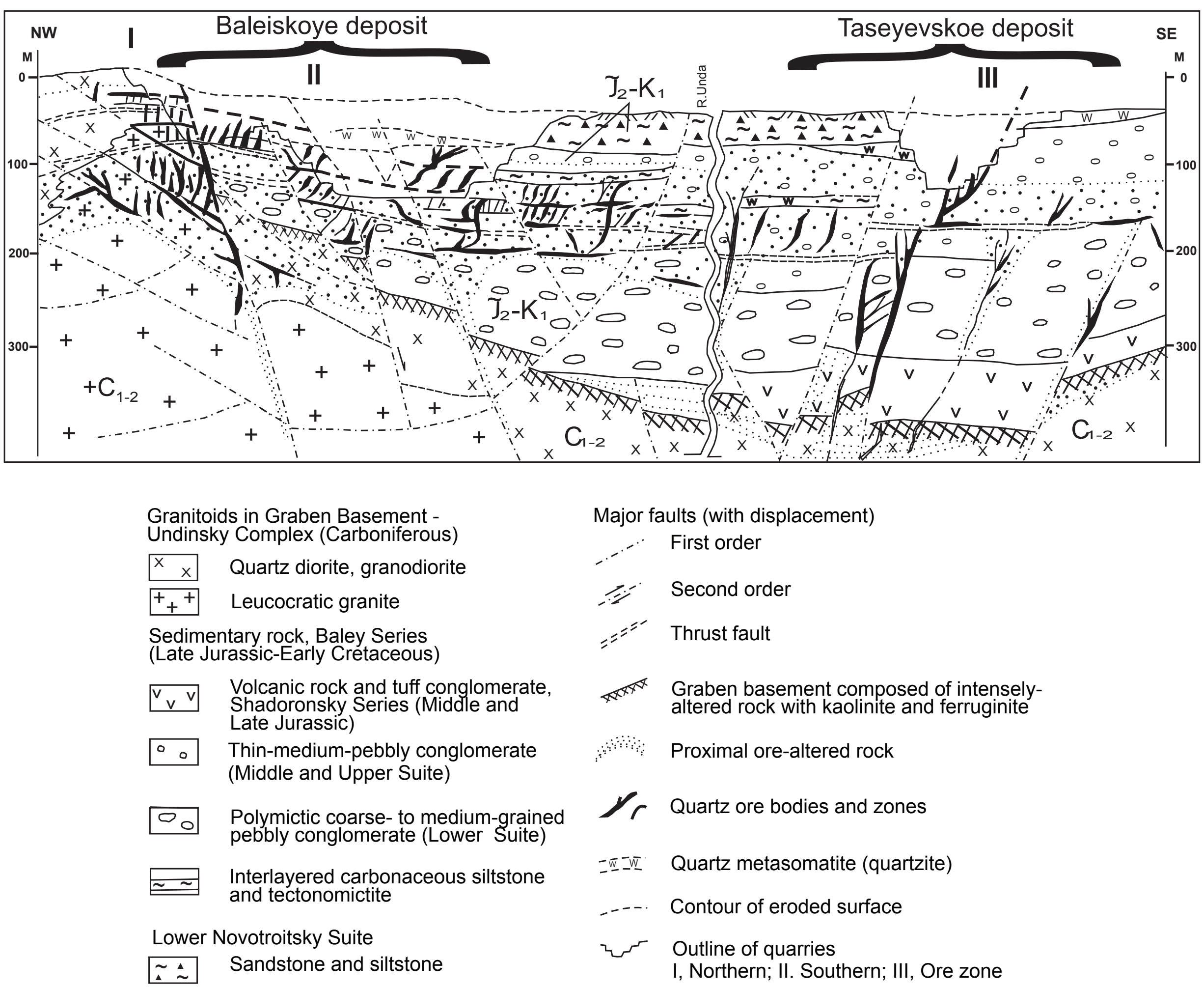


Figure 18. Schematic cross section of Baleyskoe Au-Ag epithermal-vein deposit, Shilkinsko-Tukuringrskiy metallogenic belt, Transbaikal. Adapted from Seminsky and others (2002).

belt in the North Asian cratonal margin. The metallogenic belt occurs in the central part of the South Verkhoyansk synclinorium and is bounded to the west by the Minorsk-Kiderikinsk fault and to the east by the Yudoma fault. The belt extends longitudinally for about 300 km from the Yudoma River in the south to the East Khandyga River in the north. The belt is hosted in Late Carboniferous through Middle Jurassic clastic rock that are deformed into folds that have gentle crests and smoothly undulating hinges. In the northern part of the belt are northeast-striking strike-slip faults (Suntar system) with horizontal displacements of as much as 10 km and vertical displacements ranging as much as 1 km. Related magmatic rocks consist of large polyphase plutons (Tarbagannakh, Uemlyakh, and others), stocks, dikes, and subvolcanic bodies. The belt contains Au in shear zones, quartz veins, and crush zones (Nezhdaninka deposit), Au-REE deposits that occur in and above the apices of granitoid plutons (Levo-Dybinsk district), and polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork deposits (Upper-Menkeche deposit). The major deposits are at Nezhdaninka, Upper-Menkeche, and Levo-Dybinsk.

The main references on the geology and metallogenesis of the belt are Indolev and Nevoisa (1974), Gamyanin and others (1985), Bortnikov and others (1998), and Nokleberg and others (2003).

Nezhdaninka Au in Shear Zone and Quartz-Vein Deposit

This deposit (fig. 19) (Gamyanin and others, 1985; Benevolsky and others, 1992) consists of disseminated gold that occurs in (1) steeply-dipping shear zones as much as 40 meters thick and 5.4 km long; (2) related tension-gash quartz veins that are as much as 200 meters long and 1.2 meters thick; and (3) quartz lenses in shear zones. The vein minerals are quartz, carbonate, arsenopyrite, galena, sphalerite, scheelite, sericite, albite, chalcopyrite, tetrahedrite, Pb and Cu sulfosalts, stibnite, and gold. Wallrocks display silica, sulfide, and sericite alteration. Quartz Ag polymetallic deposits cross-cut and postdate feathered quartz-veins. The deposit occurs along a major fault that cuts the core of a doubly-plunging anticline in Late Carboniferous through Early Permian sandstone and shale. The deposit extends more than 1,000 meters vertically and is explored by boreholes and seven levels of adits. The deposit is large and has proven reserves of 475 tonnes Au, and estimated resources of more than 500 tonnes Au. The average minimum grade is 5 g/t Au, as much as 6,748 g/t Au, and as much as 8,300 g/t Ag.

Upper Menkeche Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (V. Korostelev, written commun., 1963; Indolev and Nevoisa, 1974) consists of abundant Ag polymetallic sulfide lenses and veins that occur in a linear, steeply-dipping northeast-trending fault zone in Late Permian sandstone, siltstone, and shale. The fault zone is about 10 km long and 1 km wide. The sulfide bodies occur mostly parallel to the fault zone, dip steeply, range from hundred of meters to 3.5 km long, and from 1 to 10 meters (average 3 meters) thick. The main ore minerals are galena, sphalerite, pyrrhotite, arsenopyrite, and pyrite. Lesser ore minerals are cassiterite, chalcopyrite, magnetite, owyheeite, tetrahedrite, diaphorite, boulangerite, native silver, and gold. Gangue minerals are quartz, siderite, ankerite, and calcite. Three sulfide assemblages and stages of deposit formation are (1) sphalerite-quartz-siderite; (2) sulphoantimonite-galena; and (3) sulfide-carbonate. Regional metamorphism occurred between stages 2 and 3. The fault zone occurs along the dome of a plunging brachyform anticline. Part of deposit occurs within the contact metamorphic aureole of a Late Cretaceous granitoid intrusion that forms stocks and numerous dikes of granite-porphyry and granodiorite-porphyry. Lamprophyre and diabase dikes are widespread. The deposit is medium size and has an average grade of 2.7 to 11 percent Pb, 3.9 to 7.0 percent Zn, and 138 to 332 g/t Ag.

Origin and Tectonic Controls for South Verkhoyansk Metallogenic Belt

The belt is interpreted as having formed during accretion of the Okhotsk terrane to the North Asian craton and resultant deformation of the southern Verkhoyansk fold and thrust belt. The belt occurs in the Minorsk-Kiderikinsk zone of highly deformed Late Carboniferous and Permian rock in the western South Verkhoyansk synclinorium. Au-quartz veins are relatively older than large granitic plutons that intrude the South Verkhoyansk synclinorium which have ^{40}Ar-^{39}Ar isotopic ages of 123 to 120 Ma.

Taebaegsan Metallogenic Belt of Fe Skarn, Fe-Zn Skarn, Zn-Pb (Ag, Cu, W) Skarn, W±Mo±Be Skarn, Au in Shear-Zone and Quartz-Vein, and REE-Li Pegmatite Deposits (Belt TA) (South Korea)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to the Middle Jurassic through Early Cretaceous granitoids in the Jurassic Daebo granite that consists of biotite granite, two-mica granite, granophyre, and felsic and quartz porphyry. The Daebo granite intrudes the Yeongnam Metamorphic Complex and Great Limestone Group that is part of Sino-Korean craton, Yeongnam granulite-paragneiss terrane. The Yeongnam Metamorphic Complex consists mainly of metasedimentary rocks, quartzite and amphibolite and quartz-injection biotite gneiss, and the Cambrian and Ordovician Great Limestone Group that consists of the Pungchon Limestone, Hwajo Formation, Dongjom Quartzite, and Dumugol and Maggol Limestone. The major deposits are at Dongnam, Kangwon, Seojom, Susuk, Soonkyong, Yomisan (Sinyemi), Sangdong, and Wondong.

The metallogenic belt also contains polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite at Uirim-Samwon, Au skarn at Chulam, Sn-W greisen, stockwork, and a quartz-vein deposit at Soonkyong. These deposits are also interpreted herein as being related to the Jurassic Daebo granite.

The main references on the geology and metallogenesis of the belt are Seo and others (1983), Moon (1987), and Hwang, 1997).

Dongnam Fe-Zn Skarn Deposit

This deposit (fig. 20) (Seo and others, 1983) consists of contact metasomatic and porphyry Mo or disseminated molybdenum including stockwork-type ore deposits. The host rocks in the deposit are Cambrian slate (Myobong Formation) and Ordovician limestone (Poongchon and Hwajeol Formation), Jurassic(?) granitic rock, and Quaternary alluvium deposits. The diorite and quartz porphyry units includes diorite-tonalite, granite, and monzodiorite-granodiorite, quartz monzonite-granite, K-rich diorite, and potassic granite. The deposit occurs in fissure filling, contact metasomatic, hydrothemal replacement, and supergene enrichment and include iron, galena, sphalerite, manganese, and molybodenum ore deposits. Diorite and quartz porphyry contains anomalous Mo, Zn, Pb, Zr, and Fe. Ore minerals are mainly magnetite, hematite, Mn oxide, Mn carbonate, galena, sphalerite, and molybdenite. Accessory minerals are pyrite, pyrrhotite, arsenopyrite, chalcopyrite, limonite, scheelite, and fluorite. Skarn minerals are mainly garnet, epidote, and chlorite, and minor secondary calcite and quartz. Garnet is associated with magnetite, epidote, chlorite, and molybdenite. The deposit is medium size and has an average grade of 21.47 to 39.46 percent Fe, and 1 to 7 percent Pb+Zn. Reserves are 1,724,732 tonnes of ore.

Kangwon Fe skarn Deposit

This deposit (Kim and Oh, 1968) consists of Fe contact and selective replacement bodies in calcareous beds in Precambrian metasedimentary rock that consists of biotite paragneiss, amphibole schist, limestone, and quartzite in thin beds. Feldspar porphyry and granite porphyry intrude metasedimentary rock. The general strike of eastern body is NS-N 10° E and the dip is 70-80° NW; the western body trends N 40° E with a dip of 25-30° NW. The length and width of the eastern body is 130-80 meters and 10-6 meters, and the western is 100 meters and 8 meters. The average grade of each body is: Eastern body–29.8 to 35.49 percent Fe, 0.56 to 1.93 percent S, and 0.02 to 0.06 percent P; Western body–49.03 percent Fe, 5.61 percent S, and 0.01 percent P. The deposit is small and has an average grade of 38.44 percent Fe and reserves of 581,000 tonnes Fe.

Susuk Fe Skarn Deposit

This deposit (Chi, 1963) consists of magnetite and pyrite or pyrrhotite skarn in Precambrian amphibolite that is altered to serpentine or silica by regional metamorphism and hydrothermal fluids. The amphibolite is interlayered with quartzite and quartz-biotite gneiss. These rocks are intruded by granophyre, and felsite and quartz porphyry of suspected Mesozoic age. The

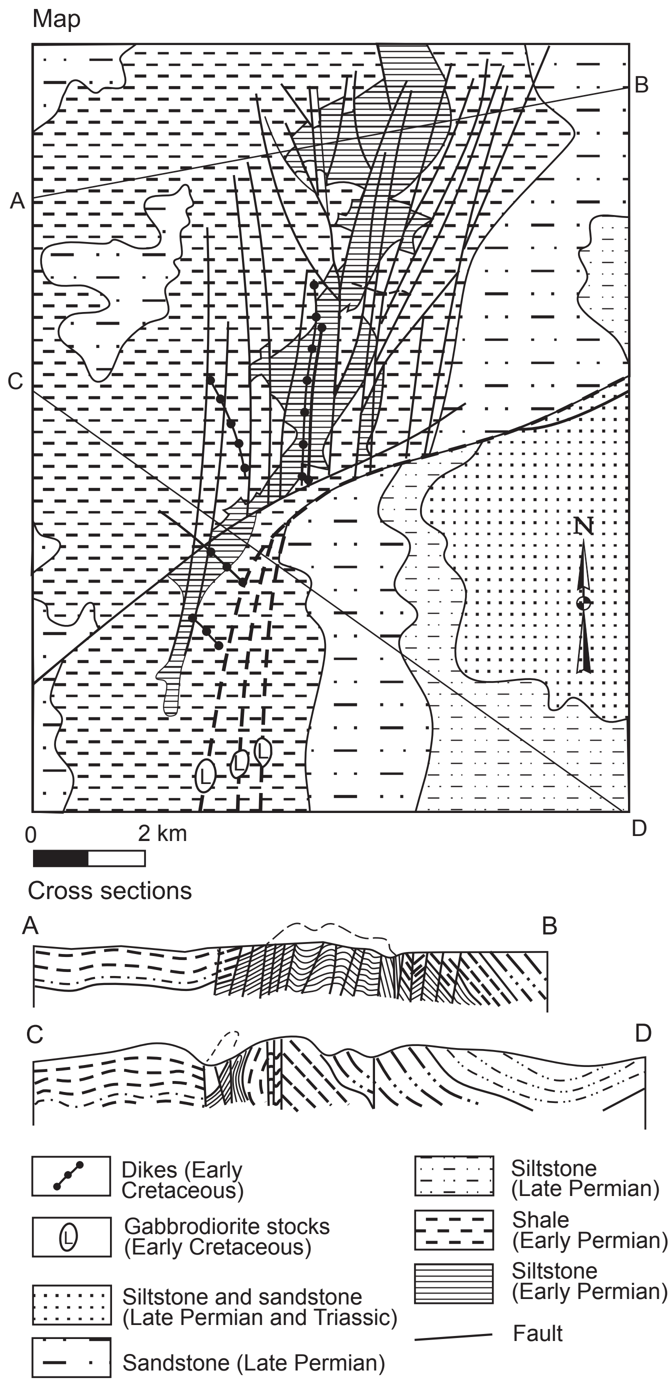


Figure 19. Generalized geologic map and schematic cross section of Nezhdaninka Au in shear zone and quartz-vein deposit, South Verkhoyansk metallogenic belt, Yakutia, Russia. Adapted from Shour (1985).

granophyre is interpreted as the deposit-related igneous body. Limonite occurs on weathered bedrock but is not economic. The deposit contains low-grade zones with 30 to 35 percent Fe and locally as much as 50 percent Fe with higher sulfide content. The deposit is small and has resources of 717,400 tonnes Fe, and reserves of 164,000 tonnes Fe grading 30 to 50 percent Fe.

Yomisan (Sinyemi) Fe-Zn Skarn Deposit

This deposit (Kim and others, 1965) consists of the West body, the East body, and the Magnetite body. The West body is layered, and the East body is a small lens with high grade that occurs along breccia and fault zone. The Magnetite body forms as a contact metasomatic unit in breccia and as massive skarn in limestone. The host rocks are the Maggol Limestone of the Ordovician Choseon System that is unconformably overlain by the Late Carboniferous Hongjeom Formation. Igneous intrusions of suspected Mesozoic age intrude the sedimentary rocks. The average grade of the West ore body is 5.38 percent Zn. Reserves are are as much as about 490,000 tonnes. The Magnetite body has estimated reserves of 100,000 tonnes grading 26.16 percent Fe. The deposit is small and has reserves of 590,000 tonnes of ore and an average grade of 5.38 percent Zn, and 26.16 percent Fe.

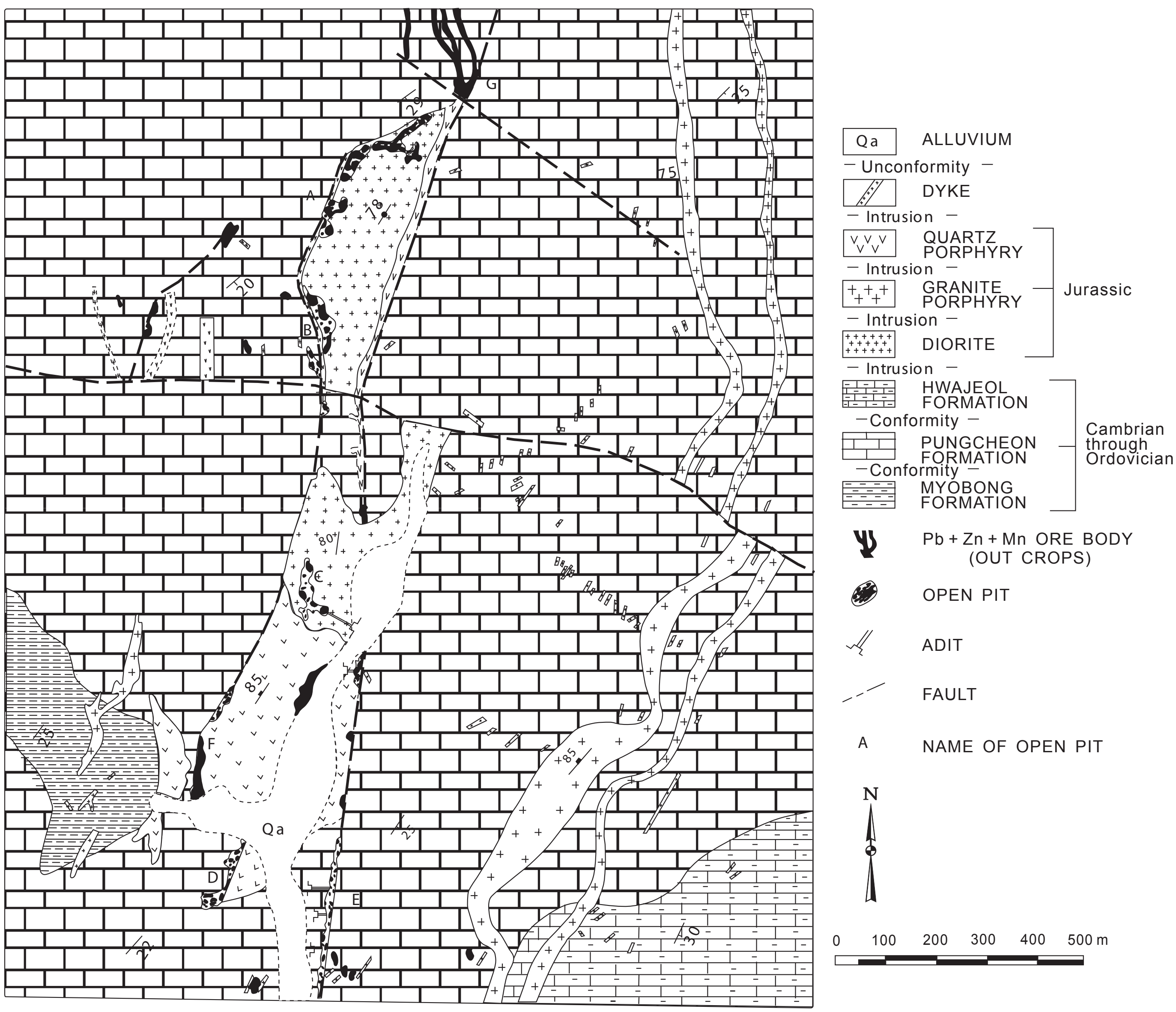


Figure 20. Generalized geologic map of Dongnam Fe-Zn skarn deposit, Taebaegsan metallogenic belt, Korea. Adapted from Seo and others (1983).

Wondong W±Mo±Be Skarn Deposit

This deposit (Hwang, 1997) consists of three types of skarn ore bodies. The skarns occur in Carboniferous-Permian formations and in a lesser Cambrrian and Ordovician formations which are intruded by rhyolite. The Weondong thrust fault occurs in the central part of the mine. A north-soutn-trending fault system cuts an east-west-trending thrust. The Pb+Zn, scheelite and iron (magnetite) ore bodies are present. Twenty-one ore bodies having the cut-off grade of WO_3 of 0.10 percent have been found. The deposit consists of upper and lower ore bodies. The upper Pb-Zn ore body is 1.15 meters thick and has an average grade of 0.56 percent Pb, 3.76 percent Zn, 0.13 percent Cu, 1.03 percent As, 260 ppm Cd, and 25 ppm Ag. The lower ore body is 0.25 meters thick and has an average grade of 0.36 percent Pb, 4.53 percent Zn, 0.42 percent As, 620 ppm Cd, and 60ppm Ag. The Fe-ore body is as much as 3.0 meters thick and has an average grade of 38 percent Fe. Fe mineralization is always associated with scheelite. Scheelite skarn, lead-zinc, magnetite deposits occur in Cambrian limestone formations and have an average grade of 0.48 percent WO_3 and are 2.80 meters thick (for three ore bodies). Stockworks and veinlets of the porphyry Co-Mo deposit occur in rhyolite and have an average grade of 0.51 percent Cu and minor molybdenite. The 15 ore bodies total 23.8 meters thick. The deposit is small and has an average grade of 0.10-0.40 percent WO_3, 0.36 to 0.56 percent Pb, 3.76 to 4.53 percent Zn, and 38 percent Fe.

Sangdong W±Mo±Be Skarn Deposit

This deposit (Moon, 1987) consists of W-Mo minerals that occur in bedded limestone in the Cambrian Myobong Slate Formation. The common skarn minerals are Ca-garnet and clinopyroxene. Abundant quartz veins in the W-Mo skarn indicate that W and Mo were transported in a silicate-rich fluid. A syncline interpreted as being related to emplacement of granitoids includes hidden skarn bodies that may occur along its northern limb. The deposit, which consists of both skarn and quartz veins, is interpreted as having formed over a long period during the Jurassic and Cretaceous. The deposit is large and has an average grade of 77.86 percent WO_3 and 6.49 percent MoS_2.

Seojom Au in Shear Zone and Quartz-Vein Deposit

This deposit (fig. 21) (Hwang and Kim, 1963) consists of veins following a fault zone in the Ochon-dong formation. The Ochon-dong formation consists of sedimentary rock of the lower formation of the Shilla series, Kyongsang system, that is overlain comformably by Shinyangdong formation. These rock formations are intruded by andesite extrusive stocks and younger quartz porphyry. The source of the veins may be the andesite porphyry stocks and quartz porphyry. Several veins are distinctively developed in the mine property. The most promising vein has an average width of 20 cm. The deposit is small and has an average grade of 2.7 g/t Au, 2000 g/t Ag, 18 percent Pb, and 9 percent Zn, resources of 26,150 tonnes, and reserves of 5,150 tonnes.

Origin and Tectonic Controls for Taebaegsan Metallogenic Belt

The belt is interpreted as having formed during intrusion of granitoids associated with Late Jurassic through Early Cretaceous Daebo granite that intruded during the Daebo orogeny. Granite consists of biotite granite, feldspar porphyry, and granite porphyry that intrude Precambrian metasedimentary rocks. The skarn deposits formed during contact metasomatism of calcareous layers in metasedimentary rock.

Tompo Metallogenic Belt of W±Mo±Be Skarn and Sn-W Greisen, Stockwork, and Quartz-Vein Deposits (Belt TO) (Russia, Verkhoyansk-Kolyma Region)

This Neocomian(?) metallogenic belt is related to replacements in the Transverse granite belt that intrudes the south-eastern part of the Verkhoyansk fold and thrust belt. The belt is about 30 km long, 20 km wide, and occurs the east of the southern termination of the Verkhoyansk metallogenic belt that occurs along a sublatitudinal zone of high-angle faults, with probable strike-slip components, that crosscut Permian through Middle Jurassic sandstone and shale that occur in sublatitudinal folds. The major granitoid plutons, with surface areas of less than 2 km^2, occur at Sosukchan and Erikag. Associated with the granitoid plutons are granitoid-dike swarms and contact metamorphism. The belt major deposits are the Agylky Cu-W±Mo±Be skarn deposit, the largest in the belt, and the Erikag and Dzhuptagan cassiterite-silicate-sulfate deposits.

The main references on the geology and metallogenesis of the belt are Shour (1985) and Parfenov and others (1999).

Agylky Cu-W±Mo±Be Skarn Deposit

This deposit (Flerov and others, 1974) consists of pyroxene-garnet-scheelite skarn that occurs in layers of metamsomatized limestone in contact metamorphosed Early Triassic argillite and siltstone. Layers are as much as 3 to 5 meters thick. Three successive metasomatic mineral assemblages occur (1) scheelite-quartz; (2) sulfide; and (3) calcite. Most W occurs in scheelite and, rarely, in wolframite. Main sulfide minerals are pyrrhotite and chalcopyrite. Subordinate minerals are pyrite, arsenopyrite, stannite, sphalerite, galena, native bismuth, and bismuthine. Contact metamorphosed argillite does not contain ore minerals. The deposit occurs on limbs of a brachyform anticline in the thermal aureole of an unexposed granitoid intrusion with numerous apophyses of

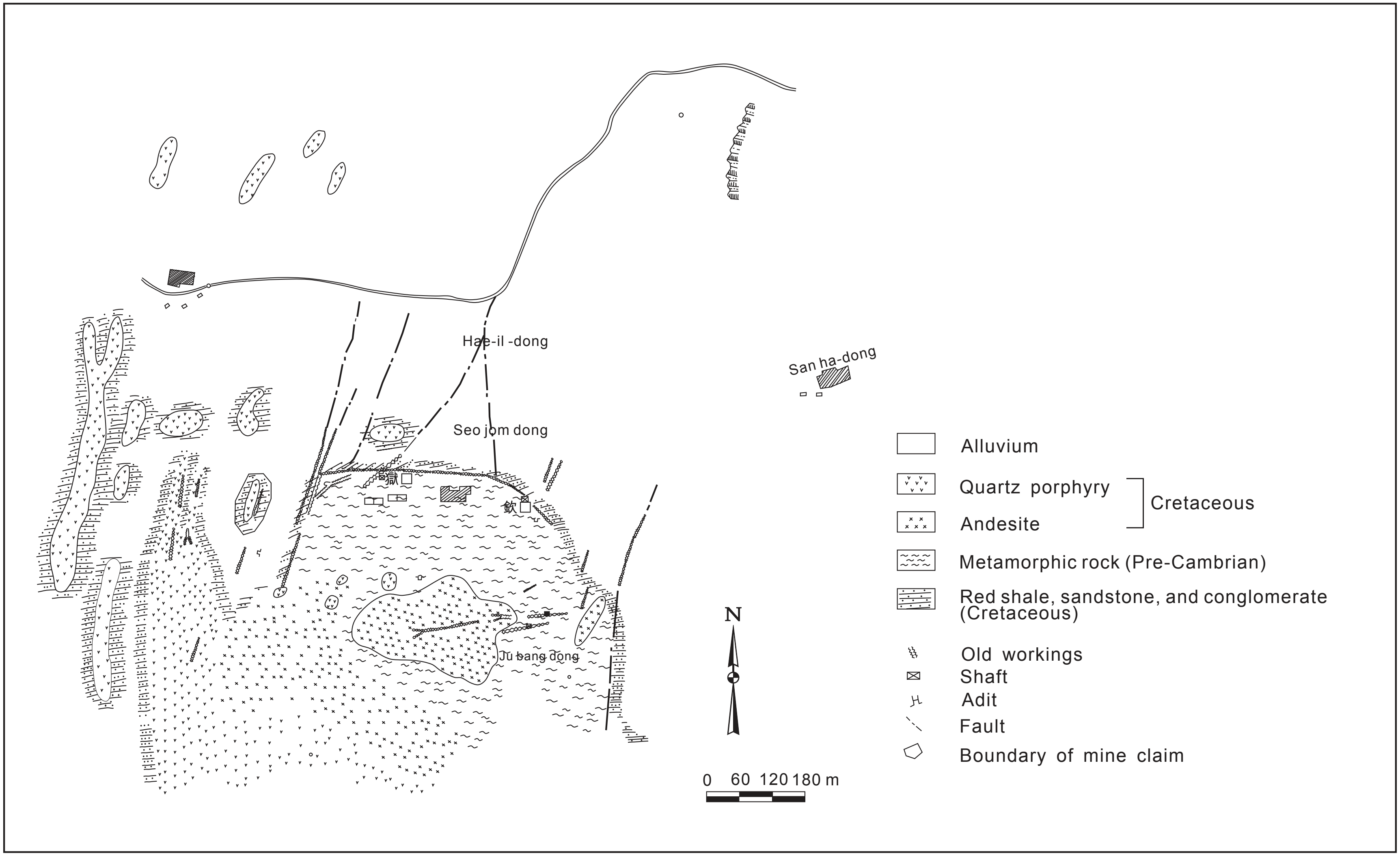


Figure 21. Generalized geologic map of Seojom Au in shear zone and quartz-vein deposit, Taebaegsan metallogenic belt, Korea. Adapted from Hwang and Kim (1963).

granodiorite porphyry dikes. The deposit dips 20 to 35° on anticline limbs. The deposit is medium size.

Erikag Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Flerov and others, 1974) consists of sulfide-quartz veins and stringers in a zone that occurs parallel to bedding. Veins and stringers extend in an east-west-trending band that dips steeply south. Major minerals are quartz, pyrite, and stannite. Subordinate minerals are arsenopyrite, cassiterite, bismuthine, bismuth, chalcopyrite, and sphalerite, and minor pyrargyrite and tetrahedrite. Wallrocks exhibit intense chlorite, sericite, and tourmaline alteration. The deposit is hosted in steeply-dipping, contact metamorphosed sandstone and shale in the contact aureole of the Erikag granodiorite pluton that has a K-Ar isotopic age of 130 to 125 Ma.

Origin and Tectonic Controls for Tompo Metallogenic Belt

The belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and associated regional metamorphism and generation of anatectic granitoids in the Transverse granite belt. The belt occurs along sublatitudinal high-angle, probable strike-slip faults that cut Permian through Middle Jurassic sandstone and shale.

Verkhne-Ingodinsky Metallogenic Belt of Cassiterite-Sulfide-Silicate Vein and Stockwork Deposits (Belt VI) (Russia, Central Transbaikalia)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to veins, volcanic complexes, and replacements related to Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Hangay-Dauria terrane and Selenga sedimentary-volcanic plutonic belt. The belt extends for 175 km, varies from 25 to 50 km wide, and trends northeast. The Late Mesozoic Trans-Baikalian-Daxinganling belt is composed of calc-alkaline and subalkaline volcanic rock of Sokhondinsky and Dzhargalantuy Suites, and calc-alkaline and subalkaline granitoids of the Sokhondinsky, Kyrinsky, Asakan-Shumilovsky, and Kharalginsky. The granite porphyries in these suites host the Sn-W deposits (Ingodinsky and Sokhondinsky deposits). The major deposits are at Ingodinskoye and Levo-Ingodinskoye.

Large cassiterite-sulfide-silicate vein and stockwork deposits occur at Ingodinskoye and Levo-Ingodinskoye. Small deposits occur at Novoye, Sokhondinskoye, Uljurtuoye, Perevalonoye, Ozernoye and, Bukukunskoye. The deposits are controlled by the Ingodinsky fault. The deposits are hosted in brecciated hornfels and siltstone. The deposits consist of (1) a thick network of veins and veinlets filled with cassiterite, arsenopyrite, chalcopyrite, quartz, fluorite, topaz, and muscovite (as at the Ingodinskoye and Levo-Ingodinsoye deposits); (2) pipes of granite porphyry with quartz-cassiterite veins and veinlets; (3) scattered, disseminated pyrite, arsenopyrite, cassiterite, and scheelite; and (4) local areas of a gradation from granite porphyries into veins (Sokhondinskoye deposit). The deposits range from 200 meters to 1 km wide.

The main reference on the geology and metallogenesis of the belt is Semenjuk and Donenko (1964).

Origin and Tectonic Controls for Verkhne-Ingodinsky Metallogenic Belt

The belt is interpreted as being related to magmatism that occurred along transpressional zones related to transform microplate boundaries and within plate (plume) environment. The belt is prospective for undiscovered Sn, W, and As deposits.

Verkhoyansk Metallogenic Belt of Au in Shear Zone and Quartz Vein Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Sn-W Greisen, Stockwork, and Quartz-Vein, and Au in Black Shale Deposits (Belt VK) (Russia, Verkhoyansk-Kolyma orogenic region)

This Late Jurassic through Early Neocomian metallogenic belt is related to veins and replacements in the Verkhoyansk fold and thrust belt (unit NSV). The age of the belt is interpreted as late Late Jurassic and Early Neocomian. The Verkhoyansk belt extends as a narrow (as much as 100 km) band for 1200 km along the western margin of the northern and central sectors of the Verkhoyansk fold and thrust belt. It is made largely of Carboniferous and Permian clastic rocks metamorphosed at greenschist facies. Metamorphism is thought to be related to thrust zones, regional metamorphism or to unexposed granitoid plutons. Initially, the Au deposits were interpreted as being associated with greenschist facies metamorphism. Later, the Au content was found to be low in higher-grade rocks of the biotite subfaces, and that the best Au values were in the muscovite-chlorite subfacies. Metamorphism consists of flow cleavage, recrystallization blastic and thorny structures of the rocks, and by the presence of metamorphogenic quartz, muscovite, and albite. The main deposits of the belt are concordant veins complicated by cross veinlets clustering into stockworks in sandstone beds. The major Au-shear zone deposit is at Djandi.

The main references on the geology and metallogenesis of the belt are Ivensen and others (1975) and Parfenov and others (1999).

Djandi Au in Shear Zone and Quartz-Vein Deposit

This deposit consists of stockworks, veins, and mineralized breccias controlled by sublongitudinal high-angle faults. The stockworks are as much as 900 meters long and 100 meters wide and averaging 20 meters). Concordant and cross-cutting veins are present, and are as much as 80 meters long and 3 meters wide. The veins and stockworks are associated with mineralized breccias. The highest Au values occur in the stockworks is as much as 4.3 g/t. Ag content of the stockworks is as much as 1 g/t. Fineness of Au is 700 to 900 and gold occurs in grains as much as 2 to 3 mm in size. The structure of the deposit area is determined by linear overturned folds and thrusts. Flow cleavage is clearly defined is parallel to thrusts.

The main references on the geology and metallogenesis of the belt are Prokopiev and others (2001) and Fridovsky and Prokopiev (2002).

Kuolanda Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (Ivensen and others, 1975; V. Tseidler, written commun., 1985) consists of a breccia with abundant veins and stringers of massive and disseminated galena and sphalerite that are hosted in Early Carboniferous siltstone and sandstone. The main ore mineral is sphalerite with lesser galena and chalcopyrite. Subordinate minerals are siderite, arsenopyrite, glaucodot, pyrite, melnikovite, pyrrhotite, and native silver. Veins are divided into sulfide and quartz-sulfide types. Some veins are as much as 20 meters long and 0.2 to 0.3 meters thick. Vein zones are as much as as much as 280 meters long and from 1.5 to 10 meters wide. The deposit occurs along the axis of an anticline. The deposit is large and has reserves of 15,000 tonnes Pb and 120,000 tonnes Zn. Average grades are 20 to 30 percent Zn, 2 percent Pb, 1.3 percent Cu, and as much as 953 g/t Ag.

Imtandzha Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Ivensen and Proschenko, 1961; Indolev and Nevoisa, 1974) occurs in a fissure zone that is as much as 500 meters wide, 2 km long, and occurs along the axis of an anticline. Intruding the sedimentary rock are granodiorite porphyry dikes that are associated with the deposit. The dikes cut polymetallic veins and in turn are cut by Sn-sulfide veins. Early-stage Ag-polymetallic veins are mostly conformable. Later-stage veins are mostly cross-cutting, but are less common. Veins range from 0.01 to 0.85 meters thick. Major ore minerals are galena, sphalerite, and siderite. Lesser vein minerals are quartz, tetrahedrite, pyrite, arsenopyrite, and boulangerite. Later-stage veins contain quartz, chlorite, pyrite, arsenopyrite, galena, cassiterite, tourmaline, and stannite and range from 0.1 to 0.6 meters thick. Stringers range from 2 to 3 meters thick and are as much as 1 km long.

Mangazeika 2 Au in Black Shale Deposit

This deposit (fig. 22) (Indolev and Nevoisa, 1974; Kostin and others, 1997) consists of high-angle veins that have a variable dip and strike, and thin or branch into closely-spaced veinlets. The veins are as much as tens of centimeters to 2 to 2.5 meters thick (in swells) and extend from a few meters to tens of meters to 700 to 1,000 meters long. Stock-like swells in veins are as much as 25 to 30 meters thick. Crush zones and closely spaced vein systems also occur. The deposit is discontinous in an area 3 km across and 19 km long and is hosted in Late Carboniferous and Early Permian clastic rock. The deposit contains native Ag, Sb Ag minerals, animikite, allargentum, acanthite, Pb-acanthite, Cu-acanthite, Ag_2S-Cu_2S sulfide series, galena, sphalerite, chalcopyrite, stannite, pyrite, arsenopyrite, bismuthinite, and stibinite. Also occurring are sulfosalts, including fahl, pyrargyrite, miargyrite, diaphorite, owyheeite, polybasite, stephanite, canfieldite, freieslebenite, geocronite, bournonite, boulangerite, gustavite, and Ag-Bi-sulfotelluride. The deposit is interpreted as having formed during Devonian rifting. Metals are interpreted as having been leached from Devonian basalt by sea water that circulated along faults. The deposit is large.

Nikolaevskoe and Otkrytoe Au in Shear-Zone and Quartz-Vein Deposits

The Au quartz-vein deposits at Nikolaevskoe and Otkrytoe (Abel and Slezko, 1988) consist of conformable and cross-cutting quartz veins, with gold, galena, arsenopyrite, pyrite, tetrahedrite, sulfosalts, carbonates, and albite, that are hosted in Early Permian sandstone beds. The veins occur in anticlinal hinges, are as much as 1 km long, and range from 0.2 to 1 meters thick, and are sometimes as much as 10 meters thick. Sulfides comprise as much as 5 percent of the veins. The Au quartz-vein deposits are not economic, but are the source for the placer Au mines of the Verkhoyansk district.

Origin and Tectonic Controls for Verkhoyansk Metallogenic Belt

The belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and associated regional metamorphism during the Late Jurassic through early Neocomian. The belt is hosted mainly in Carboniferous and Permian clastic rocks that are metamorphosed to greenschist facies. Metamorphism is interpreted as being related to thrust zones, regional metamorphism, and (or) unexposed granitoid plutons

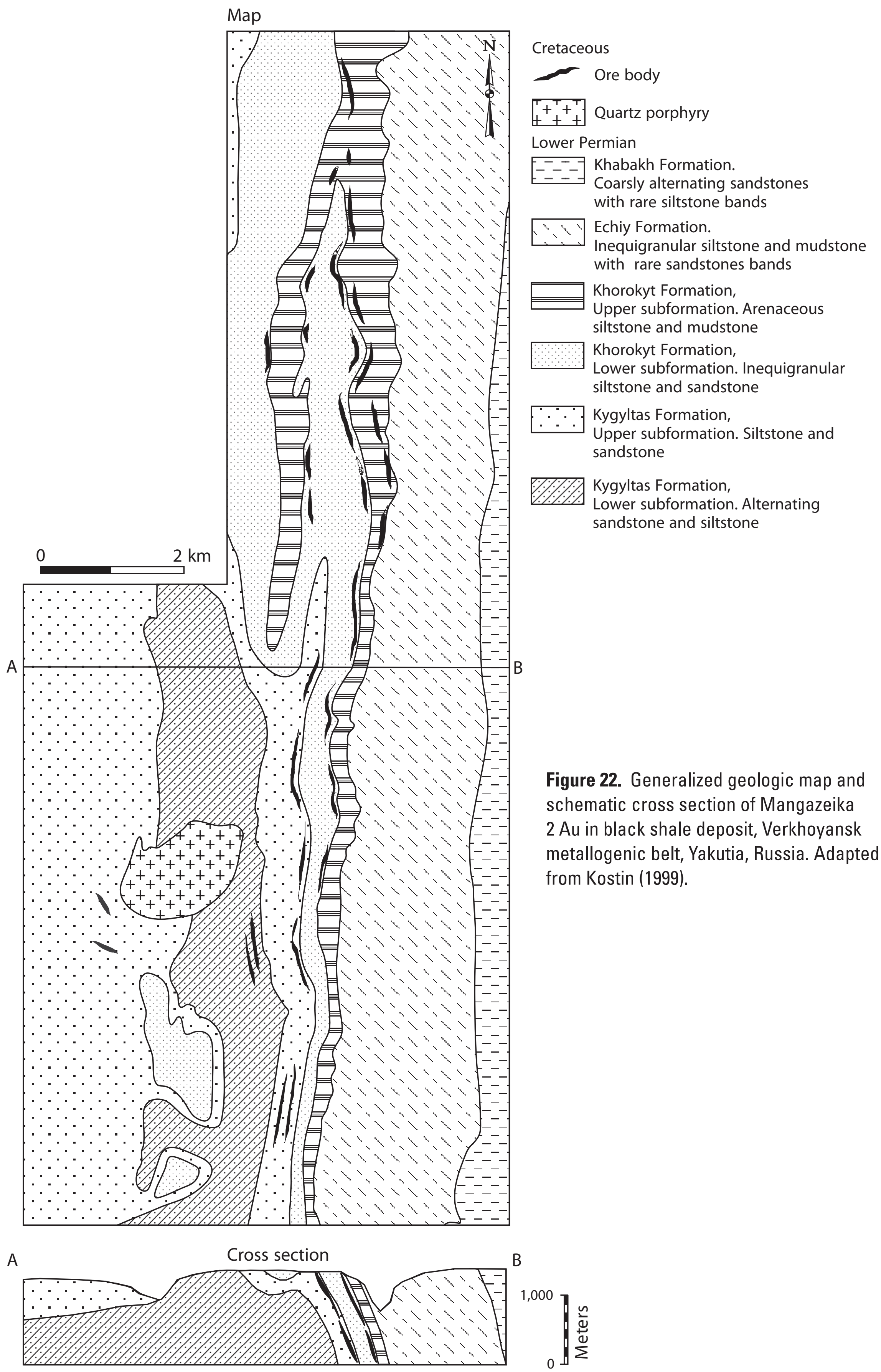


Figure 22. Generalized geologic map and schematic cross section of Mangazeika 2 Au in black shale deposit, Verkhoyansk metallogenic belt, Yakutia, Russia. Adapted from Kostin (1999).

Yana-Adycha Metallogenic Belt of Cassiterite-Sulfide-Silicate Vein and Stockwork and Sn-W Greisen, Stockwork, and Quartz-Vein Deposits (Belt YA) (Russia, Verkhoyansk-Kolyma Region)

This mid-Cretaceous (130 to 123 Ma) metallogenic belt is related to replacements in the Transverse granite belt. The host Transverse granite belt radiates from the southwestern warp of the Kolyma-Omolon superterrane boundary and crosscuts at a high angle older folds and faults of the Verkhoyansk fold and thrust belt. The belt contains the Ege-Khaya, Tirekhtyakh, and Derbeke-Nel'gese districts, each of which is hoted in part of the Transverse granite belt that bears the same name. The districts strike northeast for 150 to 200 km and range from 10 to 30 km wide. Each district contains several tens of Sn deposits and various occurrences. The major deposits are cassiterite-sulfide-silicate vein and stockwork at Ege-Khaya, Ilin-Tas, and Burgochan deposits, and a Sn-W greisen, stockwork, and quartz-vein deposit at Kester.

The main references on the geology and metallogenesis of the belt are Flerov (1974), Shour (1985), Trunilina and others (1985); Parfenov and others (1999), and Nokleberg and others (2003).

Ege-Khaya Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (Flerov, 1974; V. Spomnor and others, written commun., 1985; Shour, 1985) consists of shear zones, stringers, and less common veins that occur in zones that range from 0.7 to 4 meters thick, extend for as much as 1 km long, dip steeply, and extend downdip for about 500 meters. Host rocks are weakly contact metamorphosed Late Triassic shale and interbedded sandstone. Major minerals are quartz, chlorite, cassiterite, sphalerite, pyrrhotite, pyrite, marcasite, siderite, and calcite. Subordinate minerals are arsenopyrite, galena, stannite, chalcopyrite, wolframite, bismuth, tourmaline, and albite. Sulfides are predominant at depth. Wallrocks exhibit chlorite, silica, and sulfide alteration. Average grades are 0.1 to 3 percent Sn and 0.1 to 3 percent Zn. Limited production has occurred. The deposit is medium size.

Kester Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Flerov, 1974; V. Spomnor and others, written commun., 1985; Shour, 1985) consists of greisen with major minerals of quartz, muscovite, albite, K feldspar, molybdenite, zinnwaldite, tourmaline, topaz, amblygonite, apatite, cassiterite, wolframite, and tantaloniobate, and lesser stannite, arsenopyrite, and Pb sulfosalts. Host granite exhibits intense greisen alteration for occurrence of local tourmaline and sulfides. The deposit is irregularly shaped and occurs along the margin of a stock of subalkalic alaskite granite that intrudes the Arga-Ynnakhai granodiorite pluton. The deposit is 80 by 1,200 meters in plan view and extends to a depth of 60 meters. The deposit is small and is partly mined. Average grades are 0.3 percent Sn, and as much as 0.5 percent Nb_2O_5, and 0.35 percent Li_20.

Origin and Tectonic Controls for Yana-Adycha Metallogenic Belt

The belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and occurrence of associated regional metamorphism and generation of anatectic granitoids to form the Transverse granite belt.

Yanshan Metallogenic Belt of Cu (±Fe, Au, Ag, Mo) Skarn, W±Mo±Be Skarn, Porphyry Mo (±W, Bi), Granitoid-Related Au Vein, Polymetallic Pb-Zn±Cu (±Ag, Au) Vein and Stockwork, and Au-Ag Epithermal-Vein Deposits (Belt YS) (Northeast and North China)

This Middle Jurassic through Early Cretaceous metallogenic belt is related to veins, replacements, and small granitoids in the northeastern part of the Sino-Korean craton. The belt occurs in the Yanshan Mountains in North Hebei Province and in an eastern continuation in the West Liaoning Province. The volcanic-plutonic belt consists of Early Jurassic basalt and andesite, Middle Jurassic andesite, dacite, and trachyandesite, Late Jurassic rhyolite and pyroclastic rock, and Early Cretaceous andesite and rhyolite. Most of the volcanic rocks in the belt are calc-alkaline and or alkaline. Plutonic rocks in the belt consist of monzogranite, granodiorite, granite, K-feldspar granite, granite porphyry, and quartz porphyry and are mostly calc-alkaline. The metallogenic belt trends east-west and is about 600 km long and 200 to 250 km wide. The belt forms a shield-shaped area consisting of northeast and north-northeast-trending zones and districts. The belt contains numerous large and superlarge deposits of various types and is one of the most economic regions in North China. The significant deposits in the belt are at Shouwangfen, Yangjiazhangzi, Jinchangouliang, Xiaosigou, Dazhuangke, Caijiaying, and Niujuan.

The main references on the geology and metallogenesis of the belt are Huan (1991), Shi (1994), Deng and others (1996), Lin and others (1998), and Wu and Sun (1999).

Shouwangfen Cu (±Fe, Au, Ag, Mo) Skarn Deposit

This deposit (Xu, Qidong and others, 1993) occurs at the contact zone of the Mesozoic granodiorite and the Neoproterozoic dolomite of the Wumishan Formation. The deposits are lenticular and lensoid in skarn and are stratiform shaped in metasomatized dolomite. Seven skarn zones occur along the contact (1) granodiorite zone, (2) altered granodiorite zone, (3) garnet-epidote-vesuvianite skarn zone, (4) diopside zone, (5) magnetite-humite-diopside skarn zone, (5) wollastonite skarn zone, and (7) serpentinized dolomite zone. The main ore minerals are molybdenite, pyrrhotite, pyrite, sphalerite, galena, chalcopyrite, magnetite, hematite, and scheelite. The ore minerals comprise five types (1) magnetite, (2) pyrite-bearing magnetite, (3) pyrrhotite and Co-bearing chalcopyrite, (4) pyrite-bearing chalcopyrite, and (5) veined chalcopyrite. The ore minerals occur in masses, disseminations, veins, and veinlets, and display idiomorphic, xenomorphic, crashing, colloid textures. Four skarn stages are recognized (1) a scapolite stage with scapolite, wollastonite, vesuvianite, garnet and diopside; (2) a magnetite stage with magnetite, humite, phlogopite, sericite, tremolite, and actinolite; (3) a quartz-sulphide stage with sulphides, chlorite, and sericite; and (4) a carbonate stage with calcite and fluorite. The deposit is medium size and has reserves of 155,300 tonnes Cu grading 0.65 percent Cu.

Yangjiazhangzi W±Mo±Be Skarn Deposit

This deposit (Huan and others, 1994) consists of tabular skarns that occur along the contact zone between the coarse-grained Hongluoshan granite (with a K-Ar isotopic age of 186 to 178 Ma) and Middle Cambrian through Middle Ordovician limestone. The deposit is 500 meters long, 220 meters wide, and extends 600 meters downdip. The main skarn body, is 300 to 800 meters long, 3 to 10 meters thick, and extends 200 to 350 meters downdip. The ore minerals are mainly molybdenite and pyrite, with lesser sphalerite, galena, and chalcopyrite. Molybdenum occurs in disseminations, veinlets, and networks. Skarn is an important alteration and skarn exhibits late-stage pyrite, chlorite, carbonate, and silica alterations. Molybdenum deposition is closely related to silica alteration. Like the Lanjiagou porphyry Mo deposit, this deposit also occurs in the Proterozoic Yanshan Basin zone along the northern edge of the Sino-Korean Plate. The deposit is medium size and has reserves of 32,145 tonnes Mo grading 0.141 percent Mo.

Jinchanggouliang Granitoid-Related Au-Vein Deposit

This deposit (Zhang and others, 1994) occurs in the northwestern outer contact zone of a Mesozoic granodiorite stock. More than 50 Au-bearing altered zones occur in gneiss and amphibolite of the Archean Xiaotazhigou Formation. The zones are generally several hundred meters long and 1 to 5 meters wide and are mostly trend northwest and dip steeply southwest or northeast. The deposit occurs discontinously in these altered zones in layers or lenses. The ore minerals occur mainly in masses and dense disseminations and consist mainly of pyrite, quartz, sericite, chalcopyrite, sphalerite, and galena. Sulphur isotopes of ores are narrowly concentrated around 0. Homogenization temperatures for fluid inclusions in quartz range from 250 to 370°C. A K-Ar isotopic age for a related dike is about 120 Ma. The deposit is large and has reserves of 17.67 tonnes Au grading 13.09 g/t Au.

Caijiaying Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (fig. 23) (Zhang, 1990; Quan, 1994) consists of swarms of dense veins that range from 300 to 1,000 meters long, 1 to 18 meters thick, and extend 400 to 500 meters downdip. The ore minerals occur in masses and disseminations and are sphalerite, galena, pyrite, arsenopyrite, magnetite, hematite, gold, siliver, and electrum, and minor molybdenite, chalcopyrite, and bornite. The gangue minerals are sericite, quartz, and chlorite and sparse barite and calcite. Host rocks contain chlorite, sericite, silica, pyrite, and carbonate alterations. Early chlorite alteration was replaced by later sericite alteration. Adjacent to the deposit, the host rocks display successive wide zones of sericite and chlorite alteration. Fluid inclusion temperatures range from 200 to 350º C. The host rocks for the deposit are fine-grained amphibole gneiss derived from Paleoproterozoic volcanic and sedimentary rocks that are metamorphosed to amphibolite facies. The host rocks occur along a limb of an overturned fold and the deposit is controlled by faults. The deposit is related to a Jurassic and Cretaceous granite porphyry and quartz porphyry dikes and Late Jurassic volcanic rock and is a Mesozoic magmatic hydrothermal system. The deposit is large and has reserves of 1.44 million tonnes Zn grading 4.26 percent Zn and 2.73 percent Pb.

Dazhuangke Porphyry Mo (±W, Bi) Deposit

This deposit (Huan and others, 1994) consists of veins and stockworks in explosive breccia pipes. The main part of the deposit occurs in a pipe that is 350 to 400 meters long and 40 to 90 meters thick. Ore minerals occur in disseminations and veinlets. The main ore mineral is molybdenite with minor magnetite, pyrite, chalcopyrite, sphalerite, and scheelite. Gangue minerals consitute the breccia and are mainly plagioclase, K feldspar, quartz, biotite, fluorite, and sericite. Host rocks are altered to K feldspar, biotitie, silica, pyrite, beresite, zeolite, and propylite. The deposit is related to a Jurassic quartz diorite and quartz monzonite (with a K-Ar isotopicage of 168 to 146 Ma.) and is controlled by east-west-trending fault zones. The deposit is medium size, and the average grade is 0.10 percent Mo.

Niujuan Au-Ag Epithermal-Vein Deposit

This Ag deposit (Liu and Zhang, 1997) is hosted in metamorphic rock of the Proterozoic Hongqiyingzhi Group and the Late Jurassic volcanic rock that are intruded by the medium- to coarse-grained Gangou granite, fine-grained Dongta granite, and Yushugoumen quartz diorite. The granitoids have a U-Pb zircon isotopic age of 245.1 Ma. The main deposit occurs in veins in siliceous breccia controlled by faults. The breccias are very complicated and contain fragments of various granite, quartz veins, feldspar, and quartz. The breccia cement is chalcedony. The deposit exhibits seven stages (1) sericite, (2) siliceous rock (chalcedonite), (3) suphide, (4) pyrite-quartz, (5) purple fluorite, (6) white fluorite, and (7) kaolinite. The second stage is the most important. The main ore minerals are sericite, chlorite, pyrite, quartz, adularia, galena, sphalerite, arsenopyrite, marcasite, chacopyrite, magnetite, native silver, Ag tetrahedrite, fluorite, kaolinite, and quartz. The deposit-forming temperatures range from 220 to 350°C and pressures range from about 12.6 to 26.0 Mpa. These data suggest a hot spring origin. The deposit is medium size and has an average grade of 281 g/t Ag.

Origin and Tectonic Controls for Yanshan Metallogenic Belt

The belt is interpreted as having formed during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic Plate beneath the Eurasian Plate. Related volcanism and plutonism is interpreted as extending from the Late Triassic through the Early Cretaceous. The Au deposits in the belt are herein interpreted as being related to a separate alkaline igneous complex. Some Early Jurassic deposits may occur in the belt, but most of the belt is interpreted as having formed during the Middle Jurassic and Early Cretaceous (Shi, 1994). The metallogenic zones and districts in the metallogenic belt are apparently controlled by the north-northeast and east-west trending major faults. As for other Middle Jurassic and Early Cretaceous metallogenic belts in this region, some authors discuss the origin of the Mesozoic magmatism as related to deep lithosphere processes (Deng and others, 1996; Lin and others, 1998; Wu and Sun, 1999).

Major Cenomanian through Campanian (96 to 72 Ma) Metallogenic Belts

Badzhal-Komsomolsk Metallogenic Belt of Sn-W Greisen, Stockwork, and Quartz-Vein, Cassiterite-Sulfide-Silicate Vein and Stockwork, Cu (±Fe, Au, Ag, Mo) Skarn, and Porphyry Mo (±W, Sn, Bi) Deposits (Belt BK) (Russia, Far East)

This Late Cretaceous metallogenic belt is related to veins and replacements in the Khingan-Okhotsk volcanic-plutonic

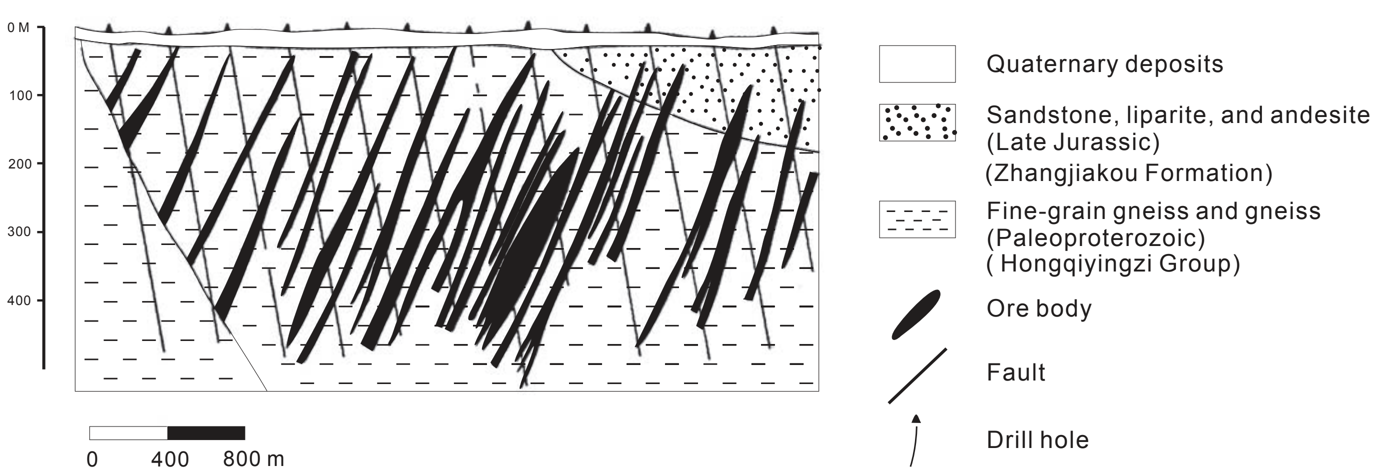


Figure 23. Schematic cross section of Caijiaying polymetallic Pb-Zn±Cu (±Ag, Au) vein and stockwork deposit, Yanshan-2 metallogenic belt, northern China. Adapted from Quan (1994).

belt. The major deposits are at Pravourmiyskoe, Solnechnoe, Festivalnoe, and Sobolinoye.

The main references on the geology and metallogenesis of the belt are Ognyanov (1986), Nokleberg and others (2003), Lebedev and others (1994), and Rodionov (2000).

Solnechnoe Sn-W Greisen, Stockwork, and Quartz-Vein Mine

This mine (fig. 24) (Ognyanov, 1986) consists of numerous highly-altered quartz-tourmaline zone apophyses that occur along, and are related to a long north-south-striking, left-lateral, strike-slip fault. The zone ranges varies from 0.5 to 15 meters thick, is 800 meters long, and extends deep more than 500 meters deep. Five vertically-zoned mineral assemblages occur, from bottom to top: (1) quartz-tourmaline; (2) quartz-arsenopyrite-cassiterite with wolframite, bismuthinite, and scheelite; (3) quartz-sulfide (pyrrhotite, chalcopyrite, and marcasite); (4) quartz-galena-sphalerite; and (5) quartz-carbonate. The deposit is closely related to a K-rich granite phase of a gabbro, diorite, granodiorite complex with a K-Ar isotopic age of 86 to 75 Ma. The deposit is medium size and has an average grade of 0.56 percent Sn, 0.05 percent W, and 0.1 percent Cu. The deposit has been mined since 1960s and is mostly exhausted.

Sobolinoye Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (G.E. Usanov, written commun., 1987; Onikhimovsky and Belomestnykh, 1996) occurs in the northern part of Amusk volcanic basin in a fault-bounded district that covers an area of 5.4 km^2. The deposit is bounded by the Leningradskiy thrust that dips west at a low angle (48°) and contains mylonite tectonic breccias. Along the thrust, folded Jurassic flysh is overthrust by Late Cretaceous andesite, dacite, and rhyolite. Units along the thrust are intruded by Late Cretaceous diorite and quartz-diorite stock and dikes. Sedimentary, volcanic, and intrusive rocks are cut by generally steeply-dipping (60 to 80°) fracture zones that occur in or near the thrust in feathering, strike-slip faults. The deposit contains about ten fracture zones quartz-tourmaline, quartz-sericite, and quartz-chlorite. Zones range as much as 1.1 km long and are about 3 to 7 meters thick, with some as much as 60 meters thick. The deposit contains Sn, W, Cu, Bi, Ag, and economic In. Quartz-tourmaline forms an older mineral assemblage that grades upward into (1) quartz-cassiterite with arsenopyrite; (2) quartz-pyrrhotite-chalcopyrite with stannite, fluorite, and magnetite; (3) quartz-galena-sphalerite; and (4) quartz-fluorite-calcite. Host rocks are generally altered to quartz-sericite and quartz-chlorite alteration in the upper parts of the deposit. The deposit is large and has an average grade of 0.3-0.7 percent Sn, 0.53 percent Cu, 0.06 percent WO_3, and 0.014 percent Bi.

Pravourmiskoe Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (fig. 25) (Ognyanov, 1986) consists of disseminations and veins that occur in a linear area more than 1,500 meters long and 5 to 25 meters thick that extends several hundred meters down dip. An earlier ore assemblage consists of quartz-topaz-cassiterite with fluorite, and a later assemblage consists of quartz-arsenopyrite-chalcopyrite, and quartz-tourmaline with cassiterite and stibnite. The deposit contains Sn, W, and Cu; Bi, Pb, and Sb. Gangue-mineral assemblages are quartz-siderophyllite (zwitters) with quartz-topaz greisen. The deposit occurs along an east-west-trending thrust fault with small offset, and is hosted in, and is genetically related to Late Cretaceous felsic volcanic rock that overlie the large, shallow, granite and leucogranite complex of the Verkhneurmiisky batholith with K-Ar isotopic ages of 85 to 75 Ma. The granite has a Rb-Sr isochron age of 95 to 83 Ma and an initial Sr ratio of 0.703 to 0.708. The deposit is medium size and has an average grade of 0.1 to 5 percent Sn, 0.05 percent $W0_3$, and 0.5 percent Cu.

Origin and Tectonic Controls for Badzhal-Komsomolsk Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along the Khingan transform continental-margin arc that is related to oblique subduction of ancestral Pacific Ocean Plate. The Khingan-Okhotsk volcanic-plutonic belt, that hosts the metallogenic belt, is divided into two main sequences (1) Berriasian through Cenomanian calc-alkalic andesite and minor tholeiitic basalt, with coeval gabbro, diorite, and granodiorite; and (2) Late Cretaceous (mainly preSenonian) K-rich felsic volcanic rock, tuff, and ignimbrite, and coeval subvolcanic intrusive and granitoids plutons. The Cretaceous granitoids include granite, leucogranite, and composite gabbro, diorite, granodiorite that are coeval and comagmatic with volcanic rock. Both suites exhibit high K contents. The Khingan-Okhotsk belt overlies the Turan and Malokhingask terranes of the Bureya continental-margin arc superterrane and the Badzhal and Ulban subduction-zone terranes.

Chelasin Metallogenic Belt of Sn-B (Fe) Skarn (ludwigite), Granitoid-Related Au Vein, Cu (±Fe, Au, Ag, Mo) Skarn, Porphyry Cu-Mo (±Au, Ag), and Porphyry Cu (±Au) Deposits (Belt CH) (Russia, Far East)

This Late Cretaceous through Paleocene metallogenic belt is related to replacements and granitoids that are part of the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies North Asian craton and Uda volcanic-plutonic belt. The belt contains several types of granitoid-related deposits. The main deposit is at Chelasin.

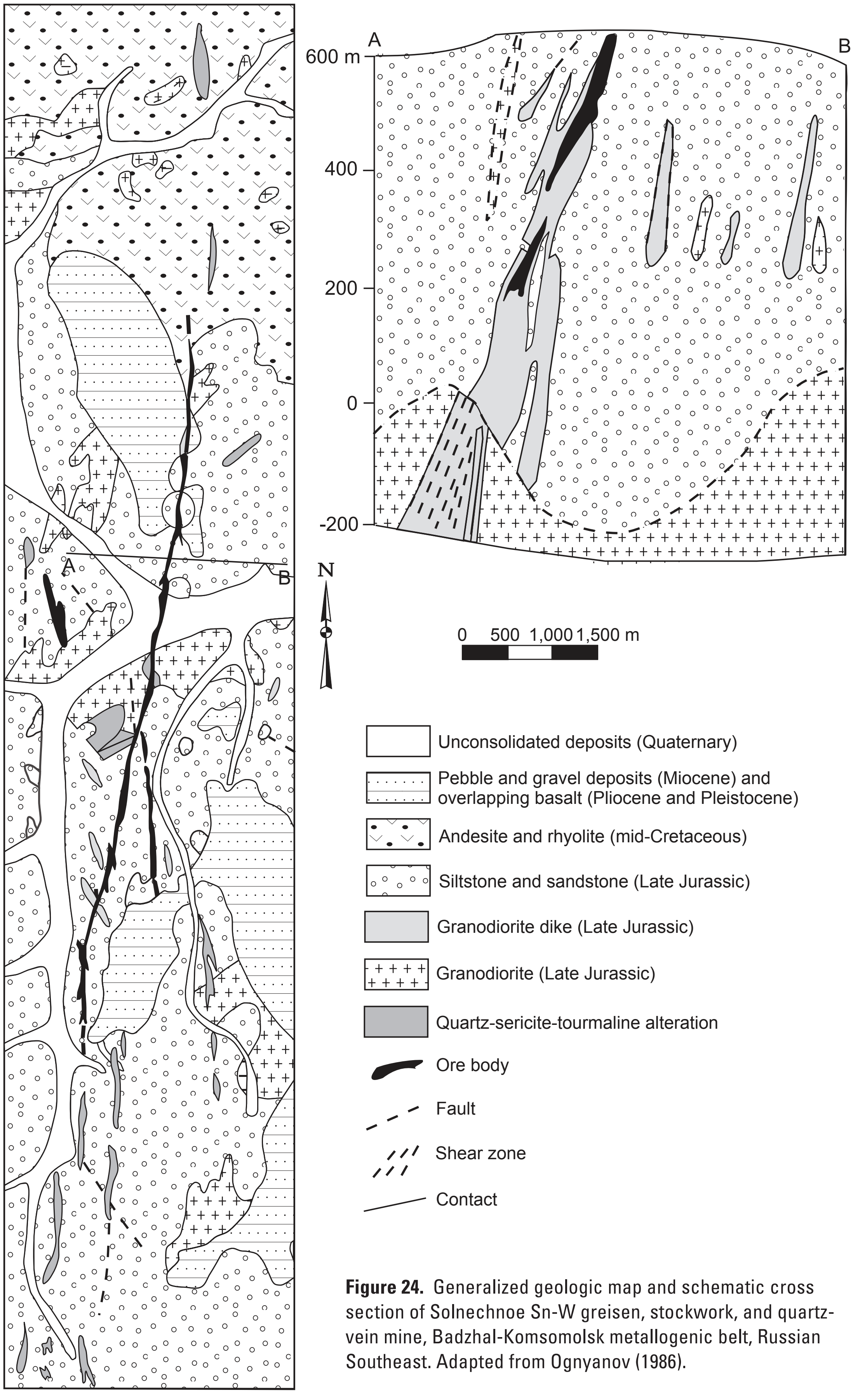


Figure 24. Generalized geologic map and schematic cross section of Solnechnoe Sn-W greisen, stockwork, and quartz-vein mine, Badzhal-Komsomolsk metallogenic belt, Russian Southeast. Adapted from Ognyanov (1986).

The main reference on the geology and metallogenesis of the belt is S.M. Rodionov, A.A. Cherepanov, and E.V. Kurbatov, written commun. (1994).

Chelasin Porphyry Cu (±Au) Deposit

This deposit (S.M. Rodionov, A.A. Cherepanov, and E.V. Kurbatov, written commun., 1994) consists of 42 stockwork zones and some quartz-sulfide veins. The zones occur in a single tract that extends about 2.5 km. One zone was dissected by three trenches, varies from 10 to 28 meters thick, and extends more than 700 meters according to geophysical data. The zone splits into several branches at the flanks. The host rocks consist of dacite and andesite flows and numerous dikes of rhyolite, andesite, diorite porphyry, and granodiorite that display silica and propylitic alteration. A K-Ar isotopic age for the altered rock is 67 to 64 Ma years. The deposit is unexplored. Average grades are 1.0 to 9.4 percent Cu, and as much as 10.0 g/t Au, 1,119.0 g/t Ag, 3.0 percent Pb, and 3.0 percent Zn.

Origin and Tectonic Controls for Chalasin Metallogenic Belt

The belt is herein interpreted as having formed during generation of granitoids along an active continental-margin arc consisting of the Albian through Late Cretaceous Okhotsk-Chukotka volcanic-plutonic belt.

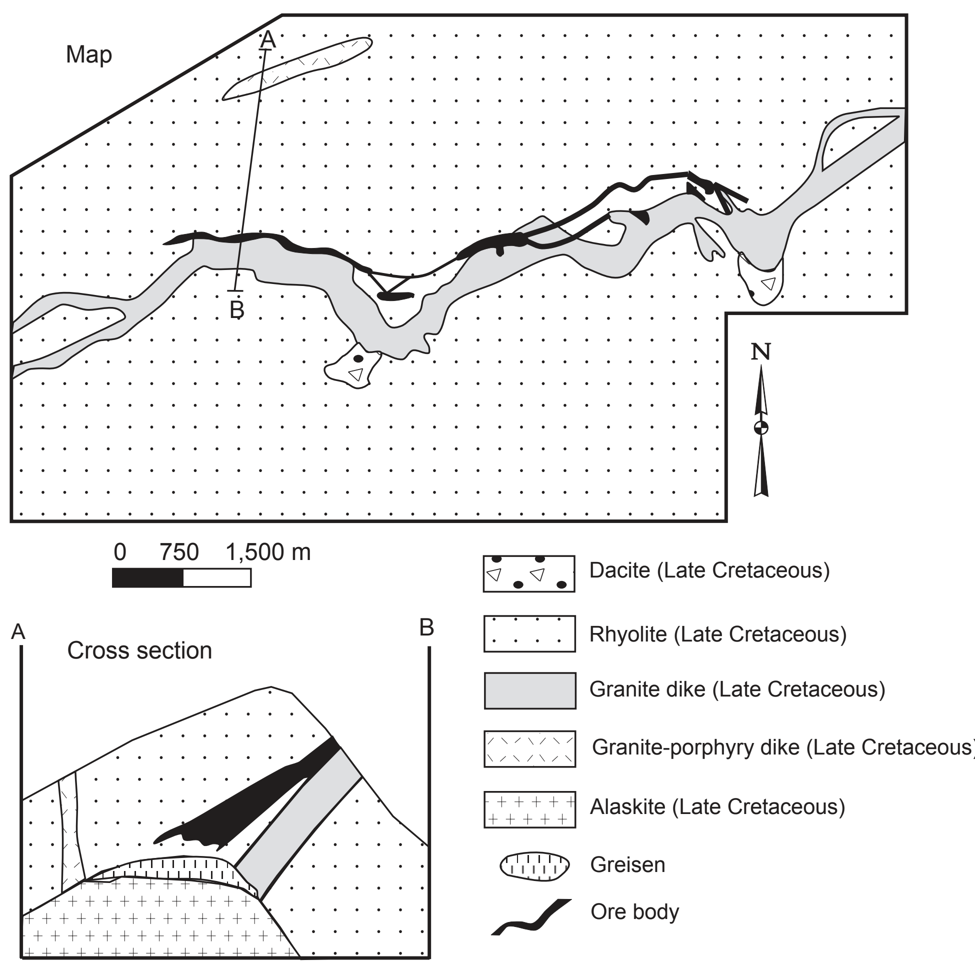


Figure 25. Generalized geologic map and schematic cross section of Pravourmiskoe Sn-W greisen, stockwork, and quartz-vein deposit, Badzhal-Komsomolsk metallogenic belt, Russian Southeast. Adapted from Ognyanov (1986).

Central Polousny Metallogenic Belt of Cassiterite-Sulfide-Silicate Vein and Stockwork and Sn-W Greisen, Stockwork, and Quartz-Vein Deposits (Belt CP) (Russia, Verkhoyansk-Kolyma Region)

This Aptian through Late Cretaceous metallogenic belt is related to veins and replacements related to the Northern granite belt that intrudes the Polousny-Debin subduction-zone terrane. The metallogenic belt covers an area of 450 by 150 km in the central part of the Polousny synclinorium that contains complexely-deformed Jurassic flysch that is intruded by granitoids in the western part of the Northern granite belt. The granitoids have $^{40}Ar/^{39}Ar$ isotopic ages of 130 to 120 Ma. The deposits are related to a Late Cretaceous REE and similar subalkali granitoids that occur in small stock-like bodies. The belt contains large Sn deposits as at Deputatskoye deposit, which is the largest in Russia. The major deposits are at Deputatskoye, Odinokoye, and Polyarnoe.

The main references on the geology and metallogenesis of the belt are Flerov and others (1971, 1979), Indolev and Nevoisa (1974), and Nokleberg and others (2003).

Deputatskoe Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Flerov, 1974) contains about 150 separate bodies in shear zones, veins, and linear stockworks. The deposit ranges as much as 18 meters thick and 1,400 meters long. The major minerals are quartz, tourmaline, chlorite, axinite, fluorite, pyrrhotite, cassiterite, chalcopyrite, pyrite, siderite, ankerite, sphalerite, galena, marcasite, wolframite, stannite, franckeite, boulangerite, bismuth, bismuthine, topaz, apatite, scheelite, and sulfosalts. The main part of the deposit is explored to depths of more than 350 meters by adits and drillholes. The wallrocks are altered to silica, tourmaline, chlorite, and less commonly to greisen and sulfides. The deposit is hosted in contact metamorphosed Middle Jurassic shale and in an unexposed granite stock that is penetrated by drilling at 377 meters depth. The stock has a K-Ar isotopic age of 108 Ma. Widespread are predeposit, coeval, and postdeposit mafic, intermediate, and felsic dikes. Abundant polymetallic veins occur in felsic and intermediate dikes. The deposit is large and has an average grade of 0.3 to 0.7 Sn and locally as much as 10 percent Sn.

Origin and Tectonic Controls for Central Polousnyy Metallogenic Belt

The belt is interpreted as having formed during postaccretionary extension related to initiation of opening of the Eurasia Basin. The belt is associated with REE and subalkali granitoids that occur in small stocks in the western sector of the Northern granite belt. The deposits are related to Late Cretaceous REE and compositionally similar subalkali granitoids in small stocks that intrude the Polousnyi-Debin subuction zone terrane that consists of complexely deformed Jurassic flysch.

Chokhchur-Chekurdakh Metallogenic Belt of Cassiterite-Sulfide-Silicate Vein and Stockwork Deposits (Belt CC) (Russia, Verkhoyansk-Kolyma Region)

This Aptian through Late Cretaceous metallogenic belt is related to veins and replacements in the Jurassic Svyatoi Nos volcanic belt. The belt extends longitudinally for 250 km and occurs in a discontinuous chain of small uplifts in Cenozoic deposits of the Primorsk lowlands. The uplifts consist of horizontal Late Jurassic volcanic and sedimentary rock that is intruded by granodiorite, amphibole-biotite granite, and subalkali granite. The granitoids have $^{40}Ar/^{39}Ar$ isotopic ages of 106 to 105 Ma and are classified as intraplate formations that intruded during extension. Small fields of Late Cretaceous dacite and rhyolite are associated with subvolcanic bodies that contain Sn deposits. The metallogenic belt is characterized by cassiterite-silicate-sulfide deposits in the northern part and by cassiterite-quartz deposits in the southern part. Also occurring are polymetallic and Sb deposits also occur. The major deposits are at Churpunya and Chokurdakh.

The main reference on the geology and metallogenesis of the belt is Parfenov and others (1999).

Churpunya Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (Zelenova, 1990; Drobot and others, 1993) is the best known in the metallogenic zone and is hosted in Late Cretaceous volcanic and plutonic rocks. At the base of the section are stratabound tuff, lahar breccia, and andesite lava that grade upward into lava breccia, tuff, and tuffaceous sandstone. These units are overlain by lavas of rhyolite and dacite and are intruded by explosive breccia veins and a rhyodacite that form the core of a paleovolcano. The deposit is associated with intrusion of steeply dipping, subvolcanic, dacite dikes that contain intense quartz-tourmaline metasomatite, intrusion of rhyolite dikes and formation of Sn deposits. The deposit consists of veins, crush zones, veinlets, and disseminations, and it occurs along extensive shear zones that strike sublatitudinally. The deposit contains a productive cassiterite-quartz stage, a pyrrhotite-chalcopyrite (sulfide) stage, and a final sulfosalt-carbonate stage. Most of the Sn reserves (about 90 percent) are in a central zone. Associated ore minerals are wolframite and Bi minerals. A general facies-stage zonation consists of occurrence of the sulfide stage in the central zone. At depth in the western section are areas of voluminous disseminated Cu-Sn minerals and quartz that are not explored. Associated with hypergene alteration of the sulfide minerals is formation of secondary sulfide zones with rich chalcocite.

Origin and Tectonic Controls for Chokhchur-Chekurdakh Metallogenic Belt

The belt is interpreted as having formed during postaccretionary extension related to initiation of the opening of the Eurasia Basin. The belt occurs along the Yana fault and is hosted in granodiorite, amphibole-biotite granite, and subalkali granite that form part of Svyatoy Nos magmatic arc. Geochemical analyses indicate intraplate formation of granitoids during extension.

Eckyuchu-Billyakh Metallogenic Belt of Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, Clastic-Sediment-Hosted Sb-Au, Hg-Sb-W Vein and Stockwork, Ag-Sb Vein, and Au-Ag Epithermal-Vein Deposits (Belt EB) (Russia, Verkhoyansk-Kolyma Region)

This Aptian through Late Cretaceous metallogenic belt is related to veins and replacements related to the Transverse granite belt that intrudes the Verkhoyansk fold and thrust belt in the North Asian cratonal margin. The metallogenic belt occurs in the central, deeply-subsided part of the fold and thrust belt in the Sartang synclinorium, extends longitudinally for 350 km, and is as much as 150 km wide. The belt is hosted in Permian, Triassic, and Early to Middle Jurassic marine clastic rocks that are deformed into large, simple, linear folds that trend longitudinally. The clastic rocks are intruded by granitoid stocks and dikes of various composition that generally occur at the terminations of the Transverse granitoid belt. Along the western margin of the metallogenic belt is the Khoboyatu-Echiy granite pluton with a $^{40}Ar/^{39}Ar$ isotopic age of 97 Ma. The metallogenic belt contains mainly epithermal deposits that are younger than the granitoids and adjacent contact-metamorphic rocks. The major deposits are at Prognoz, Billyakh, Zvyozdochka, Mugurus, and Betyugen.

The main references on the geology and metallogenesis of the belt are Indolev and others (1980), Shour (1985), Gamyanin and others (1998), and Parfenov and others (1999).

Prognoz Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (E. Vladimirtseva, written commun., 1985; Alekseenko and others, 1991) consists of long and thin sulfide-carbonate veins in Triassic clastic rock. The major ore minerals are siderite, galena, pyrargyrite, owyheeite, various Ag minerals, and sphalerite and in granite porphyry dike. The deposit is a large world-class deposit and has average grades of 3 percent Pb, 1 percent Zn, and as much as 600 g/t Ag, and probable resource of more than 2,000 tonnes Ag.

Zvyozdochka Clastic Sediment-Hosted Hg±Sb Deposit

This deposit (Maslennikov, 1977; Klimov, 1979; V. Maslennikov, written commun., 1985; Shour, 1985) is hosted in intercalated Triassic sandstone and siltstone that is deformed into small folds that strike roughly north-south. The deposit is 0.2 to 11 meters thick, dips west at 70 to 75°, and occurs along a fault that cuts an anticlinal axis. The margin of the deposit is not distinct and is defined by geochemical channel sampling. The major host lithology is sandstone along the western limb of an anticline. Cinnabar is the major ore mineral and native Hg occurs at depths greater than 100 meters. Other minor ore minerals are metacinnabarite, pyrite, maracasite, galena, sphalerite, chalcopyrite, and arsenopyrite, and rare stibnite, Au, and Ag. Gangue minerals are quartz, ankerite, calcite, dickite, and kaolinite. Wallrocks exhibit intense silica, dickite, and carbon alterations. The deposit is medium size and it has an average grade of 1.5 to 1.95 percent Hg, and it has reserves of 3,712 tonnes Hg.

Origin and Tectonic Controls for Eckyuchu-Billyakh Metallogenic Belt

The belt is interpreted as having formed during postaccretionary extension related to initiation of opening of the Eurasia Basin. The belt hosted in granitoid stocks and dikes of various compositions that occur at the terminations of the Transverse granitoid belt. The metallogenic belt occurs in the central, subsided part of the Verkhoyansk fold and thrust belt along the margins of the Sartang synclinorium. The granitoids intrude Permian, Triassic, and Early to Middle Jurassic marine clastic rock. The granitoids have $^{40}Ar/^{39}Ar$ isotopic ages that are older than 120 Ma. Near the western margin of the metallogenic belt is the Khoboyatu-Echiy granite pluton with a $^{40}Ar/^{39}Ar$ isotopic age of 97 Ma.

Ezop-Yam-Alin Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz Vein, Sn-W Greisen, Stockwork, and Quartz Vein, Cassiterite-Sulfide-Silicate Vein and Stockwork, and Porphyry Mo (±W, Sn, Bi) Deposits (Belt EY) (Russia, Far East)

This Late Cretaceous metallogenic belt is related to veins and replacements associated with the Khingan-Okhotsk volcanic-plutonic belt. The deposits occur mainly along the contacts large granite and leucogranite intrusions. K-Ar isotopic ages indicate the Sn deposits and related Sn granite formed between 100 to 75 Ma. The major deposits are at Ippatinskoe, Olgakanskoe, and Shirotnoe.

The main references on the geology and metallogenesis of the belt are Vrublevsky and others (1988), Nokleberg and others (2003), Nechaev and others (1996), and Sengor and Natal'in (1996).

Ippatinskoe Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Ognyanov, 1986) consists of veins and selvages in the northern part of a large granitic body. Sixty-five veins are recognized. The veins range from 2 cm to 2 meters wide, extend as much as 290 meters along strike, and are prospected to a depth of 100 meters. The veins occur in a north-south-trending zone that is 3,000 meters long and as much as 300 meters wide. Ore minerals are cassiterite, wolframite, and arsenopyrite, and rare chalcopyrite, pyrite, scheelite, sphalerite, and molybdenite, and very rare bismuthinite and beryl. Gangue minerals are quartz, muscovite, feldspar, fluorite, and rare tourmaline. The deposit contains minor Cu, Ph, Sb, Pb, and Au. The deposit is related to a fine-grained leucogranite with a K-Ar isotopic age of 90 7 to 5 Ma. The deposit is small and has average grades of 0.31 percent Sn and 0.19 percent WO_3 in the 6 largest veins.

Lednikovy-Sarmaka W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (A.I. Bukhanchenko, written commun., 1988) occurs in an apical portion of a Late Cretaceous granite pluton and granite-porphyry dikes that intrudes sandstone and siltstone. The deposit consists of a linear stockwork that is as much as 2 km long and about 300 meters wide. The stockwork is composed of quartz and fluorite-topaz-quartz veins and veinlets that vary from 1.0 to 30.0 cm thick and that occur in an altered zone that contains greisen, chlorite-quartz, and sericite-chlorite-quartz metasomatite. The major minerals are quartz, muscovite, wolframite, arsenopyrite, pyrite, and chalcopyrite. The ore minerals comprise 5 to 40 percent of the veins. The deposit is large and has resources of 41,000 tonnes WO_3 and 28,000 tonnes Cu. The average grades are 0.37 percent (0.31 to 0.43 percent) WO_3, and 0.18 percent (0.14 to 0.21 percent) Cu.

Origin and Tectonic Controls for Ezop-Yam-Alin Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along the Khingan transform continental-margin arc consisting of the the Khingan-Okhotsk volcanic-plutonic belt. The arc is tectonically linked to oblique subduction of ancestral Pacific Ocean Plate. Fragments of this plate are interpreted as occurring in tectonically interwoven units of the Amur River (AM), Khabarovsk (KB) (younger Early Cretaceous part), and Kiselevka-Manoma subduction-zone terranes. This tectonic linkage is based on (1) occurrence of subduction-zone terranes outboard (oceanward) of, and parallel to, the various parts of the Khinghan arc; (2) formation of melange structures during the Early and Middle Cretaceous; and (3) where not disrupted by extensive Cretaceous movement along the Central Sihote-Aline strike-slip fault, dipping of melange structures and bounding faults toward and beneath the igneous units of the arc. Formation of the Khingan-Okhotsk magmatic arc is related to subduction that is generally interpreted as having ended in the late mid-Cretaceous when oblique subduction changed into sinistral-slip faulting along the outboard margin of the arc.

Gyeongnam Metallogenic Belt of Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite, Fe Skarn, W-Mo-Be Greisen, Stockwork, and Quartz Vein, Porphyry Mo (±W, Sn, Bi), Cu-Ag Vein, Au in Shear Zone, and Quartz-Vein Deposits (Belt GN) (South Korea)

This metallogenic belt is hosted in Yeongnam Metamorphic Complex (part of Sino-Korean craton, Yeongnam granulite-paragneiss terrane), Gyeongsang Supergroup, and the Late Cretaceous Bulgugsa Granite. The age range of the belt is interpreted as being Cenomanian through Campanian (96 to 75 Ma). The Yeongnam metamorphic complex consists of leucogranite gneiss, hornblende plagioclase gneiss, biotite gneiss and schist of Wonnam Formation. The Gyeongsang Supergroup consists of shale and sandstone of the Hadong and Sindong Groups and volcanic rock of Yucheon Group that are intruded by Late Cretaceous Bulgugsa biotite granite, granodiorite, anorthosite, porphyry, and felsic and quartz porphyry dikes. The major deposits are at Cheolma, Gwymyeong, Mulkum, Kuryong, Ulsan, Goseong, Tongyoung, and Haman-Gunbuk.

The main references on the geology and metallogenesis of the belt are Hwang and Kim (1962), Park (1963), Hwang (1963), Kim and Kim (1977), and Park and others (1988).

Cheolma Au in Shear Zone and Quartz-vein deposit

This deposit (Hwang and others, 1989) consists of gold-bearing quartz veins following fault shear zones, joints, and fractures. Host rocks are Cretaceous andesitic rocks, lapilli tuffs, rhyolitic tuffs and felsophyre intruded by Cretaceous granodiorite, hornblende granite, biotite granite and aplite. Veins trend N20-40°W, dip 70-85°NE, and range in length and width 65 to 130 meters and 1.0 to 1.5 meters, respectively. Ore minerals are chalcopyrite, galena, sphalerite, pyrite, pyrrhotite and magnetite. The deposit is small and has resources of 98,700 tonnes grading 0.5 to 1.3 g/tAu, 2 to 30 g/t Ag, and 0.5 to 3.01 percent Cu.

Goseong Cu-Ag Vein Mine

This mine (Park and others 1988) is hosted in Cretaceous greenish grey shale and sandstone of the Jindong Formation and rhyolite tuff of Yucheon group that are intruded by late Cretaceous granodiorite. The deposit occurs along fissures and a fault-shear zone. The ore minerals consist of arsenopyrite, pyrite, sphalerite, chalcopyrite and galena. The mine is small and it has produced 6,900 tonnes of ore from 1929 to 1964 grading 2.6 to 10.0 percent Cu, 1.2 to 10 g/t Au and 65 to 300 g/t Ag.

Gwymyeong Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (Hwang and others, 1989) is hosted by Cretaceous tuffaceous rock and Late Cretaceous andesite and diorite. The deposit occurs along fissures and shear zones in andesite and diorite. The width, length, and depth of veins are 0.3 to 1 meters, 60 to 120 meters, and 90 to 200 meters, respectively. Ore minerals are chalcopyrite, galena, and sphalerite. The deposit is small with reserves of 6,080 tonnes of ore grading 6.8 percent Pb, 9.2 percent Zn, 1.3 percent Cu, 1.1 g/t Au, and 94.83g /t Ag.

Haman-Gunpuk Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (Kim and Kim, 1977) is hosted in light-gray chert of the Cretaceous Jindong Formation. The deposit consists of fissure-filling hydrothermal veins composed of Cu sulfide, specularite, and tourmaline. Sixteen veins crop out at the surface. Drilling reveals that the C and M veins are economic. The C vein is 0.1 to 1.2 meters wide, 130 meters long, and 120 meters deep, and has reserves of 34,920 tonnes grading 0.89 percent Cu. The M vein is 0.5 to 3.3 meters wide, 160 meters long, and 75 meters deep, and has reserves of 77,992 tonnes of ore grading 0.83 percent Cu. The deposit is medium size and has reserves of 112,912 tonnes of ore grading 0.86 percent Cu.

Kuryong Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Mine

This mine (fig. 26) (Park, 1963; Kim and Oh, 1966) is hosted in a Cretaceous granite porphyry that intrudes widespread limestone of unknown age. Associated with the granite porphyry is a succession of intrusive andesite, agglomerate, pyroxene andesite, masanite, quartz-feldspar porphyry, and altered andesite. The intrusive andesite is partly covered by the agglomerate that forms an extrusive phase. The pyroxene andesite forms a bedded flow. The deposit is mainly sulfide veins and propylitic, hydrothermal alteration zones. Quartz monzonite intrudes both the andesite and the altered andesitic. Quartz-feldspar porphyry occurs only in drill cores. The altered zone occurs in both andesite and agglomerate. The alteration is contemporaneous with, or postdates a quartz monzonite intrusion. Propylitically-altered rocks are green-grey, weathered to light grey, and contain a fine-grained pyrite in disseminations. Chlorite, epidote, sericite, kaoline, calcite, quartz, and pyrite are extensively developed in the propylitic zone. The intensity of alteration and pyrite content increases with proximity to veins. The deposit is small amd has resources of 413,280 tonnes of ore grading 41.6 percent Fe, 0.11 percent S, and 0.04 percent P.

Mulkum Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Mine

This mine is (Hwang and Kim, 1962) hosted in a Cretaceous feldspar porphyry that was intruded by an extensive Late Cretaceous biotite granite. The deposit consists of a magnetite metasomatite that occurs in fissure fillings. The ore minerals are magnetite, pyrite, chalcopyrite, galena, and sphalerite. The average width of veins ranges from 1 to 6 meters, and the average length ranges from 44 to 250 meters. The average depth ranges from 70 to 150 meters. The deposit is small a nd has reserves of 1,741,875 tonnes of ore. The average grades are 60 percent Fe, 13.61 percent SiO_2, 0.12 percent S, 0.26 percent P, and 0.006 percent TiO_2.

Tongyoung Cu-Ag Vein Mine

This mine (Park and others 1988) is hosted in the Cretaceous andesite and andesitic tuff breccia of the Yucheon group that are intruded by a Late Cretaceous quartz porphyry and diabase. The veins occur along fissures and shear zones in andesite, andesite tuff breccia, and quartz porphyry. The ore minerals are chalcopyrite, pyrite, galena, sphalerite, electrum, and argentite. The deposit is small and has a production of 5,000 tonnes of ore grading 0.3 to 5.5 g/t Au, 15 to 366 g/t Ag, and 0.2 to 1.2 percent Cu.

Ulsan Fe Skarn Mine

This mine (Hwang, 1963) is hosted in limestone and serpentine of unknown age and Cretaceous slate, hornfels, and biotite granite. The Fe skarn occurs along the bedding limestone, or on the contact zone between limestone and serpentinite. The ore minerals are magnetite, chalcopyrite, sphalerite, galena, pyrrhotite, and arsenopyrite. Drilling revealed several deposits that have a lenticular shape and vary from 170 to 180 meters long and are 140 meters wide and 80 meters deep. The deposit is medium size and has reserves of 1,708,400 tonnes of ore grading 43 percent Fe and 0.02 percent Pb.

Origin and Tectonic Controls for Gyeongnam Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids during the Late Cretaceous through Early Tertiary Bulgugsa orogeny. The deposits occur along the fissures and shear zones and formed during intrusion of Bulgugsa granite (biotite granite, granodiorite, and quartz-porphyry).

Gyeongpuk Metallogenic Belt of Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, W-Mo-Be Greisen, Stockwork, and Quartz-Vein, Sn-W Greisen, Stockwork, and Quartz Vein, Fe Skarn, and Polymetaliic Ni Vein Deposits (Belt GP) (South Korea)

This metallogenic belt is hosted in the Yeongnam Metamorphic Complex, Gyeongsang Supergroup, Yeongnam granulite-paragneiss terrane, that is part of the Sino-Korean

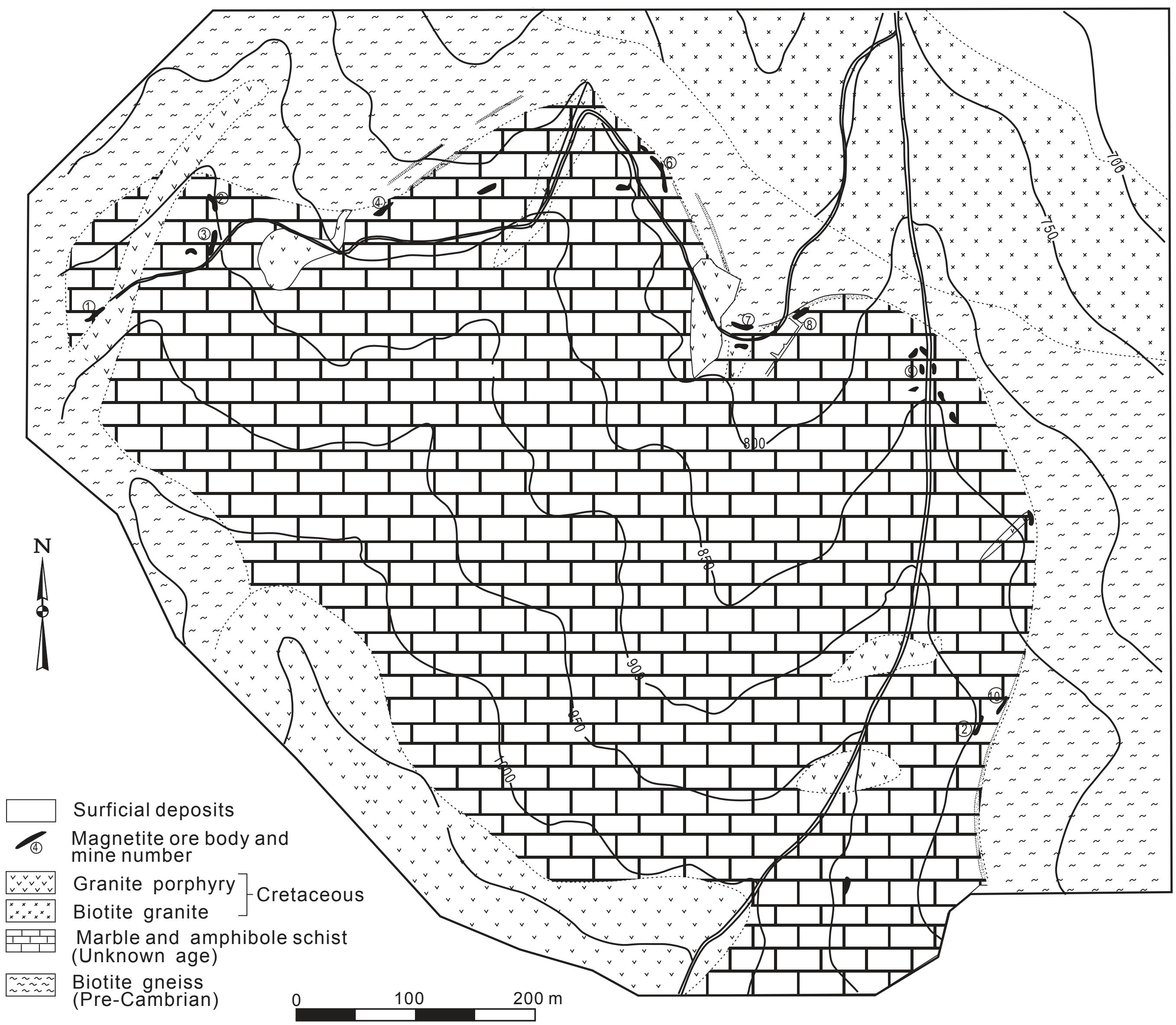


Figure 26. Generalized geologic map of Kuryong polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite mine, Gyeongnam metallogenic belt, Korea. Adapted from Park (1963).

craton, and in the Late Cretaceous Bulgugsa Granite. The age range of the belt is interpreted as Cenomanian through Campanian (96 to 75 Ma). The Yeongnam Metamorphic Complex consists of leucogranite gneiss, hornblende plagioclase gneiss, and biotite gneiss and schist of the Wonnam Formation. The Gyeongsang Supergroup consists of shale and sandstone of Hadong and Sindong Group and volcanic rock of Yucheon Group. The Bulgugsa Granite consists of biotite granite, granodiorite, anorthosite, porphyry, and felsic and quartz porphyry dikes. The major deposits are at Darak, Kyeongju, Chilgok, and Wangpiri.

The main references on the geology and metallogenesis of the belt are Cho and Lee (1966), Park and others (1969), and Kim and Shin (1966).

Chilgok Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (Koo and Kim, 1966) is hosted mainly in hornblende granite of the Cretaceous Bulgugsa granite series that intrudes older sedimentary rock of the Sindong Group. The deposit is controlled by joints and faults that mainly strike N 40° W and dip 75 to 85° northeast. The fissures are filled by quartz with ore minerals of mainly galena, sphalerite, and pyrite, lesser chalcopyrite and arsenopyrite, and rare pyrrhotite. The deposit is small and has resources of 3,000 to possibly 5,900 tonnes, and reserves of 5,300 tonnes of ore. Grades are 0.9 to 5.5 g/t Au, 154.4 to 280.8 g/t Ag, 3.9 to 8.83 percent Pb, and 4.1-7.08 percent Zn.

Darak Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (Cho and Lee, 1966) is hosted in Precambrian granite gneiss and Cretaceous biotite granite and granodiorite that are intruded by Late Cretaceous porphyry, felsite and quartz porphyry dikes. The deposit consists of sulfide veins in hydrothermal fissure fillings in granite gneiss, granodiorite, and biotite granite. The main vein strikes N 50-60° W, dips 70 to 90° southwest, and averages 70 cm wide. The average grades are 3.57 percent Pb and 3.72 percent Zn. The ore minerals are galena, sphalerite, pyrite, pyrrhotite, and chalcopyrite. Gangue minerals are quartz, feldspar, calcite, chlorite, sericite, and fluorite. The deposit is small and has resources of 85,720 tonnes of ore. The average grades are 3.01 percent Pb, 4.41 percent Zn, 1.63 g/t Au, and 41.23 g/t Ag.

Kyeongju W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (Park and others, 1969) is hosted in Cretaceous shale and sandstone of the Hadong group and volcanic rock of Yucheon group that are intruded by the Late Cretaceous Bulgugso biotite granite. The deposit consists mainly of disseminated molybdenite in leucogranite that forms the margin of a granite stock, and partly in extrusive breccia, and in quartz veins in granite. The deposit is medium size and has resources of 260,000 tonnes of ore grading 0.2 to 0.3 percent Mo.

Samkwang Polymetaliic Ni Vein Deposit

This unusual, multistage deposit (Kim, 1982) consists of Ni sulfide minerals in amphibolite bodies that are part of a Precambrian assemblage of granitic gneiss, banded gneiss, and siliceous dikes that are intruded by Cretaceous biotite granite, lamprophyre dikes, quartz veins, and pegmatitic quartz veins. The amphibolite consists of coarse-grained Ni sulfide minerals in fine- to medium-grained ultramafic rock. The deposit occurs in the top parts of amphibolite near the surface and grades downwards into barren or very low-grade parts. The major ore minerals are pyrrhotite with subordinate pentlandite, chalcopyrite, and pyrite that occur in disseminations, predominantly in the upper, subsurface part of the amphibolite. Three stages of mineralization occurred (1) magmatic segregation with formation of disseminated Ni sulfide minerals; (2) deuteric or hydrothermal alteration associated with Cretaceous plutonism with alteration of rock forming minerals; and (3) remobilization of sulfides, mainly pyrrhotite with pentlandite. The ore minerals are pyrrhotite, pentlandite, chalcopyrite, and pyrite. Gangue minerals are plagioclase, sericite, tremolite-actinolite, talc, chlorite, calcite, and quartz. Areas with sulfides vary from 5 to 8 meters thick and 45 to 50 meters long. The deposit is small and has reserves of 17,820 tonnes of ore grading 0.57 percent Ni.

Wangpiri Sn-W Greisen, Stockwork, and Quartz-Vein Mine

The mine (Kim and Shin, 1966) is hosted in Precambrian metasedimentary rock in the Wonnam and Yulri Series and in the Cretaceous Bunchon granite gneiss, granite, and granite. The deposit is hosted in granitic pegmatite that intrudes the contact between granite and the Yulri Series. The veins are mostly concordant with schistosity in phyllite, mica schist, and micaceous metasandstone; they strike north-south to N 60° E and dip 30 to 80° northwest. The deposit consists of cassiterite pegmatite veins with banded structure of alternating quartz and feldspar zones that range from 2 to 22 mm wide. Local homogeneous and coarse granular textures occur. The main ore mineral is cassiterite along with quartz, microcline, perthite, plagioclase, sericite, and muscovite and sparse tourmaline. The mine consist of small lenses, pipes, or large veins that range from 0.3 to 15 meters wide and 5 to 150 meters long. Fine cassiterite grains occur occasionally. Cassiterite is generally concentrated in quartz-rich zones in the homogeneous pegmatite vein, and also is disseminated in muscovite-rich zones on the hanging wall in fine grains; it occurs rarely in feldspar-rich zones. Average width of the veins is 1.24 meters. The deposit is small and has an average grade of 0.45 percent Sn.

Origin and Tectonic Controls for Gyeongpuk Metallogenic Belt

The belt is interpreted as having formed during generation of the Bulgugsa Granite during the Late Cretaceous through Early Tertiary Bulgugsa orogeny. The Bulgugsa Granite consists of biotite granite, granodiorite, porphyry, and felsic and quartz porphyry. The belt is hosted in the Yeongnam Metamorphic Complex, Gyeongsang Supergroup, Yeongnam granulite-paragneiss terrane, that is part of the Sino-Korean craton, and in the Late Cretaceous Bulgugsa Granite.

Hidaka Metallogenic Belt of Cyprus Cu-Zn Massive Sulfide and Besshi Cu-Zn-Ag Massive Sulfide Deposits (Belt HD) (Japan, Hokkaido)

This Middle Cretaceous through Eocene metallogenic belt is related to stratiform units in the Hidaka belt of the Shimanto subuction zone terrane. The belt occurs in the central part of the Hokkaido island, trends north-south for more than 350 km, and ranges from 20 to 70 km wide. The belt is hosted in a Cretaceous and Paleogene subduction-zone complex. The northern Hidaka belt contains mainly clastic rocks, and the southern Hidaka belt contains the Hidaka Metamorphic Rock. Saito (1958) defined this belt as the Main Central Hokkaido belt, and Tsuboya and others (1956) used the name Hidaka metallogenic province to refer to an area that contained the Kamuikotan metallogenic belt of present study. Saito and others (1967) used the name Central Hokkaido metallogenic province with a definition similar to that used for the Hidaka metallogenic province. The Hidaka metallogenic belt contains at least ten, very minor Cyprus type massive sulfide deposits (Saito, 1958). The major deposits are the Besshi Cu-Zn-Ag and Shimokawa Cu-Zn-Ag massive sulfide deposits.

The main references on the geology and metallogenesis of the belt are Saito and others (1967) and Miyashita and others (1997).

Besshi Cu-Zn-Ag Massive Sulfide Deposit

This deposit (Suyari and others, 1991; Watanabe and others, 1998) consists of four srtratiform ore bodies. The Main Motoyama body extends 1,600 meters along strike and 2,000 meters down dip, and has dimensions of 3,000 by 11,000 meters. Average thickness is 2.4 meters with a maximum thickness of 15 meters. The main ore minerals are pyrite, chalcopyrite, bornite, and magnetite. Gangue minerals are chlorite, hornblende, glaucophane, and quartz. The deposit hosted in pelitic schist of the Cretaceous Sambagawa Metamorphic Rocks that may be correlative to the Shimato belt of similar units. Mafic schist and piedmontite schist occur in the ore zone. Geochemistry indicates that the mafic schist is derived from basalt that formed in an oceanic intraplate or in constructive plate margins. The age of peak of metamorphism is 110 Ma according to Rb-Sr and K-Ar isotopic studies. The deposit was discovered in 1690, is large with a grade of 1.0 to 1.8 percent Cu, 0.1 to 1.4 percent Zn, 11.9 to 40 percent S, 0.3 to 0.7g/t Au, 7 to 20 g/t Ag. The deposit has produced 706,000 tonnes Cu and has reserves of 8 million tones of ore.

Shimokawa Cu-Zn-Ag Massive Sulfide Deposit

This deposit (Kato and others, 1990) consists of of seven sulfide bodies that occur along the same stratigraphic horizon. The horizon strikes north-south, and dips 50 to 60° east. The sulfide bodies occur along a 1,800-meters-long zone. Average thickness of the bodies is 5.2 meters, with a maximum of 30 meters. The main ore minerals are pyrite, chalcopyrite, pyrrhotite, sphalerite, and magnetite. Minor ore minerals are cubanite, valleriite, cobalt-bearing pentlandite, and cobaltite. Gangue minerals are quartz, chlorite, sericite, and cabonate minerals. The deposit occurs between tholeiitic pillow basalt and slate of the Cretaceous Hidaka Group. Tholeiitic rocks show geochemical similarity to mid-ocean ridge basalt or marginal basin basalt. Host rocks are altered from zeolite to amphibolite facies. The deposit is medium size and has an average grade of 2.3 percent Cu, 0.8 percent Zn, 0.22 percentCo, and 20.3 percent S. 6,800,000 tonnes of ore was produced from 1941 to 1982.

Origin and Tectonic Controls for Hidaka Metallogenic Belt

The belt is interpreted as having formed in basalt generated along the Kula-Pacific ridge. Subsequently, the host rocks and deposits were structurally incorporated into the Shimanto subuction zone terrane. The basalt associated with the deposits has geochemical characteristics of N-type MORB (Miyashita and others, 1997). The ages of basalt are interpreted as mid-Cretaceous through Eocene. The basalt occurs in clastic sedimentary rock, suggesting occurrence of a spreading ridge near a subduction zone (Miyashita and others, 1997). The deposits in the belt are interpreted as having formed during this magmatism along the Kula-Pacific ridge that was being subducted under the East Asia continental margin.

Inner Zone Southwest Japan Metallogenic Belt of Zn-Pb (Ag, Cu, W) Skarn, W-Mo-Be Greisen, Stockwork, and Quartz Vein, W±Mo±Be skarn, Cu (±Fe, Au, Ag, Mo) Skarn, Porphyry Mo (±W, Sn, Bi), Polymetallic Pb-Zn ±Cu (± Ag, Au) Vein and Stockwork, Fluorspar Vein, and Metamorphic Graphite Deposits (Belt ISJ) (Japan)

This Cretaceous through Paleogene metallogenic belt is related to veins and replacements in Nohi rhyolitic volcanic belt and Hiroshima granitic belt that overlie and intrude the Hida, Sangun-Hidagaien-Kurosegawa, Akiyoshi-Maizuru, and Mino-Tamba-Chichibu terranes (some units are too small to show on the summary geodynamics map). The metallogenic belt occurs in the western part of Honshu Island and northern Kyushu Island, trends east-northeast to west-southwest for more than 1,000 km, and is as much as 150 km wide. The belt contains numerous skarn deposits (Kamioka Tochibara deposit) and polymetallic veins (Ikuno deposit). Tsuboya and others (1956) used the name Inner Zone Southwest Japan metallogenic province; however, the Ikuno and Akenobe deposits were excluded because they were interpreted as being Neogene at that time. The Ikuno and Akenobe deposits are included in the Inner Zone Southwest Japan metallogenic belt.

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956), Ishihara (1978), and Ishihara and others (1992).

Kamioka Mozumi Zn-Pb (Ag, Cu, W) Skarn Mine

This mine (fig. 27) (Sato and Akiyama, 1980) consists of more than 18 skarn bodies that occur in masses, stratiform layers, and veins. The Main ore body is 300 meters long, 400 meters wide, and 10 meters thick. The main ore minerals are sphalerite, galena, chalcopyrite, magnetite, pyrite, and pyrrhotite with minor molybdenite and scheelite. The skarn minerals are hedenbergite, actinolite, diopside, garnet, wollastonite, and epidote. The skarn is clinopyroxene skarn that is replaced by garnet or by magnetite, calcite, and quartz. Replacements are likely related to deposition of Zn-Pb sulfides. Host rocks are crystalline limestone, diopside gneiss, amphibole gneiss, and amphibolite of the Hida Metamorphic Rock. K-Ar age for sericite from the Kamioka Tchibora and Kamioka Mozumi deposits are 63.8 to 67.5 Ma and a K-Ar age isotopic for hastingsite from skarn near the Kamioka Tchibora deposit is 63.3±1.6 Ma. These ages suggest mineralization during the Late Cretaceous through Paleogene. Mineralization is related to the quartz porphyry or granite intrusion. The deposit was discovered in 1589, is medium size and has produced 815,000 tonnes Zn, 52,000 tonnes Pb, and 190 tonnes Ag. The average grades are 7.9 percent Zn, 2.68 percent Pb, and 31 g/t Ag.

Bandojima Cu (±Fe, Au, Ag, Mo) Skarn Mine

This mine (Geological Survey of Japan, 1956; Mining and Metallurgical Institute of Japan, 1965) consists of nine skarn bodies that occur in masses and sheets. The main ore body is 150 meters long, 85 meters wide, and 4 meters thick. The main ore minerals are sphalerite, galena, chalcopyrite, and pyrrhotite. Skarn minerals are garnet and epidote. Host rocks are crystaline limestone, calcareous shale, and chert of the Hida Metamorphic Rock. Mineralization is related to intrusion of Mesozoic quartz diorite that occurs under the deposit. The small deposit was found before 1900. The deposit has produced 1,723 tonnes Zn, 1,464 tonnes Pb, and 105 tonnes Cu from 1952 to 1961 grading 10 to 15 percent Pb, 5 to 7 percent Zn, and 1 to 2 percent Cu. The mine contains reserves of 600,000 tonnes of ore.

Kamioka Tochibora Zn-Pb (Ag, Cu, W) Skarn Mine

This mine (Sato and Uchiumi, 1990) consists of more than 34 skarn bodies with local massive ore. The main ore body is 250 meters long, 500 meters wide, and 60 meters thick. The main ore minerals are sphalerite, galena, chalcopyrite, matildite, magnetite, pyrite, and hematite. The minor minerals are molybdenite native silver, argentite, and scheerlite. Skarn minerals are hedenbergite, actinolite, diopside, garnet, wollastonite, and epidote. Host rocks are crystaline limestone, diopside gneiss, amphibole gneiss, and amphibolite of the Hida metamorphic rock. The K-Ar ages of sericites from Kamioka Tchibora and Kamioka Mozumi deposits are 63.8 to 67.5 Ma. A K-Ar age of hastingsite from skarn near the Kamioka Tchibora deposit is 63.3±1.6 Ma. These ages suggest mineralization occurred during the Late Cretaceous through Paleogene. The mineralization may be related to the quartz porphyry. The deposit was discovered in 1580.

Ikuno Polymetallic Pb-Zn ±Cu (± Ag, Au) Vein and Stockwork Mine

This mine (Ministry of International Trade and Industry 1988) consists of more than 50 northwest and north-south striking polymetalic veins. The main vein is 1,900 meters long and and has an average width of 1.4 meters. Veins occur in an area 8 km (east-west) by 6 km (north-south). The host rocks are rhyolite, andesite, and associated pyroclastic rock, and minor sedimentary rocks of Cretaceous-Paleogene Ikuno Group. A zonal distribution of metals occurs. From the center of the deposit to margin are Cu, Cu-Zn, Zn, Pb-Zn, and Au-Ag assemblages. Sn and Sn-W zones also occur. Ore minerals are pyrargyrite, stephanite, native silver, native gold, and scheelite. Rare Se-bering benjaminite and matildite occur. Gangue minerals are quartz, calcite, fluorite, chlorite, siderite, and feldspar. The wallrocks are altered to quartz, chlorite, and sericite. A K-Ar isotopic age for adularia from the vein is 65.6±2.0 Ma and 63.0±1.9 Ma. The deposit was discovered in 807 and the mine closed in 1972. The mine is medium size with production of 47,000 tonnes Cu, 92,000 tonnes Zn, 19,000 tonnes Pb, 1,500 tonnes Sn grading 0.3 g/t Au, 60 g/t Ag, 1.4 percent Cu, 5 percent Zn, 0.8 percent Sn, and 1.5 percent Pb.

Otani W-Mo-Be Greisen, Stockwork, and Quartz-Vein Mine

This mine (Shibata and Ishihara, 1974) consists of northeast striking veins. The Main vein is 700 meters long and has an average thickness of 1.5 meters. The host rock is Cretaceous granodiorite. The main ore minerals are scheelite, cassiterite, chalcopyrite, arsenopyrite, pyrite, pyrrhotite, sphalerite, and stannite. Gangue minerals are mainly quartz, calcite, muscovite, and fluorite. Greisen alteration occurs in the wallrocks. The deposit formed during intrusion of Cretaceous granite. K-Ar isotopic age of muscovite from the vein is 91 Ma. The deposit was found in 1912, and the mine closed in 1983. The mine is medium size and has a production of 776,000 tonnes of ore (from 1951 to 1971) and has an average grade of 0.46 percent WO_3, 0.26 percent Cu, and 0.11 percent Sn.

Origin and Tectonic Controls for Inner Zone Southwest Japan Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along the East Asia magmatic arc related to subduction of the Kula and Pacific Ocean plates. The deposits in the belt are interpreted as having formed during siliceous granitoid magmatism. Granitoids in the Inner Zone of Southwest Japan are classified into three belts, from south to north, the Ryoke, Sanyo, and Sanin belts. Granitoids in the Ryoke and Sanyo belts are typically ilmenite-series, and those in the Sanin belt are magnetite-series (Ishihara and others, 1992). Ages of granitoids from the Ryoke and Sanyo belts are Cretaceous, however, ages of the Sanin belt granitoids are mostly Paleogene. The deposits are not related to granitoids of the Ryoke belt. Granitoids in the Sanyo belt host W-Sn-Cu skarn or veins deposits. Ishihara (1978) defined a W-Sn-Cu metallogenic province for this belt. Mo-Pb-Zn deposits characterize the Sanin belt, and were defined as a Mo-Pb-Zn metallogenic province by Ishihara (1978). The Inner Zone Southwest Japan metallogenic belt is thereby divided into two units–the southern W-Sn-Cu Sanyo belt and the Mo-Pb-Zn Sanin belt.

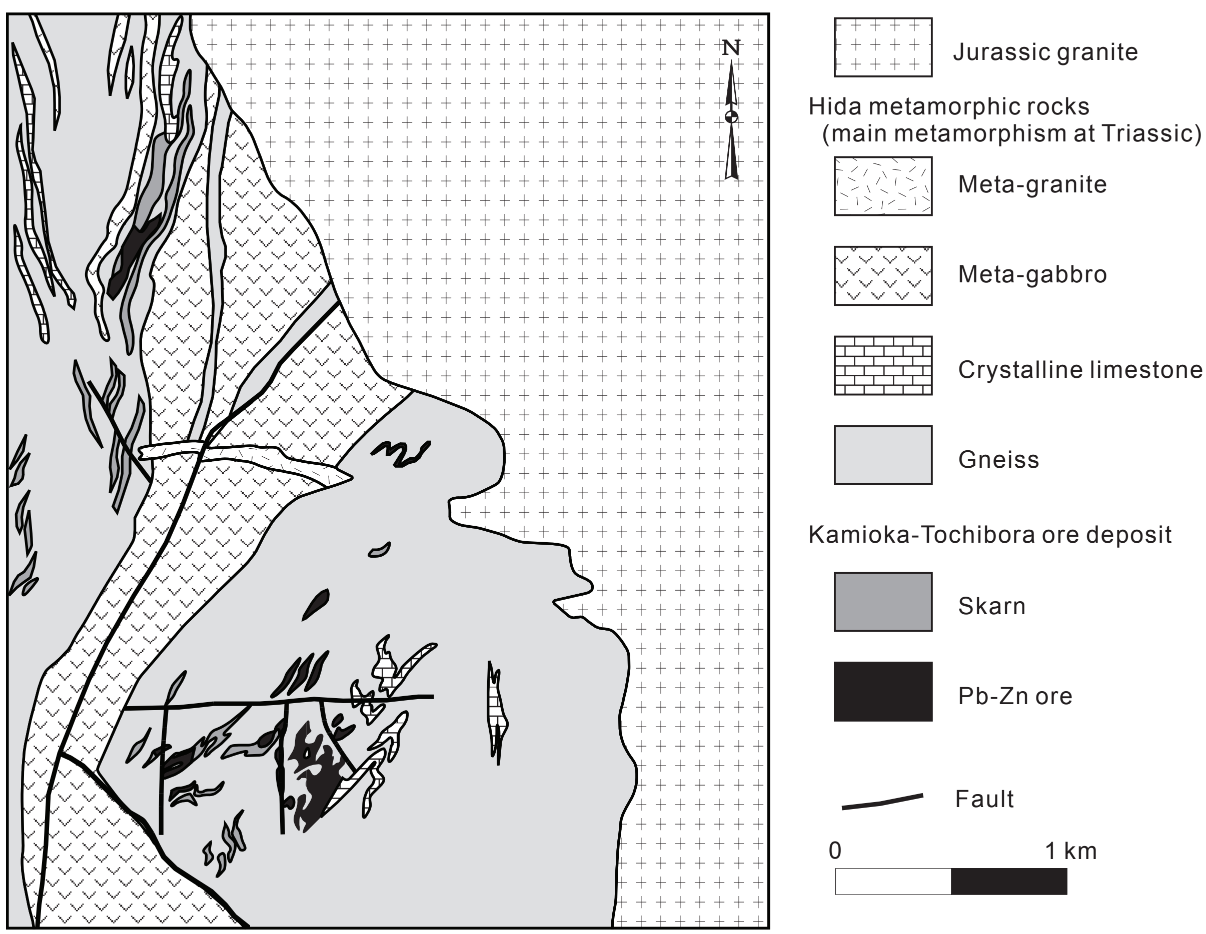


Figure 27. Generalized geologic map of Kamioka Mozumi Zn-Pb (Ag, Cu, W) skarn mine, Inner Zone Southwest metallogenic belt, Japan. Adapted from Kunugiza (1999).

Khandyga Metallogenic Belt of Ag-Sb Vein, Carbonate-Hosted As-Au Metasomatite, Clastic-Sediment-Hosted Sb-Au, and Clastic Sediment-Hosted Hg±Sb Deposits (Belt KA) (Russia, Verkhoyansk-Kolyma Region)

This Aptian through Late Cretaceous metallogenic belt is related to veins and replacements in the southern Verkhoyansk fold and thrust belt in the North Asian cratonal margin. The metallogenic belt extends longitudinally for 250 km and is as much as 30 km wide. The belt occurs (1) along the Sette-Daban tectonic zone that contains early to middle Paleozoic carbonate rock; (2) in the adjacent, eastern Kylakh tectonic zone that contains Riphean clastic and carbonate rock; and (3) in an area of periclinal closure containing Carboniferous, Permian, and Triassic marine clastic rock. The major deposits are at Senduchen, Khamamyt, Svetloe, and Khachakchan.

The main references on the geology and metallogenesis of the belt are Ozerova and others (1990) and Nokleberg and others (2003).

Senduchen Clastic-Sediment-Hosted Sb-Au Deposit

This deposit (V. Korostelev, written commun., 1963) consists of quartz-carbonate veins composed of orpiment, stibnite, realgar, arsenopyrite, sphalerite, enargite, chalcopyrite, and jamesonite. Individual orpiment concretions are as much as 10 tonnes. The veins intrude dark-gray Silurian limestone, are as much as 3.5 meters thick, and occur in a fault zone that cuts an anticline. The deposit is small and has an average grade of 10 to 58 percent As and 2.9 percent Sb.

Seikimyan Clastic Sediment-Hosted Hg±Sb Deposits

This deposit (Klimov, 1979; E. Vladimirtseva, written commun., 1987) consists of stringers and disseminations with quartz, dickite, cinnabar, calcite, and pyrite, and rare galena, sphalerite, and arsenopyrite. The deposit hosted in feathered shear and breccia zones in sandstone and has dimensions of 0.4 to 7 by 50 to 200 meters. The deposit occurs on northeastern limb of an anticline formed in Late Triassic sandstone and siltstone. The deposit is bounded by faults that occur parallel to the major, regional Bryungadin fault. The average grades are as much as 0.1 to 0.5 percent Hg.

Origin and Tectonic Controls for Khandyga Metallogenic Belt

The belt is interpreted as having formed during postaccretionary extension related to initiation of opening of the Eurasia Basin. The belt occurs in veins and replacements in the southern Verkhoyansk fold and thrust along the Sette-Daban tectonic zone.

Kukhtuy-Uliya Metallogenic Belt of Au-Ag Epithermal Vein, Porphyry Mo (±W, Sn, Bi), Porphyry Sn, and Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposits (Belt KU) (Russia, Far East)

This Late Cretaceous through Paleocene metallogenic belt is related to veins that are associated with the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies the Okhotsk terrane. The metallogenic belt occurs in the Uliya volcanic zone of Okhotsk-Chukotka volcanic-plutonic belt and in the overlapped Okhotsk cratonal terrane. The metallogenic belt contains several Au deposits and occurrences. The main deposits are at Khakandzha and Yurievka.

The main references on the geology and metallogenesis of the belt are Moiseenko and Eirish (1996) and Onikhimovsky and Belomestnykh (1996).

Khakandzha Au-Ag Epithermal-Vein Deposit

This deposit (Onikhimovkiy and Belomestnykh, 1996) occurs in the Uliya volcanic zone that overlaps the Okhotsk terrane, and it is hosted in a large domal volcanic-plutonic structure that overlies a Late Triassic clastic sequence. The lower part of the volcanic-plutonic structure is andesite and the upper part is dacite and rhyolite. The volcanic rocks are intruded by a Late Cretaceous brecciated latite sill and granosyenite porphyry dikes, and by Paleocene basalt, diabase, and andesite dikes. The deposit consists of a gently dipping (15 to 30^{o} SW) zone of breccia and silica alteration that ranges from 7 to 52 meters thick. The zone is cut by numerous branching veins and veinlets of quartz and quartz-adularia that contain the Au-Ag minerals. The ore is low-sulfide (0.5 to 3.0 percent), and the main ore minerals are native gold, pyrite, galena, sphalerite, chalcopyrite, electrum, and native silver. Gangue minerals are quartz, adularia, rodhochrosite, rhodonite, and calcite. Gold fineness ranges from 532 to 774. The deposit contains 0.1 to 1,806 g/t Au (average of 8 to 10 g/t Au) and 0.1 to 32,676 g/t Ag (average of 350 to 600 g/t Ag). The Au/Ag ratio is 1:44. A high Mn content is typical for the deposit.

Yurievka Au-Ag Epithermal-Vein Deposit

This deposit (Onikhimovkiy and Belomestnykh, 1996) is hosted in the Uliya volcanic zone that consisits of Late Cretaceous andesite, basalt, dacite, rhiolite, and dacite. The deposit occurs along a tectonic zone that strikes sublatitudinally and dips steeply. The host rocks are altered to propilite. Gold ores are high-sulfide. The average grades is about 10 to 25 g/t Au, and the deposit contains about 7.1 tonnes of gold.

Origin and Tectonic Controls for Kukhtuy-Uliya Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along an active continental-margin arc consisting of the Albian through Late Cretaceous Okhotsk-Chukotka volcanic-plutonic belt.

Luzhkinsky Metallogenic Belt of Sn-W Greisen, Stockwork, and Quartz-Vein, Cassiterite-Sulfide-Silicate Vein and Stockwork, W-Mo-Be Greisen, Stockwork, and Quartz-Vein, Porphyry Sn, Porphyry Cu (±Au), Porphyry Cu-Mo (±Au, Ag), and Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposits (Belt LZ) (Far East Russia)

This mid-Cretaceous through early Tertiary metallogenic belt is related to veins, replacements, and granitoids in the East Sikhote-Alin volcanic-plutonic belt that overlies and intrudes Zhuravlevsk-Amur River terrane. The significant deposits in the belt are cassiterite-silicate-sulfide vein and porphyry Sn deposits (Yantarnoe), and Sn-W greisen, stockwork, and quartz-vein deposits (Tigrinoe and Zabytoe). The Sn deposits are interpreted as having formed in the mid-Cretaceous through early Tertiary between 100 and 50 Ma. Also in the same area are younger, generally uneconomic Sn-W greisen, stockwork, and quartz vein occurrences with K-Ar isotopic ages of 60 to 50 Ma. In addition to Sn deposits, the northern Luzhkinsky metallogenic belt contains sparse small porphyry Cu (±Au) deposits (Verkhnezolotoe) that are hosted in Senomanian and Turonian monzodiorite in the northwestern part of the metallogenic belt near the Samarka subduction-zone terrane that contains abundant oceanic rocks. The porphyry Cu (±Au) deposits are coeval with the Sn deposits of the Luzhkinsky metallogenic belt, but presumably reflect the anomalous Cu-rich composition of the Samarka terrane.

The main references on the geology and metallogenesis of the belt are Rodionov (1988) Ruchkin and others (1986), Gerasimov and others (1990), Korostelev and others (1990), Gonevchuk and Gonevchuk (1991), Nokleberg and others (2003), and Gonevchuk and others (1998).

Tigrinoe Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (fig. 28) (Korostelev and others, 1990; Gonevchuk and Gonevchuk, 1991) is complex and consists of (1) a greisen along the contact of a Li-F granite pluton; (2) a linear stockwork consisting of a thick network (5 to 10 to 70 veinlets per meter) of parallel, north-south-trending quartz-topaz veins that range from 3 to 100 cm thick and are hosted in metasedimentary rock adjacent to the granite intrusion; and (3) a sulfide-cassiterite breccia pipe that contains rock fragments of the stockwork and greisen cemented by quartz and lesser carbonate, fluorite, and sulfides. Three stages occur (1) early stage with quartz-molybdenite-bismuthinite; (2) middle stage of REE greisen with wolframite-cassiterite with high contents of Sc, Ni, and Ta; and (3) late stage with hydrothermal quartz-fluorite-carbonate-sulfide veins. In, Cd, Ag, and Se are enriched in sulfides in the two last stages. K-Ar isotopic age of the lithium-fluorine granite is 90 Ma ± 5 percent. A Rb-Sr isochron age for the Li-F granite is 86±6 Ma with an initial Sr ratio of 0.7093. A Rb-Sr age for the greisen is 73±18 Ma with an initial Sr ratio of 0.7105. The deposit is medium size and has an average grade of 0.14 percent Sn and 0.045 percent WO_3.

Vysokogorskoe Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (fig. 29) (Litavrina and Kosenko, 1978; Ryabchenko, 1983) consists of quartz-chlorite-cassiterite, quartz-sulfide-cassiterite and sulfide-cassiterite veins,and fracture zones in Early Cretaceous olistostrome partially overlain by Late Cretaceous felsic volcanic rock. Sn minerals are related to the areas of quartz-tourmaline alteration about 5 to 6 meters thick. Average thickness of veins and zones is 1.2 to 1.4 meters, with lengths of 400 to 500 meters. The deposit extends to a depth of 700 meters. In addition to cassiterite, deposit contains chalcopyrite, arsenopyrite, and pyrrhotite, and rare galena and sphalerite. Sulfosalts of Bi and Ag are common. The deposit is medium size has a grade of 1.0 percent Sn. The deposit has been mined from the 1960s to present, and it is the largest mine in Kavalerova area.

Zimnee Sn-W Greisen, Stockwork, and Quartz-Vein Deposit

This deposit (fig. 30) (P.G. Korostelev and others, written commun., 1980; Nazarova, 1983) consists of breccia, breccia- and fracture-filling veins, zones of closely spaced veinlets, and pockets that occur in fracture zones. These structures are as much as 1,200 meters long, are extensive down dip, and vary from several tenths of a meter to several tens of meters wide. The deposit occurs near a granodiorite body and consists mainly of pyrrhotite, pyrite, arsenopyrite, sphalerite, stannite, and cassiterite. Far from the granodiorite, and in the upper part of veins, the deposit is mostly galena with fine-grained cassiterite. Near the granodiorite, the deposit consists of breccia-bearing fragments of Sn-sulfide minerals that are cemented by a quartz-mica (greisen) aggregate with arsenopyrite and cassiterite. The K-Ar age of altered rocks related to the Sn-polymetallic deposits is 75 Ma. The K-Ar isotopic age of the greisen and granodiorite is approximately 50 Ma. The deposit is regionally metamorphosed and deformed. The deposit is small and has an average grades of 0.1 to 3.0 percent Cu, 3.18 percent Pb, 0.59 percent Sn, and 4.09 percent Zn.

Arsenyevsky Sn-W Greisen, Stockwork, and Quartz-Vein Mine

This mine (fig. 31)((Rub and others, 1974; Radkevich and others, 1980) consists of a series of parallel, steeply-dipping quartz veins that extend as much as 1000 meters along strike and 600 to 700 meters downdip. The deposit is closely controlled by moderate- to steeply-dipping rhyolite dikes with a K-Ar isotopic age of 60 Ma. The ore-mineral assemblage is vertically zoned. From the top

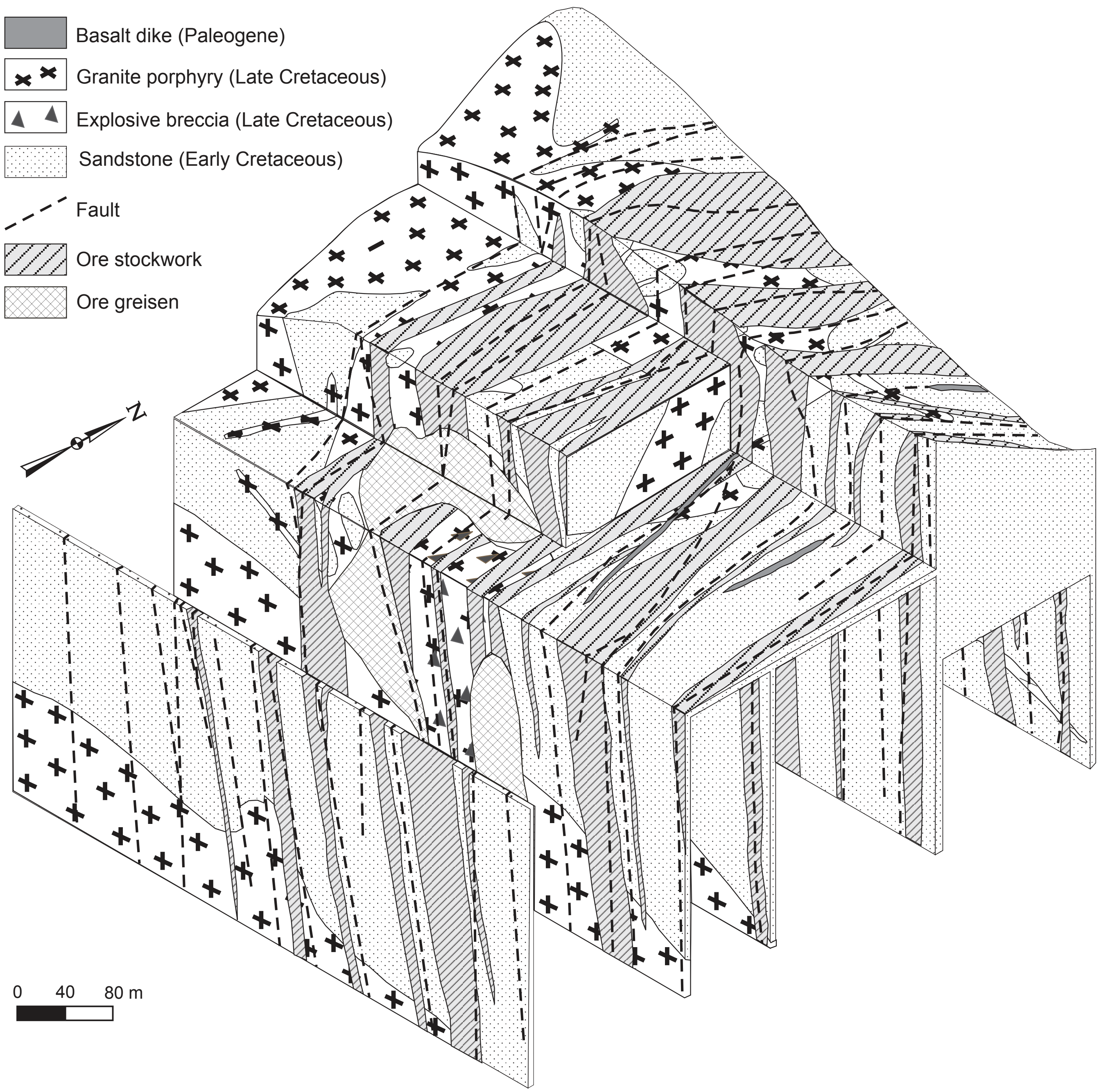


Figure 28. Generalized oblique-view geologic map and cross sections of Tigrinoe Sn-W greisen, stockwork, and quartz-vein deposit, Luzhkinsky metallogenic belt, Russian Southeast. Adapted from Gonevchuk and others (1998) and S.M., Rodionov (written commun., this study).

downwards, the assemblages are (1) quartz-cassiterite; (2) quartz-arsenopyrite-pyrrhotite; (3) polymetallic; and (4) arsenopyrite-pyrrhotite. The rhyolite exhibits quartz-sericite alteration. Local miarolithic cavities are filled with cassiterite. The deposit is medium size and has an average grade of 2 to 3 percent Sn, and locally as much as 20 to 25 percent Sn. The deposit also contains from 0.1 to 0.5 percent WO_3, 1 to 2 percent Pb and Zn , and a few hundred ppm Ag. The deposit has been mined since the 1970s.

Yantarnoe Porphyry Sn Deposit

This deposit (Rodionov, 1988) consists of veinlets and disseminations of cassiterite and sulfide minerals in a pipe-like body of volcanic breccia composed of trachyandesite and rhyolite. These units intrude Early Cretaceous clastic sedimentary rock. The older part of the deposit is in rhyolite in the pipe-like body that contains pyrite and chalcopyrite. The younger and major part of the deposit formed after intrusion of the explosive breccia and consists of metasomatic quartz-chlorite, quartz-sericite, and quartz-chlorite-sericite alterations that contain a sulfide-free cassiterite-chlorite-quartz assemblage and a Sn-polymetallic assemblage rich in galena, sphalerite, and chalcopyrite. The host igneous rocks are spatially related to Paleocene volcanic vents with K-Ar isotopic ages of about 65 Ma. The deposit is small and has an average grade of 0.1 to 2.17 percent Cu, 0.03 to 1.02 percent Pb, 7.3 percent Sn, and 0.7 to 2.22 percent Zn.

Origin and Tectonic Controls for Luzhkinsky Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids in the back-arc part of the the East-Sikhote-Aline continental-margin arc that is tectonically linked to oblique subduction of the ancestral Pacific Ocean Plate. Like the Sergeevka-Taukha and Kema metallogenic belts, the coeval Luzhkinsky metallogenic belt is hosted in the East Sikhote-Alin volcanic-plutonic belt. The differences between the coeval metallogenic belts are interpreted as being the result of the igneous rocks that host these metallogenic belts intruding different bedrock. The Sergeevka-Taukha metallogenic belt contains mainly B skarn, Zn-Pb (±Ag, Cu) skarn, and Pb-Zn polymetallic-vein deposits. The belt is hosted in, or near igneous rocks that intrude the Taukha subduction-zone terrane that contains a complex assemblage of abundant Paleozoic and early Mesozoic oceanic rocks, and lesser Jurassic and Early Cretaceous turbidite deposits. In contrast, the Kema metallogenic belt contains mainly Ag-Au epithermal deposits and is hosted in or near granitoids that intrude the Cretaceous island arc rocks of the Kema terrane. In contrast, the Luzhkinsky belt is related to a granitoid that intrudes the southern Zuravlevksk-Tumnin turbidite basin terrane. Additional controls for the Luzhkinsky metallogenic belt are (1) the turbidite deposits in the Zuravlevksk-Tumnin terrane which are enriched in Sn; and (2) the Luzhinsky belt, which occurs in the back-arc part of the East Sikhote-Alin igneous belt where magnetite-series granitoids are predominate.

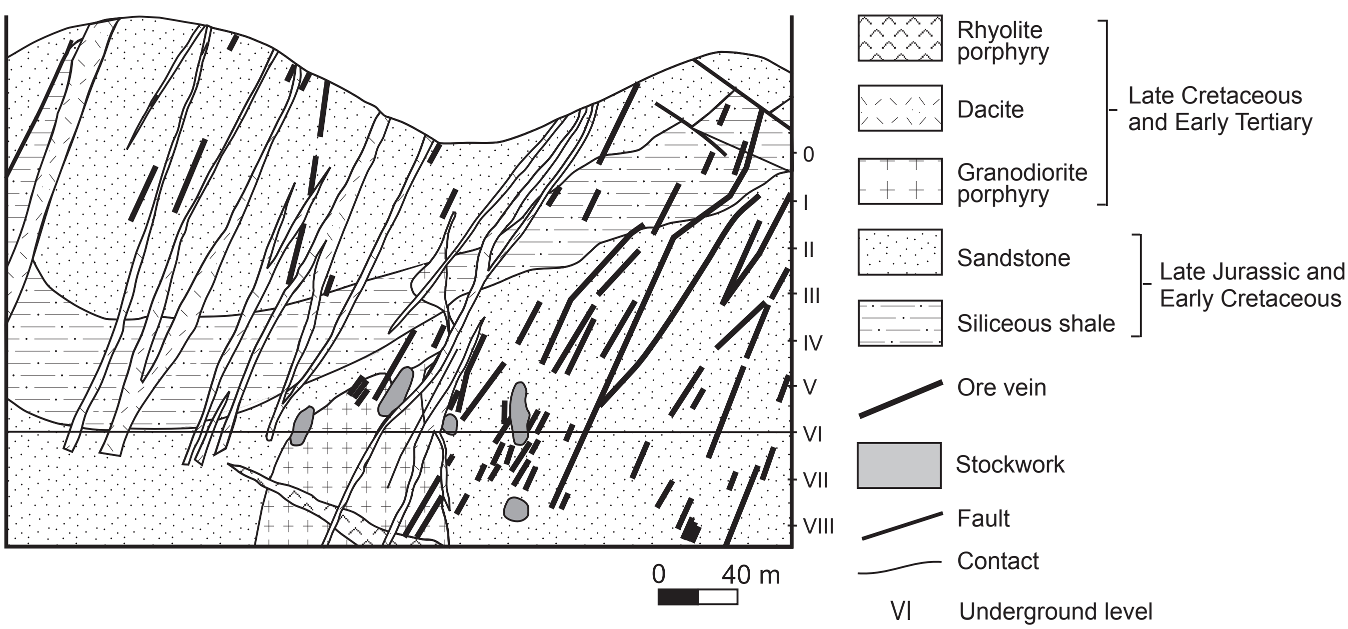


Figure 29. Schematic cross section of Vysokogorskoe cassiterite-sulfide-silicate vein and stockwork deposit, Luzhkinsky metallogenic belt, Russian Southeast. Adapted from Gonevchuk and others (1998).

Malo-Khingan Metallogenic Belt of Porphyry Sn and Rhyolite-Hosted Sn Deposits (Belt MK) (Russia, Far East)

This Late Cretaceous metallogenic belt is related to granitoids in the Khingan-Okhotsk volcanic-plutonic belt. The intrusive rocks of the Khingan-Okhotsk belt in this area are dominantly granite and are comagmatic with the volcanic rock. The granitoids are interpreted as being subduction-related, calc-alkalic igneous rocks, and they include both S-and I-type granite. The major deposit is at Khingan.

The main references on the geology and metallogenesis of the belt are Ognyanov (1986), Vrublevsky and others (1988), Natal'in (1991, 1993), Nokleberg and others (2003), Nechaev and others (1996), Sengor and Natal'in (1996), and Gonevchuk and others (1998).

Khingan Porphyry Sn Mine

This deposit (fig. 32) (Ognyanov, 1986) occurs in a pipe-shaped, hydrothermal explosion breccia that intrudes felsic volcanic rock. The deposit occurs in 15 areas in a zone that ranges from 10 to 50 meters across, varies from 100 to 400 to 500 meters long, and occurs at depth in a symmetrical breccia zone that is about 250 to 300 meters wide. The zone extends to depths of more than 1,200 meters. At the upper levels, the breccia is replaced by chlorite, and at the depths of 700 to 800 meters, the breccia is replaced by quartz-muscovite (sericite)-topaz greisen. Most of the district consists of quartz, fluorite, and cassiterite with subordinate arsenopyrite, marcasite, loellingite, chalcopyrite, and Bi-minerals. The deposit is interpreted as being probably genetically related to a subalkaline potassium granite that has a K-Ar isotopic

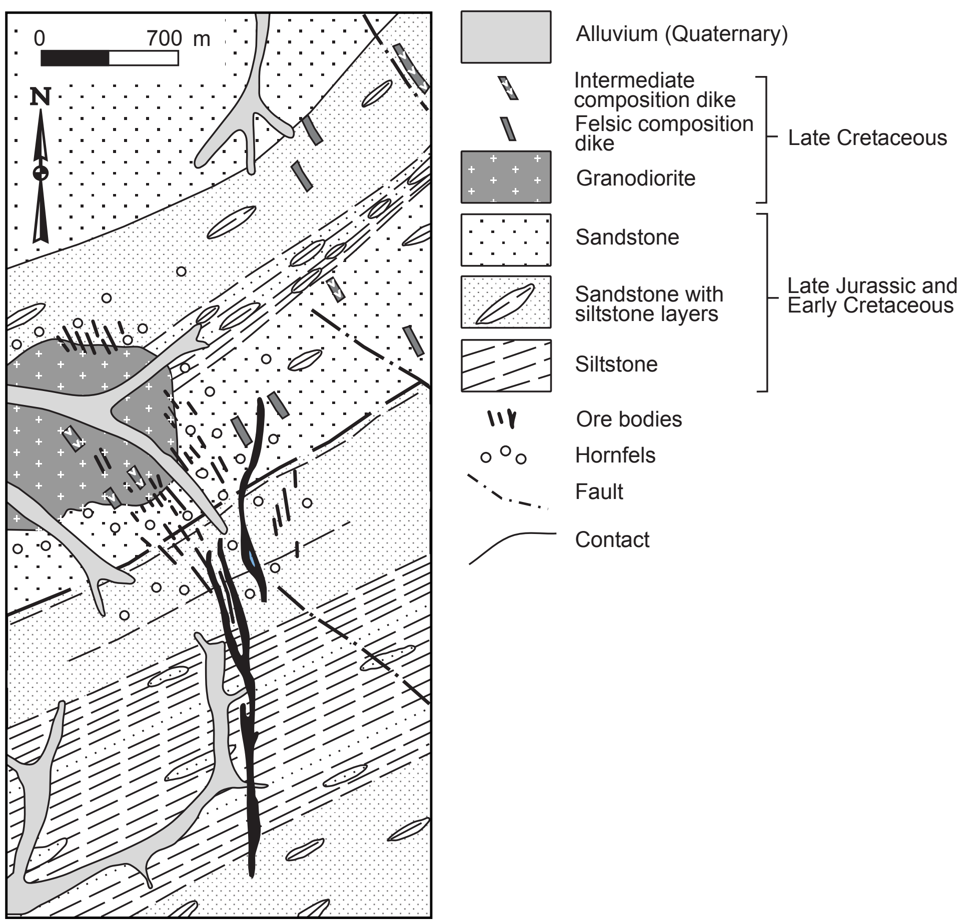


Figure 30. Generalized geologic map of Zimnee Sn-W greisen, stockwork, and quartz-vein deposit, Luzhkinsky metallogenic belt, Russian Southeast. Adapted from A.N. Ivakin and V.V. Orlovsky, written commun., 1978.

age of 90 to 80 Ma, a Rb-Sr whole-rock isochron age of 78 Ma, and an initial Sr isotopic ratio of 0.7123. The deposit has been mined since the 1960s, is medium size, and averages 0.6 to 0.7 percent Sn.

Origin and Tectonic Controls for Malo-Khingan Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along the Khingan transform continental-margin arc consisting of the Khingan-Okhotsk volcanic-plutonic belt that is tectonically related to oblique subduction of the ancestral Pacific Ocean Plate. The southwest part of Khingan-Okhotsk volcanic-plutonic belt occurs in a postaccretionary Cretaceous volcanic-tectonic basin in the eastern Bureya continental-margin arc superterrane. The basin is filled with mid-Cretaceous, intermediate volcanic rock and overlying Late Cretaceous tuff and rhyolite lava that range from 1.5 to 3.0 km thick. The basin overlies a Proterozoic metamorphic rock of the Bureya superterrane.

The Khingan-Okhotsk belt is part of the Khingan continental-margin arc that is interpreted as having formed from oblique subduction of the ancestral Pacific Ocean Plate. Fragments of this plate are interpreted as having occurred in tectonically interwoven units of the Amur River, Khabarovsk (younger Early Cretaceous part), and Kiselevka-Manoma subduction-zone terranes. This tectonic linkage of the arc to the subduction units is based on: (1) occurrence of subduction-zone terranes outboard (oceanward) of, and parallel to the various parts of the Khinghan arc; (2) the formation of melange structures during the Early and mid-Cretaceous; and (3) where not disrupted by extensive Cretaceous movement, the dipping of melange structures and bounding faults toward and beneath the igneous units of the arc. Formation of the Khingan arc and related subduction is generally interpreted as having ended in the late mid-Cretaceous when oblique subduction changed into sinistral-slip faulting along the outboard margin of the arc.

Pilda-Limuri Metallogenic Belt of Sn-W Greisen, Stockwork, and Quartz-Vein, W-Mo-Be Greisen, Stockwork, and Quartz-Vein, Ag-Sb Vein, Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, and Granitoid-Related Au-Vein Deposits (Belt PL) (Russia, Far East)

This Late Cretaceous metallogenic belt is related to veins, replacements, and granitoids related to the Evur zone of the Khingan-Okhotsk volcanic-plutonic belt. The belt occurs at the junction area of the Amgun, Zhuravlevsk-Amur, and Samarka terranes. Several small deposits of different types occur in the belt. The belt contains small deposits at Agnie-Afanasievskoye, Dyapp, and Uchaminskoye.

The main reference on the geology and metallogenesis of the belt is Moiseenko and Eirish (1996).

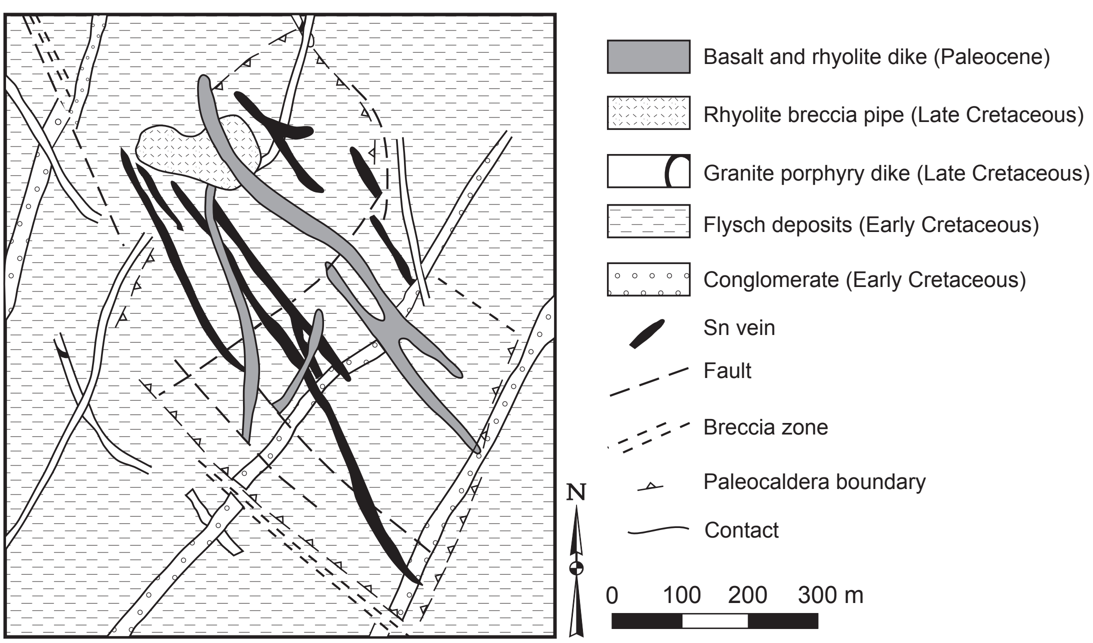


Figure 31. Generalized geologic map of Arsenyevsky Sn-W greisen, stockwork, and quartz vein mine deposit, Luzhkinsky metallogenic belt, Russian Southeast. Adapted from Ratkin (1995).

Agnie-Afanasievskoye Granitoid-Related Au Vein Mine

This mine (Moiseenko and Eirish, 1996) occurs in a vein system that ranges up 0.5 km wide and as much as 1.0 km long. The system occurs in an anticline formed in Early Cretaceous sandstone and siltstone. Several diorite dikes occur along joints that cross host rock bedding. Veins range from 200 to 700 meters long and 5 to 10 cm wide, strike northeast, and dip moderately. The veins contain mainly quartz, carbonate, feldspar, chlorite, and sericite with as much as 1 percent ore minerals. The ore minerals are pyrite, arsenopyrite, antimonite, chalcopyrite, sphalerite, chalcocite, and gold, and rare cassiterite, wolframite, sheelite, and molybdenite. Pyrite is dominant and forms disseminations and thin veinlets in quartz. The amount of arsenopyrite is less than pyrite and occurs in high-grade zones. Gold grains range from 1 to 6 mm and occur in bunches, thin veinlets, and rare octahedron crystals in fractured quartz. Gold fineness is 790.

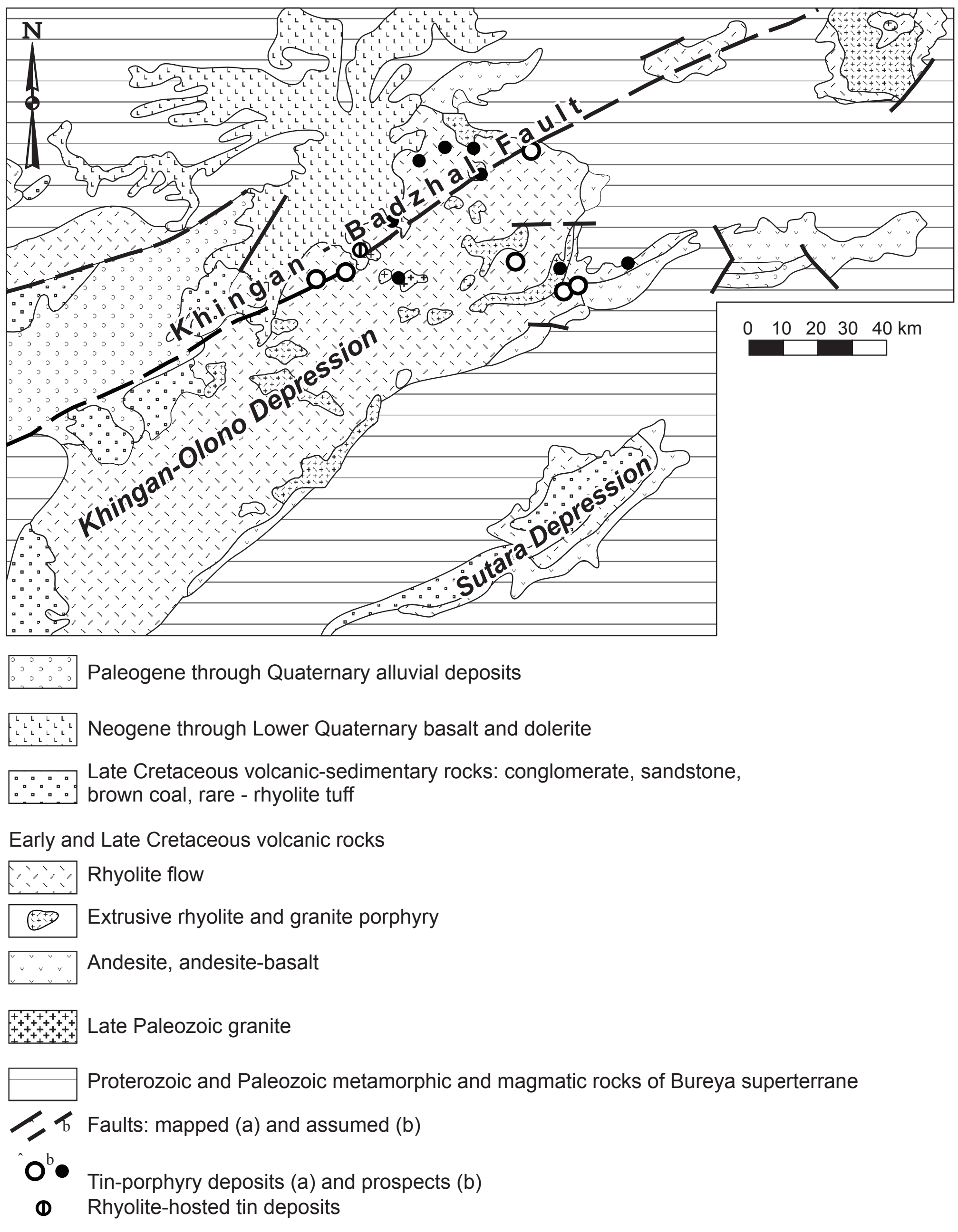


Figure 32. Generalized geologic map of Khingan porphyry Sn mine, Malo-Khingan metallogenic belt, Russian Southeast. Adapted from N.P. Emel'yanov, written commun. (1964).

Host rocks are altered near the quartz veins and contain as much as 2 to 4 g/t Au. The deposit is small and produced 12 tonnes Au. The average grades is about 25 g/t Au, with a maximum grade 1 to 2 kg/t Au. The deposit was mined from 1936 to 1962.

Dyappe Au-Sb Vein Deposit

This deposit (Moiseenko and Eirish, 1996) consists of low sulfide quartz veins and lesser vein breccia with pyrite, arsenopyrite, antimonite, magnetite, and gold. Pyrite contains from 40 to 50 g/t to 1.5 kg/t Au . Ore gold is fine-grained from 0.01 to 0.1 mm to 1.2 mm. Au fineness is 600 to 650. Ore contains Te. Several veins, dipping 65 to 85° SE, are prospected. Veins and breccia range from a 4 to 45 cm thick and from 30 to 800 meters long. The deposit occurs in the exo- and endocontact zone of diorite stock that intrudes Late Cretaceous black shale. The deposit is small. Primary ore grades as much as 5 to 6 g/t Au, and the oxidation zone grades as much as 200 to 300 g/t Au. The deposit was mined for Au from 1935 to1938 and from 1941 to 1942 for Sb.

Uchaminskoye Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (fig. 33) (V. Kochubey, written commun., 1955; Moiseenko and Eirish, 1996) occurs in folded Early Cretaceous sandstone and siltstone that is intruded by a Late Cretaceous granite porphyry stock and lamprophyre dikes. The deposit occurs in a linear zone of fractured sedimentary rock that is about 1.5 km wide and 0.8 to 30.0 meters thick. The zone contains linear stockworks and several quartz-sulfide veins that range from 1.5 to 3.0 meters thick. Veins and veinlets consist of fine-grained quartz and sulfides including pyrite, pyrrhotite, and arsenopyrite. The deposit is small and has an average grade of 7.0 to 12.2 g/t Au, 30 to 70 g/t Ag, 0.5 to 1.0 percent Pb, and 0.03 to 0.5 percent Sn.

Origin and Tectonic Controls for Pilda-Limuri Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along the Khingan transform continental-margin arc that is related to oblique subduction of ancestral Pacific Ocean Plate.

Preddzhugdzhursky Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag), Porphyry Cu (±Au), and Au-Ag Epithermal Vein Granitoid-Related Au-Vein, and Cu (±Fe, Au, Ag, Mo) Skarn Deposits (Belt PD) (Russia, Far East)

This Late Cretaceous through Paleocene metallogenic belt is related to granitoids in the Preddzhugdzhur volcanic zone of the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies the Batomga composite terrane of the East Aldan superterrane, the Dzugdzur anorthosite belt, and the Ulkan plutonic belt. Numerous deposit types occur in the belt and almost all of them are poorly studied. The best studied deposit is at Avlayakan.

The main reference on the geology and metallogenesis of the belt is Moiseenko and Eirish (1996).

Avlayakan Au-Ag Epithermal-Vein Deposit

This deposit (Moiseenko and Eirish, 1996) occurs along the southern flank of Dzhugdzhur district and is hosted in Late Cretaceous dacite, rhyolite, and andesite that overlie Precambrian gabbro and anorthosite. The deposit consists of quartz and quartz-carbonate veins that occur in several sub-longitudinal zones. Two zones are well explored. The Central zone varies from 5 to 40 meters thick, is about 3 km long, and consists of quartz and quartz-carbonate veins and veinlets with disseminated gold. Hosted volcanic rocks are altered as much as chlorite, sericite, hydromica, and quartz propilite. The average gold content for two intersections is 34.5 and 72.5 g/t Au. The Northeastern zone occurs 450 meters north of the Central zone, ranges from 50 to 120 meters thick, is 3 km long, and consists of numerous branching quartz veins and breccias with minor sulfides. The average grade is about 10.8 g/t Au for one intersection. The average for the whole deposit is 18.2 g/t Au and 38.1 g/t Ag. The Au:Ag ratio is 1:2 to 4. The deposit is small.

Origin and Tectonic Controls for Preddzhugdzhursky Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along an active continental-margin arc consisting of the Albian through Late Cretaceous Okhotsk-Chukotka volcanic-plutonic belt.

Selennyakh Metallogenic Belt of Carbonate-hosted Au-Sb-Hg, Volcanic-Hosted Hg, Au-Ag Epithermal Vein, and Ag-Sb Vein Deposits (Belt SE) (Russia, Verkhoyansk-Kolyma Rgion)

This Aptian through Late Cretaceous metallogenic belt is related to veins and replacements in the Omulevka passive continental-margin terrane of the Kolyma-Omolon superterrane and adjacent terranes. The belt contains carbonate and hosted Au-Sb-Hg (Gal Khaya, Pologoye, and Arbat deposits), volcanic-hosted Hg (Dogdo deposit), and Ag-Sb vein (Kysylga deposit) deposits. The Selennyakh metallogenic belt was previously named the Uyandina-Yasachnaya Hg ore belt (Obolenskiy and Obolenskaya, 1968; Indolev and others, 1980). The belt is 80 km wide, extends for 200 km. The veins and replacements are mainly in Late Jurassic volcanic rock of the

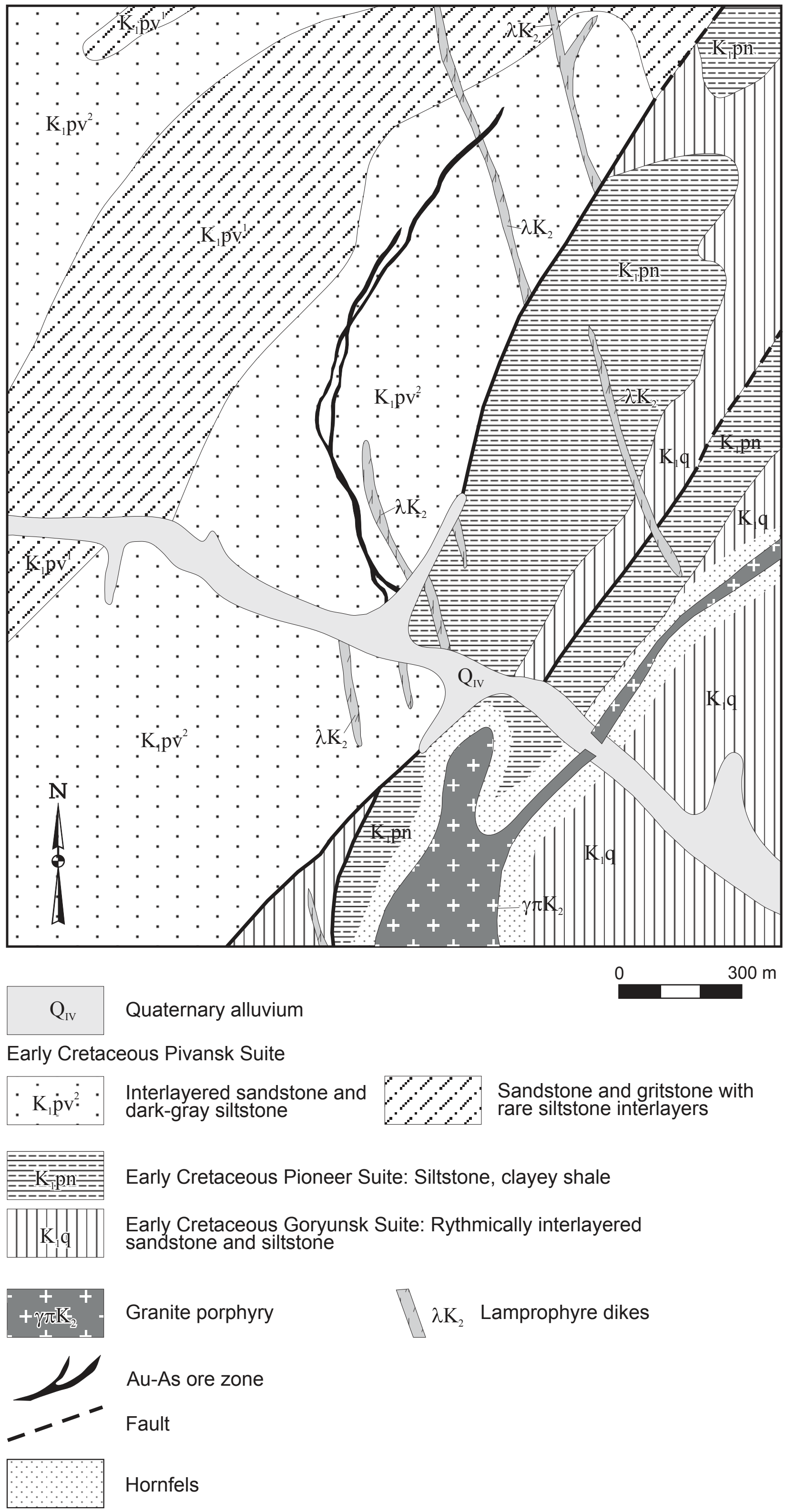


Figure 33. Generalized geologic map of Uchaminskoye polymetallic Pb-Zn±Cu (±Ag, Au) vein and stockwork deposit, Pilda-Limuri metallogenic belt, Russian Southeast. Adapted from L.V. Eyrish, written commun., 1976.

Uyandina-Yasachnaya volcanic belt that unconformably overlies the Omulevka terrane. In the northwestern part of the belt is the Sakyndzha ore district (Au-Hg-Sb) and to the southeast is the Dogdo (Hg-Au-Ag) ore district. In other areas of the belt are numerous Hg-Au occurrences.

The main references on the geology and metallogenesis of the belt are Obolenskiy and Obolenskaya (1968), Indolev and others (1980), Shoshin and Vishnevskiy (1984), Parfenov and others (1999), and Nokleberg and others (2003).

Kysylga Ag-Sb Vein Deposit

This deposit (Shoshin and Vishnevskiy, 1984; E. Vladimirtseva, written commun., 1985; Nekrasov and others, 1987; Gamyanin and Goryachev, 1988.) consists of veins in a zone that varies from 0.60 to 1.25 meters thick and as much as 400 meters long. The veins consist of gangue quartz and calcite with about 1 to 5 percent arsenopyrite, pyrite, Ag-tetrahedrite, pyrrhotite, sphalerite, galena, chalcopyrite, boulangerite, Ag-jamesonite, and Au (fineness of 638). The veins strike roughly east-west to northeast and dip steeply south. The veins exhibit brecciaiated or, less commonly, comb and massive structures, and often grade into stringers. The deposit occurs along feathered fissures in a northwest-striking major fault that cuts Late Triassic sandstone and siltstone. Host rocks are folding and are intensely contact metamorphosed adjacent to a granitic intrusive. Wallrocks exhibit sericite, chlorite, and feldspar alteration. The average grade is 3.0 to 84.5 g/t Au, 1 to 37 g/t Ag; 0.01 to 0.1 As; 0.01 to 0.04 percent Sb, 0.002 percent Sn, and 0.03 percent Pb.

Origin and Tectonic Controls for Selennyakh Metalogenic Belt

The belt is interpreted as having formed during postaccretionary extension related to initiation of the opening of the Eurasia Basin. The belt extends northwest along the Omulevka terrane, which is composed of early and middle Paleozoic carbonate rock that is unconformably overlain by Late Jurassic volcanic and sedimentary rocks of the Uyandina-Yasachnaya volcanic belt.

Sergeevka-Taukha Metallogenic Belt of Granitoid-Related Au Vein, Boron (datolite) Skarn, Zn-Pb (±Ag, Cu) Skarn, Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite, Au-Ag Epithermal-Vein, and Porphyry Cu (±Au) Deposits (Belt ST) (Russia, Far East)

This Late Cretaceous and early Tertiary metallogenic belt is related to veins and granitoids related to East Sikhote-Alin volcanic-plutonic belt that overlies and intrudes Sergeevka, Samarka, and Taukha terranes. The belt includes several deposit types.

The main references on the geology and metallogenesis of the belt are Efimova and others (1978), Garbuzov and others (1987), Ratkin and others (1990, 1991), Ratkin and Watson (1993), Ishihara and others (1992), Vasilenko and Valuy (1998), and Nokleberg and others (2003).

Progress Granitoid-Related Au-Vein Deposit

This deposit (A.N. Rodionov, written commun., 1991) consists of sulfide-poor veins and small veinlets that contain pyrite, arsenopyrite, quartz, and Au. In addition the deposit contains poorly mineralized fracture zones, mylonite zones, and zones of metasomatically-altered carbonate and chlorite-sericite rock. The deposit occurs in, or near a Late Cretaceous granitoid pluton and dikes that intrude Cambrian granitic and gabbro rocks of the Sergeevka complex. The deposit is also the source for local placer Au mines. The deposit is medium size and has an average grade of 5.89 g/t Au.

Askold Granitoid-Related Au-Vein Deposit

This deposit (M.I. Efimova and others, written commun., 1971; Efimova and others, 1978) consists of a Au-quartz vein stockwork in a Mesozoic granite that is altered to greisen and that intrudes Paleozoic volcanic and sedimentary rock. A K-Ar muscovite age for alteration associated with the vein is 83.2 Ma. The deposit is prospected to depths of more than 100 meters. The deposit is medium size and has an average grade of 5.9 to 7.6 g/t Au.

Dalnegorsk Boron (datolite) Skarn Mine

This major, world-class boron mine (fig. 34) (Ratkin, 1991; Ratkin and Watson, 1993; P. Layer, V. Ivanov, and T. Bundtzen, written commun., 1994) occurs in a thick skarn formed in a large, upturned olistolith of bedded Triassic limestone that is enclosed in Early Cretaceous clastic sedimentary rock. The skarn extends to a depth of approximately 1 km, where it is intruded by a granite pluton. The skarn formed in two stages, with a second-stage skarn over-printing an earlier skarn. The two stages of skarn formation are separated in time by intrusion of intermediate-composition magmatic bodies (with an approximate K-Ar isotopic age of 70 Ma). The first-stage skarn consists of grossular-wollastonite skarn, is concentrically zoned, and consists of finely-banded aggregates with numerous finely crystalline datolite and druse-like accumulations of danburite crystals in paleohydrothermal cavities. The second-stage skarn consists predominantly of long, radiated hedenbergite and andradite with coarsely-crystalline datolite, danburite, quartz, axinite, and calcite. An Ar-Ar isotopic age for orthoclase in the second stage skarn assemblage is 57 Ma. The silicate mineralogy of the first-stage skarn is similar to Zn-Pb (±Ag, Cu) skarn deposits in the belt. B isotopic studies indicate a magmatic source for boron. The Dalnegorsk open-pit mine at the deposit is explored to a depth of 1 km. The deposit is very large and had been mined from the 1970s to the present. The deposit produces more than 90 percent of all borate in Russia.

Nikolaevskoe Zn-Pb (±Ag, Cu) Skarn Mine

This mine (Garbuzov and others, 1987; V.V. Ratkin in Nokleberg and others, 1997) is hosted in a giant olistolith of Triassic limestone that is part of an Early Cretaceous accretionary complex. The skarn occurs along the contacts of limestone with hosting siltstone and sandstone, and with overlying felsic volcanic rock of a Late Cretaceous through Paleogene postaccretionary sequence. Small skarn bodies also occur in limestone blocks in the volcanic rock that were faulted from the underlying basement. The ore minerals are dominantly galena and sphalerite that replace an older hedenbergite skarn near the surface, and, at depth, replace a garnet-hedenbergite skarn. Subordinate ore minerals are chalcopyrite, arsenopyrite, pyrite, pyrrhotite, fluorite, and

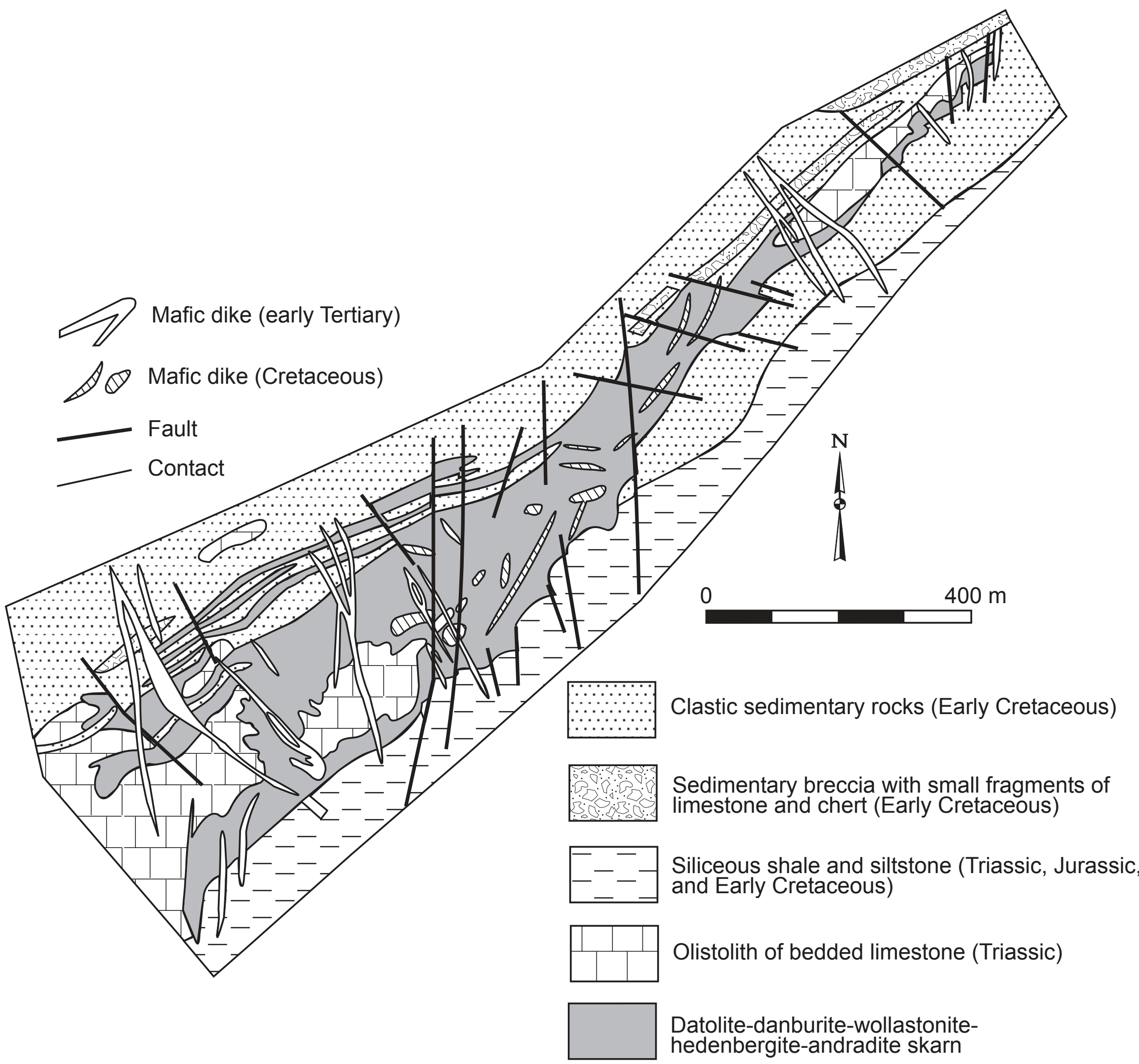


Figure 34. Generalized geologic map of Dalnegorsk boron (datolite) skarn mine, Sergeevka-Taukha metallogenic belt, Russian Southeast. Adapted from Ratkin (1991).

Ag-sulfosalts. The K-Ar age of deposits ranges from 80 to 60 Ma. Average grades are 62 g/t Ag, 1.5 to 8.7 percent Pb, and 1.36 to 10.5 percent Zn. The deposit has been mined from the 1970s to the present.

Partizanskoe Zn-Pb (±Ag, Cu) Skarn Mine

This mine (Ratkin and others, 1991) consists of numerous, small, steeply-dipping skarn bodies that occur at the contact of a Triassic limestone olistolith surrounded by Early Cretaceous clastic rock. The deposits merge and form a single skarn body about 400 meters below the surface and pinch out at a depth of approximately 600 meters. The skarn assemblages are vertically zoned, and higher temperature assemblages occur deeper. Massive, densely disseminated Ag-Pb-Zn sulfides (with a Pb/Zn ratio of about 1.0) occur above a quartz-calcite aggregate in the upper part of the deposit. Massive, densely-disseminated Pb-Zn sulfides (with a Pb/Zn ratio of about 0.8) are associated with Mn hedenbergite skarn and occur in the middle part of the deposit. Disseminated Zn sulfides (with a Pb/Zn ratio of about 0.5) occur in ilvaite-garnet-hedenbergite skarn in the lower part of the deposit. Galena and sphalerite are the dominant ore minerals; chalcopyrite and arsenopyrite are common, and minor magnetite, pyrrhotite, and marcasite also occur. Silver-bearing minerals are Ag-and Sb-sulfosalts in the upper part of the deposit and galena in the lower part. Galena contains Ag as a solid solution of matildite. The age of deposits is bracketed between 80 to 60 Ma by basalt dikes that intrude the deposit at the contact of olistolith, and by the lower part of the overlying volcanic strata that are intruded by deposit. The deposit consists of four or more related ore bodies that occur along an about 5 km strike length, including the Soviet 2, Partizansk East, Partizansk West, and Svetliyotvod bodies. The underground workings have a total length of about 11 km. The deposit is medium size, and the average grades are 67.6 g/t Ag, 1.5 to 3 percent Pb, and 0.6 to 4 Zn percent. The deposit has been mined from the 1950s to present.

Krasnogorskoye Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (fig. 35) (Ratkin and others, 1990) consists of steeply-dipping quartz-sulfide veins that extend as much as several hundred meters long along strike and range from 0.2 to 1.5 meters thick. The veins intrude Late Cretaceous tuff. Sphalerite, cassiterite, and galena are the dominant ore minerals, and the margins of veins contain pyrite-marcasite-pyrrhotite with lesser Sb-Ag-sulfosalts. In the deeper level of the deposit, galena contains as much as several percent Ag and Bi in matildite. The volcanic rock adjacent to the polymetallic veins is altered to quartz and chlorite. In the core of the veins, chlorite, Mn calcite, rhodochrosite, rhodonite, and spessartine occur with quartz gangue. The veins occur near a Late Cretaceous and Paleocene volcanic vent. The vent breccia also contains disseminated sphalerite, galena, and cassiterite. The veins formed immediately after deposits of the vent breccia, which has an approximate K-Ar isotopic age of 65 Ma. The deposit is medium size, and the average grades are 62 g/t Ag, 5 percent Pb, 0.26 percent Sn, and 6.77 percent Zn.

Origin and Tectonic Controls for Sergeevka-Taukha Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along the East-Sikhote-Aline continental-margin arc related to subduction of the ancestral Pacific Ocean Plate. This belt is hosted in, or near igneous rocks that intrude the Taukha subduction-zone terrane that contains a complex assemblage of abundant Paleozoic and early Mesozoic oceanic rocks and lesser Jurassic and Early Cretaceous turbidite deposits.

Taryn Metallogenic Belt of Clastic-Sediment-Hosted Sb-Au Deposits (Belt TAR) (Russia, Verkhoyansk-Kolyma Region)

This Aptian through Late Cretaceous metallogenic belt is related to veins and replacements in the Kular-Nera continental-margin turbidite terrane and Verkhoyansk fold and thrust belt in the North Asian cratonal margin. The belt extends northwest for 500 km along most of the Kular-Neta terrane. The belt contains numerous major Sb-Au deposits at Tan, Maltan, Kinyas'-Yuryakh, Sarylakh, Kyunkugur, Kim, El'gi-Tonor, Tobychan, Lower Tordocha, Kekhtey, Kemyustakh, Byindzha, Aulachan, Dzholakag, Nitkan, Uzlovoye, Burgavliyskoye, Sentachan, and Markovskoye, and lesser Ag and Ag-Sb polymetallic deposits at Kupol'noye and Dichek. The major deposits are at Sarylakh, Senatachan, and Kupol'noe.

The main references on the geology and metallogenesis of the belt are Berger (1978, 1986), Indolev and others (1980), V.V. Maslennikov, written commun. (1985), Shour (1985), and Gamyanin and Goryachev (1988).

Senatachan Clastic-Sediment-Hosted Sb-Au Deposit

This deposit (fig. 36) (Berger, 1978; Zharikov, 1978; Indolev and others, 1980; Maslennikov, written commun., 1985; Shour, 1985) consists of two rod-like veins that range from 85 to 200 meters long and 0.2 to 3.1 meters thick. The veins occur in shear zones that strike northwest, dip 60 to 80° NW and extend to a depth of 600 meters or more. The main ore minerals are stibnite and quartz, with lesser ankerite, muscovite, pyrite, arsenopyrite, dickite, and hydromica, and rare sphalerite, Au, chalcostibnite, berthierite, tetrahedrite, zinkenite, jamesonite, aurostibnite, and chalcopyrite. Wallrocks exhibit quartz, carbonate, hydromica and dickite alteration. Disseminated pyrite and stibnite occur in aureoles around the deposit. The deposit is hosted in Late Triassic (Norian and Rhaetian) clastic rock that is deformed into northwest-trending, gently-plunging folds. The deposit occurs along the northwest-trending Adycha-Taryn fault and is conformable to folding. The average grade is 3.2 to 40.3 percent Sb with as much as 30 percent Sb and 50 g/t Au. The deposit is medium size, has been mined, and has reserves of 100,000 tonnes of Sb.

Origin and Tectonic Controls for Taryn Metallogenic Belt

The belt is interpreted as having formed during postaccretionary extension related to initiation of the opening of the Eurasia Basin.

Tumnin-Anyui Metallogenic Belt of Porphyry Sn, Cassiterite-Sulfide-Silicate Vein and Stockwork, and Au-Ag Epithermal-Vein Deposits (Belt TA) (Russia, Far East)

This Late Cretaceous through Paleocene metallogenic belt is related to veins and granitoids in the perivolcanic zone of the East Sikhote-Alin volcanic-plutonic belt that overlies and intrudes the Kema, Luzhkinsky, and Samarka terranes. The major deposits are at Mopau and Tumninskoye.

The main references on the geology and metallogenesis of the belt are Moiseenko and Eirish (1996) and Nokleberg and others (2003).

Mopau Porphyry Sn Deposit

This deposit (Finashin, 1959; Usenko and Chebotarev, 1973) is the most important deposit of the belt and consists

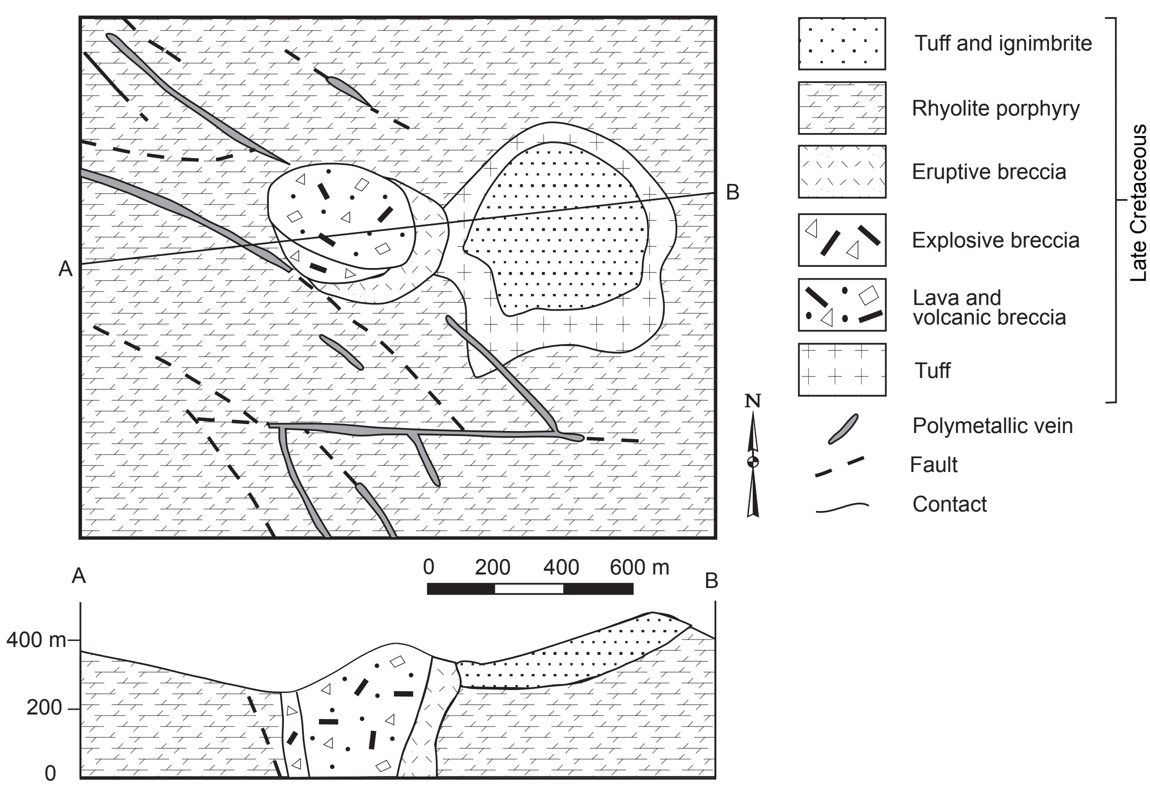


Figure 35. Generalized geologic map and schematic cross section of Krasnogorskoye polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposit, Sergeevka-Taukha metallogenic belt, Russian Southeast. Adapted from Ratkin and others (1990).

of lenticular zones in quartz-sericite rock. The zones contain abundant quartz-cassiterite, cassiterite-quartz-feldspar, quartz-cassiterite-chlorite, and quartz-cassiterite-arsenopyrite-chlorite veinlets. The veinlets range from paper-thin to 0.5 cm thick and, locally, as much as 10 cm thick. Where closely-spaced, the veinlets form an intricate stockwork as much as 100 meters across with high Sn content. The zones are more than 400 meters long and several tens of meters thick. Some zones occur at contacts with diabase porphyry dikes. The deposit extends to depths of more than 200 meters, is sulfide poor, and is easily concentrated. The deposit is hosted in a group of closely-spaced volcanic vents composed of rhyodacite breccia that is intruded by felsite porphyry intrusions and quartz porphyry dikes. The deposit is related to a major felsic pluton. The age of the deposit

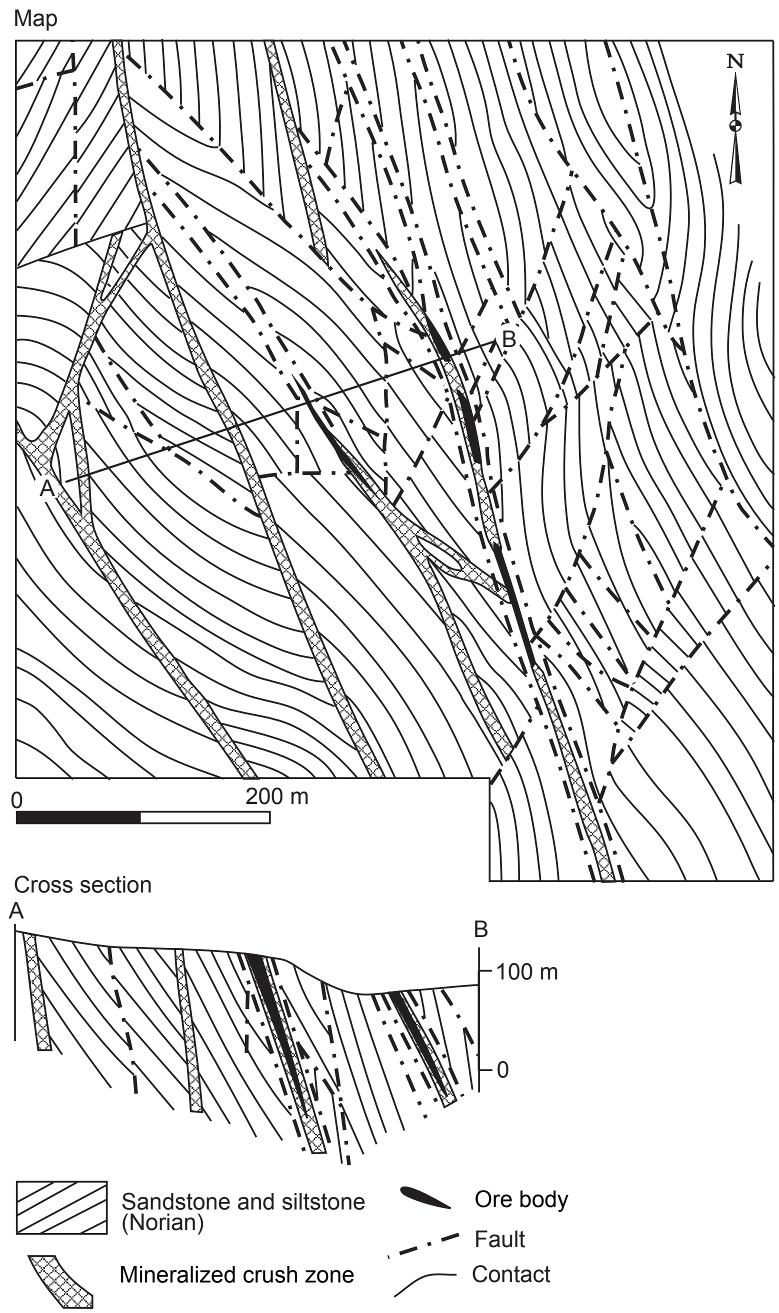


Figure 36. Generalized geologic map and schematic cross section of Senatachan clastic-sediment-hosted Sb-Au deposit, Taryn metallogenic belt, Yakutia, Russia. Adapted from Shour (1985).

interpreted as being Late Cretaceous through Paleogene. The deposit is small and has an average grade of 0.3 percent Sn.

Tumninskoye Au-Ag Epithermal-Vein Mine

This mine (Moiseenko and Eirish, 1996) occurs in the northern part of Samarka terrane. The deposit consists of low sulfide Au-quartz veins that parallel, or rarely crossut strike in wallrocks. Isolated granite porphyry dikes also contain Au. The Au-quartz veins range from about 200 to 500 meters long and from 0.2 to 6.0 meters wide (locally as much as 19 meter)s. The veins are predominantly (90 to 95 percent) composed by quartz. The ore minerals are arsenopyrite, galena, sphalerite, chalcopyrite, pyrrhotite, gold, and wolframite. The gangue minerals are quartz, by calcite, albite, adularia, sericite, and chlorite. Gangue quartz locally contains numerous host-rock fragments. The deposit is hosted in Early Cretaceous sandstone and siltstone in the Oyemku anticline that trends north-northeast. The core of the anticline consists of siltstone, and the flanks are consists of sandstone and interlayered siltstone. The main Au veins and rare dikes of granite porphyry, diorite porphyry, spessartite, and malchite occur along steeply-dipping (50 to 60^o) bedding faults. Bedding faults are widespread. The deposit is small and has produced 576 kg of Au from 1962 to 1966.

Origin and Tectonic Controls for Tumnin-Anyui Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along the East-Sikhote-Aline continental-margin arc related to subduction of the ancestral Pacific Ocean Plate.

Upper Uydoma Metallogenic Belt of Cassiterite-Sulfide-Silicate Vein and Stockwork, Polymetallic Pb-Zn±Cu (±Ag, Au) Vein and Stockwork, Sn-W Greisen, Stockwork, and Quartz-Vein, and Porphyry Mo (±W, Sn, Bi) Deposits (Belt UY) (Russia, Verkhoyansk-Kolyma Region)

This Late Cretaceous metallogenic belt is related to veins and replacements that are part of the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies the Verkhoyansk fold and thrust belt in the North Asian cratonal margin. The metallogenic belt occurs along the western margin of the Okhotsk-Chukotka volcanic-plutonic belt on the eastern limb of the South-Verkhoyansk synclinorium, extends for 200 km, and is as much as 60 km wide. The igneous rocks cut Permian and Triassic clastic rock that is deformed into folds that trend north to northeast. Typical are small fields of Late Cretaceous horizontal, volcanic and subvolcanic bodies of rhyolite and dacite. The Late Cretaceous igneous bodies and deposits are controlled by longitudinal, northwest-, and northeast-striking faults. Various Pb, Zn, Sn, Ag, Au, W, and Sb deposits are widespread and most prevalent are low-sulfide cassiterite-silicate and argentiferous Sn polymetallic deposits (galena-pyrrhotite-sphalerite). The major deposits are at Khoron, Khaardakh, Kutinskoye, and Djatonskoye.

The main references on the geology and metallogenesis of the belt are Flerov (1974), Andrianov and others (1984), Parfenov and others (2001), and Nokleberg and others (2003).

Khoron Cassiterite-Sulfide-Silicate Vein and Stockwork Deposit

This deposit (Andriyanov and others, 1984) occurs on the northeastern side of the metallogenic belt at the intersection of the Khoron and the Pravonitkansk faults. The deposit is hosted in Permian sandstone and siltstone that are simply folded. The sedimentary rocks are intruded by preore dikes and a granodiorite porphyry stock. The deposit occurs in crush zones and veins that are as much as 100 meters long and from 1 to 1.5 meters wide. The vertical span is 500 meters. The principal minerals are quartz, tourmaline, and muscovite, and local chlorite and pyrrhotite. Accessory minerals are actinolite, axinite, galena, Fe disulfide, sphalerite, cassiterite, chalcopyrite, stannite, and Bi minerals. Minor minerals are stibinite, Ag minerals, teallite, native Bi and gold. The deposit formed in five phases (1) quartz-tourmaline, (2) cassiterite-quartz with arsenopyrite, (3) greisen, (4) quartz-sulfide, and (5) quartz-carbonate. Most cassiterite formed in the second phase. The deposit is large and has an average grade of 1.17 percent Sn.

Origin and Tectonic Controls for Upper Udoma Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along an active continental-margin arc consisting of the Albian through Late Cretaceous Okhotsk-Chukotka volcanic-plutonic belt. Late Cretaceous magmatism and deposits of the belt are controlled by longitudinal, northwest, and northeast faults.

Major Maastrichtian through Oligocene (72 to 24 Ma) Metallogenic Belts

Kema Metallogenic Belt of Ag-Au Epithermal-Vein, Porphyry Cu-Mo (±Au, Ag), Porphyry Cu (±Au), and Porphyry Mo (±W, Sn, Bi) Deposits (Belt KM) (Russia, Far East)

This early Tertiary metallogenic belt is related to veins in the East Sikhote-Alin volcanic-plutonic belt that intrudes and overlies the Kema island-arc terrane. The Ag epithermal-vein deposits, as at Tayoznoe, occur in Early Cretaceous clastic and volcaniclastic rocks and in overlying Late Cretaceous and Paleogene, subalkalic, postaccretionary volcanic rock. Rare Pb-Zn polymetallic-vein deposits occur, but are not economic. The epithermal-vein deposits generally occur mostly in or near Danian (early Paleocene) and Paleocene volcanic rock; however, a few occur in granodiorite plutons. Porphyry Cu-Mo (±Au, Ag) deposits in the metallogenic belt occur mainly in the northern part of the belt. These deposits generally consist of disseminations and veinlets in, and near intrusive rocks and coeval volcanic rock that often contain anomalous Pb, Zn, W, Au, and Ag in addition to Cu and Mo. The porphyry Cu-Mo deposits occur in Late Cretaceous through Paleogene granitic and diorite intrusions. A porphyry Cu (±Au) deposit also occurs in the southern part of the belt. The major Au-Ag epithermal-vein deposits are at Burmatovskoe, Glinyanoe, Salyut, Sukhoe, Tayozhnoe, Verkhnezolotoe, and Yagodnoe. Porphyry Cu (±Au) deposits are at Nesterovskoe and Nochnoe, a porphyry Cu-Mo (±Au, Ag) deposit is at Sukhoi Creek, and a porphyry Mo (±W, Bi) deposit is at Moinskoe.

The main references on the geology and metallogenesis of the belt are Orlovsky and others (1988), Petrachenko and others (1988), Khomich and others (1989), Pakhomova and others (1997), and Nokleberg and others (2003).

Glinyanoe Ag-Au Epithermal-Vein Deposit

This deposit (A.N. Rodionov, written commun., 1986) consists of adularia-quartz, sericite-chlorite-quartz, and carbonate and chlorite-quartz veins and zones that contain pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, argentite, acanthite, Ag-tellurides, and native gold and silver. The veins and zones occur in altered, silicified volcanic rock that overlie Late Cretaceous (Santonian) felsic volcanic rock. The deposit as occurring in four stages (1) gold-pyrite-quartz,; (2) quartz-hydromica and quartz-carbonate, (3) gold-silver, and (4) quartz-chlorite-adularia with Ag-sulfosalts. The age of the deposit is interpreted as being Late Cretaceous through Paleogene. The deposit is small and has an average grade of 8.3 g/t Au and 122 g/t Ag.

Sukhoi Creek Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Petrachenko and others, 1988) consists of stockworks and an associated altered zone that are several hundred meters across. Polymetallic ore is dominant. The ore minerals are chalcopyrite, molybdenite, sphalerite, galena, cassiterite, scheelite, and pyrite, with significant Au and Ag. The deposit occurs in Early Cretaceous sedimentary rock that is overlain by Late Cretaceous volcanic rock and crosscut by deposit-hosting granitic intrusions with a K-Ar isotopic age of 73 Ma. The deposit is related to several granodiorite and granite stocks that are intensely hydrothermally altered. Quartz-sericite alteration, and medium-temperature epidote-prehnite-chlorite propylitic alteration occur at the core and grade into micaceous-chlorite-carbonate propylite at the periphery. Granite is locally altered to quartz-muscovite greisen with tourmaline and sphene and in a few places into a peculiar garnet-phlogopite rock with apatite. Host siltstone and sandstone are altered to orthoclase-actinolite-chlorite hornfels, and the felsic extrusive rocks are altered to quartz and phyllite. The deposit is small and grades as much as 0.2 percent Cu and 0.01 percent Mo.

Tayozhnoe 1 Ag-Au Epithermal-Vein Mine

This mine (A.N. Rodionov and others, written commun., 1976; Ratkin and others, 1991) consists of steeply-dipping quartz veins that occur along northwest to north-south fractures that intrude Early Cretaceous sandstone. The veins vary from 100 to 500 meters long and 0.5 to 2 meters thick, and also occur beneath a contact between sandstone and an overlying 50-m-thick section of Late Cretaceous felsic volcanic rock. The ore minerals occur in veins, and in metasomatic zones along the subhorizontal contact, and between veins and overlying volcanic rock. The major Ag minerals are Ag sulfosalts and sulfides. Pyrite and arsenopyrite are rare and formed before Ag minerals. In the upper part of veins, Ag occurs in tetrahedrite, freibergite, stephanite, pyrargyrite, and polybasite. At middle depths, Ag occurs mainly in acanthite and stephanite, along with arsenopyrite and allargentum. Acanthite is dominant at depth. The deposit is medium size and has an average grade of 50 to 2000 g/t Ag and 1 g/t Au. The deposit has been mined since the 1980s.

Verkhnezolotoe Porphyry Cu (±Au) Deposit

This deposit (Orlovsky and others, 1988) occurs at the northwest margin of a caldera that contains dikes of calc-alkaline andesite porphyry that is interpreted as tongues of a dome-like subvolcanic intrusion. A stockwork occurs in a circular aureole of hydrothermally altered rock with a surface extent of 200 m^2 over the intrusive dome. Successive alterations are (1) quartz-biotite-actinolite with pyroxene and epidote, (2) quartz-biotite-actinolite, (3) quartz-biotite-sericite and local chlorite, and (4) quartz-hydromica with carbonate. The stockwork contains the first three alterations and consists of a thick network of quartz-epidote-actinolite veinlets and lenses as much as 2 to 3 cm thick with chalcopyrite, bornite, and pyrite. The stockwork is related to a diorite stock. The stockwork boundary coincides with the aureole of the biotite alteration. An intensely-fractured breccia of mineralized siliceous siltstone was encountered by drill holes that extend to 100 meters depth. The ore minerals in the breccia zones are chalcopyrite and bornite. Molybdenite and pyrite, and rare pyrrhotite, cubanite, arsenopyrite, galena, and sphalerite also occur. Carbonate and chalcopyrite veinlets also occur. The richest ore is associated with Sn, Cu, and local W tungsten minerals. A zone of oxidized ore as much as 20 to 30 meters thick caps the deposit. The deposit is small and has an average grade of 3 g/t Au, 86 g/t Ag, 0.35-2.27 percent Cu, 0.69 percent Pb, and 0.26 percent Sn.

Origin and Tectonic Controls for Kema Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along a continental-margin arc related to subduction of the ancestral Pacific Ocean Plate. The granitoids hosting the belt are part of the Late Cretaceous and early Tertiary East Sikhote-Alin volcanic-plutonic belt. This belt consists chiefly of five major units (1) Early Cenomanian rhyolite and dacite,; (2) Cenomanian basalt and andesite, (3) thick Turonian through Santonian ignimbrite sequences, (4) Maastrichtian basalt and andesite, and (5) Maastrichtian through Danian (early Paleocene) rhyolite. The East Sikhote-Alin belt also contains coeval, mainly intermediate-composition granitoid plutons that in the frontal (eastern) part of the belt are predominantly Early Cretaceous magnetite-series granitoids. The East-Sikhote-Alin belt is correlative with the Okhotsk-Chukotka volcanic-plutonic belt on strike to the north in the Russian Northeast, and it is tectonically linked to the Aniva, Hidaka, and Nabilsky subuction zone and subduction-zone terranes.

Lower Amur Metallogenic Belt of Au-Ag Epithermal-Vein, Epithermal Quartz-Alunite, Porphyry Au, Porphyry Cu (±Au), Sn-W Greisen, Stockwork, and Quartz-Vein Deposits (Belt LA) (Russia, Far East)

This Late Cretaceous and Paleocene metallogenic belt is related to veins in the East Sikhote-Alin volcanic-plutonic belt that intrudes or overlies the Amur River and Kiselyovka-Manoma subduction-zone terranes. The Au-Ag epithermal-vein deposits, as at Mnogovershinnoe, range from medium to large and are generally hosted in Paleocene alkaline granitoids that are closely related to coeval andesite to dacite volcanic rock. A few Au-Ag epithermal-vein deposits are related to Eocene and Oligocene volcanism. The Au-Ag epithermal-vein deposits, as at Belaya Gora and Bukhtyanskoe, are closely associated with rhyolite and trachyrhyolite flows and vent rocks that are commonly hydrothermally-altered to siliceous and adularia phases. Au is either disseminated throughout the hydrothermally-altered rock or is concentrated in small quartz veins. The adularia phases also locally contain Au. Placer Au deposits, as at Kolchanskoe, Ulskoe, and Oemku, are derived from Au-Ag epithermal-vein deposits. In addition to the Au-Ag epithermal-vein deposits, the Lower Amur metallogenic belt contains a few, small porphyry Cu (±Au) deposits that are all hosted in or near Paleogene alkaline granitoids. The major Au-Ag epithermal-vein deposits are at Belaya Gora, Bukhtyanskoe, and Mnogovershinnoe; a porphyry Cu (±Au) deposit is at Tyrskoe; and a major and large quartz-alunite deposit is at Iskinskoe.

The main references on the geology and metallogenesis of the belt are Mel'nikov (1978), Zalishchak and others (1978), Ivanov and others (1989), Khomich and others (1989), and Nokleberg and others (2003).

Mnogovershinnoe Au-Ag Epithermal-Vein Deposit

This large deposit (Zalishchak and others, 1978; Ivanov and others, 1989) consists of hydrothermally altered, adularia-sericite-quartz vein zones that are as much as 800 meters long and contain a series of adularia-quartz veins and veinlets. Some deposits consist of rhodonite-carbonate veins, and lenses of skarn and sulfides. The ore minerals are pyrite, marcasite, gold, argentite, Au-and Ag-tellurides, galena, sphalerite, chalcopyrite, and freibergite. The ore minerals comprise as much as 1 percent veins and the Au:Ag ratio is 1:1. The deposit is hosted in Paleocene andesite and dacite that are genetically related to a multiphase intrusion of highly alkaline granitoids. K-Ar isotopic studies indicate a deposit age of 69 to 49 Ma. During formation of local Au-bearing skarn, that is related to intrusion of Paleogene subalkaline granite, Au was remobilized. The deposit is medium size.

Belaya Gora Au-Ag Epithermal-Vein Deposit

The deposit (fig. 37) (Mel'nikov, 1978) consists of disseminations and stockworks that occur in extrusive bodies of subalkalic rhyolite and dacite, and in explosive breccia of an Eocene-Oligocene igneous complex. Alteration minerals are quartz (50 to 90 percent), kaolinite, dickite, sericite, hydromica, and adularia. The ore minerals are gold, silver, argentite, pyrite, marcasite, chalcopyrite, sphalerite, galena, hematite, and cinnabar. The ore assemblages are gold-quartz and Au-sulfosalts-sulfide-quartz. Gold distribution is highly irregular, and the deposits have gradational boundaries. The deposit is medium-size.

Iskinskoe Epithermal Quartz-Alunite Deposit

The deposit (Onikhimovkiy and Belomestnykh, 1996) is hosted in intensively altered Tertiary dacite and rhyolite. The deposit consists of a metasomatic body of quartz-alunite surrounded by a concentric zone of quartz-sericite alteration, and an outer zone of propylitic alteration. The deposit is 2.3 km long, 1.2 km wide, and as much as 360 meters deep. The ore minerals are 29.4 to 32.0 percent alunite; 60.0 to 66.0 percent quartz; 2.0 percent halloysite; 1.5 to 5.0 percent Fe oxides; 1.5 to 1.6 percent kaolinite; and as much as 2.0 percent beudantite. Rare minerals are pyrite, diaspore, andalusite, dickite, montmorillonite, and kaolinite. Pure alunite occurs in descrete masses ranging as much as 8 to 10 cm in diameter. The deposit is large and has reserves of 336,581,000 tonnes alunite ore and has an average grade of 26.1 percent alunite.

Origin and Tectonic Controls for Lower Amur Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids along a continental-margin arc related to subduction of the ancestral Pacific Ocean Plate. The granitoids hosting the belt are part of the Late Cretaceous and early Tertiary East Sikhote-Alin volcanic-plutonic belt. This belt consists chiefly of five major units (1) Early Cenomanian rhyolite and dacite, (2) Cenomanian basalt and andesite, (3) thick Turonian through Santonian ignimbrite sequences, (4) Maastrichtian basalt and andesite, and (5) Maastrichtian through Danian (early Paleocene) rhyolite. The East Sikhote-Alin belt also contains coeval, mainly intermediate-composition granitoid plutons that. in the frontal (eastern) part of the belt. are predominantly Early Cretaceous magnetite-series granitoids. The East-Sikhote-Alin belt is correlative with the Okhotsk-Chukotka volcanic-plutonic belt on strike to the north in the Russian Northeast, and it is tectonically linked to the Aniva, Hidaka, and Nabilsky subuction zone and subduction-zone terranes.

Popigay Metallogenic Belt of Impact Diamond Occurrences (Belt PP) (Russia, Northern North Asian Craton)

This Eocene metallogenic belt is related to an astrobleme or impact ring structure developed on Early Precambrian crystalline basement and Phanerozoic sedimentary rock of the North Asian craton. The age of the belt is interpreted as being Eocene. The belt occurs in the Popigay ring structure.

The main references on the geology and metallogenesis of the belt are Masaitis and others (1975, 1998).

Popigay Impact Diamond Deposit

This deposit (Masaitis and others, 1975, 1998) occurs in an impact structures that is about 80 km in diameter on the northeastern margin of the Anabar shield. The ring structure forms a round basin with a floor that is 200 to 300 meters lower relative to the surrounding plateau. The basin contains a specific rock complex, including volcanic-like rock. Masaitis and others (1975, 1998) identified an impactite with varying amounts of glass that chemically corresponds to (1) andesite and dacite rock and mineral fragments, (2) explosive allogenic breccia that fell in or beyond the limits of the crater after the explosion, and (3) authigenic breccia formed from brecciated material at the bottom of the crater and that underwent high-grade shock metamorphism with melting and formation of pseudotachylite. The impactite is classified as a massive lava-like tagamite and glassy-clastic suevite. The tagamite and impact glasses have an $^{40}Ar/^{39}Ar$ isotopic age of 35.7±0.2 Ma. Diamond occurs in graphite gneiss and tagamite that formed during shock metamorphism (Masaitis and others, 1998). Diamond crystals range from 0.05 to 2.0 mm in diameter. Adjacent placer deposits contain diamonds as big as 8 to 10 mm. The most abundant diamonds are yellow; colourless, transparent, grey, and black crystals are rare. Diamonds from the gneiss retain morphological and structural features inherited from crystalline graphite. Common are tabular crystals with a characteristic striation of basal planes due to repeated twinning, parallel intergrowths, irregular intergrowths, and aggregates.

Origin and Tectonic Controls for Popigay Metallogenic Belt

The belt is hosted in the Popigay ring structure for which two origins are proposed, either meteoritic impact, or cryptovolcanic eruption. The most popular idea is meteoritic origin (Masaitis and others, 1975, 1998) with structure forming from the impact of a giant meteorite. Supporting the meteoric idea are numerous indications of shock metamorphism and partial melting of Early Precambrian crystalline rock. The cryptovolcanic hypothesis suggests explosion during a volcanic eruption with the ring structure being the stage of kimberlite formation, both alnoite kimberlite and carbonatite, and cryptoexplosion.

Major Miocene through Quaternary (24 Tto 0 Ma) Metallogenic Belts

Hokuriku-Sanin Metallogenic Belt of Au-Ag Epithermal-Vein, Polymetallic Pb-Zn ± Cu (± Ag, Au) Vein and Stockwork, Ag-Sb vein, and Clastic-Sediment-Hosted U Deposits (Belt HS) (Japan)

This Miocene to Pleistocene metallogenic belt is related to veins and replacements in the Japan Cenozoic sedimentary basin that overlies and intrudes the Hiroshima granitic plutonic belt and the Akiyoshi-Maizuru and Mino-Tamba-Chichibu terranes. The belt occurs in the western part of Honshu and northern Kyushu Islands, trends east-northeast to west-southwest for more than 900 km, and is as much as 50 km or more wide. The belt occurs in northern part of the Inner Zone of southwestern Japan and contains Au-Ag epithermal-vein deposits (Omori) and polymetallic-vein deposits (Taishu).

The deposits are associated with siliceous and intermediate magmatism. Tsuboya and others (1956) used the names Toyama, Noto, and Shimane provinces for the Hokuriku-Sanin metallogenic belts. A small number of the Kuroko-type deposits occur in the belt, but they are not described in the mineral deposit database. Ishihara (1978) defined this belt as a Ag-Cu-Pb-Zn province. The belt was originally interpreted as Miocene; however, new K-Ar isotopic ages for the Omori Au-Ag deposit suggest the deposits continued to form into the Pleistocene (Sakoda and others, 2000).

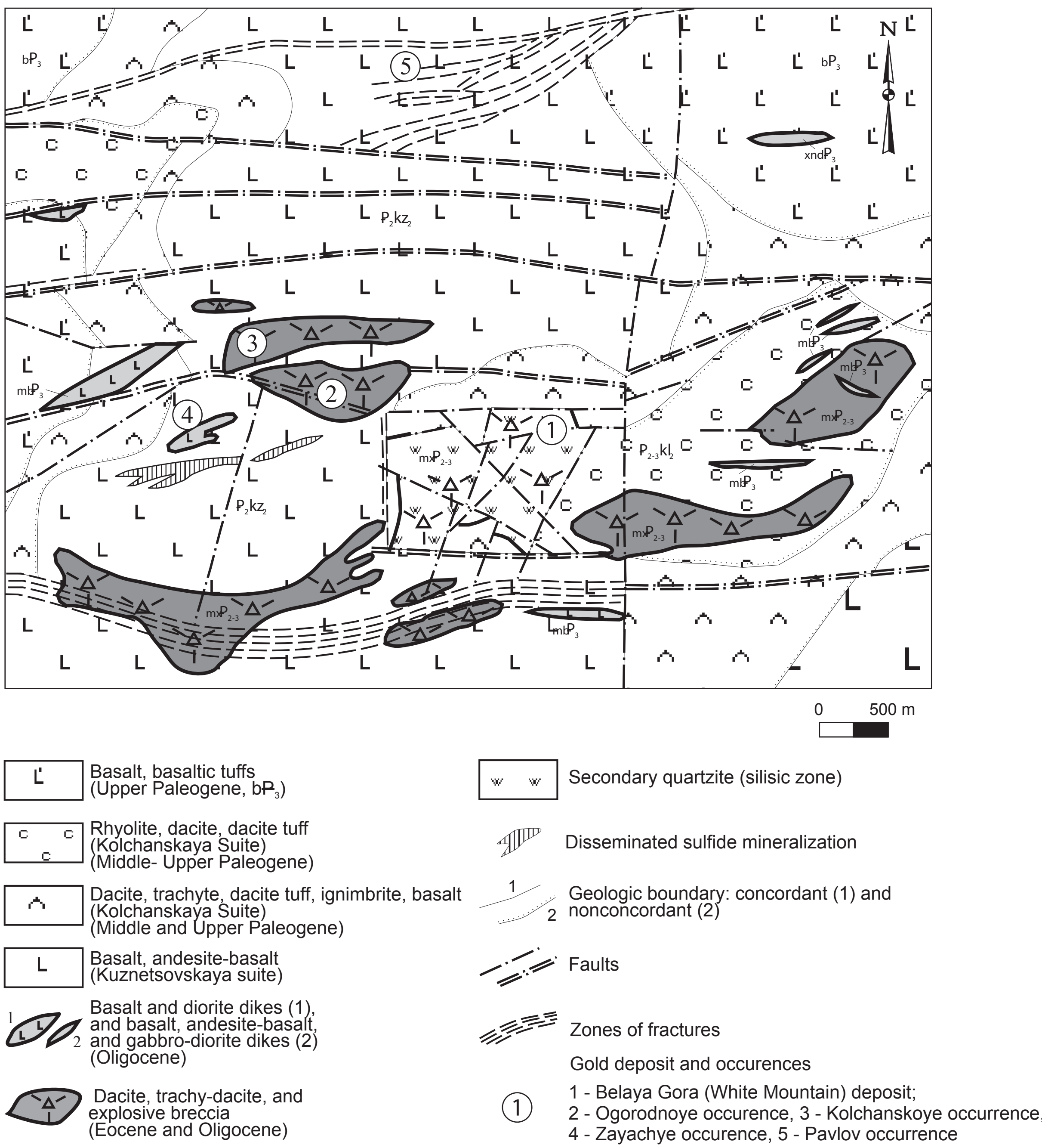


Figure 37. Generalized geologic map of Belaya Gora Au-Ag epithermal-vein deposit, Lower Amur metallogenic belt, Russian Southeast. Adapted from E.P. Khokhlov, written commun., 1978.

The main references on the geology and metallogenesis of the belt are Ishihara (1978) and Sakoda and others (2000).

Omori Au-Ag Epithermal-Vein Mine

This mine (fig. 38) (Mining and Materials Processing Institute of Japan, 1994b; Sakoda and others, 2000) consists of seven main northeast striking veins. The Main vein is 400 meters long and 0.5 meters wide. The veins occur in an area that 0.5 km side (east-west) by 0.7 km long (north-south). The host rocks are Miocene dacite. The ore minerals are argentite, chalcopyrite, pyrite, galena, sphalerite, siderite, and hematite. Gangue minerals are quartz, barite, and chalcedony. Wallrocks are altered to quartz and chlorite. A K-Ar sericite age for the alteration zone is 1.07±0.04 Ma. A stockwork with disseminated silver occurs 1 km east of the Main vein. Mining started from 1309 and stopped in 1923. The deposit was also known as the Iwami silver deposit, and it was one of the biggest silver mines in Japan. The mine is small and it produced 1.4 tonnes of Au, 65.7 tonnes of Ag, and 6,300 tonnes of Cu (from 1891 to 1919). The average grades are 1,000 to 2,000 g/t Ag.

Taishu Polymetallic Pb-Zn ± Cu (± Ag, Au) Vein and Stockwork Mine

This mine (Karakida and others, 1992) consists of three main north-south and northeast striking vein systems. The Main vein is 2,200 meters long and 2 meters thick. The host rocks are Paleogene sandstone and shale. The deposit formed during intrusion of a Miocene granitoid that occurs 5 km south. The granitoid consists of fine- to medium-grained monzogranite, granodiorite, and local quartz diorite. The average K-Ar biotite age for the granite is 16.1±0.8 Ma. The main ore minerals are sphalerite, galena, pyrrhotite, arsenopyrite, and chalcopyrite. Gangue minerals are calcite and quartz. Wallrocks are altered to chlorite, calcite, sericite, and lesser quartz. The deposit was discovered in 674 and the mine closed in 1973. The mine is medium size and produced 230,000 tonnes of Zn, and 139,000 tonnes of Pb from 5 million tonnes of ore. The average grade is 6.4 percent Zn, and 2.9 percent Pb.

Origin and Tectonic Controls for Hokuriku-Sanin Metallogenic Belt

The belt is interpreted as having formed along an island arc during back-arc rifting or along the axial part of an island arc that was related to subduction of Philippine Sea Plate. The deposits are associated with siliceous through intermediate magmatism in a back-arc rift or in an island arc.

Kyushu Metallogenic Belt of Au-Ag Epithermal-Vein Deposits (Belt KY) (Japan)

This Pliocene to Quaternary metallogenic belt is related to veins and replacements in the Quaternary Japan volcanic belt and Japan Cenozoic sedimentary basin that overlies and intrudes the Akiyoshi-Maizuru, Shimanto, and Mino-Tamba-Chichibu terranes. The belt occurs in central and southern Kyushu Island, trends northeast to southwest for more than 400 km, and ranges from 50 to 100 km wide. The belt extends south along the Ryukyu Island arc. The belt contains a large number of Au-Ag epithermal-vein deposits (Taio and Hishikari). The Satsuma metallogenic province was defined by Iwasaki (1912) and Watanabe (1923) and is similar to the Kyushu belt. However, the Satsuma province contains Sado and other Au-Ag deposit in other areas of Japan. Tsuboya and others (1956) used the name Kyushu Au-Ag epithermal vein metallogenic province that is similar to the Kyushu metallogenic belt, but excluded sulfur and limonite deposits related to recent volcanoes.

The deposits in the Kyushu metallogenic belt occur mainly in the Central and Southern Kyushu districts. The Central Kyushu district contains the Taio metallogenic district, and the southern Kyushu district contains the Kushikino metallogenic district of Kinoshita (1961). The Central Kyushu district is closely related to the Beppu-Shimabara graben that trends northeast-southwest, extends for 100 km long, and is as much as 40 km wide. The Beppu-Shimabara graben is an early Pliocene volcano-tectonic basin. Au-Ag deposits in the area range from 3.5 to 2.7 Ma (Ministry of International Trade and Industry, 1999). Although, some Au-Ag epithermal-vein deposits are Quaternary, most deposits formed in the Pliocene. The Pliocene Au-Ag deposits occur along the northern side of the graben, whereas the Quaternary deposits occur in the graben (Izawa and Urashima, 1989).

The Southern Kyushu district is subdivided into two areas, the northern Hokusatsu and southern Nansatsu areas. Typical low sulfidation Au-Ag epithermal-vein deposits (Hishikari and Kushikino) occur in the Hokusatu area. High sulfidation type epithermal Au deposits occur in the Nansatsu area. The Kushikino deposit in the Hokusatsu area, and high sulfidation-type epithermal-Au deposits in the Nansatsu area formed in the Pliocene (Ministry of International Trade and Industry, 2000a, b). These deposits occur along the western side of the district. The Hishikari, Fuke, and other low sulfidation Au-Ag epithermal-vein deposits in the Hokusatsu area formed in the Quaternary along the eastern side of the district. Migration of mineralizing centers from the western backarc side to the eastern volcanic front side occurs with with younger volcanic units (Izawa and Urashima, 1989). Most Au-Ag deposits range from Pliocene to Quaternary in the Southern Kyushu district. Host rocks are generally andesite; however, veins in the deep portion of the Hishikari deposit occur in the underlying Shimanto Group. The Kyushu metallogenic belt also contains minor sulfur and limonite deposits in Quaternary volcanoes (Kinoshita, 1961). The Kuju sulfur deposit occurs in the Kuju volcano, and the Iojima deposit occurs on the small Iojima Island south of Kyushu Island. Limonite deposits occur in the Aso volcano. However, these deposits are small and not significant, and they are not listed in the mineral-deposit database. The Kagoshima graben, which formed during Quaternary volcanism, occurs in the eastern Southern Kyushu district.

The main references on the geology and metallogenesis of the belt are Iwasaki (1912), Watanabe (1923), Tsuboya and others (1956), Kinoshita (1961), and Ministry of International Trade and Industry (2000a,b).

Hishikari Au-Ag Epithermal-Vein Deposit

This deposit (fig. 39) (Ibaraki and Suzuki, 1989; Naito, 1993; Izawa and others, 1989; Sekine and others, 1998) consists of northeast-striking veins. Three main vein systems are Honko, Yamada, and Sanjin. Veins occur in an area 2.5 km (east-west) by 0.8 km (north-south). Veins in Honko range from 1 to 3 meters wide with a maximum strike length of 400 meters. Maximum width of the vein is 13 meters. Host rock is preMiocene Shimanto Supergroup and Quaternary andesite. Ore minerals are electrum, pyrite, chalcopyrite, marcasite, spahlerite, galena, and stibnite. The Au/Ag ratio is high, typically about 2 and

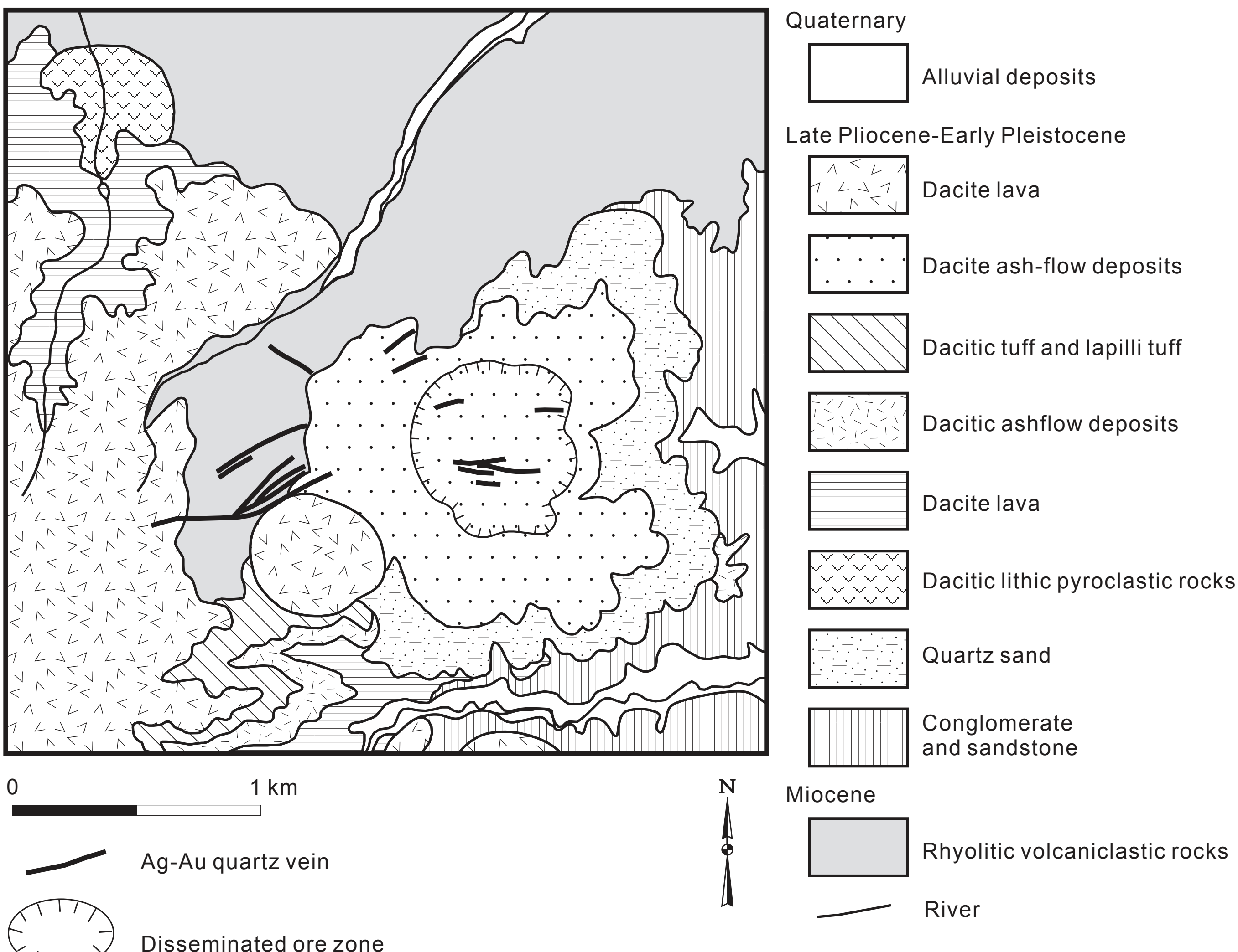


Figure 38. Generalized geologic map of Omori Au-Ag epithermal-vein mine, Hokuriku-Sanin metallogenic belt, Japan. Adapted from Kano and others (2001).

the average Ag grade is about 100 g/t. Gangue minerals are quartz, adularia, smectite, kaolinite, sericite, chlorite, and calcite. About 20 percent of gangue is adulaia. Grain size of electrum is about 10 microns. Wallrocks show zonal alteration from the center outwards to the chlorite-sericite zone, interstratified clay mineral zone, quartz smectite zone, and cristobalite smectite zone. K-Ar isotopic ages of adularia range from 0.78±0.07 Ma to 1.05±0.07 Ma. The deposit was discovered in 1981. The deposit is medium size and has an average grade of 46 g/t Au and resources of 250 tonnes of Au.

Kushikino Au-Ag Epithermal-Vein Mine

This mine (Karakida and others, 1992) consists of northeast-striking veins. The Main vein is 2,600 meters long and ranges from 3 to 50 meters wide. The veins occur in a area 3 km (east-west) by 2.5 km (north-south). The host rocks are Miocene andesite and andesite tuff. The ore minerals are electrum, native silver, argentite, pyrargyrite, stibnite, naumannite, hessite, and stephanite. Gangue minerals are quartz, adularia, sericite, and calcite. Wallrocks are altered to quartz, pyrite, chlorite, calcite, sericite, and kaolinite. A K-Ar isotopic age is 4.0±0.3 Ma. Mining started in the 1600s. The mine is medium size and produced 54.7 tonnes of Au and 497 tonnes of Ag from 8,270,000 tonnes of ore. The average grades are 6.6 g/t Au and 60 g/t Ag.

Taio Au-Ag Epithermal-Vein Mine

This mine (Mining and Materials Processing Institute of Japan, 1989; Karakida and others, 1992) consists of two main vein systems that strike east-northeast and northwest and dip north. The veins occur in an area 3 km (east-west) by 2 km (north-south). The Main vein is 1,750 meters long and 2.5 meters thick Host rocks are altered Miocene andesite. The main ore minerals are native gold, argentite, miargyrite, chalcopyrite, pyrite, galena, and sphalerite. Gangue minerals are mainly quartz, calcite, adularia, and rhodonite. Wallrocks are altered to quartz, chlorite, sericite, montmorillonite, and kaolinite. A K-Ar adularia age for the vein is 3.6 Ma. The deposit was discovered in 1894. The mine closed in 1970. The mine is medium size and produced 37 tonnes of Au and 160 tonnes of Ag from from 5,870,000 tonnes of ore. The average grades are 6.3 g/t Au and 27 g/t Ag.

Origin and Tectonic Controls for Kyushu Metallogenic Belt

This belt is interpreted as having formed during hydrothermal activitiy along a Pliocene and Quaternary island arc during back-arc rifting or along the axial part of an island arc that was related to subduction of Philippine Sea Plate.

Northeast Hokkaido Metallogenic Belt of Au-Ag Epithermal Vein, Volcanic-Hosted Hg, Hg-Sb-W Vein and Stockwork, and Clastic Sediment-Hosted Hg±Sb Deposits (Belt NH) (Japan, Hokkaido)

This Miocene to Quaternary metallogenic belt is related to veins and replacements in the Quaternary Japan volcanic belt and in the Japan Cenozoic sedimentary basin that overlies and intrudes the Hidaka zone of the Shimanto accretionarry wedge terrane. The metallogenic belt occurs in northeastern Hokkaido island in an area that is 250 km by 130 km and extends to the east of the study area. Saito (1958) defined five districts in the Northeast Hokkaido belt. The Kitami metallogenic province of Urashima (1961) is similar to this belt, but excludes Quaternary deposits. Saito and others (1967) defined a Northeast Hokkaido metallogenic province for Neogene deposits in the area, and Yahata and others (1988) named the Northeast Hokkaido metallogenic province of Quaternary epithermal-vein deposits. Most of deposits of the metallogenic belt occur in the Monbetsu-Kamishihoro Graben that ranges from 10 to 60 km wide and trends for 120 km north-south in the middle of the belt. The Kitami district of Saito (1958) covers the graben. The Utoro and Ohmu districts of Saito (1958) occur in the northwestern Northeast Hokkaido metallogenic belt and include the Motokura Pb-Zn-Cu deposit and some gold deposits. Au epithermal deposits also occur near the Quaternary volcanic front. Limonite and sulfur deposits are associated with the volcano, but they are not described in the mineral deposit database. Ages of epithermal deposits vary from 14.4 Ma to 0.3 Ma, and tend to young southward (Yahata and others, 1999). The ages of deposits indicate two stages of deposits in the belt, an early stage (14.4 to 11.2 Ma) and a late stage (8.1 to 0.3 Ma). The belt contains Au-Ag epithermal-vein deposits (Konomai), volcanic-hosted Hg deposits (Itomuka), and Pb+Zn+Cu veins (Saito).

The main references on the geology and metallogenesis of the belt are Saito (1958), Urashima (1961), Saito and others (1967), and Yahata and others (1988).

Konomai Au-Ag Epithermal-Vein Mine

This mine (fig. 40) (Kato and others, 1990; Mining and Materials Processing Institute of Japan, 1990; Maeda, 1990) consists of of east-west and northeast striking quartz veins. More than 18 veins occur in an area 15 by 5 km. One typical vein is 10 meters thick and 2,100 meters long. The veins consist mainly of quartz, chalcedony, calcite, and adularia. The main ore minerals are native gold, native silver, argentite, and miargyrite. Minor ore minerals are chalcopyrite, galena, and sphalerite. The veins are hosted in Miocene rhyolitic tuff, mudstone and altered andesite. A K-Ar age isotope age for adularia from the vein is 12.9 ± 0.4 Ma. The deposit was discovered in 1915 and the mine closed in 1973. The deposit is medium size and produced 11,486,000 tonnes of ore, 73.2 tonnes of Au, and 1,240 tonnes of Ag from 1917 to 1973. The average grade is 6.4 g/t Au and 108 g/t Ag.

Itomuka Volcanic-Hosted Hg Mine

This mine (Saito and others, 1967) consists of disseminated and vein ore bodies that occur along faults. The ore bodies occur in a area 3 km east-west by 1.5 km north-south. A typical ore body has an average thickness of 6 meters and length of 140 meters. The main ore minerals are native mercury and cinnabar. Quartz, calcite, pyrite, and marcasite also occur. The deposit is hosted in altered Miocene andesite. Miocene rhyolite occurs near the deposit and is part of the host-rock sequence. The deposit was discovered in 1936, and was the largest Hg mine in Japan. The mine is medium size and it produced 3,300 tonnes Hg grading 0.35 percent Hg.

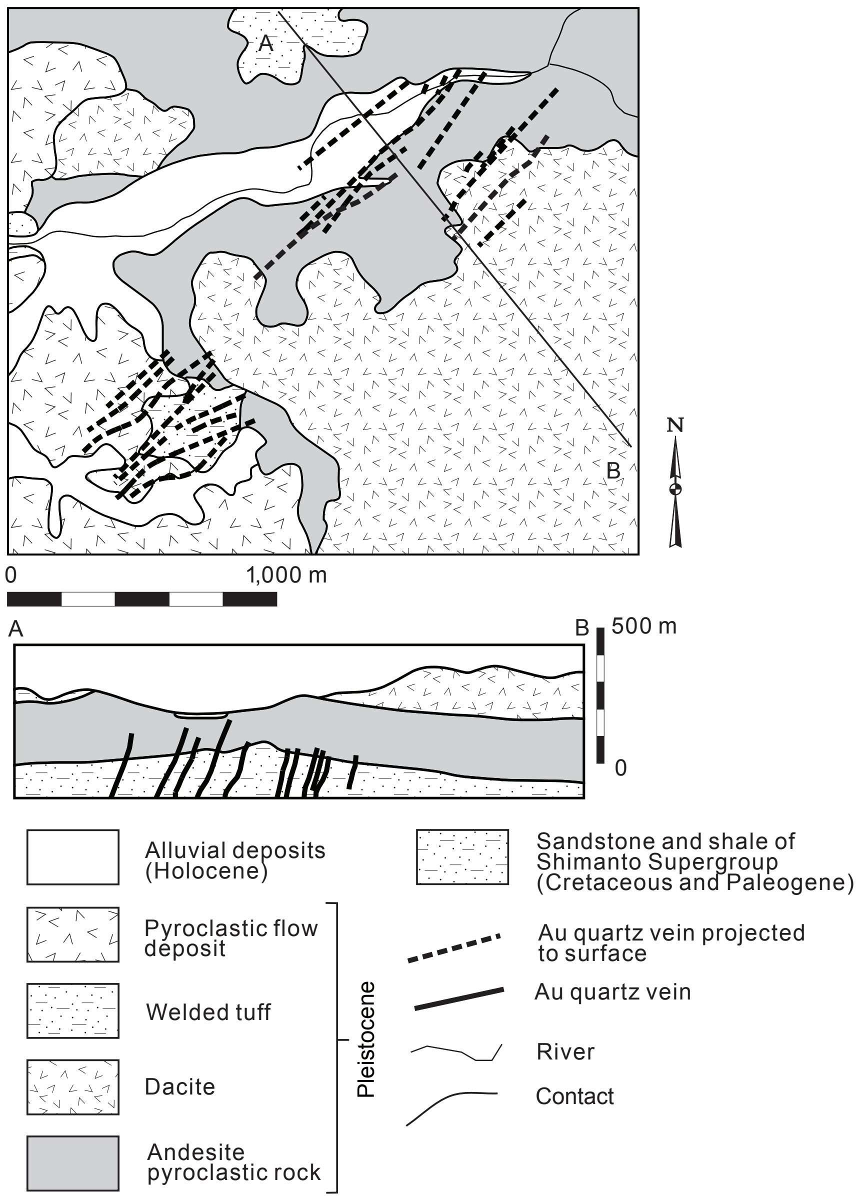


Figure 39. Generalized geologic map and schematic cross section of Hishikari Au-Ag epithermal-vein deposit, Kyushu metallogenic belt, Japan. Adapted from Naito and others (1993).

Ryushoden Hg-Sb-W Vein and Stockwork Mine

This mine (Mining and Metallurgical Institute of Japan, 1968; Kato and others, 1990) consists of dissemination that occur along faults. Pyrite, cinnabar, and calcite veins occur in the disseminated zone. The main ore mineral is cinnabar, and minor ore minerals are native mercury and pyrite. Gangue mineals are quartz, chlorite, and calcite. The deposit is hosted in Miocene sandstone. Rhyolite is present southwest of the deposit and may be related to the deposit. The deposit is medium size and it produced 880 tonnes of Hg (from 1947-1974). The average grade is 0.27 percent Hg.

Origin and Tectonic Controls for Northeast Hokkaido metallogenic belt

This belt is interpreted as having formed along an island arc related to subduction of the Pacific Plate beneath eastern Hok-

Figure 40. Generalized geologic map of Konomai Au-Ag epithermal vein mine, Northeast Hokkaido metallogenic belt, Japan. Adapted from Yahata and others (1988).

kaido Island. The deposits formed during Miocene and Quaternary island arc volcanism and related hydrothermal activity.

Northeast Japan Metallogenic Belt of Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types), Au-Ag Epithermal-Vein, Sulfur-Sulfide (S, FeS2), Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite, Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, Mn vein, Volcanogenic-Sedimentary Mn, Chemical-Sedimentary Fe-Mn, and Limonite from Spring Water Deposits (Belt NJ) (Japan)

This Miocene to Quaternary belt is related to layers and veins in the Quaternary Japan volcanic belt and Japan Cenozoic sedimentary basin that overlie and intrude the Hiroshima granitic plutonic belt, and the Mino-Tamba-Chichibu and South Kitakami terranes. The metallogenic belt occurs in the western part of northeastern Honshu and southwestern Hokkaido Islands, trends north-south for more than 1,300 km, and varies from 100 to 150 km wide. The belt extends into the Izu-Bonin island arc. Most of the associated deposits occur in Miocene volcanic rock in the Neogene sedimentary basin. The volcanic rock is mostly altered and is generally described as the Green Tuff. The southwestern margin of the belt in Honshu Island is bounded by the Itoigawa-Shizuoka tectonic line.

The belt contains a large number of Kuroko deposits (Kosaka, Shakanai), Au-Ag epithermal-vein deposits (Sado), polymetallic-vein deposits (Hosokura), and sulfur-sulfide (S, FeS_2) deposits. Iwasaki (1912) used the name Kosaka metallogenic province that covers most of the Northeast Japan metallogenic belt of this study. Watanabe (1923) also used the name Kosaka metallogenic province, and he slightly modified the definition to the Ikuno-Kosaka metallogenic province. Tsuboya and others (1956) used the name Hokkaido-Northeast Japan Green Tuff metallogenic province with four provinces (1) Nemuro-Shiretoko province (in eastern Hokkaido Island), (2) Kitami province (in northeastern Hokkaido Island), (3) Inner Zone of Northeast Japan province, and (4) Fossa Magna province (major graben in central Honshu Island). The Northeast Japan metallogenic belt of this study contains the Inner Zone of Northeast Japan province and the Fossa Magna province. Ishihara (1978) classified three metallogenic provinces in an area that is similar to this belt on the basis of metals in the deposits (1) the Mn Au-Ag-Cu-Pb-Zn province in southwestern Hokkaido Island, (2) the Au-Ag-Cu-Pb-Zn province in northern Honshu Island, and (3) and the Ag-Pb-Zn province for central Japan. Many Kuroko-type deposits occur in the Hokuroku area in Akita Prefecture, northern Honshu. These deposits formed in the middle Miocene around 13 Ma. Available K-Ar ages of-vein deposits suggest two stages of ore formation (1) an early stage (15 to 10 Ma), and (2) a late stage (8 to 2 Ma). Sulfur-sulfide (S, FeS_2) and limonite deposits formed along with Quaternary volcanoes. Tsuboya and others (1956) defined a separate Pleistocene-Holocene metallogenic province around the volcanoes that is included herein in the Northeast Japan metallogenic belt.

The main references on the geology and metallogenesis of the belt are Iwasaki (1912), Watanabe (1923), Tsuboya and others (1956), and Ishihara (1978).

Ashio Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Mine

This mine (Shibata and Ishihara, 1974; Omori and others, 1986) consists of northeast, east-northeast, and east-west striking veins. Eight main vein systems occur. Each vein system consists of 100 to 300 veins. About 1,400 veins were mined. The main vein is 2,100 meters long and 0.2 meters thick. The host rock is Miocene rhyolite (Ashio Rhyolite) that occurs as a slightly elongated circular shape (4.4 by 3.3 km) on the surface and is funnel-shaped. Most of veins occur in the rhyolite. At depth the deposit extends into a Mesozoic accretionary complex. The main ore minerals are chalcopyrite, arsenopyrie, and pyrite. Minor ore minerals are bornite, chalcocite, covellite, pyrrhotite, sphalerite, galena, wolframite, cassiterite, stannite, bismuthinite, and native gold. Gangue minerals are mainly quartz, calcite, fluorite, and apatite. A zonal distribution of ore minerals occurs a central zone with Sn-W-Bi-Cu, an intermediate zone with Cu-As-Zn, and a marginal zone with Zn-Pb-Cu-As. Massive replacement ore bodies also occur with ore minerals similar to the veins. Wallrocks are altered to quartz, sericite, chlorite, and calcite. Quartz-sericite-calcite alteration is the most common. A K-Ar isotopic age for altered tuff is 14.8$\pm$1.1 Ma. The deposit was discovered in 1550, mining started around 1,600 for Au, and the mine closed in 1973. The deposit is medium size and it produced about 800,000 tonnes of Cu, 4.5 tonnes of Au, 600 tonnes of Ag, and 22,000 tonnes of Zn. The average grade is 20 to 30 percent Cu.

Gumma Limonite Mine

This mine (Geological Survey of Japan, 1954) occurs in the eastern foothill of Ksatsu-Shirane volcano above tuff breccia and andesite. The deposit is more than 10 meters thick, and it occurs along an old valley for 2,200 meters and is several tens to 200 meters wide. The deposit formed by precipitation in the valley from a mineral spring from the Ksatsu-Shirane volcano. The ore mineral is limonite that is generally porous and reddish brown or dark brown. Jarosite occurs mainly in the upstream part of the deposit. At the upper part of the deposit, the mineral spring is still active. The deposit is small and it produced 850,000 tonnes of ore from 1950 to 1955, and has resources of about 2,000,000 tonnes. The average grade is 49 percent Fe.

Horobetsu Sulfur-Sulfide (S, FeS_2) Mine

This mine (Saito and others, 1967) consists of three ore connected bodies. The ore bodies are about 300 meters long, 150 meters wide, and 10 to 20 meters thick. The host rock is Pliocene andesite lava. The ore minerals are native sulfur and pyrite. One ore body consists of pyrite that occurs above the sulfur-ore body. The deposit is surrounded by alteration zones, including opal, allunite, and kalonite. The deposit was discovered in 1902, is small, and produced 1,571,000 tonnes of ore grading 39.7 percent S.

Hosokura Au-Ag Epithermal-Vein Mine

This mine (Takahashi and Suga, 1974) consists of 13 main vein systems that strike east-west, north-south, and northwest. The veins occur in a 4 km by 5 km area. The main vein is 2,200 meters long and 1.3 meters thick. The main ore minerals are sphalerite, galena, chalcopyrite, tetrahedrite, pyrargyrite, stibnite, pyrite, marcasite, pyrrhotite, magnetite, hematite, chalcocite, covellite, native copper, and native silver. Gangue minerals are mainly quartz, chlorite, sericite, kaolin, calcite, montmorillonite, and fluorite. Wallrocks are latered to quartz, K-feldspar, albitized plagioclase, chlorite, sericite, kaolin, montmorillonite, and calcite. The host rocks are Miocene altered andesite and tuff. A K-Ar adularia age for the vein is 5.8$\pm$0.2 Ma and for adularia from the host dacite is 9.7 $U_2 0_5$ Ma. The deposit was discovered in the early 800s and the mine closed in 1987. The deposit is medium size and it produced 26,000,000 tonnes of ore, 775,000 tonnes of Zn, 280,000 tonnes of Pb, 400 tonnes of Ag, 1 tonne of Au, and 9,500 tonnes of Cu. The average grades are 4.12 percent Zn, 1.59 percent Pb, 0.05 percent Cu, 0.2 g/t Au, and 40 g/t Ag.

Kinjo Volcanogenic-Sedimentary Mn Mine

This mine (Saito and others, 1967) consists of a horizontal stratiform-ore body. Maximum thickness is 3 meters. The deposit extends 120 meters north-south and 100 meters east-west. The ore body occurs between a lower greenish Miocene tuff breccia and an upper hornblende dacite and mudstone. Mn minerals were deposited in the Miocene. The ore minerals are psilomelane and pyrolusite. Gangue minerals are quartz and calcite. The deposit was discovered in 1952. The mine closed in 1961. The deposit is small and it produced 2,289 tonnes of MnO_2 (from 1953 to 1955) and 4,699 tonnes of Mn (from 1955 to 1958). The average grade is 53.79 percent MnO_2.

Kosaka Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Mine

This mine (Oshima and others, 1974; Hashiguchi, 1983; Nakajima, 1989) consists of three main ore bodies, Motoyama, Uchinotai, and Uwamuki. The Motoyama ore body is 600 meters long by 250 meters wide and 30 meters thick. The Uchinotai ore body is 700 meters long by 400 meters wide and 20 meters thick. The kuroko deposit is divided into three types of ores–kuroko, yellow, and siliceous ores. The main ore minerals of the kuroko are chalcopyrite, pyrite, galena, sphalerite, and tennantite. The main ore minerals of the yellow and siliceous ores are pyrite, chalcopyrite, sphalerite, bornite, chalcocite, and covellite. Minor minerals are quartz and barite. Barite is enriched at the top of the kuroko deposit. The host rocks are Miocene rhyolite and rhyolitic tuff. The Motoyama ore body was discovered in 1861 and the Uchinotai ore body was discovered 1959. The deposit is medium size and it produced 510,000 tonnes of Cu, 520,000 tonnes of Zn, 150,000 tonnes of Pb, and has reserves of 30 million tonnes. The average grades are 8.48 percent Zn, 2.84 percent Pb, 2.59 percent Cu, 1.15 g/t Au, and 184.7 g/t Ag.

Shakanai Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type) Deposit

This deposit (fig. 41) (Ohtagaki and others, 1974; Tanimura and others 1983; Nakajima, 1989) consists of eleven main bodies. The bodies are located in area of 4 km long and 2 km wide, with a depth of 200 meters. The main deposit minerals of the kuroko (black ore) are chalcopyrite, pyrite, galena, sphalerite, tetrahedrite and tennantite. The main deposit minerals of the yellow and siliceous ores are pyrite, chalcopyrite, and a small amount of sphalerite and galena. Siliceous and gypsum ore occurs below the unit of black ore and yellow ore. Minor minerals are quartz and barite. Host rock is Miocene rhyolite, rhyolite tuff and mudstone. Matsuki, Takadate, Takadate South deposits occur several hundred meters W of the Shakanai deposit. The deposit was discovered in 1961 and the mine closed in 1987. The deposit is medium size and has an average grade of 3.3 percent Zn, 2.15 percent Cu, 0.9 percent Pb, 0.35 g/t Au, and 77 g/t Ag. The deposit has produced 320,000 tonnes of Zn, 130,000 tonnes of Cu, 670,000 tonnes of Pb, and has reserves of 30 million tonnes.

Sado Au-Ag Epithermal-Vein Mine

This mine (fig. 42) (Mining and Materials Processing Institute of Japan, 1994a) consists of seven main east-west striking veins. The main vein is 2,100 meters long and 6 meters wide. Host rocks are Miocene dacite tuff, andesitic tuff, and mudstone. The main ore minerals are native gold, argentite, pyrargyrite, pyroustite, miargyrite, chalcopyrite, tetrahedrite, pyrite, galena, and sphalerite. Gangue minerals are mainly quartz, chalcedony, calcite, barite, adularia, rhodochrosite, gypsum, and sericite. Wallrocks are altered to chlorite, albite, sericite, quartz, and pyrite. K-Ar adularia ages for the vein are 134$\pm$0.5 Ma and 14.5$\pm$0.5 Ma. The deposit was discovered in 1601 and the mine closed in 1989. The deposit is medium size and it produced 78 tonnes of Au, 2,330 tonnes of Ag, 5,400 tonnes of Cu, and 15,300,000 tonnes of ore. The average grades are 1 to 5 g/t Au, 30 to 100 g/t Ag, and 0.1 to 0.3 percent Cu.

Toyoha Au-Ag Epithermal-Vein Mine

This mine (Mining and Metallurgical Institute of Japan, 1968; Kuwahara and others, 1983; Kato and others, 1990) consists of east-west and northwest striking veins. About 50 veins are present an area 2 km east-west by 3 km north-south. The veins have a maximum thickness of 4 meters and are about 1,300 meters long. The main ore minerals are sphalerite, galena, pyrite, and rhodochrosite. Minor ore minerals are chalcopyrite, hematite, pyrrhotite, stibnite, and marcasite. Indium minerals are found in the ore. The gangue minerals are quartz and small amounts of chlorite and calcite. Wallrocks altered to quartz, chlorite, and sericite. The deposit was one of the largest mines in Japan. The deposit is hosted in Miocene pyroclastic rocks. The K-Ar age of sericite in the vein is 2.2 Ma. The deposit is medium size and has an average grade of 9.6 percent Zn, 3.4 percent Pb, and 179g/t Ag. The mine produced 12 million tonnes of ore with 1,400 tonnes of Ag, 300,000 tonnes of Pb, and 780,000 tonnes of Zn. Reserves of 13 millon tonnes of ore grade 7.0 percent Zn, 2.1 percent Pb, and 124g/t Ag.

Origin and Tectonic Controls for Northeast Japan Metallogenic Belt

The volcanogenic massive sulfide deposits are interpreted as having formed in back-arc region of an island arc related to subduction of the Pacific Plate beneath eastern Hokkaido Island. Pliocene Au-Ag epithermal-vein deposits on Izu Peninsula formed in the Izu-Bonin island arc that accreted to Honshu Island before the formation of the deposits. Sulfur-sulfide and limonite deposits formed in the active island arc. Island arc magmatism is related to subduction of Pacific Plate.

Outer Zone Southwest Japan Metallogenic Belt of Sn Skarn, Sn-W Greisen, Stockwork, and Quartz Vein, Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork, Au-Ag Epithermal-Vein, Volcanic-Hosted Hg, Ag-Sb Vein, Zn-Pb (±Ag, Cu, W) Skarn, W-Mo-Be Greisen, Stockwork, and Quartz Vein, Hg-Sb-W Vein and Stockwork, Cassiterite-Sulfide-Silicate Vein and Stockwork, and Clastic-Sediment-Hosted Sb-Au Deposits (Belt OS) (Japan)

This middle Miocene metallogenic belt is related to veins and replacements in the Japan Cenozoic sedimentary basin that overlies the Hiroshima granitic plutonic belt, Sambagawa, Shimanto, and Mino-Tamba-Chichibu terranes. The belt occurs in the outer zone of the Southwestern Japan, trends roughly northeast-southwest for more than 1,000 km, and

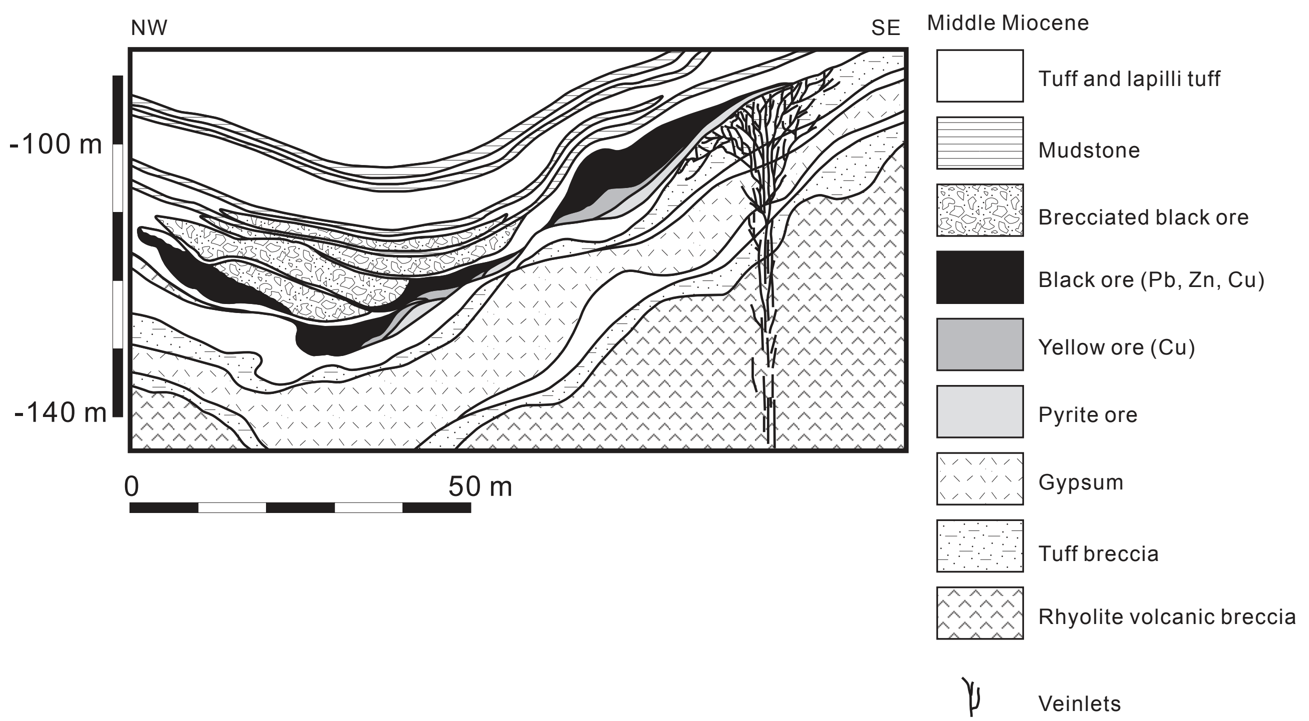


Figure 41. Schematic cross section of Shakanai Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type) deposit, Northeast Japan metallogenic belt, Japan. Adapted from Kajiwara (1970).

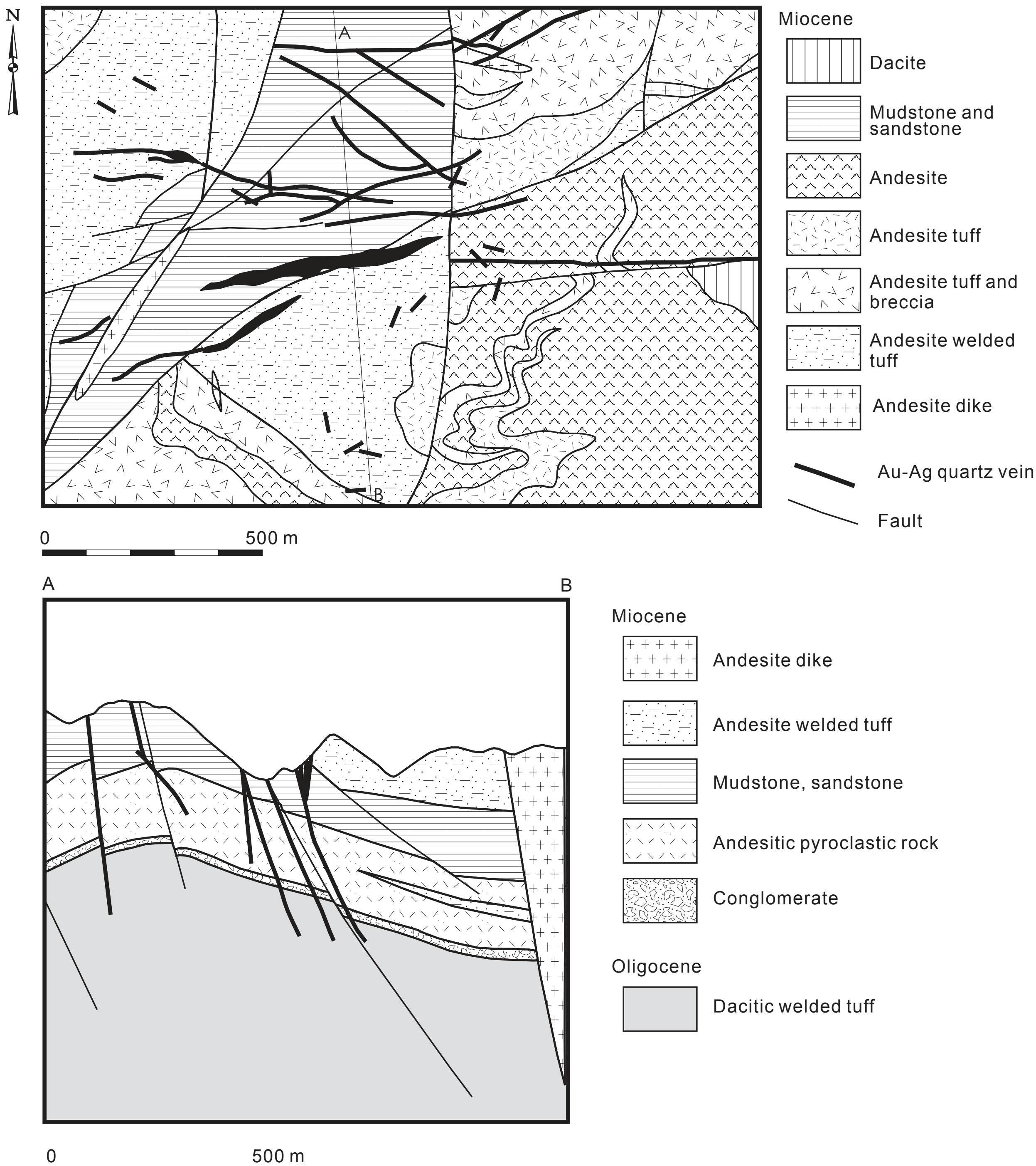


Figure 42. Generalized geologic map and schematic cross section of Sado Au-Ag epithermal vein mine, Northeast Japan metallogenic belt, Japan. Adapted from Ministry of International Trade and Industry (MITI) (1989).

varies from 50 to 150 km wide. The belt extends south along the Ryukyu island arc. Most of deposits occur south of Median tectonic line (MTL), but some Hg and Sb deposits occur north of the MTL. The metallogenic belt extends east of the Itoigawa-Shizuoka tectonic line to the Chichibu deposit.

The deposits are formed during mainly siliceous Miocene magmatism around the igneous bodies. The siliceous igneous rocks are scattered in mainly four areas (1) the Kii Peninsula (Kumano siliceous igneous rocks) on Honshu Island, (2) the Okueyama-Osuzuyama area on central Kyushu Island, and (3) the Osumi Peninsula on southern Kyushu and Yakushima Islands. The siliceous igneous rocks range from 15.5 to 13 Ma. The associated granitoids are mainly ilmenite-series. S-type granitoids occur in the southern part of the belt, and I-type granitoids occur in the northern part of the belt. The granitoids are interpreted as occurring along a forearc. The occurrence of siliceous igneous activity in the forearc is unusual. The igneous rock related to the Hg deposit is interpreted as being a member of the Miocene Setouchi volcanic rock that consists of high-Mg andesite. Tsuboya and others (1956) used the name Outer Zone Southwest Japan siliceous igneous rock metallogenic province, and Ishihara (1978) used the name Sn-W-Cu-As-Sb province for this metallogenic belt.

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956) and Ishihara (1978).

Chichibu Zn-Pb (±Ag, Cu, W) Skarn Mine

This mine (Mining and Materials Processing Institute of Japan, 1994a) consists of four ore bodies. The main ore body is 350 meters wide, 600 meters long, and 40 meters thick. The skarn occurs along the margin of a quartz-diorite and averages 30 to 50 meters wide. The ore bodies occur between limestone and skarn. The skarn was formed during intrusion of Miocene quartz-diorite and quartz-diorite porphyry. The granitoids have I-type characteristics. The main ore minerals are native gold, native silver, sphalerite, galena, magnetite, chalcopyrite, pyrite, pyrrhotite, arsenopyrite, and limonite. The gangue minerals are hedenbergite, garnet, epidote, and diopside, quartz, and calcite. Host rocks are Paleozoic limestone and mudstone. K-Ar biotite ages from the quartz-diorite are 5.87±0.37 and 6.59±0.27 Ma. The age of the ore deposit formation is interpreted to be 6.6 Ma. The deposit was discovered in 1205 and the mine closed in 1978. The mine is medium size and it produced 16.3 tonnes of Au, 72 tonnes of Ag, 100,000 tonnes of Zn, 7,000 tonnes of Pb, and 440,000 tonnes of Fe and has resources of 8 million tonnes. The average grades are 5 g/t Au, 60 g/t Ag, 5.5 percent Zn, 0.45 percent Pb, and 27.2 percent Fe.

Kishu Au-Ag Epithermal-Vein Mine

This mine (Mining and Metallurgical Institute of Japan, 1968; Mining and Materials Processing Institute of Japan, 1994b) consists of 24 east-west striking vein systems. The veins occur in an area 3 km (east-west) by 5 km (north-south). The main vein is 1,800 meters long and 0.5 meters thick. The host rocks are Shimanto Supergroup and Miocene sandstone. The main ore minerals are native gold, argentite, chalcopyrite, pyrite, sphalerite, galena, pyrrhotite, cassiterite, and wolframite. Gangue minerals are mainly quartz, calcite, chlorite, fluorite, sericite, and adularia. Wallrocks are altered mainly to chlorite. The deposit is associated with Miocene Kumano siliceous igneous rocks. The mine is medium siz-eand has produced 0.6 tonnes of Au, 153 tonnes of Ag, and 93,000 tonnes of Cu from 9,400,000 tonnes of ore. The average grades are 0.2 g/t Au, 26 g/t Ag, and 1.4 percent Cu.

Obira Cassiterite-Sulfide-Silicate Vein and Stockwork Mine

This mine (Mining and Metallurgical Institute of Japan, 1965; Karakida and others, 1992) consists of four main northeast striking veins. The main vein is 1,400 long and 1.5 meters thick. The host rocks are slate of Chichibu Group and Miocene granite porphyry and granite. The deposit formed during intrusion of Miocene granite. The ore minerals are cassiterite, arsenopyrite, pyrite, pyrhotite, and wolframite, molybdenite, chalcopyrite, and sphalerite. Gangue minerals are quartz, tourmaline, and fluorite. The deposit was discovered in 1574. The mine is medium size and has produced 800,000 tonnes of Sn ore and 5,000 tonnes of Sn. The average grades are 1.2 percent Sn, 1.56 percent Cu, and 11.2 percent As.

Yamatosuigin Hg-Sb-W Vein and Stockwork Mine

This mine (Geological Survey of Japan, 1955; Mining and Metallurgical Institute of Japan, 1968) consists of six northwest striking veins. The Main vein is 400 meters long, 500 meters wide, and extends 440 meters downdip. The host rocks are Cretaceous biotite granite of the Ryoke belt. The ore minerals are cinnabar, native marcury, realgar, and pyrite. Gangue minerals are quartz, chalcedony, sericite, calcite, and adularia. Wallrocks are altered to kaolinite, montmorillonite, and sericite. The deposit formed during Miocene igneous activity. The mine is medium size and has prooduced 645 tonnes of Hg grading 0.5 percent Hg.

Origin and Tectonic Controls for Outer Zone Southwest Japan Metallogenic Belt

The belt is interpreted as having formed along an island arc during back-arc rifting or along the axial part of an island arc that was related to subduction of the Philippine Sea Plate.

Late Jurassic through Early Cretaceous Tectonic and Metallogenic Model

Major Tectonic and Metallogenic Events

For the Late Jurassic through Early Cretaceous (154 to 96 Ma), the major metallogenic and tectonic events were (figs. 3, 43, tables 1, 2): (1) final closure of the Mongol-Okhotsk Ocean with resultant displacement of collisional processes eastward; (2) formation of collisional Stanovoy granite belt that is composed predominantly of granodiorite, granite, and granosyenite along the southern margin of the Aldan-Stanovoy shield of the North Asian craton and westward into the eastern Transbaikalia region; (3) continued formation of the Transbaikal volcano-plutonic belt and associated metallogenic belts along the axis of the closed Mongol-Okhotsk Ocean in a transpressional fault setting; (4) continued formation of transpressional fault zones along the axis of the closed Mongol-Okhotsk Ocean and formation of associated metallogenic belts; (5) postcollisional transform faulting along within-plate transpression zones in northeast China and formation of associated metallogenic belts; (6) accretion of the Kolyma superterrane and Okhotsk cratonal terrane against the Verkhoyansk (North Asian) cratonal margin and formation of collision-related granitoids and volcanic units, veins, and associated metallogenic belts; (7) formation of the Oloy continental-margin arc along the outboard edge of the accreted Kolyma-Omolon superterrane; (8) continued formation of the Uda-Murgal continental-margin arc and associated metallogenic belts; (9) beginning of underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along the Khingan transform continental margin in the Russian Far East; and (10) in oceanic settings, but now preserved as tectonic fragments in subduction-zone terranes, formation of oceanic lithosphere and assocated metallogenic belts.

The major Middle Jurassic through Early Cretaceous metallogenic belts in Northeast Asia are shown on figure 3. The tectonic setting of each metallogenic belt is shown on figure 43.

Metallogenic Belts and Tectonic Origins

Metallogenic Belts Related to Trans-Baikalian-Daxinganling Transpressional Arc

Ten metallogenic belts are hosted in the major Late Jurassic through Early Cretaceous Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlaps terranes that were previously accreted to the southern margin (present-day coordinates) of the North Asian craton (figs. 3, 43). The host rocks and metallogenic belts are interpreted as having formed during interplate extensional tectonism along the Trans-Baikalian-Daxinganling transpressional arc that formed along the major Mongol-Okhotsk suture that cuts previously-accreted terranes south of the southern margin (present-day coordinates) of the North Asian craton and cratonal margin. Displacement along the suture and arc formation occurred after the closing of the Mongol-Okhotsk Ocean. The belts contain a wide variety of siliceous igneous-rock related deposits. The host rocks and metallogenic belts occur along interplate extensional faults that are coeval with generation of subalkaline to alkaline volcanism and related sedimentation along northeast and east-west regional faults.

The Daxinganling belt (DX, figs. 3, 43) contains Zn-Pb (±Ag, Cu) skarn, Sn skarn, cassiterite-sulfide-silicate vein and stockwork, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork, peralkaline granitoid-related Nb-Zr-REE, and Au-Ag epithermal-vein deposits that are hosted in veins, replacements, and granitoids.

The Dzid-Selenginskiy belt (DS, figs. 3, 43) contains W-Mo-Be greisen, stockwork, and quartz vein; granitoid-related Au vein; Au skarn, porphyry Mo (±W, Bi); fluorspar vein; and magmatic and metasomatic apatite deposits.

The East Mongolian-Priargunskiy-Deerbugan belt (EM, figs. 3, 43) contains polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite; Zn-Pb (±Ag, Cu, W) skarn; Au skarn; polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite; volcanic-hosted Au-base-metal metasomatite; W-Mo-Be greisen, stockwork, and quartz vein; porphyry Cu-Mo (±Au, Ag); porphyry Mo (±W, Bi); granitoid-related Au vein; carbonate-hosted As-Au metasomatite; Au-Ag epithermal vein; sedimentary siderite Fe; Sn-W greisen, stockwork, and quartz vein; carbonate-hosted Hg-Sb; fluorspar vein; and volcanic-hosted U deposits.

The Govi-Tamsag belt (GT, figs. 3, 43) contains sediment-hosted U, evaporite sedimentary gypsum, sedimentary celestite, and volcanic-hosted zeolite deposits.

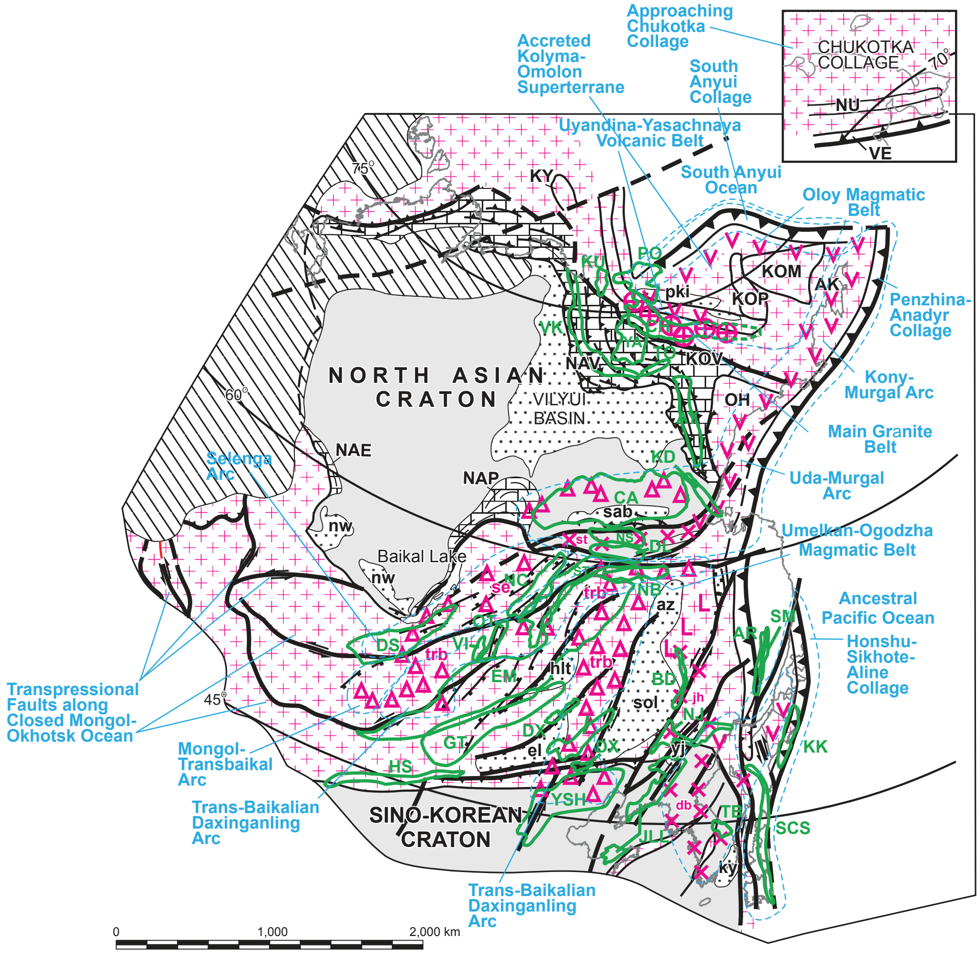
The Hartolgoi-Sulinheer belt (HS, figs. 3, 43) contains Au-Ag epithermal vein, Ag-Pb epithermal vein, porphyry Mo, W±Mo±Be skarn, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork, carbonate-hosted Ag-Pb, carbonate-hosted Hg-Sb, and silica-carbonate (listvenite) Hg deposits.

The Nerchinsky belt (NC, figs. 3, 43) contains granitoid-related Au vein; W-Mo-Be greisen, stockwork, and quartz vein; and fluorspar-vein deposits.

The Onon-Turinskiy belt (OT, figs. 3, 43) contains granitoid-related Au vein, porphyry Au, and cassiterite-sulfide-silicate vein and stockwork deposits.

The Shilkinsko-Tukuringrskiy belt (ST, figs. 3, 43) contains granitoid-related Au vein, porphyry Au; Au skarn; Au-Ag epithermal vein; porphyry Mo (±W, Bi); W-Mo-Be greisen, stockwork, and quartz vein; cassiterite-sulfide-silicate vein and stockwork; Ta-Nb-REE alkaline metasomatite; polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Au-Ag epithermal vein; and fluorite-vein deposits.

And the Verkhne-Ingodinsky belt (VI, figs. 3, 43) contains cassiterite-sulfide-silicate vein and stockwork deposits.



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Intracontinental Sedimentary Basins

az - Amur-Zeya sedimentary basin (Late Jurassic to Quaternary)
el - Erlian sedimentary basin (Jurassic through Quaternary)
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
ky - Kyongsang sedimentary basin (Early Cretaceous)
nw - Western Siberia sedimentary basins (Mesozoic and Cenozoic)
pki - Ilin'-Tas back-arc basin (Late Jurassic)
sab - South Aldan sedimentary basin (Jurassic)
sol - Songliao sedimentary basin (Jurassic through early Tertiary)

Terranes and Superterranes

AK - Avekov terrane
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
NU - Nutesyn terrane
OH - Okhotsk terrane
VE - Velmay terrane

Overlap Continental-Margin Arcs and Granite Belts

db - Daebo granite belt (Early to Late Jurassic)
jh - Jihei volcanic and plutonic belt (Mesozoic)
se - Selenga sedimentary-volcanic plutonic belt (Permian through Jurassic)
st - Stanovoy granite belt (Jurassic and Early Cretaceous)
trb - Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt (Middle Jurassic through Early Cretaceous)

METALLOGENIC BELTS

AR - Ariadny
AY - Allakh-Yun'
BD - Bindong
CA - Chara-Aldan
CH - Chybagalakh
DL - Djeltulaksky
DS - Dzid-Selenginskiy
DX - Daxinganling
EM - East Mongolian-Priargunskiy-Deerbugan
GT - Govi-Tamsag
HS - Hartolgoi-Sulinheer
JLL - Jiliaolu
KD - Kondyor-Feklistov
KK - Kitakami
KU - Kular
NB - North Bureya
NC - Nerchinsky
NJ - North Jilin
NS - North Stanovoy
OT - Onon-Turinskiy
PO - Polousny
SCS - Sambagawa-Chichibu-Shimanto
SM - Samarka
ST - Shilkinsko-Tukuringrskiy
TB - Taebaegsan
TO - Tompo
VI - Verkhne-Ingodinsky
VK - Verkhoyansk
YA - Yana-Adycha
YSH - Yanshan

Figure 43. Middle Jurassic through Early Cretaceous (145 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).

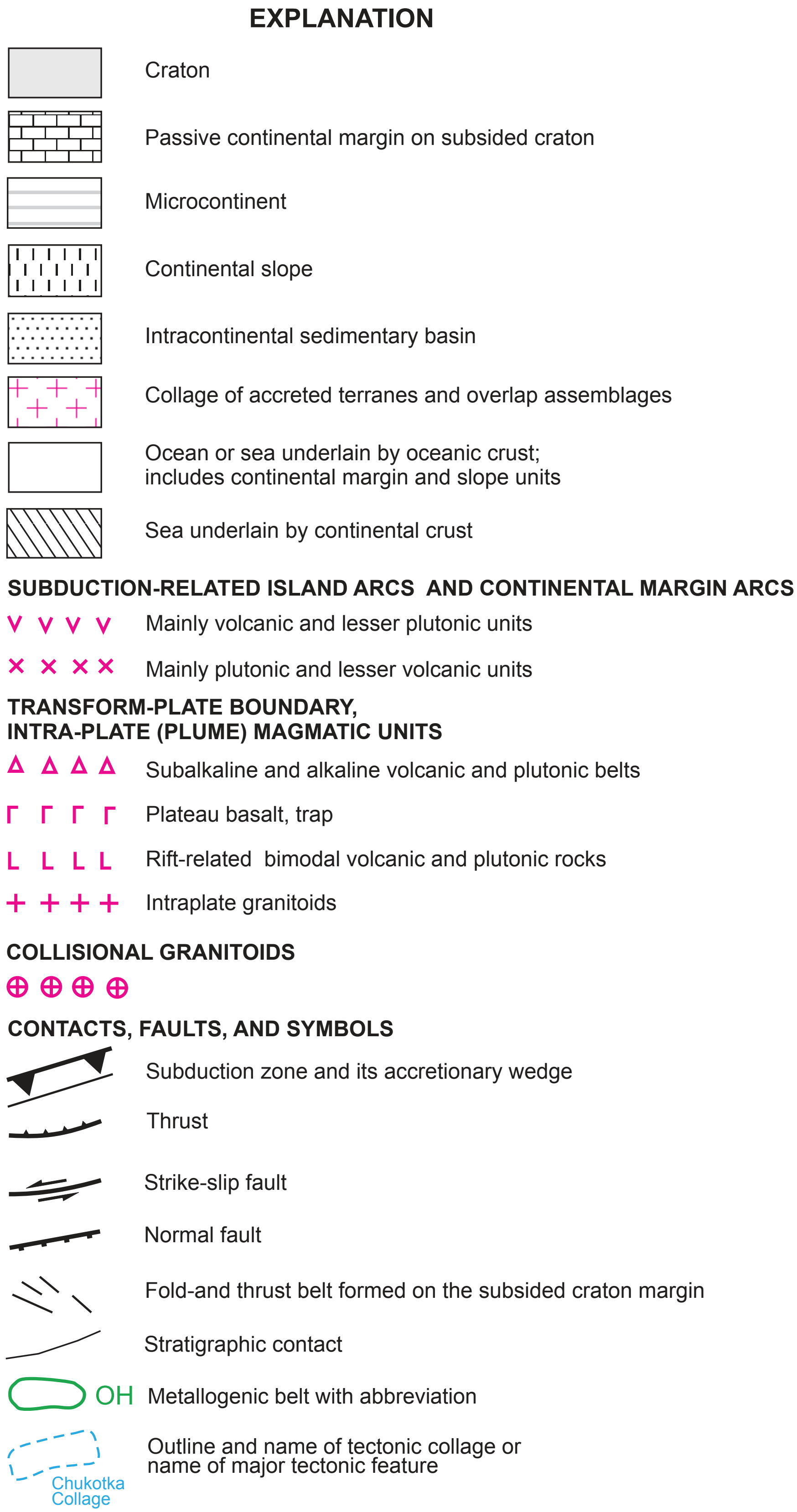


Figure 43.—Continued.

Metallogenic Belts Related to Accretion of the Kolyma-Omolon Superterrane and Okhotsk Terrane

Eight metallogenic belts possess geologic units favorable for a wide variety of Au-vein deposits and collisional granite-related deposits. The ages of the veins and associated granites range from Late Jurassic through Aptian. The belts and deposits are hosted in veins and granitoids (such as the South Verkhoyansk, Main, and Northern granite belts) that intrude the Verkhoyansk (North Asian) cratonal margin and (or) the margin of the adjacent Kolyma-Omolon superterrane. The host rocks and metallogenic belts are interpreted as having formed during collision and accretion of the Kolyma-Omolon superterrane to the North Asian cratonal margin, or immediately before the accretion of the Okhotsk terrane to the North Asian cratonal margin, with resultant regional metamorphism and generation of anatectic granitoids and related hydrothermal fluids.

The Allakh-Yun belt (AY, figs. 3, 43) contains Au in shear zone and quartz vein and Cu (±Fe, Au, Ag, Mo) skarn deposits that are hosted in veins in the Verkhoyansk (North Asian) cratonal margin.

The Chybagalakh belt (CH, figs. 3, 43) contains cassiterite-sulfide-silicate vein and stockwork, Sn-B (Fe) skarn (ludwigite), and granitoid-related Au-vein deposits that are hosted in veins and replacements in the Main granite belt that intrudes the southern margin of the Kolyma-Omolon superterrane.

The Kular belt (KU, figs. 3, 43) contains Au in shear zone and quartz vein, granitoid-related Au Vein, and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in veins in the Kular-Nera terrane, part of the Verkhoyansk-Kolyma collage.

The Polousny belt (PO, figs. 3, 43) contains cassiterite-sulfide-silicate vein and stockwork and polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork deposits that are hosted in granitoids related to the Northern granite belt that intrudes the Kolyma-Omolon superterrane and adjacent units.

The South Verkhoyansk belt (SV, figs. 3, 43) contains Au in shear zone and quartz vein, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; granitoid-related Au vein; W-Mo-Be greisen, stockwork, and quartz vein; and Au-Ag epithermal-vein deposits that are hosted in veins related to Early Cretaceous granitoids in South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous) intruding the Verkhoyansk (North Asian) cratonal margin.

The Tompo belt (TO, figs. 3, 43) contains W±Mo±Be skarn and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in replacements in the Northern and Transverse granite belts along northwestern margin of the Kolyma-Omolon superterrane.

The Verkhoyansk belt (VK, figs. 3, 43) contains Au in shear zone and quartz vein, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Sn-W greisen, stockwork, and quartz vein; and Au in black shale deposits that are hosted in veins and replacements in the Verkhoyansk (North Asian) cratonal margin.

The Yana-Adycha belt (YA, figs. 3, 43) contains cassiterite-sulfide-silicate vein and stockwork and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in replacements in the Transverse granite belt along the northwestern margin of the Kolyma-Omolon superterrane.

Metallogenic Belts Related to Uda-Stanovoy Continental-Margin Arc

Three metallogenic belts contain granitoid-related deposits that formed during intrusion of granitoids of the Jurassic through Early Cretaceous Stanovoy granite belt that was part of the Uda-Stanovoy continental-margin arc. The arc is interpreted as having formed during subduction and closure of the Mongol-Okhotsk Ocean beneath the North Asian craton to the north (present-day coordinates).

The Chara-Aldan belt (CA, figs. 3, 43) contains Au potassium metasomatite, Au skarn, U-Au, and Au in shear-zone and quartz-vein deposits.

The Djeltulaksky belt (DL, figs. 3, 43) contains granitoid-related Au-vein deposits.

The North Stanovoy belt (NS, figs. 3, 43) contains granitoid-related Au-vein and Au-Ag epithermal-vein deposits.

Metallogenic Belts Related to Transpression

Four metallogenic belts possess geologic units favorable for a wide variety of transpressional granitoid-related deposits (figs. 3, 43). The granitoids and veins intrude either overlap assemblages on the Sino-Korean craton or the Samarka subduction-zone terrane (part of Honshu-Sikhote-Alin collage). The metallogenic belts are interpreted as having formed during intrusion of granitoids along transpressional zones along micro plate boundaries, underthrusting of the Kula oceanic ridge, and formation of bimodal igneous rocks along a transform continental margin, or during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic Plate beneath the Eurasian Plate.

The Jiliaolu belt (JLL, figs. 3, 43) contains Zn-Pb (±Ag, Cu) skarn, Cu (±Fe, Au, Ag, Mo) skarn, granitoid-related Au vein, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork, and volcanic-hosted Au-base metal metasomatite deposits that are hosted in replacements and granitoids related to the Jilin-Liaoning-East Shandong volcanic-plutonic belt that overlies and intrudes Sino-Korean craton–Jilin-Liaoning-East Shandong terrane. The belt interpreted as having formed during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic Plate beneath the Eurasian Plate.

The North Jilin belt (NJ, figs. 3, 43) contains Zn-Pb (±Ag, Cu) skarn, granitoid-related Au vein, porphyry Cu

(±Au), porphyry Mo (±W, Bi), polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, Au-Ag epithermal vein, and fluorspar-vein deposits that are hosted in replacements and granitoids intruding the North Margin Plutonic belt that overlies the North China Platform, the Laoling terrane, part of the Wundurmiao collage, and the Zhangguangcailing superterrane. The belt is interpreted as being related to magmatism along transpression zones along transform microplate boundaries and within plate (plume) environment.

The Samarka belt (SM, figs. 3, 43) contains porphyry Cu-Mo (±Au, Ag), porphyry Mo (±W, Sn, Bi), and W±Mo±Be skarn deposits that are hosted in replacements and granitoids in the Khungari-Tatibi granite belt that intrudes the Samarka terrane, part of Honshu-Sikhote-Alin collage. The belt is interpreted as having formed during generation of S-type grantitoid plutons during underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along a transform continental margin.

The Yanshan belt (YS, figs. 3, 43) contains Cu (±Fe, Au, Ag, Mo) skarn, W±Mo±Be skarn, porphyry Mo (±W, Bi), granitoid-related Au vein, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork, and Au-Ag epithermal-vein deposits that are hosted in veins, replacements, and granitoids related to the Yanliao volcanic and sedimentary basin and plutonic belt that overlies and intrudes the Sino-Korean craton, including the West Liaoning-Hebei-Shanxi terrane, and adjacent units. The belt is interpreted as having formed during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic Plate beneath the Eurasian Plate.

Unique Metallogenic Belts

Six unique metallogenic belts formed during this time span (figs.3, 43). (1) The Ariadny belt (AR, figs. 3, 43), with mafic-ultramafic rock-related deposits is hosted in Middle Jurassic and Early Cretaceous plutons intruding the Samarka subduction-zone terrane, part of the Honshu-Sikhote-Alin collage. The belt is interpreted as having formed during generation of ultramafic and gabbroic plutons during underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along a transform continental margin. (2) The Bingdong belt (BD, figs. 3, 43) contains Zn-Pb (±Ag, Cu) skarn, W±Mo±Be skarn, and Fe skarn deposits that are hosted in replacements related to small Late Jurassic through Early Cretaceous granitoids in the Mesozoic Jihei volcanic and plutonic belt that intrudes and overlies the Zhangguangcailing superterrane and is interpreted as having formed during interplate extensional tectonism and generation of sub-alkaline to alkaline volcanism and related sedimentation along northeast and east-west regional faults. (3) The Kitakami belt (KK, figs. 3, 43), with Cu skarn and granitoid-related Au deposits is hosted in the Early Cretaceous part (with isotopic ages of 120 to 110 Ma) of the Hiroshima granite belt and is interpreted as having formed during intrusion of granitoids associated with a continental-margin arc and siliceous magmatism. (4) The Kondyor-Feklistov belt (KD, figs. 3, 43), with zoned mafic-ultramafic Cr-PGE deposits, is hosted in mafic-ultramafic intrusions and is interpreted as having formed during intrusion of mafic-ultramafic plutons along a deep-seated fault that formed along the North Asian cratonal margin during collision and accretion of outboard terranes. (5) The North Bureya belt (NB, figs. 3, 43), with Au-Ag epithermal-vein and granitoid-related Au-vein deposits, is hosted in the Umlekam-Ogodzhin volcanic-plutonic belt. The belt is interpreted as having formed during formation of Umlekan-Ogodzhin continental-margin arc that formed during subduction of part of ancestral Pacific Ocean Plate. (6) The Taebaegsan belt (TB, figs. 3, 43), with a wide assortment of granitoid-related deposits, is hosted in the Daebo granite and is interpreted as having formed during intrusion of granitoids associated with the Late Jurassic through Early Cretaceous Daebo granite. The granitioids are interpreted as being part of a continental-margin arc that was linked to subduction of the ancestral Pacific Ocean Plate.

Cenomanian through Campanian Tectonic and Metallogenic Model

Major Tectonic and Metallogenic Events

For the Cenomanian through Campanian (96 to 72 Ma), the major metallogenic and tectonic events were (figs. 4, 44, tables 1, 2) (1) formation of granitoids and associated metallogenic belts along the Khingan transform continental margin that formed in response to oblique subduction of ancestral Pacific Ocean Plate in the Russian Far East; (2) after accretion of the Kolyma-Omolon superterrane and Okhotsk terrane and accretion of the Koryak collage (composed of Late Jurassic and Early Cretaceous island arc and tectonically-linked subduction-zone terranes) in the Late Jurassic and Early Cretaceous, outboard stepping of subduction and formation of the major Late Cretaceous and early Tertiary Okhotsk-Chukotka continental-margin arc and associated metallogenic belts; (3) after accretion of the Bureya-Jiamusi superterrane and Sino-Korean craton in the Late Jurassic through Early Cretaceous and accretion of outboard terranes, outboard stepping of subduction and formation of the East Sikote-Alin continental-margin arc (containing the East Sikote-Alin volcanic-plutonic belt) and associated metallogenic belts; (4) formation of major back-arc basins in the Russian Northeast behind the Okhotsk-Chukotka continental-margin arc and in northern China behind the East Sikhote-Alin continental-margin arc. (5) late-stage continuation of transpressional fault zones along the axis of the closed Mongol-Okhotsk Ocean and formation of associated metallogenic belts; (6) postcollisional transform faulting along within-plate transpression zones in northeast China and formation of associated metallogenic belts; (7) in the late part of this time span, in the area of the East Sikhote-Alin fault, formation of a major continental-margin transform-fault system in the Russian Southeast along with generation of granitic and volcanic rocks and associated metallogenic belts; (8) rifting and formation of the Eurasian Basin and formation of the Arctic Ocean and associated metallogenic belts; and (9) accretion into the area of Japan of the Honshu-Sikhote-Alin collage that is composed of mainly island-arc, continental-margin turbidite (flysch), and subduction-zone terranes.

The major Cenomanian through Campanian metallogenic belts in Northeast Asia are portrayed on figure 4. The tectonic setting of each metallogenic belt is portrayed on figure 44.

Metallogenic Belts and Tectonic Origins

Metallogenic Belts Related to Okhotsk-Chukotka and East Sikhote-Alin Continental-Margin Arcs

Seven metallogenic belts are hosted in the Okhotsk-Chukotka and East Sikhote-Alin continental-margin arcs (figs. 4, 44) that formed in response to subduction of the ancestral Pacific Ocean Plate. The belts are the Chelasin, Kukhtuy-Uliya, Luzhkinsky, Preddzhugdzhursky, Sergeevka-Taukha, Tumnin-Anyui, and Upper Uydoma belts that contain a wide variety of granitoid-related deposits. The ages of the hosting granites and associated veins range from mid-Cretaceous through Paleocene. The major host rock units are the Okhotsk-Chukotka volcanic-plutonic belt and the East Sikhote-Alin volcanic-plutonic belt. Both units are major overlap assemblages in the Russian Far East and are interpreted as being part of an extensive, nearly coeval, and colinear continental-margin arcs that overlie the North Asian craton and cratonal margin and previously accreted terranes to the west (present-day coordinates).

The Chelasin belt (CH, figs. 4, 44) contains Sn-B (Fe) skarn (ludwigite), granitoid-related Au vein, Cu (±Fe, Au, Ag, Mo) skarn, and porphyry Cu (±Au) deposits that are hosted in the Okhotsk-Chukotka volcanic-plutonic belt.

The Kukhtuy-Uliya belt (KU, figs. 4, 44) contains Au-Ag epithermal vein, porphyry Mo (±W, Sn, Bi), porphyry Sn, and polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposits that are hosted in the Okhotsk-Chukotka volcanic-plutonic belt.

The Luzhkinsky belt (LZ, figs. 4, 44) contains Sn-W greisen, stockwork, and quartz vein; Cassiterite-sulfide-silicate vein and stockwork; W-Mo-Be greisen, stockwork, and quartz vein; porphyry Sn; porphyry Cu (±Au); porphyry Cu-Mo (±Au, Ag); and polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork deposits that are hosted in the Okhotsk-Chukotka volcanic-plutonic belt.

The Preddzhugdzhursky belt (PD, figs. 4, 44) contains porphyry Cu-Mo (±Au, Ag), porphyry Cu (±Au), Au-Ag epithermal vein, granitoid-related Au vein, and Cu (±Fe, Au, Ag, Mo) skarn deposits that are hosted in the Okhotsk-Chukotka volcanic-plutonic belt.

The Sergeevka-Taukha belt (ST, figs. 4, 44) contains granitoid-related Au vein, boron (datolite) skarn, Zn-Pb (±Ag, Cu) skarn, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork, Au-Ag epithermal vein, and porphyry Cu (±Au) deposits that are hosted in the East-Silhote Alin volcanic-plutonic belt.

The Tumnin-Anyui belt (TA, figs. 4, 44) contains porphyry Sn, cassiterite-sulfide-silicate vein and stockwork, and Au-Ag epithermal-vein deposits that are hosted in the East-Silhote Alin volcanic-plutonic belt.

The Upper Uydoma belt (TA, figs. 4, 44) contains cassiterite-sulfide-silicate vein and stockwork; polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Sn-W greisen, stockwork, and quartz vein; and porphyry Mo (±W, Sn, Bi) deposits that are hosted in the East-Silhote Alin volcanic-plutonic belt.

Metallogenic Belts Related to Khingan Transform Continental-Margin Arc

Four major metallogenic belts are hosted in granitioids of the Khingan-Okhotsk volcanic-plutonic belt that is interpreted as having formed during the generation of granitoids along the Khingan transform continental-margin arc. The belts are Badzhal-Komsomolsk, Ezop-Yam-Alin, Malo-Khingan, and Pilda-Limuri. The isotopic ages for the granitoids hosting or associated with the deposits range from 100 to 75 Ma. The arc is interpreted as having formed during oblique subduction of the ancestral Pacific Ocean Plate and formation of the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes, part of the Honshu-Sikhote-Alin collage.

The Badzhal-Komsomolsk belt (BK, figs. 4, 44) contains Sn-W greisen, stockwork, and quartz vein; cassiterite-sulfide-silicate vein and stockwork; Cu (±Fe, Au, Ag, Mo) skarn; and porphyry Mo (±W, Sn, Bi) deposits.

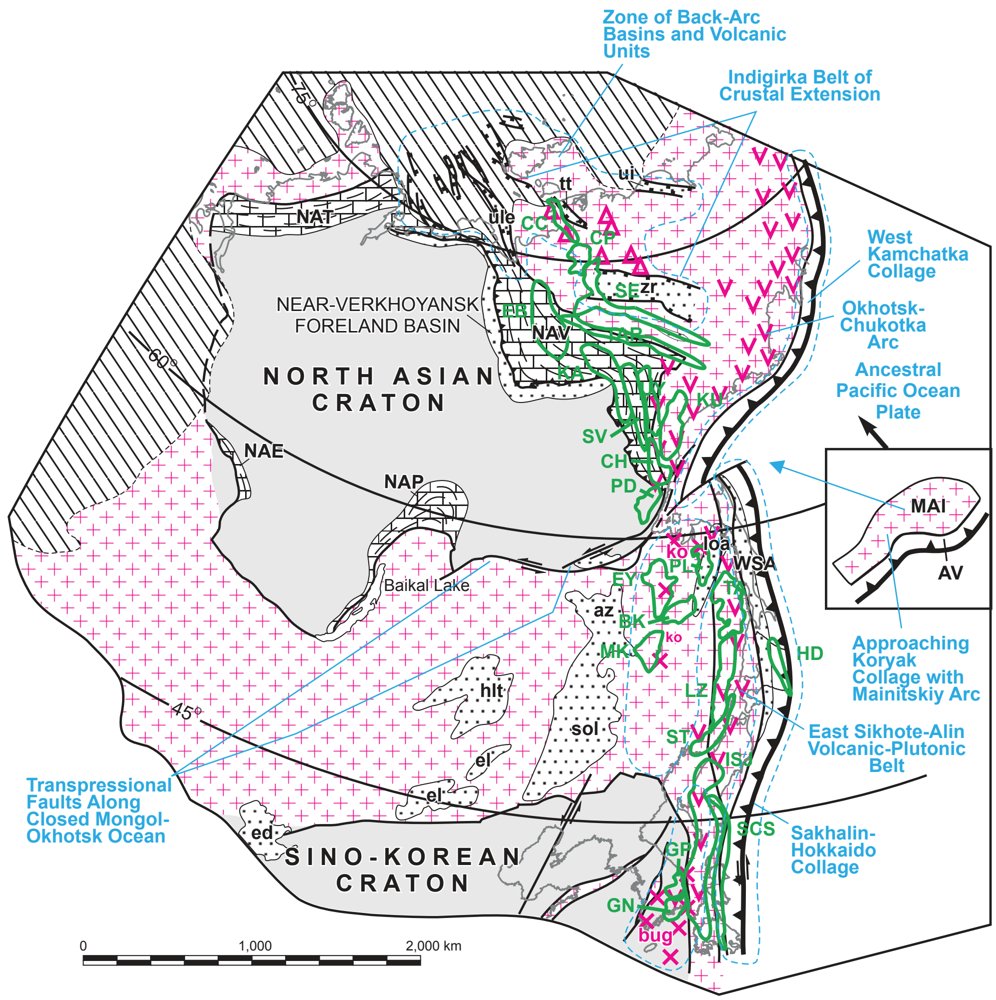
The Ezop-Yam-Alin belt (EY, figs. 4, 44) contains W-Mo-Be greisen, stockwork, and quartz vein; Sn-W greisen, stockwork, and quartz vein; cassiterite-sulfide-silicate vein and stockwork; and porphyry Mo (±W, Sn, Bi) deposits.

The Malo-Khingan belt (MK, figs. 4, 44) contains porphyry Sn and rhyolite-hosted Sn deposits.

The Pilda-Limuri belt (PL, figs. 4, 44) contains Sn-W greisen, stockwork, and quartz vein; W-Mo-Be greisen, stockwork, and quartz vein; Ag-Sb vein; polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; and granitoid-related Au-vein deposits.

Metallogenic Belts Related to Opening of the Eurasia Basin

Five metallogenic belts are interpreted as having formed during extension related to the formation of the Eurasia Basin during initial opening of the Arctic Ocean. The extension resulted in the formation of the Indigirka belt of crustal extension (fig. 44). The belts contain a variety of vein, replacement, and granitoid-related deposits and include the Central Polousny, Chokhchur-Chekurdakh, Eckyuchu-Billyakh,



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental Sedimentary Basins

az - Amur-Zeya sedimentary basin (Late Jurassic to Quaternary)
ed - Erduosi sedimentary basin (Triassic through Cretaceous)
el - Erlian sedimentary basin (Jurassic through Quaternary)
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
loa - Lower Amur overlap assemblage (Late early and early Late Cretaceous)
sol - Songliao sedimentary basin (Jurassic through early Tertiary)
tt - Tastakh Basin
ui -Ust-Indigirka Basin
ule - Ust-Lena Basin
zr - Zyryanka sedimentary basin (Late Jurassic through Cenozoic)

Terranes

AV - Alkatvaam terrane
MAI - Mainitskiy terrane
WSA - West Sakhalin terrane (Accretionary wedge, type A) (Cretaceous)

Overlap Continental-Margin Arcs and Granite Belts

ko - Khingan-Okhotsk volcanic-plutonic belt (Cretaceous)
bug - Bulgugsa granite (Late Cretaceous

METALLOGENIC BELTS

BK - Badzhal-Komsomolsk
CC - Chokhchur-Chekurdakh
CH - Chelasin
CP - Central Polousny
EB - Eckyuchu-Billyakh
EY - Ezop-Yam-Alin
GN - Gyeongnam
GP - Gyeongpuk
HD - Hidaka
ISJ - Inner Zone Southwest Japan
KA - Khandyga
KU - Kukhtuy-Uliya
LZ - Luzhkinsky
MK - Malo-Khingan
PD - Preddzhugdzhursky
PL - Pilda-Limuri
SCS - Sambagawa-Chichibu-Shimanto
SE - Selennyakh
ST - Sergeevka-Taukha
SV - South Verkhoyansk
TA - Tumnin-Anyuy
TAR - Taryn
UY - Upper Uydoma

Figure 44. Cenomanian through Companian (87 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).

Khandyga, and Selennyakh belts. The isotopic ages for the-vein deposits range from 120 to 97 Ma (Aptian through Late Cretaceous). The belts and deposits are hosted in units that intrude the Northern and Transverse granite belts, the Svyatoi Nos volcanic belt, and the Uyandina-Yasachnaya volcanic belt that intrude or overlie the Verkhoyansk (North Asian) cratonal margin and outboard accreted terranes.

The Central Polousny belt (CP, figs. 4, 44) contains cassiterite-sulfide-silicate vein and stockwork, and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in Veins and replacements in the Northern granite belt along the northwestern margin of the Kolyma-Omolon superterrane.

The Chokhchur-Chekurdakh belt (CC, figs. 4, 44) contains cassiterite-sulfide-silicate vein and stockwork deposits that are hosted in veins and replacements in the Svyatoi Nos volcanic belt that occurs along southern margin of the Kolyma-Omolon superterrane.

The Eckyuchu-Billyakh belt (EB, figs. 4, 44) contains polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; clastic-sediment-hosted Sb-Au; Hg-Sb-W vein and stockwork; Ag-Sb vein; and Au-Ag epithermal-vein deposits that are hosted in veins and replacements related to the Transverse granite belt that intrudes the Verkhoyansk (North Asian) cratonal margin.

The Khandyga belt (EB, figs. 4, 44) contains Ag-Sb vein, carbonate-hosted As-Au metasomatite, clastic-sediment-hosted Sb-Au, and clastic sediment-hosted Hg±Sb deposits that are hosted in veins and replacements in the Verkhoyansk (North Asian) cratonal margin.

The Selennyakh belt (EB, figs. 4, 44) contains Carbonate-hosted Hg-Sb, volcanic-hosted Hg, and Ag-Sb-vein deposits that are hosted in veins and replacements in the Uyandina-Yasachnaya volcanic belt along the southern margin of the Kolyma-Omolon superterrane.

Unique Metallogenic Belts

Four unique metallogenic belts formed during this time span.

(1) The Gyeongpuk belt (GP, figs. 4, 44) and the Gyeongnam belt (GN, figs. 4, 44) (with polymetallic Pb-Zn vein and stockwork, Au in shear zone and quartz vein; porphyry Mo; W-Mo-Be greisen, stockwork, and quartz vein; Sn-W greisen, stockwork, and quartz vein; Fe skarn; and polymetallic Ni-vein deposits) have isotopic ages of Cenomanian through Campanian, and are hosted in the Cretaceous Bulgugsa granite that intrudes the Sino-Korean craton. The belts and deposits are interpreted as having formed in a continental-margin arc during subduction of the ancestral Pacific Ocean Plate.

(2) The Hidaka belt (HD, figs. 4, 44) with Cyprus Cu-Zn massive sulfide deposits is hosted in Middle Cretaceous through Eocene stratiform units that occur in tectonic fragments in the Shimanto subduction-zone terrane, part of the East Sakhalin collage. The belt is interpreted as having formed in basalt generated along the Kula-Pacific oceanic ridge, with subsequent structural incorporation of host rocks and deposits into a subduction zone.

(3) The Inner Zone Southwest Japan belt (ISJ figs. 4, 44) with a wide variety of vein and replacement and granitoid-related deposits (Zn-Pb skarn; W-Mo-Be greisen; stockwork, and quartz vein; W skarn; Cu skarn; porphyry Mo; polymetallic Pb-Zn vein and stockwork; fluorspar vein; and metamorphic graphite deposits), is hosted in the Nohi rhyolite volcanic belt and coeval Hiroshima granitic belt that overlie and intrude previously-accreted terranes. The host rocks and deposits have isotopic ages of Cretaceous through Paleogene and are interpreted as having formed during generation of granitoids along an East Asia continental-margin arc that was tectonically-linked to subduction of the Kula and Pacific Ocean Plates. The East Asia continental-margin arc is interpreted as being the southern extension of the East Sikhote-Alin arc.

Maastrichtian through Eocene Tectonic and Metallogenic Model

Major Tectonic and Metallogenic Events

For the Maastrichtian through Eocene (72 to 34 Ma), the major metallogenic and tectonic events were (figs. 5, 45, tables 1, 2): (1) migration of the Olyutorka-Kamchatka island arc toward the northeast margin of Northeast Asia and formation of associated metallogenic belts; (2) slightly later, accretion of the Olyutorka-Kamchatka island arc and formation of collision-related metallogenic belts; (3) migration of the Terprniya-Nemuro island arc towards the eastern margin of Northeast Asia and formation of associated metallogenic belts; (4) continuation of transpressional-fault zones along the axis of the closed Mongol-Okhotsk Ocean and formation of associated metallogenic belts; (5) postcollisional, transform faulting along within-plate transpression zones in northeast China and formation of associated metallogenic belts; (6) continued formation of a major continental-margin transform-fault system and generation of the East Sikhote-Alin volcanic-plutonic belt (and East Sikhote-Alin transform continental-margin arc) in the Russian Southeast and northeast China and formation of associated metallogenic belts; and (7) continued rifting and formation of the Eurasia Basin and the Arctic Ocean.

The major Maastrichtian through Eocene metallogenic belts in Northeast Asia are portrayed on figure 5. The tectonic setting of each metallogenic belt is portrayed on figure 45.

Major Maastrichtian through Eocene Metallogenic Belts

Metallogenic Belts Related to East Sikhote-Alin Continental-Margin Arcs

The Kema and Lower Amur metallogenic belts (KM, LA, figs. 5, 45; table 2) (with Ag-Au epithermal vein; porphyry Cu-Mo; porphyry Cu; porphyry Au; porphyry Mo; Au-Ag epithermal vein; epithermal quartz-alunite; and Sn-W greisen, stockwork, and quartz-vein deposits) are hosted in the granitoids and associated veins in the Late Cretaceous through Paleocene East Sikhote-Alin volcanic-plutonic belt that is a major overlap assemblage in the Russian Far East. The isotopic ages for the granitoids hosting or associated with the deposits range from Late Cretaceous through Paleocene. The belt is part of a very extensive continental-margin arc that formed along the eastern margin (present-day coordinates) of the North Asian craton and cratonal margin and previously-accreted terranes to the east. The arc is interpreted as having formed during oblique subduction of the ancestral Pacific Ocean Plate.

Metallogenic Belt Related to Meteorite Impact

The unique Popigay metallogenic belt (PP, figs. 5, 45) contains impact diamond deposits and is hosted in the Popigay ring structure. The isotopic age from tagamite (impact melt rock) and impact glasses is 35.7 Ma. The belt is interpreted as having resulted from meteoritic impact with formation of pseudotachylite, diamond, high-grade shock metamorphic minerals, and allogenic breccia.

Oligocene through Quaternary Tectonic and Metallogenic Model

Major Tectonic and Metallogenic Events

For the Oligocene through Miocene (34 to 5.3 Ma), the major tectonic and metallogenic events were (figs. 5, 46, tables 1, 2) (1) formation of the short-lived Central Kamchatka continental-margin arc along the outboard margin of northern Northeast Asia; (2) migration of the Kronotskaya island arc towards the northeast margin of Northeast Asia; (3) slightly later, accretion of the Kronotskaya island arc outboard of the Central Kamchatka arc; (4) formation of the Japan continental-margin arc and back-arc spreading between the arc and the southern part of Northeast Asia; (5) formation of the Izu Bonin intraoceanic arc to the south; and (6) continued rifting and formation of the Eurasian Basin and formation of the Arctic Ocean.

For the Pliocene through Present (5.3 to 0 Ma), the major tectonic and metallogenic events were (figs. 5, 47, tables 1, 2) (1) formation of the Kuril-Kamchatka continental-margin arc along the eastern margin of Northeast Asia; (2) continued formation of the Japan continental-margin arc and back-arc spreading between the arc and the southern part of Northeast Asia; (3) continued formation of the Izu Bonin continental-margin arc to the south; (4) continued rifting and formation of the Eurasian Basin and formation of the Arctic Ocean; and on the basis of modern-day earthquake foci, formation of several new tectonic plates across the region.

The major Oligocene through Quaternary metallogenic belts in Northeast Asia are portrayed on figure 5. The tectonic setting of each metallogenic belts is portrayed on figures 46 and 47.

Major Oligocene through Quaternary Metallogenic Belts Hosted in the Japan Arc

Five major metallogenic belts are hosted in the Japan arc. The arc is interpreted as having formed from subduction of the Pacific Ocean and Philippine Sea Plates beneath the East Asia continental margin. The belts are the Hokuriku-Sanin, Kyushu, Northeast Hokkaido, Northeast Japan, and Outer Zone Southwest Japan. The isotopic ages of host rocks or deposits range from Miocene to Quaternary (15 to 2 Ma). Some deposits are probably still forming in these belts along the axial or back-arc parts of the arc.

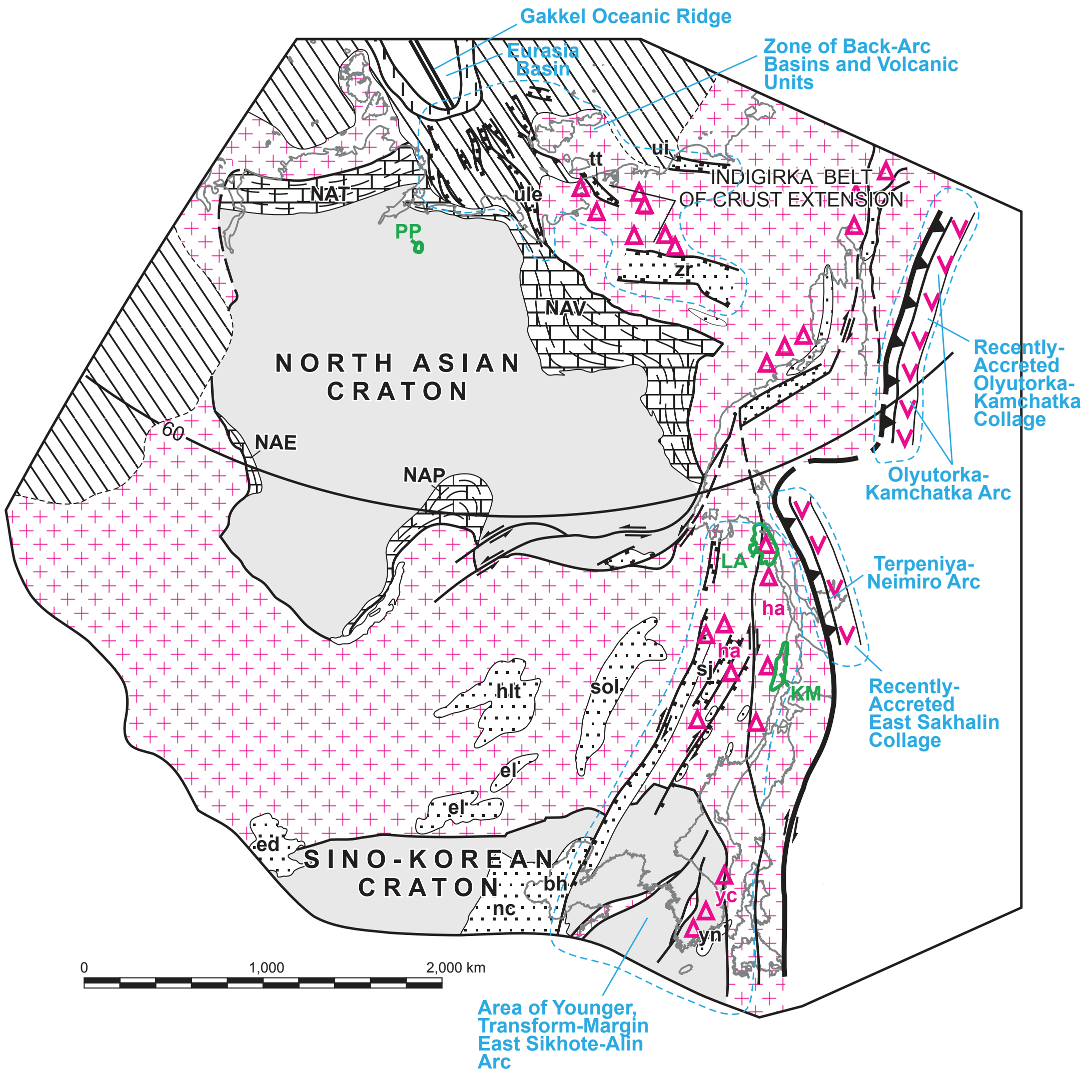
The Hokuriku-Sanin belt (HS, figs. 5, 46, 47) contains Miocene to Pleistocene Au-Ag epithermal vein, polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork, Ag-Sb vein, and clastic-sediment-hosted U deposits that are hosted in veins and replacements related to the Neogene Japan sedimentary basin that overlies the Hiroshima granitic plutonic belt and the Akiyoshi-Maizuru and Mino-Tamba-Chichibu terranes, both part of Honshu-Sikhote-Alin collage. The belt is interpreted as having formed along an island arc during back-arc rifting or along the axial part of the Japan arc.

The Kyushu belt (KY, figs. 5, 47) contains Pliocene to Quaternary Au-Ag epithermal-vein deposits that are hosted in veins and replacements related to the Quaternary Japan volcanic belt and Neogene Japan sedimentary basin that overlie and intrude Akiyoshi-Maizuru, Shimanto, and Mino-Tamba-Chichibu terranes and are both part of Honshu-Sikhote-Alin collage. The belt is interpreted as having formed during hydrothermal activitiy along the Japan arc in either back-arc rifting or the axial part of the arc

The Northeast Hokkaido belt (NH, figs. 5, 46, 47) contains Miocene to Quaternary Au-Ag epithermal vein, volcanic-hosted Hg, Hg-Sb-W vein and stockwork, and clastic sediment-hosted Hg±Sb deposits that are hosted in veins and replacements in the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that overlies and intrudes the Hidaka zone of the the Shimanto accretionary-wedge terrane that is part of the Honshu-Sikhote-Alin collage.

The Northeast Japan belt (NJ, figs. 5, 46, 47) contains volcanogenic Miocene to Quaternary Zn-Pb-Cu massive sulfide (Kuroko, Altai types), Au-Ag epithermal vein, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, sulfur-sulfide (S, FeS2), polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork, Mn vein, volcanogenic-sedimentary Mn , chemical-sedimentary Fe-Mn, and limonite from spring-water deposits that are hosted in layers and veins in the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that overlies the Hiroshima granitic plutonic belt and the Mino-Tamba-Chichibu and South Kitakami terranes, both part of the Honshu-Sikhote-Alin collage. The volcanogenic massive sulfide deposits are interpreted as having formed in back-arc and axial regions of the Japan arc.

The Outer Zone Southwest Japan belt (OS, figs. 5, 46) contains middle Miocene Sn skarn; Sn-W greisen, stockwork, and quartz vein; polymetallic Pb-Zn ± Cu (±Ag, Au) vein and



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental Sedimentary Basin

bh - Bohai sedimentary basin (Cenozoic)
ed - Erduosi sedimentary basin (Triassic through Cretaceous)
el - Erlian sedimentary basin (Jurassic through Quaternary)
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
nc - North China sedimentary basin (Cenozoic)
sj - Sanjiang sedimentary basin and Yishu graben (Mesozoic and Cenozoic)
sol - Songliao sedimentary basin (Jurassic through early Tertiary)
tt - Tastakh Basin
ui -Ust-Indigirka Basin
ule - Ust-Lena Basin
yn - Yonil Group (Cenozoic)
zr - Zyryanka sedimentary basin (Late Jurassic through Cenozoic)

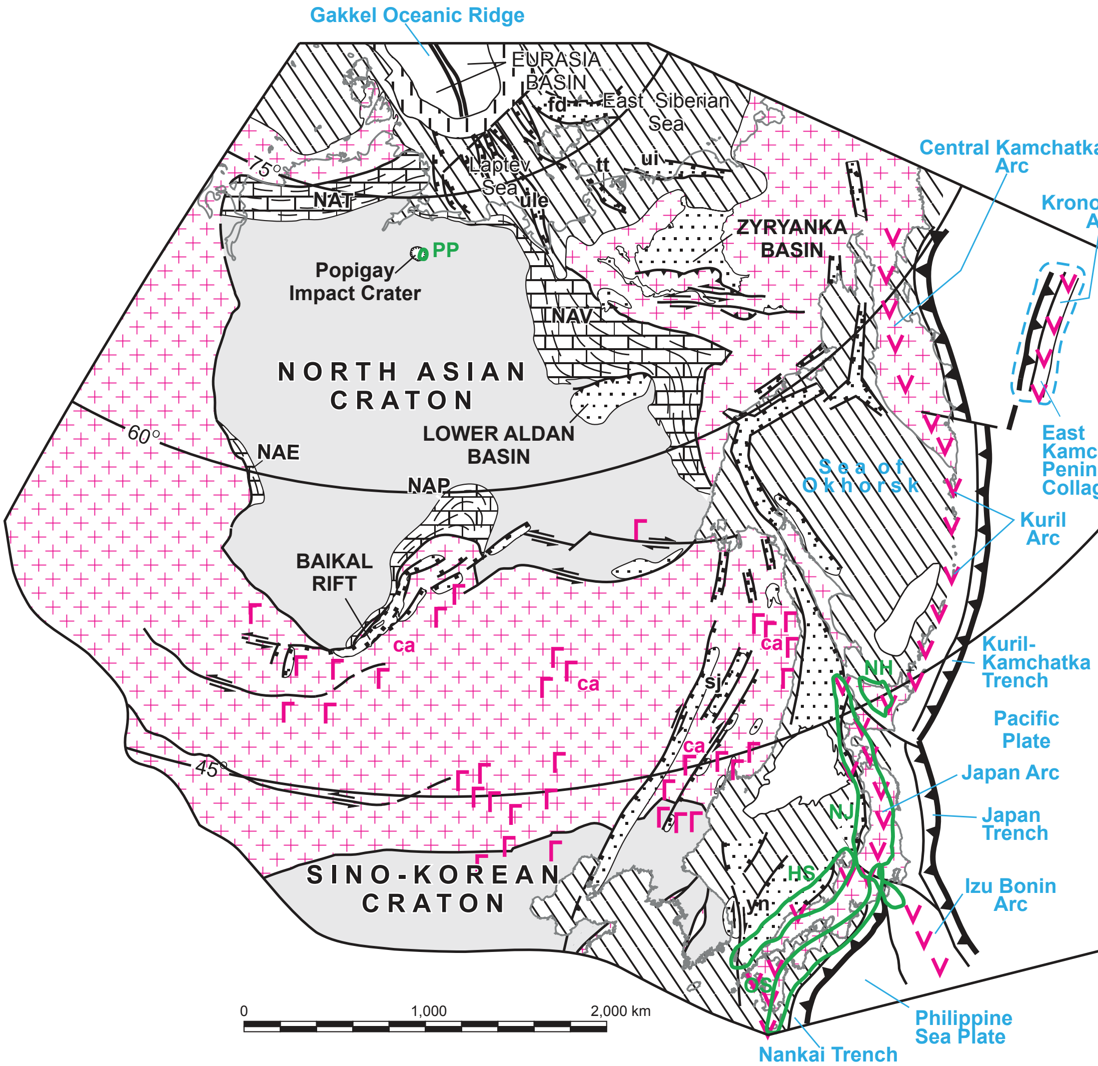
Overlap Continental-Margin Arcs and Granite Belts

yc -Yucheon volcanic belt
ha - Hasan-Amurian volcanic-plutonic belt (Paleocene to early Miocene)

METALLOGENIC BELTS

KM - Kema
LA - Lower Amur
PP - Popigay

Figure 45. Maastrichtian through Eocene (50 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental Sedimentary Basins

fd - Faddeevskiy Basin
sj - Sanjiang sedimentary basin and Yishu graben (Mesozoic and Cenozoic)
tt - Tastakh Basin
ui -Ust'-Indigirka Basin
ule - Ust'-Lena Basin
yn - Yonil Group (Cenozoic)

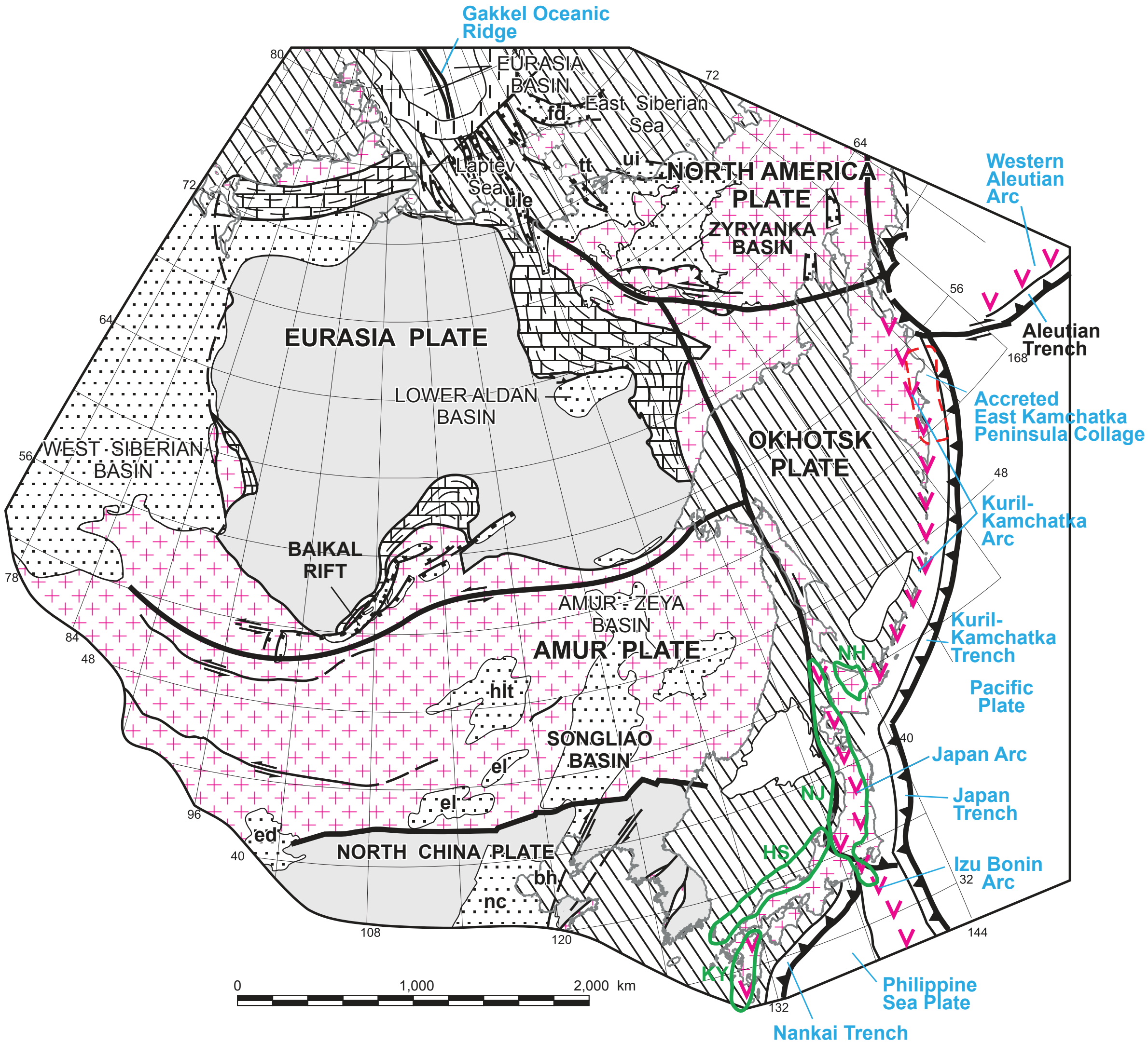
Plateau Basalt Belt

ca - Central Asian plateau basalt belt (Neogene and Quaternary)

METALLOGENIC BELTS

HS - Hokuriku-Sanin
NH - Northeast Hokkaido
NJ - Northeast Japan
OS - Outer Zone Southwest Japan
PP - Popigay

Figure 46. Oligocene through Miocene (10 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).



GEOLOGIC UNITS

Intracontinental Sedimentary Basins

bh - Bohai sedimentary basin (Cenozoic)
ed - Erduosi sedimentary basin (Triassic through Cretaceous)
el - Erlian sedimentary basin (Jurassic through Quaternary)
fd - Faddeevskiy Basin
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
nc - North China sedimentary basin (Cenozoic)
tt - Tastakh basin
ui -Ust'-Indigirka Basin
ule - Ust'-Lena Basin

METALLOGENIC BELTS

HS - Hokuriku-Sanin
KY - Kyushu
NH - Northeast Hokkaido
NJ - Northeast Japan

Figure 47. Present (0 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).

stockwork, clastic-sediment-hosted Sb-Au; Au-Ag epithermal vein, volcanic-hosted Hg; Ag-Sb vein; Zn-Pb (±Ag, Cu, W) skarn; W-Mo-Be greisen, stockwork, and quartz vein; Hg-Sb-W vein and stockwork; cassiterite-sulfide-silicate vein and stockwork; and clastic-sediment-hosted Sb-Au deposits that are hosted in veins and replacements related to the Neogene Japan sedimentary basin that overlies the Hiroshima granitic plutonic belt, and the Sambagawa, Shimanto, and Mino-Tamba-Chichibu terranes, all of which are part of the Honshu-Sikhote-Alin collage. The belt is interpreted as having formed in back-arc rifting or axial part of Japan arc.

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Table 1

Table 1. Summary of major Late Jurassic through Cenozoic (154 to 0 Ma) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit. Map Symbol	Type of Unit (Craton, Terrane, Overlap Assemblage)	Age range	Tectonic Environment	Tectonic Linkage
		NORTHEAST ASIA CRATONS		
North Asian. NAC Sino Korean. SKC	Craton	Archean through Mesozoic	Cratonal and passive continental margin	Primary units.
		NORTH ASIAN CRATONAL MARGIN UNITS		
Baikal-Patom. BP East Angara. EA South Taimyr. ST Verkhoyansk. VR	Overlap assemblages	Neoproterozoic through Mesozoic	Passive continental margin.	Original overlap assemblages on North Asian craton that were subsequently transformed into fold and thrust belts and terranes.
		SUPERTERRANE		
Bureya-Jiamusi. BJ7	Superterrane	Proterozoic through Permian	Composite.	Consists of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island-arc terranes. Interpreted as being a fragment of Gondwana. Accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic.
		TECTONIC COLLAGES EAST OF NORTH ASIAN AND SINO-KOREAN CRATONS		
Badzhal. BD	Collage	Triassic through Early Cretaceous	Composite.	Consists of Umlekan-Ogodzhin continental-margin arc and tectonically-linked subduction-zone terranes to the east with Tethyan fauna. Accreted in Late Cretaceous.
Chukotka. CH	Collage	Paleozoic through Triassic	Composite.	Consists of passive continental-margin terranes that formed along the long-lived Neoproterozoic through early Mesozoic North American continental margin. Accreted to the northern Verkhoyansk-Kolyma collage in the Late Cretaceous.
East Kamchatka Peninsula. EP	Collage	Paleocene	Composite.	Consists of the Kronotskiy island Pliocene.
East Sakhalin. ES	Collage	Late Cretaceous through early Tertiary	Composite.	Consists of the Late Cretaceous through middle Eocene Terpeniy-Tokoro-Nemuro-Shmidt island arc and tectonically-linked subduction-zone terranes. Accreted in early Tertiary.
Honshu-Sikhote-Alin. HS	Collage	Jurassic and Early Cretaceous	Composite.	Consists of fragments of island arc, continental-margin turbidite (flysch) and subduction-zone terranes that formed along a transform continental margin. Accreted in Cretaceous.
Koryak. KOR	Collage	Late Triassic through Cretaceous	Composite.	Consists of the Late Jurassic and Early Cretaceous Manitskiy island-arc and tectonically-linked subduction-zone terranes to the east. Accreted in Late Cretaceous.

Table 1. Summary of major Late Jurassic through Cenozoic (154 to 0 Ma) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).—Continued

Olyutorka-Kamchatka. OK	Collage	Late Cretaceous and Paleocene	Composite.	Consists of the Olyutorka island arc and tectonically-linked subduction-zone terranes to the east. Accreted in early Cenozoic.
Penzhina-Anadyr. PA	Collage	Late Jurassic through Early Cretaceou	Composite.	Consists of the Murgal island-arc terrane and tectonically-linked subduction-zone terranes to the east. Collage rims the eastern Kolyma-Omolon superterrane and Verkhoyansk-Kolyma collage. The collage is also linked to the Uda continental-margin arc. Accreted in Late Cretaceous.
Sakhalin-Hokkaido. SK	Collage	Cretaceous	Composite.	Consists of the Late Cretaceous flysch terranes of Sakhalin and Hokkaido Islands, and tectonically-linked subduction-zone terranes to the east. Interpreted as a continental-margin forearc basin and tectonically-linked subduction-zone terranes that are associated with the East Sikhote-Alin continental-margin arc. Accreted in Eocene.
South Anyui. SA	Collage	Permian through Early Jurassic	Composite.	Consists of the Oloy island arc and tectonically-linked subduction-zone terranes. Accreted in Late Cretaceous.
West Kamchatka. WK	Collage	Mid-Cretaceous through early Tertiary	Composite.	Consists of late Paleozoic through Cretaceous subduction-zone terranes. Tectonically linked to Okhotsk-Chukotka continental-margin arc. Accreted in early Cenozoic.
Verkhoyansk-Kolyma. VK	Collage	Late Paleozoic through Early Jurassic	Composite.	Consists of a deformed passive continental margin, accreted ophiolite and subduction-zone terranes. Interpreted as having formed during accretion of the outboard Kolyma-Omolon superterrane. Accreted in Late Jurassic through early Early Cretaceous.
TECTONIC COLLAGE BETWEEN NORTH ASIAN AND SINO-KOREAN CRATONS				
Mongol-Okhotsk. MO	Collage	Devonian through Late Jurassic	Composite.	Consists mainly of the Permian through Jurassic Selenga, Late Carboniferous and Early Permian Hangay, and Uda-Murgal and Stanovoy continental-margin arcs. Composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically-linked, outboard subduction-zone terranes. Interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean with oblique subduction of terranes beneath the southern North Asian cratonal margin and previously-accreted terranes.
JURASSIC TO EARLY CRETACEOUS CONTINENTAL-MARGIN ARCS				
Selenga. se	Overlap assemblage	Permian through Jurassic	Transform continental-margin arc.	Interpreted as having formed along the margin of the North Asian craton as a continental-margin transform system.
Uda-Murgal. us	Overlap assemblage	Jurassic through Early Cretaceous	Subduction-related arc.	Interpreted as having formed along the margin of the North Asian craton and cratonal margin during subduction of ancestral Pacific Ocean Plate.

Table 1. Summary of major Late Jurassic through Cenozoic (154 to 0 Ma) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).—Continued

JURASSIC AND EARLY CRETACEOUS ISLAND ARCS OCCURRING ON OR ADJACENT TO KOLYMA-OMOLON SUPERTERRANE				
Oloy. ol	Island arc	Late Jurassic	Subduction-related arc.	Interpreted as having formed on the Kolyma-Omolon superterrane during subduction of the South Anyui Ocean Plate beneath the superterrane.
Uyandina-Yasachnaya. uy	Island arc	Late Jurassic through Early Cretaceous	Subduction-related arc.	Interpreted as having formed during subduction of the Oimyakon Ocean Plate between the North Asian cratonal margin and the Kolyma-Omolon superterrane.
JURASSIC THROUGH EARLY TERTIARY CONTINENTAL-MARGIN ARCS AND GRANITE BELTS OCCURRING ALONG EASTERN MARGIN OF NORTHERN ASIA				
East Sikhote-Alin. ea	Continental-margin arc	Late Cretaceous through early Tertiary	Subduction-related arc.	Interpreted as having formed during subduction of the ancestral Pacific Ocean Plate.
Umlekan-Ogodzhin. uo	Continental-margin arc	Jurassic and Cretaceous	Subduction-related arc.	Interpreted as having formed during subduction of the ancestral Pacific Ocean Plate.
Khingan-Okhotsk. ko	Continental-margin arc	Early and mid-Cretaceous	Subduction-related arc.	Interpreted as having formed during subduction of the ancestral Pacific Ocean Plate.
Main granite belt. ma	Continental-margin arc	Late Jurassic	Subduction-related arc.	Interpreted as having formed during and immediately after collision of the Kolyma-Omolon superterrane onto the North-Asian cratonal margin.
Northern granite belt. nb	Continental-margin arc	Early Cretaceous	Subduction-related arc.	Interpreted as having formed during the subduction of oceanic crust during a closure of a small oceanic basin during late stage of accretion of the Kolyma-Omolon superterrane.
Okhotsk-Chukotka. oc	Continental-margin arc	Late Cretaceous through early Tertiary	Subduction-related arc.	Interpreted as having formed during subduction of the ancestral Pacific Ocean Plate.
South Verkhoyansk granite belt. sv	Continental-margin arc	Late Jurassic through mid-Cretaceous	Subduction-related arc.	Interpreted as having formed during the accretion of the outboard Okhotsk terrane.
Transverse granite belt. tr	Continental-margin arc	Early Cretaceous	Subduction-related arc.	Interpreted as having formed during the late stage of accretion of the Kolyma-Omolon superterrane.
ACTIVE CONTINENTAL-MARGIN ARCS OCCURRING ALONG EASTERN MARGIN OF NORTHERN ASIA				
Izu-Bonin arc (ib)	Intraocean arc	Miocene through Present	Subduction-related arc.	Interpreted as having formed from subduction of the ancestral Pacific Ocean Plate.
Japan arc (ja)	Continental-margin arc	Miocene through Present	Subduction-related arc.	Interpreted as having formed during subduction of the Pacific Ocean and Philippine Sea Plates.
Kuril-Kamchatka arc (kk)	Continental-margin arc	Miocene through Present	Subduction-related arc.	Interpreted as having formed during subduction of the Pacific Ocean Plate.
TRANSPRESSIONAL ARCS				
Mongol-Transbaikal. mt	Transpressional arc	Late Triassic through Early Cretaceous.	Transpressional faulting after closure of Mongol-Okhotsk Ocean.	Interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.
Trans-Baikal-Daxinganling. tb	Transpressional arc		Middle Jurassic through Early Cretaceous.	Interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk fault during, and after the final closure of the Mongol-Okhotsk Ocean.

Chapter 9

Tectonic and Metallogenic Model for Northeast Asia

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Introduction

This article presents a major new tectonic and metallogenic model of Northeast Asia from the Neoproterozoic through the Present (1000 to 0 Ma). This article is the final chapter in a major book on the metallogenesis and tectonics of Northeast Asia. The other major chapters in the book are an overview of the regional geology, metallogenesis, tectonics of the region (Chapter 1), a review of the methodology for the metallogenic and tectonic analysis of this region (Chapter 2), descriptions of mineral-deposit models (Chapter 3), and Archean through Present metallogenesis and tectonics (Chapters D through H). In addition, three appendices contain information on project publications (appendix A), descriptions of major geologic units (appendix B), and summaries of metallogenic belts (appendix C).

Compilations Employed for Synthesis, Project Area, and Previous Study

This tectonic and metallogenic model is based on a major compilation of regional geologic and metallogenic data and synthesis of interpretations (appendix A) that were done by a major international collaborative study of the metallogenesis and tectonics of Northeast Asia that was led by the U.S. Geological Survey (USGS). These studies have produced two broad types of publications. One type of publication is a series of regional geologic, mineral deposit, and metallogenic belt maps and companion descriptions for the regions. Examples of major publications of this type are Obolenskiy and others (2003, 2004), Parfenov and others (2003, 2004a,b), Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006). The other type of publication is a suite of metallogenic and tectonic analyses of these same regions. Examples of major publications of this type are Rodionov and others (2004), Nokleberg and others (2000, 2004, 2005), Scotese and others (2001), Naumova and others (2006), and Seltman and others (2007). Detailed descriptions of lode deposits are available in Ariunbileg and others (2003). For more detail than presented in this chapter, refer to the detailed descriptions of geologic units and metallogenic belts in the publications listed above.

The Northeast Asia project area consists of eastern Russia (most of Siberia and most of the Russian Far East), Mongolia, Northern China, South Korea, Japan, and adjacent offshore areas (fig. 1). This area is approximately bounded by 30 to 82° N. latitude and 75 to 144° E. longitude. The major participating agencies are the Russian Academy of Sciences; Academy of Sciences of the Sakha Republic (Yakutia); VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation; Mongolian Academy of Sciences; Mongolian University of Science and Technology; Mongolian National University; Jilin University, Changchun, China; the China Geological Survey; the Korea Institute of Geosciences and Mineral Resources; the Geological Survey of Japan/AIST; University of Texas Arlington; and the USGS.

The Northeast Asia project extends and build on data and interpretations from a previous project on the "Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far

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East, Alaska, and the Canadian Cordillera" (below figure) that was conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada. A summary of the major products of this project are contained online at http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.pdf and in appendix A.

Geologic Time Sca- scale units are according to the IUGS Global Stratigraphic Chart (Remane, 1998). In this study, for descriptions of some Proterozoic geologic units in Russia, the term *Riphean* is used for the Mesoproterozoic through middle Neoproterozoic (1650 to 600 Ma), and the term *Vendian* is used for Neoproterozoic III (650 to 540 Ma) (Harland and others, 1989).

General Tectonic Concepts

Construction of a tectonic and metallogenic model in order to adequately describe specific geologic structure is the most important task of tectonic investigations. The plate tectonics concept permits recognizing fundamental events of the Earth's evolution and the formation of major geologic and tectonic belts. A model must be consistent with geologic data and be based on the modern principles of plate tectonics. The importance of a model is both to portray a unified interpretation of earth formation and evolution and to permit prediction of regions of past and present tectonic events, and prediction of areas with potential for undiscovered mineral and fuel

Figure 1. Regional summary geographic map for Northeast Asia showing major regions and countries

resources. A model provides a better understanding of tectonics and the interrelation of major geologic units, enables the understanding of the tectonic origin of metallogenic belts, and provides the ability to define areas with potential for undiscovered mineral deposits.

The major tectonic (orogenic) belts between the North Asian and Sino-Korean cratons in Central Asia formed over a long period from the Proterozoic through the Mesozoic. In Northeast Asia major tectonic (orogenic) belts are Mesozoic and Cenozoic age and occur mainly along the western margin of the Pacific Ocean. Many tectonic models for Central and Northeast Asia have been proposed over the last 20 years (Zonenshain and others, 1976, 1990; Pecherskiy and Didenko, 1995; Ruzhentsev and Pospelov, 1992; Mossakovskiy and others, 1994; Parfenov, 1984; Berzin, Dobretsov, 1994; Şengör and Natal'in, 1996; Parfenov and others, 1993; Ren Jishun and others, 1999; Nokleberg and others, 2000; Scotese and others, 2001; Yakubchuk, 2002). Although all are based on plate tectonics, the models differ greatly because of being based on differing and evolving field geologic-data sets. In addition, a model must consider the precision geochronological, geochemical, paleobiogeographic, paleomagnetic, and other data. As a result the models for Central Asia are highly debated.

Following the pioneer work of Zonenshain and others (1976, 1990), many authors constructed models based on relationships between the terranes of orogenic belts and paleotectonic elements such as island arcs, microcontinents, and oceanic plates. With this methodology, independent island arcs, microcontinents, and other units were recognized for every time span, and with exotic terranes and fragments of the Gondwana supercontinent (Mossakovskiy and others, 1994). In contrast, Şengör and Natal'in (1996) interpreted that a single giant island arc formed along the southern margin of the North Asian craton and cratonal margin from the Neoproterozoic through nearly the end of the Mesozoic. The arc migrated from east to west (present-day coordinates) with fragments accreting sequentially to the southern margin of the North Asian craton and cratonal margin to form tectonic belts of varying age. In contrast, this study analyzes the Neoproterozoic through Present tectonic and metallogenic evolution of the entire region framing the North Asian craton and cratonal margin, the Sino-Korean craton, other major microcontinents, and the western margin of the Pacific Ocean. This study thereby produces a new interpretation of the major tectonic and metallogenic events that can be applied to the formation and evolution of major intracontinental tectonic belts.

The methodology of this study is derived from previous detailed investigations carried out early in the 1980s in the Russian Far East, Alaska, and the Canadian Cordillera. These investigations showed that the region consists of tectonic collage (see definition, table 1) or mosaic of terranes (fault-bounded crustal blocks) that differ in structure and geologic history (Coney and others, 1980; Jones and others, 1983; Howell, 1989; Howell and others, 1985). Terranes are derived from larger tectonic units, such as island arcs, subduction zones, cratons, and active and passive continental margins. Accretion and collision of terranes with each other or with continents produced major tectonic (orogenic) belts and were accompanied by major zones of subduction, obduction, regional thrusting, and regional strike-slip faulting. In some cases, accretions caused dismembering of previously single tectonic units, their dispersion and subsequent recombination into a new major tectonic unit. The conducted studies clearly show that construction of a model for the formation of an orogenic belt and paleotectonic reconstructions must be preceded by hard work that consists of recognizing terranes, establishing their geodynamic nature, and mutual correlations, a type of study now defined as terrane analysis (Parfenov and others, 1998; Nokleberg and others, 2000, 2005; Scotese and others, 2001).

Principles of Construction of the Model

Three main principles are utilized for construction of the Northeast Asia tectonic and metallogenic model.

First, an actualistic principle of plate tectonics is employed for elaborating a Neoproterozoic and Phanerozoic model for the formation of Late Precambrian and Phanerozoic orogenic belts. This principle employs the interpretation that island arc systems (arcs, forearcs, backarcs, and tectonically-linked subduction zones), whose ancient fragments can be established in most orogenic belts, originally extended for many thousands of kilometers. These elongate island-arc systems (tectonic collages or collages) surrounded ancient continents, much like modern arcs on the eastern margin of Asia. During the accretion, these island-arc systems were dismembered into various fragments and dispersed over large distances. Detailed studies of the orogenic belts (tectonic collages), for example in the North American Cordillera, show that dispersion of tectonic elements of the orogenic belts may also occur after the accretion of island arcs, mainly during longitudinal strike-slip faults. The displacements may be for hundreds to thousands of kilometers, and are roughly parallel to the continent-ocean boundary (Plafker and Berg, 1994; Monger andNokleberg, 1996; Nokleberg and others, 2000). A similar mechanism is interpreted to have occurred in Central Asia (Şengör and others, 1993; Berzin and Dobretsov, 1994; Berzin, 1995). Inherent to this interpretation is the correlation and original continuity of dispersed fragments (terranes) of once continuous island-arc systems and component parts and the determination of original and evolving position with respect to major cratons on the basis of paleomagnetic, paleobiogeographic, structural, and other data.

Second, a tectonic model must not only adequately describe the relative positions of components relative to one another and to the adjacent craton at different time spans, but also deduce the kinematics and reasons for major deformational events. The model that most closely meets these requirements is that proposed by Şengör and others (1993) and Şengör and Natal'in (1996) for the formation of orogenic

Table 1. Definitions of key terms for analysis of regional geology and metallogenesis.

[Adapted from Howell and others (1985), Jones and others (1983), Nokleberg and others (2000, 2005), or cited references.]

Term	Definition
Accretion	Tectonic juxtaposition of terranes to a craton or continental margin. Accretion of terranes to one another or to a cratonal margin also defines a major change in the tectonic evolution of terranes and cratonal margins.
Amalgamation	Tectonic juxtaposition of two or more terranes before accretion to a continental margin.
Collage	A series of linear island arcs or continental-margin arcs and tectonically-linked (companion) subduction zones, and (or) fore-arc and back-arc basins that formed in a major tectonic event during a relatively narrow geologic time span. A few collages consist of fragments of cratonal margin and cratonal terranes that were amalgamated before accretion to a continent.
Continent	A large section of continental crust surrounded by oceans on all sides, which consists, in its core, of one or more cratons framed by younger tectonic collages (accretionary and collisional orogenic belts).
Continental-margin arc terrane	Fragment of an igneous belt of coeval plutonic and volcanic rocks and associated sedimentary rocks that formed above a subduction zone dipping beneath a continent. Inferred to possess a sialic basement.
Craton	Chiefly regionally metamorphosed and deformed shield assemblages of Archean, Paleoproterozoic, and Mesoproterozoic sedimentary, volcanic, and plutonic rocks, and overlying platform successions of Paleoproterozoic, Paleozoic, and local Mesozoic and Cenozoic sedimentary and lesser volcanic rock.
Cratonal margin	Chiefly Neoproterozoic through Jurassic sedimentary rocks deposited on a continental shelf or slope. Consists mainly of platform successions. Locally has, or may have had an Archean and Early Proterozoic cratonal basement.
Cratonal terrane	Fragment of a craton.
Island-arc system	An island arc and tectonically linked subduction-zone terranes.
Island-arc terrane	Fragment of an igneous belt of plutonic rocks, coeval volcanic rocks, and associated sedimentary rocks that formed above an oceanic subduction zone. Inferred to possess a simatic basement.
Metallogenic belt	A geologic unit (area) that either contains or is favorable for a group of coeval and genetically-related, significant lode and placer deposit models. A metallogenic belt has the following characteristics: (1) is favorable for known or inferred mineral deposits of specific type or types; (2) may be irregular in shape and variable in size; (3) need not contain known deposits; and (4) is based on a geologic map as the primary source of information for delineation of areas that are favorable for specific deposit models. An essential part of the definition is that a belt is defined as the geologically-favorable area for a group of coeval and genetically-related mineral deposit models. This definition provides a predictive character for undiscovered deposits in each belt.
Metamorphic terrane	Fragment of a highly metamorphosed or deformed assemblage of sedimentary, volcanic, or plutonic rocks that cannot be assigned to a single tectonic environment because the original stratigraphy and structure are obscured. Includes intensely deformed structural melanges that contain intensely deformed fragments of two or more terranes.
Mine	A site where valuable minerals have been extracted.
Mineral deposit	A site where concentrations of potentially valuable minerals for which grade and tonnage estimates have been made. In this study, also used as a general term for any mineral deposit, mineral occurrence, or prospect.
Mineral occurrence	A site of potentially valuable minerals on which no visible exploration has occurred, or for which no grade and tonnage estimates have been made.

Table 1. Definitions of key terms for analysis of regional geology and metallogenesis.—Continued

[Adapted from Howell and others (1985), Jones and others (1983), Nokleberg and others (2000, 2005), or cited references.]

Term	Definition
Oceanic crust, seamount, and ophiolite terrane	Fragment of part or all of a suite of deep-marine sedimentary rocks, pillow basalt, gabbro, and ultramafic rocks (former eugeoclinal suite) that are interpreted as oceanic sedimentary and volcanic rocks and the upper mantle. Includes both inferred offshore oceanic and marginal ocean basin rocks, minor volcaniclastic rocks of magmatic-arc derivation, and major marine volcanic accumulations formed at a hotspot, fracture zone, or spreading axis.
Overlap Assemblage	A postaccretion unit of sedimentary or igneous rocks deposited on, or intruded into, two or more adjacent terranes.
Passive continental-margin terrane	Fragment of a craton (continental) margin.
Subduction-zone terrane	Fragment of a mildly to intensely deformed complex consisting of varying amounts of turbidite deposits, continental-margin rocks, oceanic crust and overlying units, and oceanic mantle. Units are interpreted to have formed during tectonic juxtaposition in a zone of major thrusting of one lithosphere plate beneath another, generally in zones of thrusting along the margin of a continent or an island arc. May include large fault-bounded fragments with a coherent stratigraphy. Many subduction-zone terranes contain fragments of oceanic crust and associated rocks that exhibit a complex structural history, occur in a major thrust zone, and possess blueschist-facies metamorphism.
Superterrane	A fault-bounded geologic entity or fragment that is characterized by a distinctive geologic history that differs markedly from that of adjacent terranes (Jones and others, 1983; Howell and others, 1985).
Tectonic collage	A series of linear island arcs or continental-margin arcs and tectonically-linked (companion) subduction zones, and (or) fore-arc and back-arc basins that formed in a major tectonic event during a relatively narrow geologic time span. The collages of igneous arcs and companion subduction-zone terranes have been successively accreted to the margins of major cratons. The ages of collages with subduction zone units are for time of active formation of a subduction zone, rather than the older range of units that comprise the subduction zone. A few collages consist of fragments of cratonal margin and cratonal terranes that were amalgamated before accretion to a continent. Approximate synonyms are tectonic belt, orogenic belt, and fold belt.
Tectonic linkage	A genetic relation of a continental-margin arc or an island arc with a companion accretionary wedge that formed in a subduction zone that was adjacent to and was underthrusting the arc.
Tectonostratigraphic terrane (terrane)	An aggregate of terranes that is interpreted to share either a similar stratigraphic kindred or affinity, or a common geologic history after accretion (Jones and others, 1983; Howell and others, 1985). An approximate synonym is composite terrane (Plafker and Berg, 1994).
Turbidite terrane	Fragment of a basin filled with deep-marine clastic deposits in either an orogenic fore-arc or back-arc setting. May include continental-slope and continental-rise turbidite deposits, and submarine-fan turbidite deposits deposited on oceanic crust. May include minor epiclastic and volcaniclastic deposits.

belts of Central Asia. Their model delineates an island arc that existed from the Neoproterozoic through the Middle Mesozoic and that extended latitudinally (present-day coordinates) for several thousand kilometers, roughly parallel to the southern margin of the North Asian craton and cratonal margin. Formation of orogenic belts is related to the east-westward (present-day coordinates) movement of the arc and consecutive accretion of its western fragments to the southern margin of the North Asian craton and cratonal margin. However, there is a major objection to this model. In Central Asia, no island-arc terranes and fossil active continental margins are recognized that existed from the Neoproterozoic through the Mesozoic, as is assumed by the model. On the contrary, island arcs of differing ages occur, including Late Riphean, Vendian-Early Cambrian, and Silurian-Mississippian. Our study shows that island arcs in each age group were independent island-arc systems that were successively accreted. Along with the island arcs are former active continental margins with ages of Vendian, late Paleozoic, late Paleozoic-Early Triassic, and Late Triassic-Early Cretaceous.

Third, as discussed by Şengör and others (1993) and Şengör and Natal'in (1996), large longitudianl strike-slip faulting played a decisive role in the formation of tectonic (orogenic belts) in Central Asia. The strike-slip nature of the largest faults of the Gorny Altay, East Sayan, and Sikhote-Alin regions was determined starting the 1960s (Kuznetsov, 1963; Berzin, 1967; Ivanov, 1972). Later, early Mesozoic, late Paleozoic, and Devonian strike-slip faults were recognized in the late Riphean through early Paleozoic orogenic belts of the Altay-Sayan region, with displacements of hundreds to even thousands of kilometers (Berzin, 1995; Buslov, 1998; Şengör and others, 1994; Vladimirov and others, 1996; Buslov and others, 2001). Evidence for large left-lateral strike-slip motions that define the structure of the Mongol-Okhotsk orogenic belt was published in several studies (Parfenov and others, 1992b; Yakubchuk and Edwards, 1999). The existence of longitudinal left-lateral strike-slip motions along the Mongol-Okhotsk orogenic belt, caused by the eastward (present-day coordinates) movement of Paleozoic orogenic belts, located to the east of the Mongol-Okhotsk belt, is supported by paleomagnetic data (Kravchinskiy and others, 2002a,b).

Utilization of Paleomagnetic Data

The proper use of paleomagnetic data for paleotectonic reconstructions is important. However, even the best of these data, obtained at the best national laboratories and evaluated by the main tests of paleomagnetic analysis, cannot be regarded as absolute. As an example, the paleomagnetic and paleobiogeographic data for Permian units in the central Mongol-Okhotsk orogenic belt differ greatly (Parfenov and others, 1999b, c). Other examples of discrepancies are given below.

Paleomagnetic data indicate that the North Asian craton rotated counter-clockwise in the Neoproterozoic and early Paleozoic and rotated clockwise and from the Silurian through the late Mesozoic (Pecherskiy and Didenko, 1995). (However, a recent hypothesis of only clockwise rotation of the craton, beginning in the Early Cambrian, was proposed by Kazanskiy (2002).) Accordingly, Silurian-Mesozoic left-lateral strike-slip faults and Neoproterozoic and early Paleozoic right-lateral strike slips are to have been active within the orogenic belts surrounding the craton. At the same time, based on geological data, prevailing right-lateral strike slips of early and middle Paleozoic age are reconstructed for the southern margin of the North Asian craton (Berzin, 2001). The inconsistency between the direction of the craton rotation and the kinematics of motions along the strike-slip faults may be only apparent, assuming that in the middle Paleozoic, the oceanic plate and the terranes moved in the same direction as did the North Asian craton, but at a higher rate. After the accretion, with reduced space, the rotation of the North Asian craton resulted in the transformation of dextral strike-slip faults into sinistral ones and in initiation of new left-lateral strike-slip faults.

Construction of Time Stages of Tectonic Model

In this study, the formation of major tectonic events is portrayed in a series of paleotectonic reconstructions that are compiled for a series of time spans from the Neoproterozoic through the Present. The reconstructions were started with the Present time stage and sequentially progressed to older ones in order to eliminate the effect of late deformations superposed on the older structures. The restoration of mutual positions of terranes prior to their motions along large longitudinal strike-slip faults was an important interpretation. For instance, reconstruction of the middle Paleozoic South Mongol-Khingan island-arc system in Central Asia is based on the assumption that the South Mongol collage (orogenic belt) represents a once single island arc that was subsequently duplexed by the left-lateral strike-slip faults.

Previous studies of the related Mesozoic and Cenozoic tectonics of Northeast Asia and the Circum-North Pacific include those of Parfenov and others (1999a,b), Nokleberg and others (2000, 2005), and Scotese and others (2001). These prior reconstructions were used in this study with additions and refinements for Northeast Asia. The global paleotectonic reconstructions of Scotese (1997) also were utilized.

Major Geologic and Tectonic Units of Northeast Asia

The major geologic and tectonic units of Northeast Asia (fig. 1) are cratons and cratonal margins; cratonal terranes and superterranes, tectonic collages, overlap and transform continental-margin arcs, island arcs, and pelagic and oceanic rocks (fig. 2). Detailed descriptions of geologic units were provided by Nokleberg and others (2000, 2004) and Parfenov and others (2004b). The abbreviations in parentheses in the following list are the same as those used on the summary geodynamics map (fig. 2); more detailed descriptions of map units are provided in appendix B. Two geologic ages are stated for each collage; one for the time of formation of the contained units and another for the time of accretion (formation) of the tectonic collage to another terrane, superterrane, or continent.

Major Cratons and Cratonal Margins

The backstop or core tectonic units for Northeast Asia (fig. 1) are six Archean and Proterozoic cratons and their cratonal margins.

(1) The North Asian craton (NAC), which consists of Archean and Proterozoic metamorphic basement and nondeformed, flat-laying platform cover consisting of late Precambrian, Paleozoic, and Mesozoic sedimentary and volcanic rocks.

(2) The Sino-Korean craton (SKC), which consists of several major Archean and Proterozoic metamorphic-basement terranes and later Paleozoic through Cenozoic overlap units.

(3) The Baikal-Patom cratonal margin (BP), which consists of a fault-bounded basin containing Riphean carbonates and terrigenous sedimentary rocks, and later Vendian and Cambrian sedimentary rocks that discordantly overlie a fragment of preRiphean basement of the North Asian craton.

(4) The East Angara cratonal margin (EA), which consists of late Riphean terrigenous carbonate sedimentary rocks (sandstone, siltstone, and mudstone with interlayered dolomite and limestone) that overlie a fragment of the North Asia craton.

(5) The South Taimyr cratonal margin (ST), which consists chiefly of a thick wedge of Ordovician through Jurassic cratonal margin and deep basin deposits.

(6) The Verkhoyansk (North Asian) cratonal margin (VR), which consists chiefly of a thick wedge of Devonian through Jurassic miogeoclinal deposits.

Cratonal Terranes and Superterranes

Three cratonal terranes occur along the margins of the North Asian and Sino-Korean cratons and are interpreted as rifted and reaccreted fragments of these cratons.

(1) The Gyenggi-Yeongnam terrane (GY) consists of two major Archean and Proterozoic basement-rock terranes. The terrane is interpreted as being a displaced fragment of the Sino-Korean craton, or possibly a fragment of the South China (Yangzi) craton.

(2) The Jiaonan cratonal terrane (JA) consists of a Paleoproterozoic major high pressure terrane that is interpreted as being a displaced fragment of the Sino-Korean craton.

(3) The Okhotsk terrane (OH) consists of Archean and Proterozoic gneiss and schist and early and middle Paleozoic miogeoclinal sedimentary rock. The terrane is interpreted as being a fragment of the North Asian craton and cratonal margin that was rifted in the Late Devonian or Early Carboniferous.

Along the margins of the North Asian and Sino-Korean cratons are several superterranes, which are interpreted as being rifted and reaccreted fragments of these cratons and others interpreted as having originally formed elsewhere.

The Proterozoic through Cambrian Argun-Idermeg superterrane (AR) consists of the Paleoproterozoic through late Paleozoic Argunsky and Idermeg, passive continental-margin terranes. This superterrane may be either exotic, with respect to the North Asian craton, or a rifted fragment of that craton.

The Proterozoic through Permian Bureya-Jiamusi superterrane (BJ) consists of a tectonic collage of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island-arc terranes. This superterrane is interpreted as being a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

The Proterozoic through Ordovician Kara superterrane (KR) consists of the late Neoproterozoic through Ordovician Kara continental-margin turbidite terrane. This superterrane is interpreted as being a rifted fragment of the North Asian craton that was reaccreted in the Jurassic.

The Archean through Jurassic Kolyma-Omolon superterrane (KOM) consists of a tectonic collage of cratonal, passive-continental-margin, island-arc, and ophiolite terranes. The cratonal and passive-continental core of this superterrane was rifted from the North Asian craton and cratonal margin in the Late Devonian or Early Carboniferous, and after subsequent building of overlying island arcs, reaccreted to the North Asian cratonal margin in the Late Jurassic with the formation of collisional granites of the Main and Northern granite belts.

The late Riphean and older Tuva-Mongolia superterrane (TM) consists of a series of Archean and Paleoproterozoic cratonal terranes (Gargan and Baydrag), the Sangilen passive continental-margin terrane, and the Muya metamorphic terrane. All of these terranes are interpreted as having been accreted together to form the backarc of the Baikal-Myra island arc, described below.

Tectonic Collages between North Asian and Sino-Korean Cratons

Between the North Asian and Sino-Korean cratons are a series of accreted tectonic collages composed primarily of Paleozoic island arcs and tectonically linked subduction zones. Most of these tectonic collages, which were successively accreted southward during closures of the Paleo-Asian and Solon Oceans, contain one or more island arcs and tectonically linked subduction zones. Because of these successive accretions, the collages are generally young southward; however, this pattern is locally disrupted because some tectonic collages, or parts them were interspersed by subsequent strike-slip faulting.

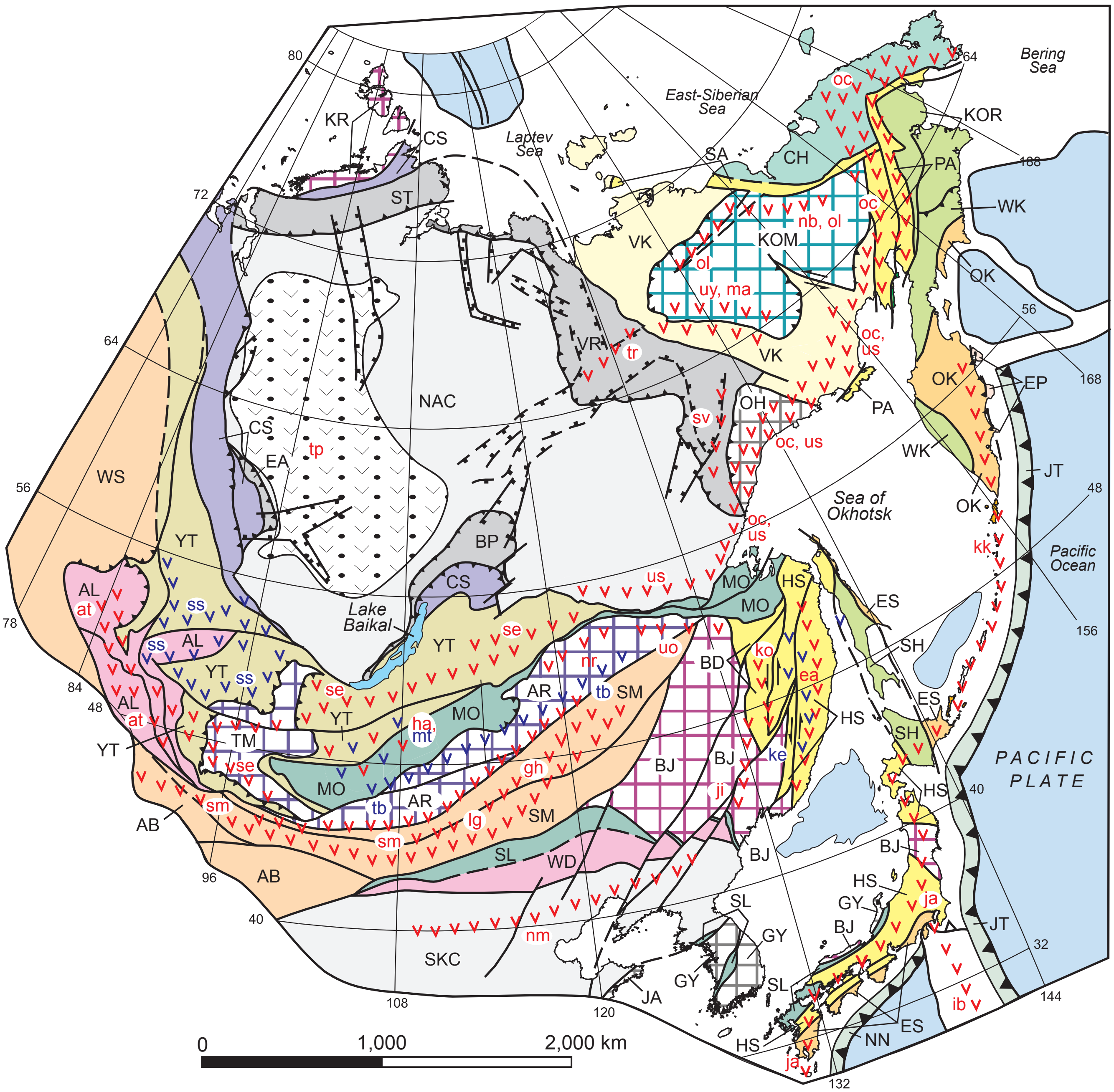


Figure 2. Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North Pacific tectono-stratigraphic terrane map at 10 million scale (Nokleberg and others, 1997). Map shows locations of major geologic and tectonic units including cratons; cratonal margins; cratonal terranes and superterranes; tectonic collages; overlap and transform continental-margin arcs; island arcs; and sea and ocean units. Refer to text for unit descriptions

EXPLANATION

Cratons and Cratonal Margins

Cratons: NAC - North Asian (Archean and Proterozoic); SKC - Sino-Korean (Archean and Proterozoic)

Cratonal Margin: BP - Baikal-Patom (Riphean through Cambrian and older basement; EA - East Angara (Riphean and older basement; ST - South Taimyr (Ordovician through Jurassic); VR - Verkhoyansk (Devonian through Jurassic).

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

AL - Altay (Vendian to Ordovician)
WD - Wundurmiao (Riphean through Ordovician)

AB - Atasbogd (Ordovician through Permian); SM - South Mongolia-Khingan (Ordovician through Carboniferous); WS - West Siberian (Ordovician through Carboniferous)

MO - Mongol-Okhotsk (Devonian through Late Jurassic); SL - Solon (Carboniferous and Permian)

Tectonic Collages Along the Northern and Eastern Margins of North Asian and Sino-Korean Cratons

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

BD - Badzhal (Triassic through Early Cretaceous); PA - Penzhina-Anadyr (Late Jurassic and Cretaceous); HS - Honshu-Sikhote-Alin (Jurassic and Early Cretaceous); SA - South Anyui (Permian through Jurassic);

KOR - Koryak (Late Jurassic through Paleocene; SH - Sakhalin-Hokkaido (Cretaceous); WK - West Kamchatka (Mid-Cretaceous through Early Tertiary)

ES - East Sakhalin (Late Cretaceous and Early Tertiary); OK - Olyutorka-Kamchatka (Late Cretaceous to Paleocene)

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

JT- Japan Trench (including Kuril-Kamchatka trench) (Miocene through Holocene; NN - Nankai (Miocene through Holocene)

Cratonal Terranes and Superterranes

Cratonal terranes (Archean and Proterozoic): GY - Gyeonggi-Yeongnam; JA - Jiaonan; OH - Okhotsk

Late Proterozoic and Cambrian superterranes: AR - Argun-Idermeg; TM - Tuva-Mongolia

Archean through Permian superterranes: BJ - Bureya-Jiamusi; KR - Kara

Jurassic Superterrane: KOM - Kolyma-Omolon (Archean through Jurassic)

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

at - Altay arc (Devonian and early Carboniferous, 381 to 290 Ma)
ea - East Sikhote-Alin arc (Late Cretaceous through early Tertiary, 96-65 Ma)
gh - Gobi-Khankaisk-Daxing'anling arc (Permian, 295 to 250 Ma)
ha - Hangay arc (Late Carboniferous and Early Permian, 320 to 272 Ma)
ji - Jihei arc (Permian, 295 to 250 Ma)
ko - Khingan arc (Early and mid-Cretaceous)
lg - Lugyngol arc (Permian and Triassic, 295 to 250 Ma)
ma - Main granite belt (Late Jurassic, 144 to 134 Ma)
nb - Northern granite belt (Early Cretaceous, 138 to 120 Ma)
nm - North Margin (Late Carboniferous and Permian, 320 to 272 Ma)
nr - Norovlin arc (Devonian and Early Carboniferous, 410 to 255 Ma)
oc - Okhotsk-Chukotka arc (Late Cretaceous and early Tertiary, 96 to 53 Ma)
ol - Oloy arc (Late Jurassic, 154 to135 Ma)
se - Selenga arc (Permian through Jurassic, 295 to135 Ma)
sm - South Mongolian arc (Carboniferous through Triassic, 320 to 203 Ma)
ss - South Siberian arc (Devonian)
sv - South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157 to 93 Ma)
tr - Transverse granite belt (Early Cretaceous, 134 to 124 Ma)
uo - Umlekan-Ogodzhin arc (Cretaceous, 135 to 65 Ma)
us - Uda-Murgal and Stanovoy arc (Jurassic and Early Cretaceous, 203 to 96 Ma)
uy - Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154 to 120 Ma)

Plume-Related Igneous Province

tp - Tungus Plateau igneous province - (Late Permian and Early Triassic, 245 Ma)

Active Arcs

ib - Izu-Bonin (late Cenozoic, 20 to 0 Ma)
ja - Japan (late Cenozoic, 23 to 0 Ma)
kk - Kuril-Kamchatka (late Cenozoic, 11 to 0 Ma)

Transpressional Arcs

ke - Kema (Mid-Cretaceous)
mt - Mongol-Transbaikal (Late Triassic through Early Cretaceous, 230 to 96 Ma)
ss - South Siberian (Early Devonian, 415 to 400 Ma)
tb - Transbaikalian-Daxinganling (Middle Jurassic through Early Cretaceous,175 to 96 Ma)

Symbols, Faults, and Contacts

Overlap-continental-margin arc
Transform-continental-margin arc
Active subduction zone
Thrust
Strike-slip fault
Fault
Contact
Riphean aulacogen
Devonian aulacogen
Modern rift system (Gakkel Ridge)
os Metallogenic belt

Figure 2.—Continued.

(1) The Altai tectonic collage (AL; Vendian through Ordovician, accreted in the Late Silurian) consists of the Vendian through Early Ordovician Salair island-arc terrane and various fragments of arc-related turbidite terranes, subduction-zone terranes, metamorphic terranes derived from arc-related rocks, thick Cambrian and Ordovician overlap turbidites that formed on a continental slope and rise, and fragments of originally adjacent oceanic terranes. This tectonic collage is interpreted as being an island-arc system that was active near the southwestern margin (present-day coordinates) of the North Asian craton and previously accreted terranes.

(2) The Atasbogd tectonic collage (AB; Ordovician through Permian, accreted in the Late Carboniferous or Early Permian) consists of the Ordovician through Permian Waizunger-Baaran terrane, the Devonian and Carboniferous Beitianshan-Atasbogd terrane, and (3) the Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. This tectonic collage is interpreted as being a southwestard continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. This tectonic collage was initially separated from the North Asian craton by a large backarc basin.

(3) The Circum-Siberia tectonic collage (CS; Paleoproterozoic and Mesoproterozoic, accreted in the Neoproterozoic) consists of the Baikal-Muya island arc, the Near Yenisey Ridge island arc, and the Zavhan continental-margin arc, all of Neoproterozoic age, as well as small fragments of cratonal and metamorphic terranes of Archean and Proterozoic age. These three separate Neoproterozoic island-arc systems formed south (present-day coordinates) of the North Asian craton and cratonal margin.

(4) The Mongol-Okhotsk tectonic collage (MO; Devonian through Late Jurassic, accreted in the late Paleozoic through early Mesozoic) consists mainly of the Permian through Jurassic Selenga, the Late Carboniferous and Early Permian Hangay, and the Uda-Murgal and Stanovoy continental-margin arcs. These arcs are composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically linked, outboard subduction-zone terranes, and they overlap the southern margin of the North Asian craton and cratonal margin and previously accreted terranes. This tectonic collage is interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean with oblique subduction of terranes beneath the southern margin of the North Asian craton and previously accreted terranes.

(5) The Solon tectonic collage (SL; Carboniferous through Permian, accreted in the late Paleozoic through early Mesozoic) consists of the Carboniferous and Early Permian North Margin, the Late Carboniferous through Permian Solon, the Devonian Imjingang, the Paleozoic Ogcheon, and the Silurian through Permian Sangun-Hidagaien-Kurosegawa subduction-zone terranes. Parts of this tectonic collage are interpreted as being fragments of the Solon Ocean plate that were subducted to form the South Mongolian, Lugyngol, Gobi-Khankaisk-Daxing'anling, and Jihei continental-margin arcs, and other parts are interpreted as being fragments of the Solon Ocean plate that were subducted to form the North Margin continental-margin arc on the Sino-Korean craton.

(6) The South Mongolia-Khingan tectonic collage (SM; Ordovician through Carboniferous, accreted in the Late Carboniferous or Early Permian) consists of the South Mongolia-Khingan island-arc and tectonically linked subduction-zone terranes. This tectonic collage is interpreted as being a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. This tectonic collage was initially separated from the North Asian craton by a large backarc basin.

(7) The Wundurmiao tectonic collage (WD; Mesoproterozoic through Silurian, accreted in the Late Silurian) consists of the Late Ordovician and Silurian Laoling island-arc terrane, the Mesoproterozoic through Middle Ordovician Wundurmiao subduction-zone terrane, and the Neoproterozoic Seluohe subduction-zone terrane. The collage is interpreted as being the Laoling island-arc system that formed near the ino-Korean craton. Both the island-arc system and craton were widely separated from the North Asian craton in the early Paleozoic.

(8) The West Siberian tectonic collage (WS; Ordovician through Carboniferous, accreted in the Late Carboniferous or Early Permian) onsists of the Late Silurian through Early Carboniferous Rudny Altai island-arc and the tectonically linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. This tectonic collage is interpreted as being a northwest continuation (present-day coordinates) of the South Mongolia-Khingan tectonic collage.

(9) The Yenisey-Transbaikal tectonic collage (YT; Vendian through Devonian, accreted in the Vendian through Early Ordovician) consists of the Vendian through Middle Cambrian Kuznetsk-Tannuola and the Dzhida-Lake island-arc terranes, tectonically linked backarc basins, and now tectonically eroded subduction-zone terranes. This tectonic collage is interpreted as being a linear array of island-arc systems that formed south (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. The eastern part of the tectonic collage includes the West Stanovoy metamorphosed terrane, which may be a displaced fragment of the North Asian craton or of another craton.

Tectonic Collages East of the North Asian and Sino-Korean Cratons

East of the North Asian and Sino-Korean cratons are a series of tectonic collages that were successively accreted eastward during closures of parts of the ancestral and modern Pacific and older oceans in the region (fig. 1). Thus, these tectonic collages are generally younger toward the east; however, this pattern is locally disrupted because some of them were interspersed by subsequent strike-slip faulting. Except for the first two collages (Verkhoyansk-Kolyma and Chukotka) the others contain one or more island-arcs or continental-margin arcs and tectonically linked subduction-zone terranes.

(1) The Badzhal collage (BD, Triassic through Early Cretaceous; accreted in the Late Cretaceous) consists of the Umlekan continental-margin arc and tectonically linked subduction-zone terranes to the east with Tethyan fauna.

(2) The Chukotka tectonic collage (CH, Paleozoic and Triassic; accreted in the Late Jurassic and Early Cretaceous) consists of passive continental-margin terranes that formed along the long-lived Neoproterozoic through early Mesozoic North American continental margin. This collage is interpreted as having been accreted to the northern Verkhoyansk-Kolyma tectonic collage in the Late Cretaceous after subsequent rifting of the North American cratonal margin in the Late Jurassic and Early Cretaceous and subsequent translation.

(3) The East Kamchatka Peninsula tectonic collage (EP, mainly Paleocene, and accreted in the Pliocene) consists of the Kronotskiy island arc and associated ophiolite.

(4) The East Sakhalin collage (ES, Late Cretaceous through early Tertiary; accreted in the early Tertiary) consists of the Late Cretaceous through middle Eocene Terpeniy-Tokoro-Nemuro-Shmidt island-arc and tectonically linked subduction-zone terranes.

(5) The Honshu-Sikhote-Alin collage (HS, Jurassic and Early Cretaceous; accreted in the Cretaceous) consists of fragments of island-arc, continental-margin turbidite (flysch), and subduction-zone terranes. This collage is interpreted as having formed along a transform continental margin.

(6) The Koryak collage (KOR, Late Triassic through Cretaceous; accreted in Late Cretaceous) consists of the Late Jurassic and Early Cretaceous Manitskiy island-arc and tectonically linked subduction-zone terranes to the east.

(7) The Olyutorka-Kamchatka tectonic collage (OK, Late Cretaceous and Paleocene; accreted in the early Cenozoic) consists of the Olyutorka island-arc and tectonically linked subduction-zone terranes to the east.

(8) The Penzhina-Anadyr collage (PA, Late Jurassic and Early Cretaceous; accreted in the Late Cretaceous) consists of the Murgal island-arc terrane and tectonically linked subduction-zone terranes to the east. This collage rims the eastern Kolyma-Omolon superterrane and Verkhoyansk-Kolyma tectonic collage and is also linked to the Uda continental-margin arc.

(9) The South Anyui collage (SA, Permian through Early Jurassic; accreted in the Late Cretaceous) consists of the Oloy island-arc and tectonically linked subduction-zone terranes.

(10) The Sakhalin-Hokkaido collage (SK; Cretaceous; accreted in the Eocene) consists of the Late Cretaceous flysch terranes of Sakhalin and Hokkaido Islands, and tectonically linked subduction-zone terranes to the east. This collage is interpreted as being a continental-margin forearc basin and tectonically linked subduction-zone terranes that are associated with the East Sikhote-Alin continental-margin arc.

(11) The Verkhoyansk-Kolyma tectonic collage (VK, late Paleozoic through Early Jurassic age, accreted in the Late Jurassic and Early Cretaceous) consists of a deformed passive continental margin, accreted ophiolites, and subduction zone; it is interpreted as having formed during accretion of the outboard Kolyma-Omolon superterrane.

(12) The West Kamchatka tectonic collage (WK; mid-Cretaceous through early Tertiary; accreted in the early Cenozoic), which consists of late Paleozoic through Cretaceous subduction-zone terranes in the Russian Northeast. This collage was tectonically linked to the Okhotsk-Chukotka continental-margin arc.

Carboniferous and Permian Continental-Margin Arcs Occurring South of the North Asian Craton and on the Sino-Korean Craton

Several major continental-margin arcs occur on previously accreted terranes south of the North Asian craton and on the Sino-Korean craton. These arcs are interpreted as related to subduction of the late Paleozoic and early Mesozoic Solon Ocean plate beneath the North Asian and Sino-Korean cratons. The Solon Ocean lay between the Argun-Idermeg superterrane to the north (present-day coordinates) and the Sino-Korean craton to the south.

(1) The Altay continental-margin arc (at; Devonian and early Carboniferous) occurs on the Altay and Yenisey-Transbaikal collages. This arc is interpreted as having formed along an active continental margin in an oblique subduction-zone environment.

(2) The Gobi-Khankaisk-Daxing'anling continental-margin arc (gh; Permian) which occurs on the Argun-Idermeg superterrane, South Mongolian and Solon collages. The arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane.

(3) The Jihei continental-margin arc (ji; Permian) occurs on the South Mongolia-Khingan collage and intrudes the Bureya-Jiamusi superterrane and South Mongolia-Khingan collage, is interpreted as having formed during subduction of the northern part of the Solon Ocean plate under the southern margin (present-day coordinates) of the Bureya-Jiamusi superterrane and adjacent units.

(4) The Lugyngol continental-margin arc (lg; Permian) occurs on the South Mongolian and Solon collages. This arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane.

(5) The North Margin continental-margin arc (nn; Late Carboniferous through Permian) occurs on the northeastern margin (present-day coordinates) of the Sino-Korean craton. This arc is interpreted as having formed during subduction of

the southern (present-day coordinates) part of Solon Ocean plate under the northeastern margin of the Sino-Korean craton.

(6) The South Mongolian continental-margin arc (sm; middle Carboniferous through Triassic) overlies and intrudes the South Mongolian and Atasbogd collages. This arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the Argun-Idermeg superterrane.

Devonian through Early Cretaceous Continental-Margin Arcs Occurring along the Southeastern Margin of the North Asian Craton and Adjacent Accreted Terranes

Several major continental-margin arcs occur along the southeastern margin of the North Asian craton, or on adjacent accreted terranes. These arcs are interpreted as related to subduction of the late Paleozoic and early Mesozoic Mongol-Okhotsk Ocean plate beneath the North Asian craton and cratonal margin. The Mongol-Okhotsk Ocean lay between the North Asian craton to the north and the Argun-Idermeg superterrane to the south (present-day coordinates).

(1) The Hangay continental-margin arc (ha; Late Carboniferous through Early Permian occurs on the Yenisey-Transbaikal collage and Mongol-Okhotsk collage. This arc is interpreted as having formed during subduction of the northern part of Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously accreted terranes.

(2) The Norovlin continental-margin arc (nr; Devonian through Early Carboniferous) occurs on the Argun-Idermeg superterrane (Amur microcontinent-Argunsky and Idermeg passive continental-margin terranes). This arc is interpreted as having formed during subduction of the Mongol-Okhotsk Ocean plate beneath northern margin (present-day coordinates) of the Argun-Idemeg superterrane (Amur microcontinent).

(3) The Selenga continental-margin arc (se; Permian through Jurassic) overlies and intrudes the Yenisey-Transbaikal collage and Tuva-Mongolia superterrane. This arc is interpreted as having formed during oblique subduction of the Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously accreted terranes.

(4) The Uda-Murgal and Stanovoy continental-margin arcs (us; Jurassic and Early Cretaceous) occur on the southern margin of the North Asian craton. These arcs are interpreted as having formed during final stage of subduction of the Mongol-Okhotsk Ocean plate.

Jurassic through Early Cretaceous Island Arcs Occurring on or Adjacent to Kolyma-Omolon Superterrane

Two major island arcs occur along the margin of the Kolyma-Omolon superterrane.

(1) The Oloy island arc (ol; Late Jurassic) is interpreted as having formed on the Kolyma-Omolon superterrane during subduction of the South Anyui Ocean plate beneath this superterrane to form the South Anyui subduction-zone terrane. The South Anyui ocean formed north (present-day coordinates) of the Kolyma-Omolon superterrane.

(2) The Uyandina-Yasachnaya island arc (uy; Late Jurassic and Early Cretaceous) is interpreted as having formed during subduction of the Oimyakon Ocean plate between the North Asian cratonal margin and the Kolyma-Omolon superterrane. Remnants of Oimyakon oceanic crust are preserved in small obducted ophiolites along the western margin of the superterrane. This Oimyakon Ocean lay between the Verkhoyansk (North Asian) cratonal margin to the southwest (present-day coordinates) and the Kolyma-Omolon to the northeast.

Jurassic through Early Tertiary Continental-Margin Arcs and Granite Belts Occurring along the Eastern Margin of Northern Asia

A series of Jurassic through early Tertiary continental-margin arcs and granite belts occur along the eastern margin of the North Asian and Sino-Korean cratons and outboard accreted terranes to the east.

(1) The East Sikhote-Alin continental-margin arc (ea; Late Cretaceous through early Tertiary) occurs along the margin of southern Russian Far East. This arc is interpreted as having formed during subduction of the ancestral Pacific Ocean plate with formation of the older part of the Hidaka, the younger part of the Aniva terrane, and the Nabilsky and Tokoro subduction-zone terranes.

(2) The Khingan-Okhotsk continental-margin arc (ko; Early and mid-Cretaceous) occurs in the Russian Southeast and consists of the Khingan-Okhotsk volcanic-plutonic belt. This arc was tectonically paired to the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes (part of the Honshu-Sikhote-Alin collage).

(3) The Main granite belt (ma; Late Jurassic) occurs along the adjacent margins of the North Asian cratonal margin and Kolyma-Omolon superterrane. This belt is interpreted as having formed during and immediately after collision of the Kolyma-Omolon superterrane with the North-Asian cratonal margin.

(4) The Northern granite belt (nb; Early Cretaceous, 120 to 138 Ma) occurs along the northwestern margin of the Kolyma-Omolon superterrane. The belt is interpreted as having formed during the subduction of oceanic crust in a closure of a small oceanic basin during the late stage of accretion of the Kolyma-Omolon superterrane.

(5) The Okhotsk-Chukotka continental-margin arc (oc; Late Cretaceous through early Tertiary) occurs along the eastern margin of the central and northern Russian Far East. This arc is interpreted as having formed during subduction of

the ancestral Pacific Ocean plate with formation of the West Kamchatka, Ekonay, and Yanranay subduction-zone terranes.

(6) The South Verkhoyansk granite belt (sv; Late Jurassis through mid-Cretaceous) occurs in central Russian Far East. This belt, which extends longitudinally along the central part of the South Verkhoyansk synclinorium in the Verkoyansk (North Asian) cratonal margin, is interpreted as having formed during the accretion of the outboard Okhotsk terrane.

(7) The Transverse granite belt (tv; Early Cretaceous) radiates outwards from the southwestern bend in the Kolyma-Omolon superterrane. This belt is interpreted as having formed during the late stage of accretion of the Kolyma-Omolon superterrane.

(8) The Umlekan-Ogodzhin continental-margin arc (uo; Jurassic and Cretaceous occurs along the margin of the Kolyma-Omkolon superterrane. This arc is interpreted as having formed during subduction of the ancestral Pacific Ocean plate to form the Badzhal and Nadanhada terranes (parts of the Badzhal collage).

Active Continental-Margin Arcs along the Eastern Margin of Northern Asia

Three active continental-margin arcs occur along the eastern margin of the North Asian and Sino-Korean cratons and outboard accreted terranes to the east.

(1) The Izu-Bonin continental-margin arc (ib; Miocene through Holocene) occurs south of southern Japan and consists of a volcanic arc composed chiefly of basalt to rhyolite, associated volcaniclastic rock, and intercalated hemipelagic mudstone. This arc is interpreted as having formed from subduction of the Philippine Sea Plate with the creation of the Nankai subduction zone.

(2) The Japan continental-margin arc (ja; Miocene through Holocene) occurs along the Japan Islands and consists of extensive Quaternary volcanic and associated rocks. This arc is interpreted as having formed during subduction of the Pacific Ocean and Philippine Sea Plates with formation of the Japan Trench and the Nankai subduction zones.

(3) The Kuril-Kamchatka continental-margin arc (kk; Miocene through Holocene) occurs along the Kamchatka Peninsula and the Kuril Islands and consists of the Pliocene to Quaternary Central Kamchatka volcanic belt, central Kamchatka volcanic and sedimentary basin, and the East Kamchatka volcanic belt. This arc is interpreted as having formed during subduction of the Pacific Ocean Plate with the creation of the Japan Trench subduction zone.

Transpressional Arcs—Devonian through Early Cretaceous

Four major transpressional arcs occur along the margins of the North Asian craton and previously accreted terranes to the south. These arcs are associated with a combination of strike-slip faulting and local compression and extension.

(1) The Kema arc (ke) (Mid-Cretaceous) occurs in the Russian Southeast and consists of the Kema island-arc terrane, and the Late Jurassic and Early Cretaceous Zhuravlevsk-Amur River continental-margin turbidite terrane. The arc is part of the Honshu-Sikhote-Alin collage (Jurassic and Early Cretaceous) described above. The Zhuravlevsk-Amur River continental-margin turbidite terrane and the companion Kema arc terranes are interpreted as having formed along a Late Jurassic and Early Cretaceous continental-margin transform fault.

(2) The Mongol-Transbaikal arc (mt) (Late Triassic through Early Cretaceous, 230 to 96 Ma) occurs in northern Mongolia and southern Transbaikal regions. The arc is preserved in the Late Triassic through Early Cretaceous Mongol-Transbaikal region volcanic-plutonic belt (mt) that consists of volcanic rocks in separate major basins and is composed of trachyandesite, dacite, and trachyrhyolite flows, stocks, necks, and extrusive domes. The arc also includes coeval granite plutons composed of granodiorite, alkaline gabbro-granite, granite, leucogranite, and Li-F granite. The arc is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean. The arc is also referred to as the North Gobi arc.

(3) The South Siberian arc (ss) (Early Devonian, 400 to 415 Ma) occurs in the Eastern Altai-Sayan region and consists of the South Siberian volcanic-plutonic belt. Volcanic rocks are composed of bimodal mafic and siliceous volcanic rock including andesite, olivine basalt, trachybasalt, essexite, phonolite, alkaline trachyte, trachyandesite, and trachyrhyolite. Plutonic rocks are composed of subalkaline to alkaline gabbro to granite, alkaline-syenite, granosyenite, leucogranite, and latite-bearing subalkaline gabbro, monzonite, and syenogranite. The arc is interpreted as having formed along the southern margin of the North Asian craton and cratonal margin during Early Devonian rifting that successively evolved into a continental-margin transpressive-fault margin and into a convergent margin.

(4) The Trans-Baikal-Daxinganling arc (tb) (Middle Jurassic through Early Cretaceous, 175 to 96 Ma) occurs in the Transbaikal region, Mongolia, Northeastern China, and consists of the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt. Volcanic rocks are composed of shoshonite, latite, trachyte, trachyandesite, trachybasalt, trachyrhyolite, shoshonite, latite subalkaline basalt, and basalt andesite. Plutonic rocks are composed of large calc-alkaline to subalkaline plutons of granite, leucogranite, quartz syenite, quartz monzonite, granodiorite, and biotite-amphibole diorite, and small calc-alkaline subvolcanic bodies of dacite and rhyolite. The arc is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.

Riphean (1000 to 650 Ma) (Early and Middle Neoproterozoic) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

Cratons, Passive Continental-Margin, and Cratonal Terranes

The major tectonic events in the Neoproterozoic for cratons, passive continental margins, and cratonal terranes (fig. 3) were as follows.

(1) Passive continental margins formed on the submerged margins of the North-Asian craton, including the East Angara (EA), Baikal-Patom (BP), and Verkhoyansk (VK) cratonal margins. In addition, passive continental margins formed on the Argun-Idermeg superterrane (Argunsky, Central Angara, Idermeg, West Angara passive continental-margin terranes).

(2) Widespread intracontinental rifting was initiated along these passive continental margins.

(3) Platform cover accumulated onto the inner parts of the North Asian craton.

(4) Shallow-water marine sediments accumulated on the Sino-Korean craton.

(5) Several major island-arc systems and tectonically-linked subduction zones formed offshore or far away from the North Asian craton, including the Near-Yenisey, Baikal-Muya, and Zavhan magmatic arcs.

Near-Yenisey Island Arc

Remnants of the Late Proterozoic Near-Yenisey arc are part of the Circum-Siberia collage (figs. 2, 3), that was accreted in the Neoproterozoic. The major units in the arc are the Isakov (IS) and Predivinsk (PR) island-arc terranes (Kuzmichev and others, 2001; Vernikovskiy, 1996, Vernikovskiy and Vernikovskaya, 2001). The terranes are overthrust eastwards onto the East Angara (EA) passive continental-margin terrane and older units of the North Asian craton. The polarity of the subduction zone based on the structural position of the ophiolite-clastic melange is interpreted as dipping oceanward, away from continent (fig. 3). The age of the arc is still a question. Dating of island-arc plagiogranites and volcanic units has yielded ages ranging from 630 to 700 Ma (Vernikovskiy and Vernikovskaya, 2001). The Isakov terrane is unconformably overlapped by the Neoproterozoic through Vendian sediments of the Vorogovka-Chapa basin.

Baikal-Muya Island Arc

Remnants of the Neoproterozoic Baikal-Muya arc are part of the Circum-Siberia collage that was accreted in the Late Neoproterozoic (figs. 2, 3). The arc is preserved in the Baikal-Muya (BM) and Sarkhoy (SR) terranes in the Transbaikal region and northern Mongolia (Berzin and Dobretsov, 1994; Konnikov and others, 1994; Kuzmichev and others, 2001; Obolenskiy and others, 1999). Remnants of the arc are unconformably overlapped by Vendian-Cambrian rocks of the Upper Angara Basin and Huvsgol-Bokson overlap assemblage.

Tectonically paired to the Baikal-Muya island arc was a subduction zone that is now preserved in the Hug (HU) and Olokit-Delunuran subduction-zone (OD) terranes (fig. 2). The position of subduction-zone terranes relative to the island-arc igneous-rock units, and the lack of subduction units along the periphery of the Baikal-Patom passive continental margin suggest that the subduction zone dipped to the southeast under the island arc (fig. 3) (Berzin and Dobretsov, 1994). Strike-slip faulting occurred between the Baikal-Muya and Near-Yenisey arcs along the Main Sayan strike-slip fault (fig. 3). The arc is associated with back-arc, forearc, rift, and mélange units in the Kuvai terrane (KUV). The terrane is unconformably overlapped by the Vendian through Cambrian sediments of the Mana Basin.

Zavhan Magmatic Arc

A fragment of the Late Proterozoic Zavhan magmatic arc occurs in Central Mongolia in the Zavhan (ZA) active continental-margin terrane (Tomurtogoo, 1989) that is also a part of the Circum-Siberia collage (figs. 2, 3) that was accreted in the Neoproterozoic. The initial relation of the magmatic arc to the adjacent Baydrag (BY) cratonal terrane is unknown. The Zavhan and Baydrag terranes are unconformably overlapped by the latest Neoproterozoic through Middle Cambrian Huvsgol-Bokson sedimentary assemblage. The subduction zone was southwest of the magmatic arc. Alpine-type ultramafic and associated units in the Tasuul terrane form part of a subduction-zone assemblage that was obducted onto the western margin of the Zavhan terrane (Tomurtogoo, 1989). The western and eastern ends of the magmatic arc occurred along dextral shear zones that were subparallel to the continental margin (fig. 3).

Important Geologic Details

(1) The Upper Riphean island arcs, now preserved in the Taimyr, Enisey Ridge, East Sayan, and North Transbaikal regions, are associated with ophiolites and boninites, indicating formation of the island arcs on oceanic crust (Dobretsov and others, 1995; Kuzmichev and others, 2001; Vernikovsky andVernikovskaya, 2001). The island-arc formations are dated by isotopic methods at 730 to 740 Ma (Taimyr), 670 Ma

(Enisey Ridge), and 770 to 920 Ma (North Transbaikal region) (Konnikov and others, 1994; Izokh and others, 1998). Paleomagnetic data are absent, so positions of the arcs with respect to the continent are not defined. The polarity of the arcs is also unknown in most cases.

(2) A characteristic element of the Late Riphean Circum-Siberian collage is the occurrence of relatively small (tens of kilometers across) cratonal terranes composed of Early Precambrian crystalline rocks (Muya terrane in the North Transbaikal region, Gargan and Kan terranes in East Sayan, and Mamontovskiy and Faddeevskiy terranes in Taimyr). These terranes are interpreted as being fragments of the North Asian craton that were detached during the break-up of the Rodinia supercontinent.

(3) Data are limited for the Upper Riphean sediments on the eastern margin of the North Asian craton**.** Present knowledge of the Paleozoic evolution of this margin (Parfenov, 1984) indicates that the Okhotsk and Omolon cratonal terranes and the Prikolyma miogeoclinal terrane were part of the North Asian craton in the Late Riphean. A higher rate of sedimentation in the Late Riphean, the occurrence of highly alkaline basalts in the Upper Riphean rocks in some regions (Prikolyma and Omolon terranes), and occurrence of ultramafic plutons dated at 673 to 752 Ma (Biryukov, 1997) near the cratonal margin suggests rifting.

(4) Accretion of the Late Riphean island arcs to the North Asian craton and accretion of the Late Riphean Circum-Siberian collage occurred in the Late Riphean. Vendian and Cambrian sedimentary units, similar to coeval rocks of the Siberian platform, but much thicker and more marine in nature, overlie, with a sharp unconformity, the Upper Riphean island-arc formations.

(5) In the Central Taimyr superterrane, Zonenshain and others (1990) compare Upper Riphean island-arc formations of this unit with similar formations of the Polar Urals and the basement of the Pechora basin and interpreted an exotic origin. They believed that the Central Taimyr superterrane with Upper Riphean island-arc formations and the more northerly Kara terrane amalgamated in the late Paleozoic, and then were jointly accreted to the North Asian craton in the late Late Jurassic. Positions of the Upper Riphean island-arc formations of Taimyr are similar to those of analogous framing formations of the Enisey Ridge, East Sayan, and the North Transbaikal region, thereby implying a North Asian origin (Khain and others, 2001; Khain and others, 1997).

(6) The northern margin of the Sino-Korean craton is remarkably rectilinear. The Early Paleozoic Wenduermiao orogenic belt adjacent to the craton contains Late Precambrian ophiolites associated with metamorphic schist (Hu Xiao and Niu Shuying, 1986; Chen Qi, 1992; Li, 1996. The boundary of the craton was probably a transform fault.

(7) After the break-up of the Rodinia supercontinent in the Late Riphean, the Sino-Korean and North Asian cratons were relatively close (Scotese, 1997). During the Cambrian through Ordovician, the two cratons migrated apart (Lee and others, 1997). The Sino-Korean craton remained close to the eastern margin of East Gondwana during the entire early Paleozoic, and opening of the ocean was mainly caused by the movement of the North Asian craton away from Gondwana.

Riphean Metallogenesis

Metallogenic Belts Related to Sedimentary Basins formed on Cratonal Margins

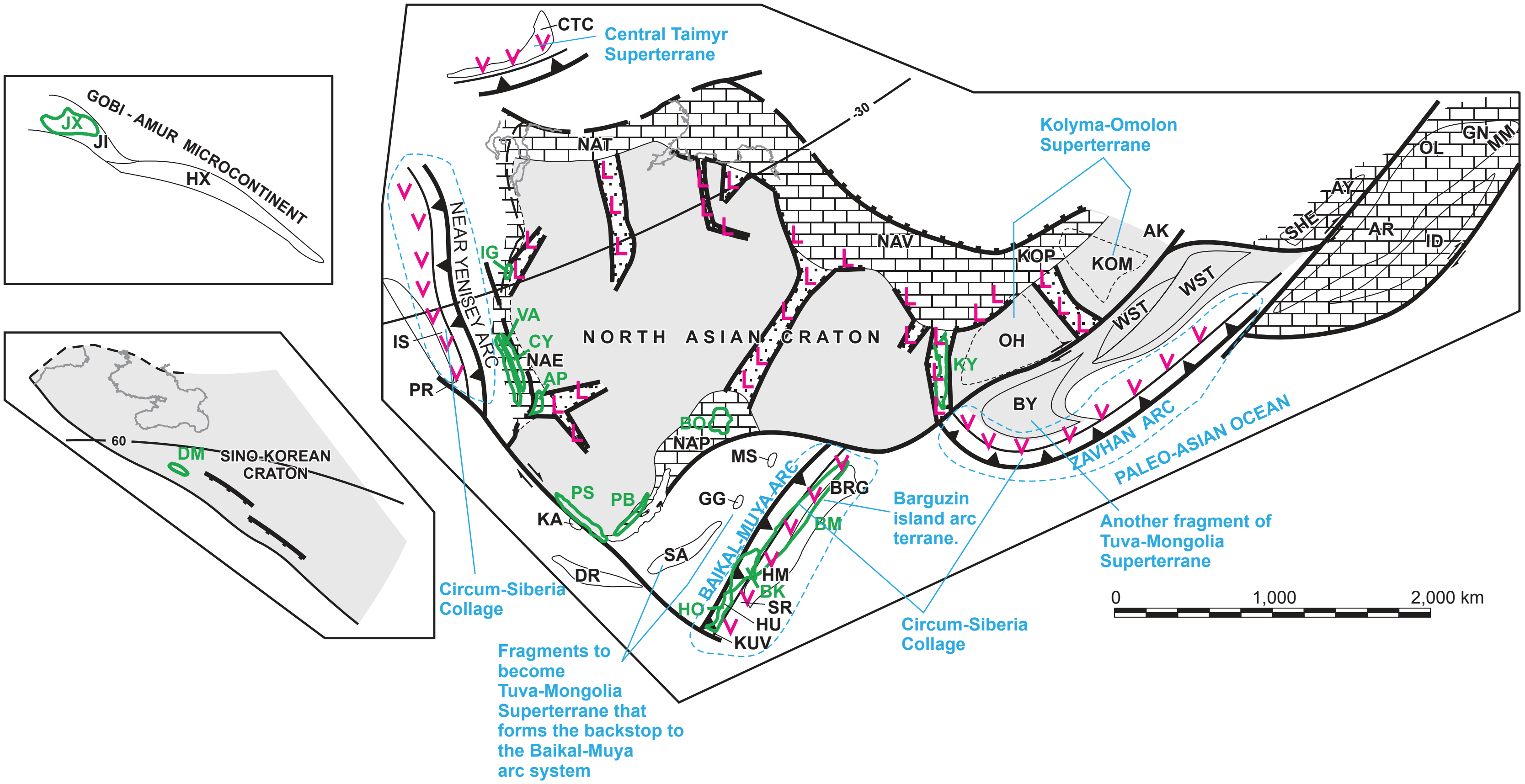
Several metallogenic belts possess geologic units favorable for major stratiform sediment-hosted deposits, including the Angara-Pit belt (with sedimentary siderite Fe and volcanogenic-sedimentary Fe deposits), Bodaibinskiy and Central-Yenisei belts (with Au in black shale deposits), Jixi belt (with banded iron formation--BIF, Algoma Fe deposits), Kyllakh and Pribaikalskiy belts (with carbonate-hosted Pb-Zn deposits), and Vorogovsko-Angarsk belt [with sedimentary exhalative Pb-Zn (SEDEX), and carbonate-hosted Pb-Zn [Mississippi valley type) deposits]. Where known, the fossil or isotopic ages of host rocks or deposits range from Riphean through Vendian. These deposits are hosted either in sedimentary units on the North Asian cratonal margin (Angara-Pit, Bodaibinskiy, and Kyllakh belts), or in sedimentary basins deposited on passive continental-margin terranes that were possibly derived from the cratonal margin (Central-Yenisei and Vorogovsko-Angarsk belts). These favorable geologic units and deposits are interpreted as having formed during sedimentation on continental shelves, or during rifting of a continental shelf.

Metallogenic Belts Related to Island Arcs

Several metallogenic belts possess geologic units favorable for major volcanic-hosted and/or granite-hosted deposits, including the Baikalo-Muiskiy belt [with volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn deposits) and the Lake belt (with volcanogenic Cu-Zn massive sulfide (Urals type), volcanogenic-sedimentary Fe, Cu-skarn, Fe-skarn, granitoid-related Au-vein, mafic-ultramafic related Cu-Ni-PGE, podiform Cr, mafic-ultramafic related Ti-Fe deposits]. These favorable geologic environments were in island-arcs or on sea floors underlying the arcs in the Baikal-Muya island-arc terrane (part of the Circum-Siberia collage), the Lake island-arc terrane (part of the Yenisey-Transbaikal collage), and island-arc terranes in the Tuva-Mongolia superterrane.

Metallogenic Belts Related to Terrane Accretion

Several metallogenic belts possess geologic units favorable for Au in shear-zone and quartz-vein deposits, including the Bokson-Kitoiskiy (with sedimentary bauxite deposits) and Central-Yenisei belts that are hosted in either the western North Asian craton or the Yenisey-Transbaikal and Circum Siberia collages. These favorable geologic environments consisted of regional metamorphism and hydrothermal



GEOLOGIC UNITS

AK - Avekov terrane
AR - Argunsky terrane
AY - Ayansk terrane
BRG - Barguzin terrane
BY - Baydrag terrane
CTC - Chelyuskin terrane
DR - Derba terrane
GG - Gargan terrane
GN - Gonzha terrane
HM - Hamar-Davaa terrane
HX - Hutaguul-Xilinhot terrane
HU - Hug terrane
ID - Idermeg terrane
IS - Isakov terrane
JI - Jiamusi terrane
KA - Kan terrane
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KUV - Kuvai terrane
MM - Mamyn terrane
MS - Muya terrane
NAE - North Asian Craton Margin (East Angara fold and thrust belt
NAP - North Asian Craton Margin (Patom-Baikal fold and thrust belt
NAT - North Asian Craton Margin (South-Taimyr fold belt
NAV - North Asian Craton Margin (Verkhoyansk fold and thrust belt
OH - Okhotsk terrane
OL - Oldoy terrane
PR - Predivinsk terrane
SA - Sangilen terrane
SHE - Shevli terrane
SR - Sarkhoy terrane
WST - West Stanovoy terrane

METALLOGENIC BELTS

AP - Angara-Pit
BK - Bokson-Kitoiskiy
BM - Baikalo-Muiskiy
BO - Bodaibinskiy
CY - Central-Yenisei
DM - Damiao
HO - Hovsgol
IG - Igarsk
JX - Jixi
KY - Kyllakh
PB - Pribaikalskiy
PS - Prisayanskiy
VA - Vorogovsko-Angarsk

Figure 3. Neoproterozoic (850 Ma) time stage of tectonic and metallogenic model and explanation. See text for explanation of tectonic events and origins of major metallogenic belts.

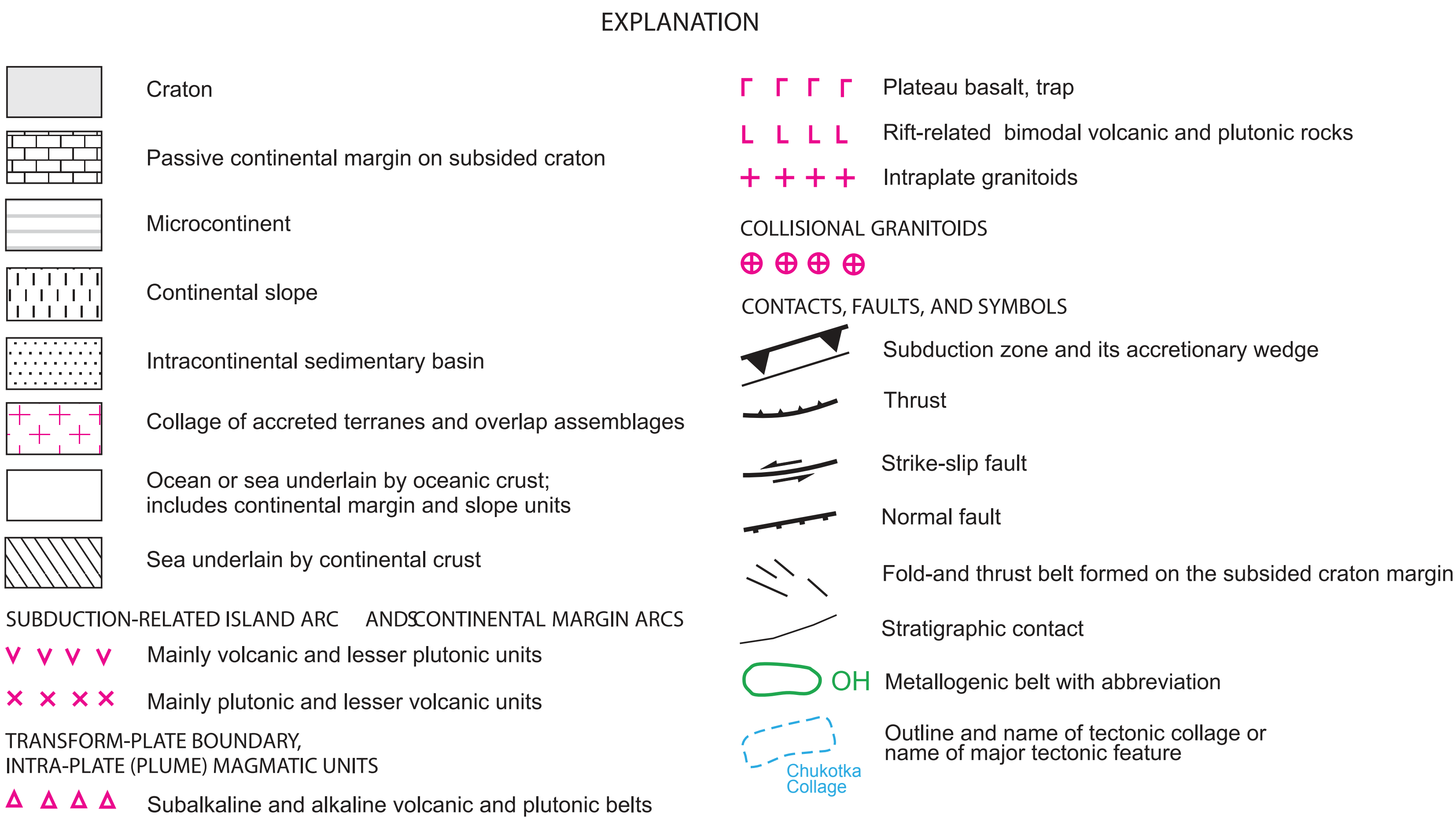


Figure 3.—Continued.

alteration that were associated with accretion of terranes to the North Asian cratonal margin. The Bokson-Kitoiskiy metallogenic belt also contains serpentine-hosted asbestos deposits that are interpreted as having formed in the same tectonic environment. The Prisayanskiy belt is hosted in terranes derived from the North Asian craton and contains REE carbonatite and mafic-ultramafic related Ti-Fe deposits that are interpreted as having formed in Neoproterozoic magmatic events. The Jixi metallogenic belt contains minor Homestake Au deposits for which the tectonic origin is unclear.

Vendian (Neoproterozoic III) through Early Cambrian (650 to 520 Ma) Stage of Tectonic Model

Major Tectonic Events

The major tectonic events in the Vendian through Early Cambrian (figs. 2, 4) were as follows.

(1) Completion of Neoproterozoic accretion of several major island-arc systems and tectonically-linked subduction zones onto the North Asian craton, including the Near-Yenisey, Baikal-Muya, and Zavhan magmatic arcs.

(2) Formation of new island-arc systems, including the Salair, Kuznetsk-Tannuola and Dzhida-Lake arcs and tectonically-linked subduction zones. The island arcs consist mainly of Vendian ophiolites and Vendian through Early and Middle Cambrian igneous rock-units. The Salair arc also includes Late Cambrian and early Early Ordovician igneous rock-units. These Late Neoproterozoic through Early Cambrian magmatic arcs formed a sublatitudinal system that extended along the northern border of the Siberian continent (ancient coordinates) (fig. 2) and according to paleomagnetic data, was close to the equator (Berzin and Kungurtsev, 1996; Kazanskiy, 2002; Kungurtsev and others, 2001).

(3) Associated with these arcs was subduction of the Paleo-Asian ocean plate to form the Alambai (AL), Amil (AI), Borus (BS), Dzhebash (DZE), Ih Bogd (IB), Kurtushiba (KRT), and Teletsk (TL) oceanic and subduction-zone terranes (figs. 2, 4). Behind the island arcs were the Minusa-Tuva and the Transbaikal marginal seas that are interpreted as the fragments of an oceanic plate separated by island arcs. The most intense island-arc activity occurred in the Early Cambrian and the beginning of the Middle Cambrian.

(4) Passive continental margins formed on the submerged margins of the North-Asian craton (East Angara, Baikal-Patom, South Taimyr and Verkhoyansk fold-and-thrust belts).

(5) Intracontinental rifting formed on the eastern part of the North Asian craton (Omolon and Kharaulakh rifts). On the western North Asian craton occurred a shallow-water basin filled with lagoonal sediments with evaporites, while in the east there was a deep-water basin accumulating black shales. The basins were separated by the Anabar-Sinsk barrier reef, one of the largest worldwide.

Major Units

Dzhida-Lake Island Arc

Remnants of the Dzhida-Lake island arc are preserved in the Yenisey-Transbaikal collage (figs. 2, 4). This collage has an age range of Vendian through Devonian and a timing of accretion of Vendian through Early Ordovician. The collage occurs in Transbaikalia, Northern and Central Mongolia. The collage includes the Lake, Eravna, Orkhon-Ikatsky, and Dzhida terranes that are separated by dextral strike-slip faults that have resulted in major modification of original positions (compare figures 3 and 4).

Kuznetsk-Tannuola Island Arc

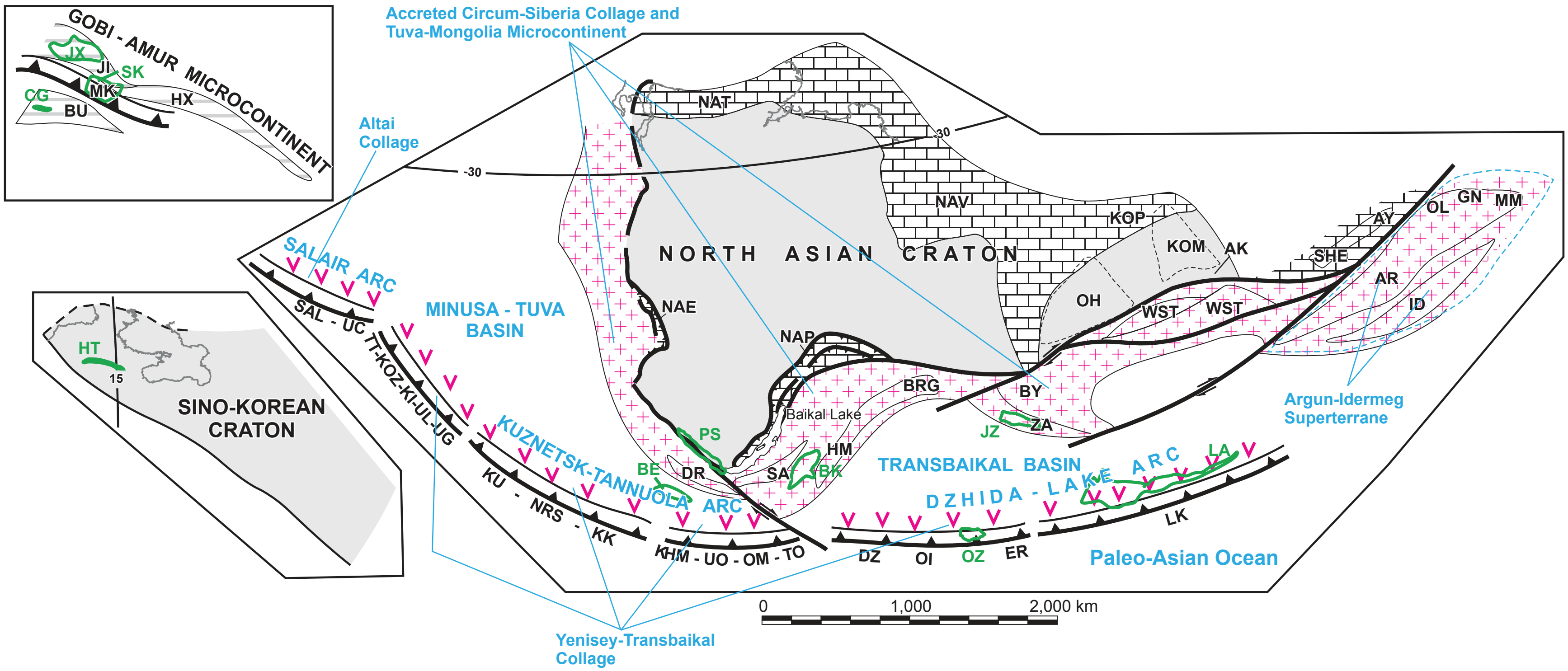
Remnants of the Kuznetsk-Tannuola island arc occur in a Z-shaped belt that is part of the Yenisey-Transbaikal collage (figs. 2, 4). The arc consists of the Telbes-Kitat (TT), Uimen-Lebed (UL), North Sayan (NRS), Khamsara (KHM), Ulugo (UO), Ondum (OM), and Tannuola (TO) terranes (fig. 4). Oceanward of, and parallel to, the Kuznetsk-Tannuola island arc were tectonically-linked subduction-zone terranes, including the Teletsk (TL), Dzhebash (DZE), Amil (AI), Borus (BS), and Kurtushiba (KRT) terranes that consist of Late Neoproterozoic and Early Cambrian oceanic crustal rock, upper mantle rocks, and turbidite deposits. Blueschist facies assemblages occur in the Borus and Kurtushiba terranes. During the Vendian, Early and Middle Cambrian, mainly sedimentary rocks were deposited in the Minusa-Tuva Basin that separated the island arc from the North Asian cratonal margin.

Salair Island Arc

Remnants of the Salair island arc are preserved in the Altai collage (figs. 2, 4; appendix B) in the Salair (SAL) and Ulus-Cherga (UC) island-arc terranes that are tectonically linked to the Alambai (AL) and Baratal (BR) subduction-zone terranes. As with the eastern segments of the Late Neoproterozoic and Cambrian island-arc system occurring south of the North Asian craton and cratonal margin, the major igneous activity occurred in the Early Cambrian. The Salair arc is the westernmost extent of the Late Neoproterozoic and Cambrian island-arc system.

Origin of Late Neoproterozoic (Vendian) through Early Cambrian Island Arcs

The Late Neoproterozoic through Early Cambrian island-arc units are interpreted by most workers as having formed from subduction of the Paleo-Asian Ocean plate (fig. 4) (Berzin and Dobretsov, 1994; Gordienko, 1987; Mossakovskiy and



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Terranes

AK - Avekov terrane
AR - Argunsky terrane
AY - Ayansk terrane
BRG - Barguzin terrane
BU - Bureya terrane (Metamorphic)
BY - Baydrag terrane
DR - Derba terrane
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GN - Gonzha terrane
HM - Hamar-Davaa terrane
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
JI - Jiamusi terrane
KHM - Khamsara terrane (Island arc)
KI - Kanim terrane (Island arc)
KK - Kizir-Kazir terrane (Island arc)
KOM - Kolyma-Omolon superterrane
KOP - Prekolyma
KOZ - Kozhukhov terrane (Island arc)
KU - Kurai terrane (Island arc)
LK - Lake terrane (Island arc)
MK - Malokhingansk terrane (Accretionary wedge, type B) (Neoproterozoic and Cambrian)
MM - Mamyn terrane
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
OI - Orhon-Ikatsky terrane (Continental margin arc)
OL - Oldoy terrane
OM - Ondum terrane (Island arc)
SA - Sangilen terrane
SAL - Salair terrane (Island arc)
SHE - Shevli terrane
TO - Tannuola subterrane (Island arc)
TT - Telbes-Kitat terrane (Island-arc)
UC - Ulus-Cherga terrane (Island arc)
UG - Ulgey terrane (Island arc)
UL - Uimen-Lebed terrane (Island arc)
UO - Ulugo terrane (Island arc)
WST - West Stanovoy terrane
ZA - Zavhan terrane (Continental margin arc) (Late Neoproterozoic)

METALLOGENIC BELTS

BE - Bedobinsk
BK - Bokson-Kitoiskiy
CG - Chagoyan
HT - Hunjiang-Taizihe
JZ - Jinzhong
JX - Jixi
LA - Lake
PS - Prisayanskiy
OZ - Ozerninsky
SK - South Khingan

Figure 4. Early Cambrian (545 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

others, 1994; Pecherskiy and Didenko, 1995; Sengör and others, 1993; Zonenshain and others, 1990**).** The island arcs commenced activity after the formation of the Late Neoproterozoic accretional-collisional belt along the continent and after the jumping of the subduction zone towards into the Paleo-Asian Ocean. The underthrusting of oceanic plate occurred northward (present-day coordinates) toward the North Asian craton and itis confirmed by mutual arrangement of island-arc, subduction-zone, and turbidite terranes**.** It is assumed that the mechanism of the oblique subduction (combination of strike-slip and underthrusting) was proceeding already in the Cambrian (Berzin, 1995).

Associated with magmatic arcs are the Minusa-Tuva and Transbaikal back-arc basins (fig. 4) that were separated by island arcs and fragments of oceanic plates. During the Vendian and Early Cambrian, dominantly carbonate-terrigenous rocks and closely associated underlying sediments were deposited. Coeval sediments unconformably overlapped the Neoproterozoic terrane collage along the periphery of the North Asian craton. These units are preserved in the Mana (ma), Huvsgol-Bokson (hb), Upper Angara (ua), Gazimur (ga), and Argun (ags) overlap units.

The formation of the island arcs is interpreted as having ended in the early Middle Cambrian when oblique subduction changed into dextral-slip faulting along the outboard (oceanward) margin of the arcs (Berzin, 1995).

Important Geologic Details

(1) The Vendian through Early Paleozoic (650 to 410 Ma) (fig. 4) was a period of major sea transgression onto the North Asian craton. Transgression developed from the subsided margins of the craton toward its center. A change of terrigenous sedimentation in the Early Vendian through largely carbonate in the second half of the Vendian was typical (Shenfil’, 1991; Mel’nikov and others, 1989a,b). Maximum transgression occurred in the Early to Middle Cambrian (Mel’nikov and others, 1989a,b). The Late Cambrian was marked by sea regression that resulted in the drainage of most of the craton by the Early Devonian, except along the northeastern and northern subsided margins.

(2) After Riphean rifting on the northeastern margin of the North Asian craton, including the Okhotsk and Omolon cratonal terranes and the Prikolyma passive continental-margin terrane, the Verkhoyansk passive continental margin started to form with the accumulation of thick Vendian terrigenous and carbonate sedimentary units, and, subsequently by Cambrian through Lower Devonian largely carbonate units (Parfenov, 1984). The slope and rise of the continental margin are marked by Ordovician turbidite and hemipelagic sedimentary units along the northern margin of the Omulevka terrane (Merzlyakov, 1971).

(3) The passive margin extended far northwest into the South Taimyr region, where the South Taimyr passive continental margin started to form with the accumulation of thick, early Paleozoic carbonate sedimentary units that are similar to those in the Verkhoyansk passive continental margin (Uflyand and others, 1991; Vernikovskiy, 1996; Inger and others, 1999). In the Vendian through early Paleozoic, the South Taimyr passive continental margin was probably part of the Central Taimyr superterrane as compared to the Upper Riphean island-arc units with conglomerate that were unconformably overlain at their bases by the uppermost Upper Riphean clastic units and younger, mostly carbonate rocks of Vendian and Cambrian age (Bezzubtsev, 1981). The overlying Ordovician through Silurian graptolitic clay shale units probably mark the slope and rise of this continental margin.

(4) Paleomagnetic data (Metelkin and others, 2000) indicate that the Kara terrane, including North Taimyr and Severnaya Zemlya Islands, was located 1,500 km to the south of the North Asian craton and cratonal margin. The convergence of the Kara terrane and the South Taimyr continental margin probably occurred along major strike-slip faults that were nearly parallel to the continent margin. This conclusion is supported by the absence of subduction-related magmatic arcs on the adjacent margins of the continent and the Kara terrane.

(5) On the western and southern margins of the North Asian craton, within the Late Riphean Circum Siberian collage, just as in the Taimyr area, Cambrian, Vendian and, locally, uppermost Upper Riphean thick shelf terrigenous-carbonate units were deposited. These units are deposited along an angular unconformity. On the margins of the craton, the sedimentary units are thinner, contain more marine units, and conformably overlie older units. These thick wedges of sedimentary rocks are generally similar to the passive continental margin units, but differ in that away from the craton, they change back-arc basin units that were separated from the ocean by island arcs. The Vendian through Middle Cambrian Dzhida-Ozernaya and Kuznetsk-Tannuola island arcs and the Vendian through Early Ordovician Salair arc were active at this time. The polarity of the island arcs is determined from the position of the conjugate subduction zones. According to paleomagnetic data, the Kuznetsk-Tannuola island arc had a E-NE strike and occurred at 10±5º N (Kungurtsev, and others, 2001), 1,000 to 1,500 km away from the North Asian craton.

(6) In the western part of the well-studied Minusinsk back-arc basin, that formed behind the Kuznetsk-Tannuola island arc, the Late Riphean volcanic oceanic uplifts and islands with shallow-water siliceous-carbonate deposits were deposited. They occur in eastern the Gorny Altay, Kuznetsk Altai and Gornaya Shoriya regions. In the Vendian through early Cambrian, mostly carbonate rocks were deposited in the uplifts, with highly bituminous carbonate-shale sequences forming between them in deeper water.

Middle and Late Cambrian (520 to 500 Ma) and Early Ordovician through Late Silurian (500 to 410 Ma) Stages of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Middle and Late Cambrian (fig. 5) were as follows.

(1) Completion of accretion of the Late Neoproterozoic and Early Cambrian island-arc systems described above.

(2) Start of formation of a passive continental margin along the northern and northeastern periphery of the North Asian craton in the South Taimyr (NAT) and Verkhoyansk (NAV) fold-and-thrust belts.

(3) Formaton of turbidite basins along the southern transform margin of the North Asian craton in the area of accreted terranes.

(4) Deformation of the accreted island arcs and back-arc basins that started at the end of the Middle Cambrian and continued through the Silurian in a transpressional and dextral-slip faulting environment. This deformation was accompanied by intrusions of granitoids, local high-temperature metamorphism, and uplift and accumulation of marine and nonmarine molasses. In some regions, formation of high-temperature metamorphism (Fedorovskiy and others, 1995) resulted in obscuring of initial characteristics of terranes, as in the Hamar-Davaa terrane (HM) in the Transbaikal region. Layered gabbro-hyperbasite plutons intruded local zones of extension of litospheric blocks.

(5) Accumulation of flysch along the North Asian (Verkhoyansk) cratonal margin.

(6) Formation of turbidite units related to a continental margin arc along the southern margin of the North Asian craton in southern Siberia, central and northwestern Mongolia, and adjacent regions of China. These units are preserved in the Anyui-Chuya (ACH), Charysh (CHR), West Sayan (WSY), Altai (AT), Hovd (HV) and Govi-Altai (GA) terranes. These turbidite-margin sediments also occur in the stratigraphic basement of the Middle Paleozoic magmatic arcs in the Mandalovoo-Onor (MO) terrane. The molasse basins were strongly deformed in a transpressive dextral-slip environment.

The major tectonic events in the Early Ordovician through Late Silurian were (figs. 6, 7) as follows.

(1) Continued formation of a passive continental margin along the northern and northeastern periphery of the North-Asian craton in the South Taimyr (NAT) and Verkhoyansk (NAV) fold-and-thrust belts.

(2) Continued accumulation of flysch along the southern Siberian transform continental margin with uplift and erosion and transport of clastic material into abyssal basins. During the filling with the abyssal sediments, the basins evolved into shallow-water types.

(3) Continued deformation of accreted island arcs and back-arc basins in a transpressional and dextral-slip faulting environment. This deformation was accompanied by intrusions of granitoids, local high-temperature metamorphism, uplift and accumulation of marine and nonmarine molasses. Layered gabbro-hyperbasite plutons intruded local zones of extension of lithospheric blocks. Flysch continued to accumulate along the southern margin of the North Asian craton.

(4) Formation of the Early and Middle Ordovician East Mongolia-Khingan continental-margin arc along the southern margin of the North Asian craton and cratonal margin.

(5) Continued formation of turbidite units related to the Early and Middle Ordovician East Mongolia-Khingan continental margin arc that formed along the southern margin of the North Asian craton in southern Siberia and central and northwestern Mongolia, and adjacent regions of China. These units are preserved in the Anui-Chuya (ACH), Charysh (CHR), West Sayan (WSY), Altai (AT), Hovd (HV) and Govi-Altai (GA) terranes. These turbidite-margin sediments also occur in the stratigraphic basement of the Middle Paleozoic magmatic arcs in the Mandalovoo-Onor (MO) terrane.

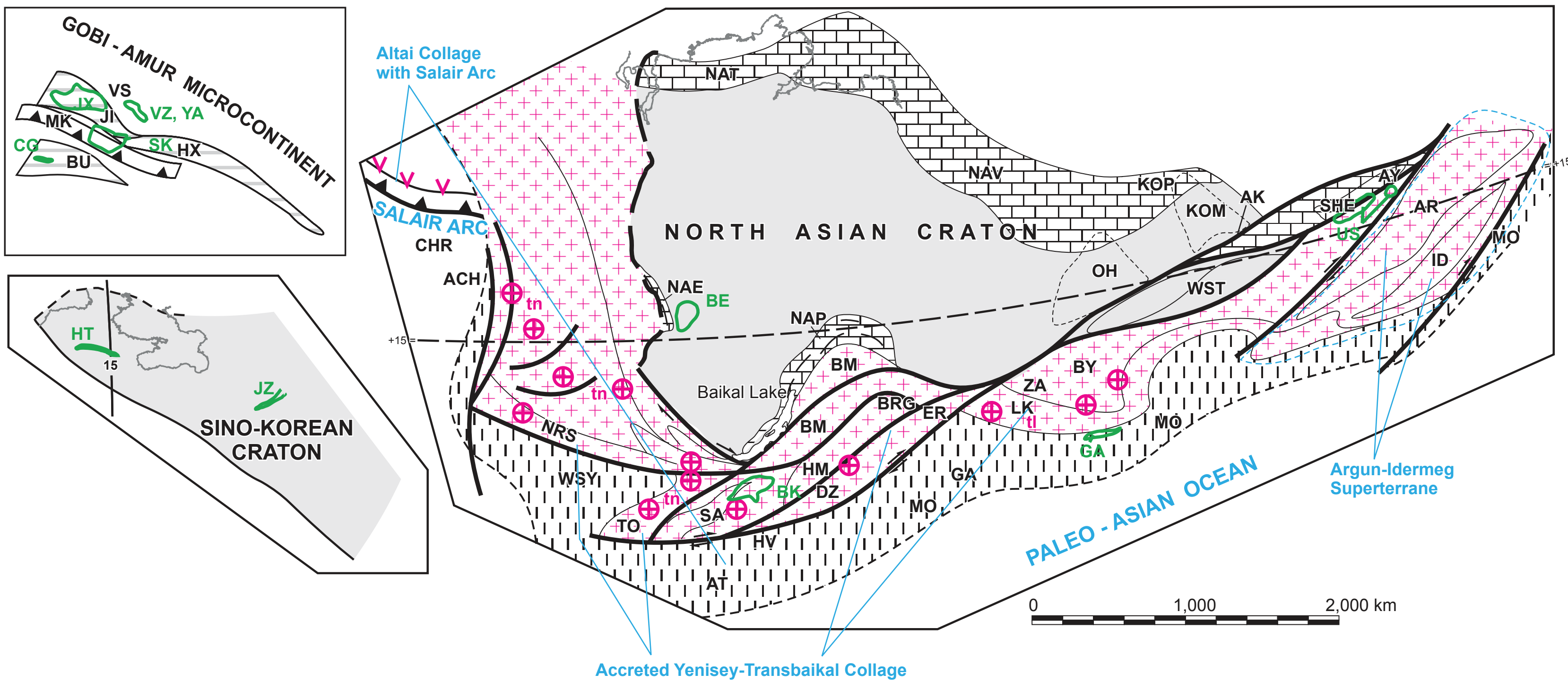
(6) In the eastern North Asian craton (in present-day coordinates) an active continental margin formed along with back-arc rifts.

(7) The position of the Sino-Korean craton relative to the North-Asian craton in the Late Neoproterozoic-Early Paleozoic is not resolved. No sedimentary or magmatic complexes of this age interval exist along the northern periphery of the Sino-Korean craton that might indicate the closing of the Paleo-Asian Ocean.

(8) Fragments of a series of mainly Ordovician magmatic arcs are preserved in terranes in the Wundurmiao collage (figs. 2, 6; appendix B). This complex collage, with a Mesoproterozoic through Silurian age and a late Silurian timing of accretion, occurs along the northern margin of the Sino-Korean craton and southern margin of the North Asian craton and previously-accreted terranes (figs. 2, 6; appendix B). The major terranes are: (1) Dongujimgin-Nuhetdavaa (DN), Nora-Sukhotin-Duobaoshan (ND), and Laolin (LA) island-arc terranes; (2) Tsagaan Uul-Guoershan (TG), and Zhangguangcailing (ZN) continental margin arc terranes; and (3) the Wundurmiao (WD) and Helongjing (HE) subduction-zone terranes (Fig. 6). The formation of these arcs, in contrast to island arcs that were active in the northern Paleo-Asian Ocean, occurred mainly in the Ordovician. The size and time of the origination and duration of associated subduction zones is also unknown.

Important Geologic Details

(1) In the Middle Cambrian (fig. 5), the system of island arcs underwent structural reorganization, accompanied by the alkaline basaltic volcanism in the Minusinsk back-arc basin.



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Terranes

ACH - Anui-Chuya terrane (Continental margin turbidite)
AK - Avekov terrane
AR - Argunsky terrane
AT - Altai terrane (Continental margin turbidite) (Precambrian and Cambrian through Devonian)
AY - Ayansk terrane
BM - Baikal-Muya terrane (Island arc) (Neoproterozoic)
BRG - Barguzin terrane
BU - Bureya terrane (Metamorphic)
BY - Baydrag terrane
CHR - Charysh terrane (Continental margin turbidite) (Cambrian through Devonian)
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
HM - Hamar-Davaa terrane
HV - Hovd terrane (Continental-margin turbidite) (Neoproterozoic through Silurian)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
JI - Jiamusi terrane
KOM - Kolyma-Omolon superterrane
KOP - Prekolyma
LK - Lake terrane (Island arc)
MK - Malokhingansk terrane (Accretionary wedge, type B) (Neoproterozoic and Cambrian)
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
SA - Sangilen terrane
SHE - Shevli terrane
TO - Tannuola subterrane (Island arc)
VS - Voznesenka terrane (Passive continentalal margin) (Cambrian through Permian)
WST - West Stanovoy terrane
WSY - West Sayan terrane (Continental margin turbidite) (Late Neoproterozoic through Devonian)
ZA - Zavhan terrane (Continental margin arc) (Late Neoproterozoic)

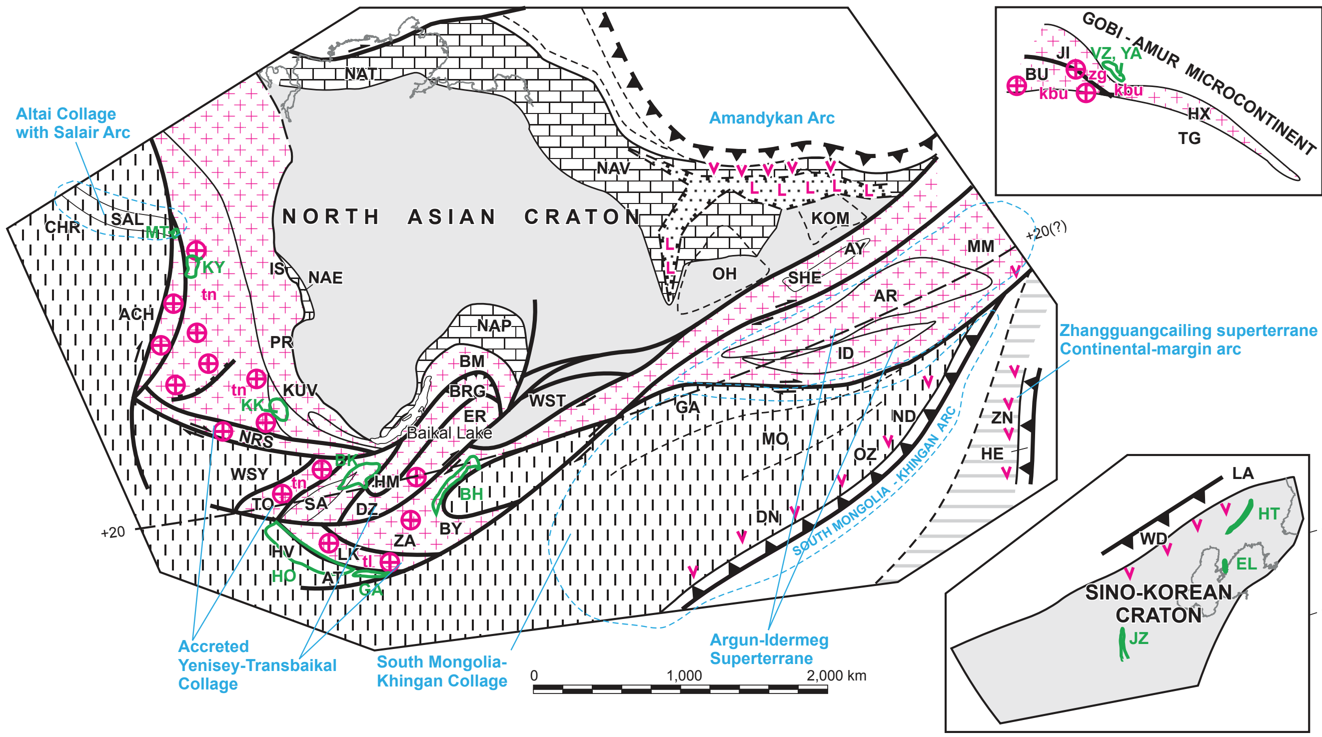
Overlap Continenta-Margin Arcs and Granite Belts

tl - Telmen plutonic belt (Middle Cambrian through Early Ordovician)
tn - Tannuola plutonic belt (Cambrian and Ordovician)

METALLOGENIC BELTS

BE - Bedobinsk
BK - Bokson-Kitoiskiy
CG Chagoyan
GA - Govi-Altai
HT - Hunjiang-Taizihe
JX - Jixi
JZ - Jinzhong
SK - South Khingan
US - Uda-Shantar
VZ - Voznesenka
YA - Yaroslavka

Figure 5. Late Cambrian (500 to 520 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Terranes

ACH - Anui-Chuya terrane (Continental margin turbidite)
AR - Argunsky terrane
AT - Altai terrane (Continental margin turbidite) (Precambrian and Cambrian through Devonian)
AY - Ayansk terrane
BM - Baikal-Muya terrane (Island arc) (Neoproterozoic)
BRG - Barguzin terrane
BU - Bureya terrane (Metamorphic)
BY - Baydrag terrane
CHR - Charysh terrane (Continental margin turbidite) (Cambrian through Devonian)
DN - Dongwuzhumuqin-Nuhetdavaa terrane (Island arc) (Cambrian through Middle Devonian)
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
HE - Heilongjiang terrane (Accretionary wedge, type B) (Ordovician and Silurian)
HM - Hamar-Davaa terrane
HV - Hovd terrane (Continental-margin turbidite) (Neoproterozoic through Silurian)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
IS - Isakov terrane (Island arc) (Neoproterozoic)
JI - Jiamusi terrane
KOM - Kolyma-Omolon superterrane
KUV - Kuvai terrane (Accretionary wedge, type A) (Neoproterozoic)
LA - Laoling terrane (Island arc) (Late Ordovician through Silurian)
LK - Lake terrane (Island arc)
MM - Mamyn terrane
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
ND - Nora-Sukhotin-Duobaoshan terrane (Island arc) (Neoproterozoic through Early Carboniferous)
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
OZ - Orogen-Zalantun terrane (Metamorphic) (Proterozoic)
PR - Predivinsk terrane (Island arc) (Late Neoproterozoic)
SA - Sangilen terrane
SAL - Salair terrane (Island arc)
SHE - Shevli terrane
TG - Tsagaan Uul-Guoershan Terrane (Continental margin arc) (Paleoproterozoic through Permian)
TO - Tannuola subterrane (Island arc)
WD - Wundurmiao terrane (Accretionary wedge, type B) (Mesoproterozoic through Middle Ordovician)
WST - West Stanovoy terrane
WSY - West Sayan terrane (Continental margin turbidite) (Late Neoproterozoic through Devonian)
ZA - Zavhan terrane (Continental margin arc) (Late Neoproterozoic)
ZN - Zhangguangcailing superterrane (Continental margin arc) (Neoproterozoic through Devonian)

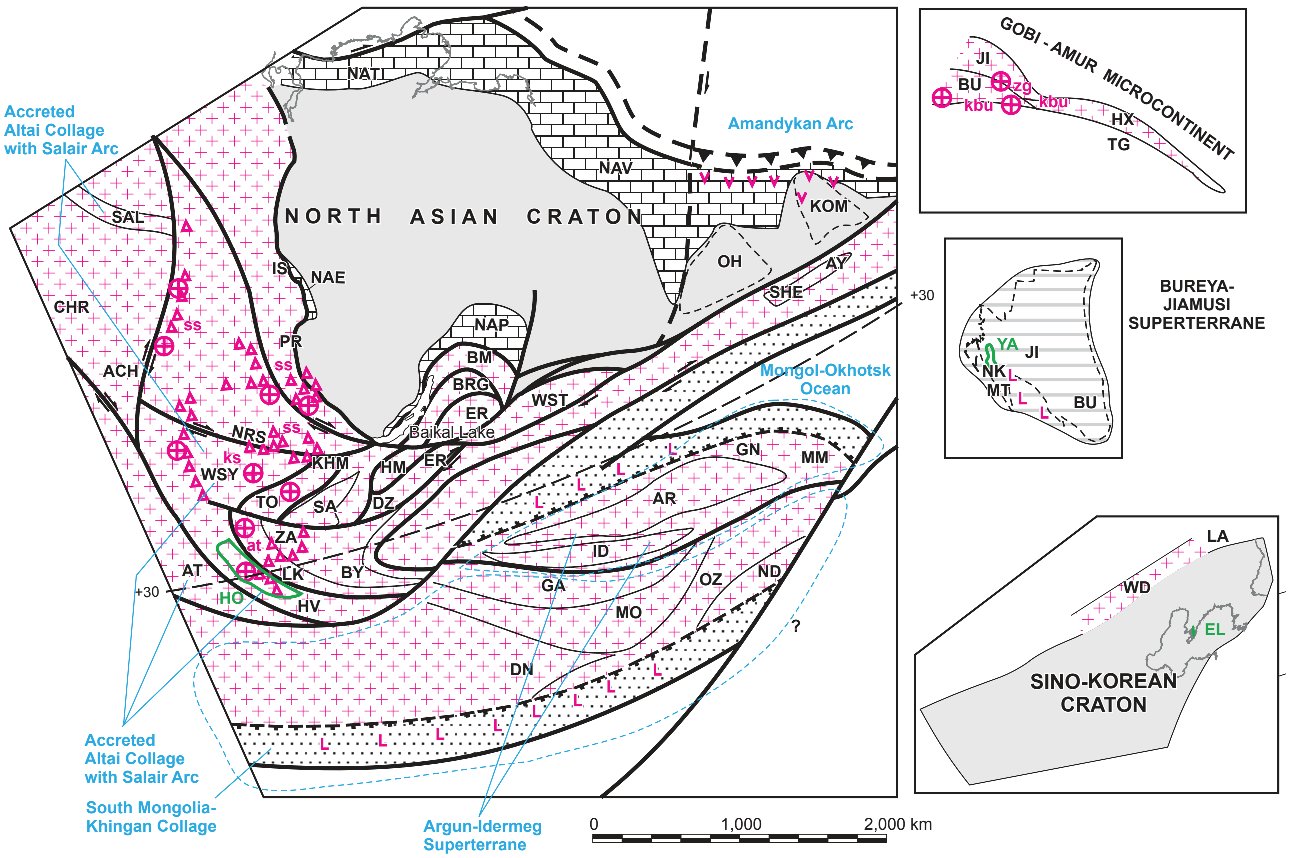
Overlap Continental Margin Arcs and Granite Belts

kbu - Khanka-Bureya granitic belt (Ordovician and Silurian)
tl - Telmen plutonic belt (Middle Cambrian through Early Ordovician)
tn - Tannuola plutonic belt (Cambrian and Ordovician)
zg - Zhangguangcailing plutonic belt (Silurian through Ordovician)

METALLOGENIC BELTS

BH - Bayanhongor
EL - East Liaoning
BK - Bokson-Kitoiskiy
GA - Govi Altai
HO - Hovd
HT Hunjiang-Taizihe
JZ Jinzhong
KK - Kizir-Kazyr
KY - Kiyalykh-Uzen
MT- Martaiginsk
VZ - Voznesenka
YA - Yaroslavka

Figure 6. Early and Middle Ordovician (450 to 500 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
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Terranes

ACH - Anui-Chuya terrane (Continental margin turbidite)
AR - Argunsky terrane
AT - Altai terrane (Continental margin turbidite) (Precambrian and Cambrian through Devonian)
AY - Ayansk terrane
BM - Baikal-Muya terrane (Island arc) (Neoproterozoic)
BRG - Barguzin terrane
BU - Bureya terrane (Metamorphic)
BY - Baydrag terrane
CHR - Charysh terrane (Continental margin turbidite) (Cambrian through Devonian)
DN - Dongwuzhumuqin-Nuhetdavaa terrane (Island arc) (Cambrian through Middle Devonian)
DZ - Dzhida terrane (Island arc)
ER - Eravna terrane (Island arc)
GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
GN - Gonzha terrane (Passive continental margin) (Late Archean(?), Paleoproterozoic(?), and early Paleozoic)
HM - Hamar-Davaa terrane
HV - Hovd terrane (Continental-margin turbidite) (Neoproterozoic through Silurian)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
IS - Isakov terrane (Island arc) (Neoproterozoic)
JI - Jiamusi terrane
KHM - Khamsara terrane (Island arc) (Cambrian)
KOM - Kolyma-Omolon superterrane
LA - Laoling terrane (Island arc) (Late Ordovician through Silurian)
LK - Lake terrane (Island arc)
MM - Mamyn terrane
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
MT - Matveevka terrane (Metamorphic)
ND - Nora-Sukhotin-Duobaoshan terrane (Island arc) (Neoproterozoic through Early Carboniferous)
NK - Nakhimovka terrane (Metamorphic)
NRS - North Sayan terrane (Island arc)
OH - Okhotsk terrane
OZ - Orogen-Zalantun terrane (Metamorphic) (Proterozoic)
PR - Predivinsk terrane (Island arc) (Late Neoproterozoic)
SA - Sangilen terrane
SAL - Salair terrane (Island arc)
SHE - Shevli terrane
TG - Tsagaan Uul-Guoershan Terrane (Continental-margin arc) (Paleoproterozoic through Permian)
TO - Tannuola subterrane (Island arc)
WD - Wundurmiao terrane (Accretionary wedge, type B) (Mesoproterozoic through Middle Ordovician)
WST - West Stanovoy terrane
WSY - West Sayan terrane (Continental-margin turbidite) (Late Neoproterozoic through Devonian)
ZA - Zavhan terrane (Continental-margin arc) (Late Neoproterozoic)

Overlap Continental-Margin Arcs and Granite Belts

at - Altai volcanic-plutonic belt (Devonian and Early Carboniferous)
kbu - Khanka-Bureya granitic belt (Ordovician and Silurian)
ks - Kuznetsk-Sayan plutonic belt (Early Silurian to Early Devonian)
ss - South Siberian volcanic-plutonic belt (Early Devonian)
zg - Zhangguangcailing plutonic belt (Silurian through Ordovician)

METALLOGENIC BELTS

EL - East Liaoning
HO - Hovd
YA - Yaroslavka

Figure 7. Late Silurian (410 to 420 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

Subsequently, volcanism ceased along the entire length of the island-arc systems, except in the Salair arc.

(2) The formation of the Late Cambrian through Early Ordovician Yenisey-Transbaikal collage may be related to the counter-clockwise rotation of the North Asian craton, which caused the amalgamations of island arcs, duplexing, and closure of back-arc basins. As a result, most of the subduction zones and conjugate island arcs disappeared in the Middle Cambrian. In the Late Cambrian through Early Ordovician, collisional granitoid batholiths were emplaced and high-temperature metamorphic belts were formed (Zonenshain and others, 1990; Berzin and Dobretsov, 1994; Fedorovskiy and others, 1995).

(3) Paleomagnetic data indicate that the Kuznetsk-Tannuola island arc (fig. 4) moved into the southern hemisphere (10-15º S.) in the Middle Cambrian and was several hundred kilometers away from the North Asian craton and cratonal margin. Convergence was accompanied by the deformation of the magmatic arc and the back-arc basin, tectonic stacking, and rotation of some fragments of the island arc. As early as the Middle Cambrian, the western part of the arc (Kurai, Uimen-Lebed, Telbes-Kitat terranes) rotated clockwise through approximately 90º, whereas orientation of the central segment (North Sayan terrane) remained unchanged (Kungurtsev and others, 2001).

(4) In the Late Cambrian, Ordovician, and Silurian (figs. 5, 6, 7, on the western and southern margins of the growing North Asian craton and cratonal margin, thick clastic sequences were deposite that consisted of turbidites and hemipelagic rocks at the bottom of the section and grading upward into shelf and littoral units, thereby indicating progradation of the sedimentary wedge towards the adjacent Paleo-Asian Ocean. Stratigraphic breaks, unconformities, and deposit of various Ordovician units on Vendian and Cambrian ophiolites, turbidites, and island-arc units occurred. N.A. Berzin (in Obolenskiy and others, 1999) interprets these thick sedimentary sequences as subduction-zone deposits that formed along the transform margin of the continent. In the Late Silurian, the Altay orogenic belt formed on the transform margin, in a manner similar to the Mesozoic transform margin in the Sikhote-Alin region of the Russian Southeast (Natal'in, 1991; Khanchuk and others, 1989; Khanchuk and Ivanov, 1999; Şengör and Natal'in, 1996).

(5) On the opposite side of the Paleo-Asian Ocean, separating the North Asian and Sino-Korean cratons, in the Early and Middle Ordovician, a series of island arcs formed (fig. 7) for which various fragments occur throughout the entire length of the early Paleozoic Wenduermiao collage. The polarity of the arcs and position relative to the North Asian and Sino-Korean cratons are unknown. Accretion of the arcs to the craton and formation of the Wenduermiao collage occurred in the Late Ordovician, as indicated by Silurian sedimentary units overlying Ordovician units with an angular unconformity.

(6) The Mongol-Okhotsk Ocean likely opened in the late early Paleozoic (fig. 7). The oldest organic remains known within the belt are Silurian. The opening of the Mongol-Okhotsk Ocean may have occurred in the Late Ordovician through Early Silurian.

Cambrian through Silurian Metallogenesis

Metallogenic Belts with Granitoid-Hosted Deposits Related to Continental-Margin Arcs, Transpression, or Terrane Accretion

Several metallogenic belts possess geologic units favorable for major granitoid-hosted or related deposits (figs. 4 through 7), including the Bayanhongor belt (with Au in shear zone and quartz-vein, granitoid-related Au-vein, Cu-Ag-vein, Cu-skarn deposits), the Hovd belt (with granitoid-related Au-vein, Au-skarn, and Cu-skarn deposits), the Kizir-Kazyr belt (with Fe-skarn and granitoid-related Au-vein deposits), and the Martaiginsk belt (with granitoid-related Au-vein and Au-skarn deposits). The isotopic ages of the deposits or hosting units range from 420 to 490 Ma. The favorable geologic units and deposits are in the Altai and Yenisey-Transbaikal collage and are interpreted as having formed in a continental-margin arc or associated continental-margin turbidite terranes, back-arc basin associated with continental-margin arc magmatism, transform continental-margin faulting, island arc, or terrane accretion. The Kiyalykh-Uzen belt (with Cu-skarn, W-skarn, Fe-skarn, and W-Mo-Be greisen, stockwork, and quartz-vein deposits) and the Martaiginsk belt (with granitoid-related Au-vein and Au-skarn deposits) contain collisional granitoids that are interpreted as having been intruded during transpressive (dextral-slip) movement along the Kuznetsk Alatau fault, or during terrane accretion.

Metallogenic Belts with Volcanic-Hosted Deposits Related to Continental-Margin or Island Arcs

Several metallogenic belts possess geologic units favorable for major volcanic-rock hosted deposits (figs. 4 thorugh 7), including the Govi-Altai, Ozerninsky, and Uda-Shantar belts (with volcanogenic-sedimentary Fe, volcanogenic-sedimentary Mn, volcanogenic-hydrothermal-sedimentary massive sulfide, and sedimentary phosphate deposits). The fossil ages of the deposits or host units range from Cambrian through Silurian. The favorable geologic units and deposits are in the Mongol-Okhotsk, South Mongolia-Khingan, and Yenisey-Transbaikal collages and are interpreted as having formed in either continental-margin or island arcs, or in sea floor sedimentation. The Bedobinsk belt with sediment-hosted Cu deposits is hosted in early Paleozoic sedimentary units of the North Asian craton and is interpreted as having formed in an inland-sea basin during the post-saline stage of rock deposition.

Unique Metallogenic Belts

Three unique metallogenic belts (figs. 4 through 7) possess favorable geologic units for diamond-bearing kimberlite deposits in the Sino-Korean craton (East Liaoning belt)--evaporite sedimentary gypsum deposits in platform sedimentary cover on the Sino-Korean craton (Hunjiang-Taizihe and Jinzhong belts) and banded-iron formation (BIF) deposits in continental-margin sedimentary cover on the Sino-Korean craton (South Khingan belt). The latter two belts formed during sedimentation along a cratonal margin. The origin of the diamond-bearing kimberlite deposits is not well known.

Devonian through Early Carboniferous (410 to 320 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Devonian through Early Carboniferous (fig. 8) were as follows.

(1) Formation of the South Mongolia-Khingan arc and associated subduction zone.

(2) Back-arc spreading behind the South Mongolia-Khingan island arc resulting in formation of the Bayanleg back-arc basin.

(3) Beginning assembly of cratonal and passive continental-margin terranes in the Russian Far East and Northeastern China to form the Bureya-Jiamusi superterrane.

(4) Inception of the North Okhotsk continental-margin arc and associated subduction zones that were associated with subduction of the Mongol-Okhotsk ocean plate.

(5) Oblique convergence between the Mongol-Okhotsk ocean plate and the North Asian craton, resulting in transform displacement and oroclinal wrapping of the southern and western margins of the North Asian craton and formation of the South Siberian and Altai transpressional arc.

(6) Continued sea-floor spreading in the PaleoAsian, Mongol-Okhotsk, and Ancestral Pacific Oceans.

(7) Rifting and associated sedimentation along the northeast continental margin of the North Asian craton.

Important Geologic Details

(1) In the Devonian and Early Carboniferous (410 to 320 Ma) (fig. 8), near the western and southwestern margins of the North Asian craton and cratonal margin was the extensive South Mongol-Khingan island arc (part of the South Mongol-Khingan collage) was separated from the continent by a large back-arc basin comparable in size to the modern Philippine sea. The arc contains Silurian, Devonian, and Mississippian units. Both terminations of the arc, that now occur in the Rudnyi Altay and northeast China (including the adjacent part of the left bank of the Amur River), are under Proterozoic and Cambrian metamorphic rocks and Ordovician sedimentary and island-arc volcanic and sedimentary rocks. The central sector of the South Mongol-Khingan arc consists of the Edrengin and Gurvansaikhan terranes with volcanic units that rest on oceanic crustal rocks and that are geochemically similar to those from the Lesser Antilles arc (Lamb and Badarch, 1997, 2001). The arc was reconstructed through mutual rotation of the terranes making up the South Mongol-Khingan collage belt along the separating left-lateral strike-slip faults.

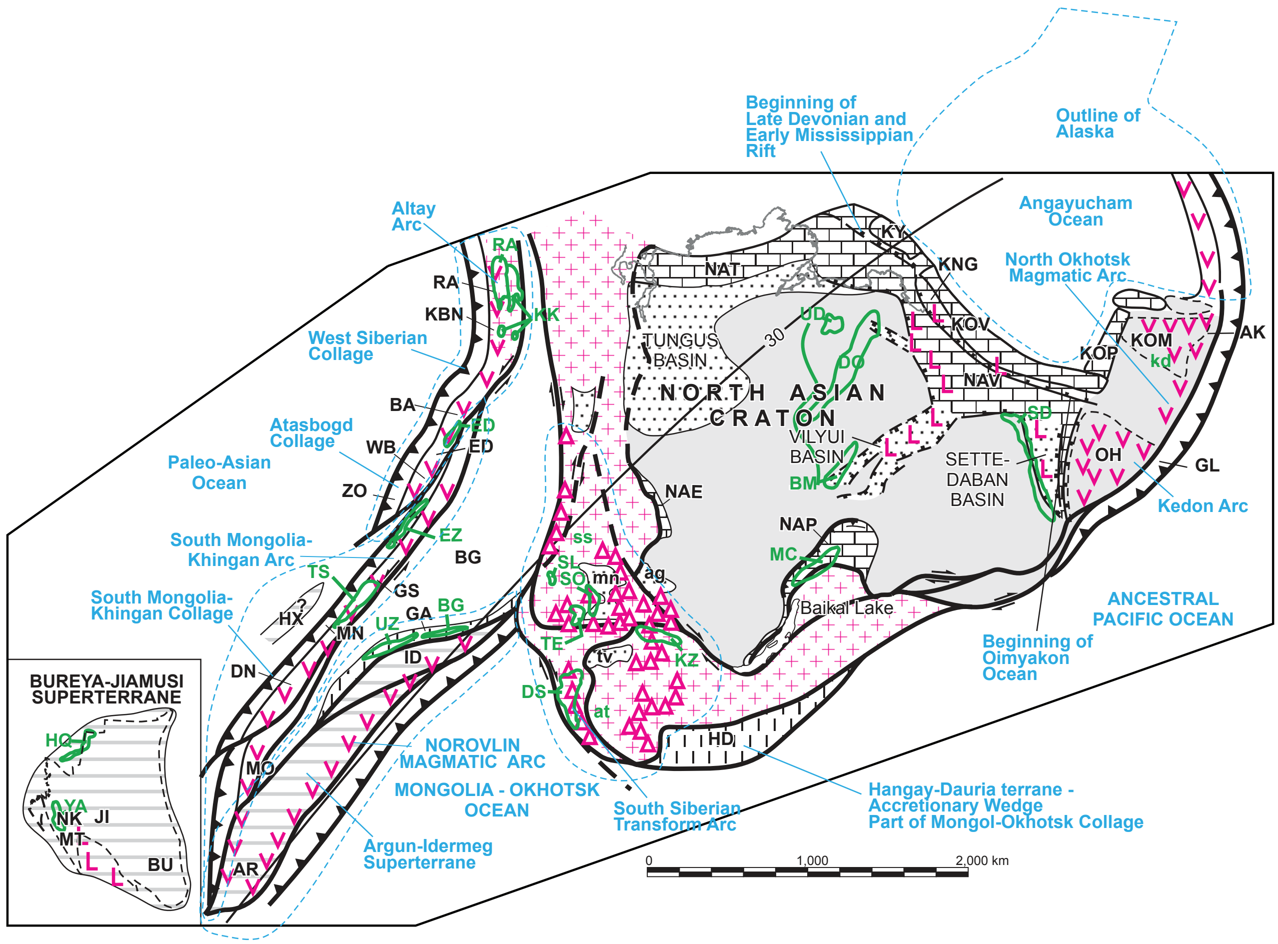
The subduction-zone complex that is tectonically-related to the arc (and the other major part of the South Mongol-Khingan collage) consists of the Dzolen terrane that extends for 700 km along the southern (present-day coordinates) margin of the arc (fig. 8). The complex consists of greenschist melange with fragments of tholeiitic basalt, andesite, tuff, volcaniclastic rock and chert of Silurian and Devonian and, presumably, Ordovician age, and also fragments of ophiolite and serpentinite melange (Zonenshain and others, 1975; Ruzhentsev and others, 1985, 1992).

Formations of the related back-arc basin include Silurian-Mississippian volcanic and sedimentary units of the Govi-Altai terrane and the melange of the Mandakh terrane that contains fragments of metavolcanic and metasedimentary rock, coral limestone, amphibolite, and gabbro in a serpentinite and aleurolite matrix (Suetenko, 1967; Tomurtogoo, 1989; Ruzhentsev and others, 1985, 1987).

(2) Formation of the South Mongol-Khingan collage was preceded by rifting and associated volcanism occuring to the northwest in the Altai-Sayan region along the continental margin. Rrifting probably occurred along systems of conjugate strike-slip faults (Şengör and others, 1994; Berzin, 1995, 1998, 2001).

(3) The Norovlin continental-margin arc formed along the margin of the Mongol-Okhotsk Ocean and consists of Early and Middle Devonian calc-alkaline volcanic rocks and Middle and Late Devonian volcanoclastic rock, chert, and mudstone (Marinov, 1973). The arc units overlie the northern part of the Argun superterrane and are associated with granites and syenites of the Tsagaanunder complex. The tectonically-related subduction zone of the arc consists of the Ononsky terrane containing blueschist facies metamorphic rocks and Devonian and Early Carboniferous volcanic and sedimentary rocks (Gordienko, 1987). An ophiolite fragment in the western part of the terrane has an U-Pb zircon age of 325 Ma (Windley and others, 2003).

(4) In the middle Paleozoic, the Mongol-Okhotsk Ocean reached its maximum size.



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental sedimentary basin

ag - Agul (Rybinsk) molasse basin (Middle Devonian to Early Carboniferous)
mn - Minusa molasse basin (Middle Devonian through Early Permian)
tv - Tuva molasse basin (Middle Devonian through Late Carboniferous)

Terranes

AK - Avekov terrane
AR - Argunsky terrane
BU - Bureya terrane (Metamorphic)
DN - Dongwuzhumuqin-Nuhetdavaa terrane (Island arc) (Cambrian through Middle Devonian)
ED - Edren terrane (Island arc) (Devonian and Early Carboniferous)GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
GL - Galam terrane (Subduction zone) (Cambrian through Early Carboniferous)
GS - Gurvansayhan terrane (Island arc) (Silurian through Early Carboniferous)
HD - Hangay-Dauria terrane (Subduction zone) (Silurian through Late Carboniferous)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
JI - Jiamusi terrane
KBN - Kalba-Narim terrane (Subduction zone) (Ordovician through Early Carboniferous)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
MN - Mandah terrane (Subduction zone) (Devonian)
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
MT - Matveevka terrane (Metamorphic)
NK - Nakhimovka terrane (Metamorphic)
OH - Okhotsk terrane
RA - Rudny Altai terrane (Island arc) (Late Silurian through Early Carboniferous)
WB - Waizunger-Baaran terrane (Island arc) (Ordovician through Permian)
ZO - Zoolen terrane (Subduction zone) (Ordovician(?) and Devonian)

Overlap Continental-Margin Arcs and Granite Belts

at - Altai volcanic-plutonic belt (Devonian and Early Carboniferous)
kd - Kedon volcanic-plutonic belt (Devonian and Early Carboniferous)
ss - South Siberian volcanic-plutonic belt (Early Devonian)

METALLOGENIC BELTS

BG - Bayangovi
BM - Botuobiya -Markha
DO - Daldyn-Olenyok
DS - Deluun-Sagsai
ED - Edrengiin
EZ - Edren-Zoolon
HQ - Hongqiling 331 to 350 Ma.
KK - Korgon-Kholzun
KZ - Kizhi-Khem
MC - Mamsko-Chuiskiy
RA - Rudny Altai
SL - Salair
SD - Sette-Daban
SO - Sorsk
TE - Teisk
TS - Tsagaan-suvarga
UD - Udzha
UZ - Ulziit
YA - Yaroslavka

Figure 8. Late Devonian (370 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

(5) On the eastern and northern sides of the North Asian craton and cratonal margin, the Verkhoyansk and South Taimyr passive continental margins continued to form. On the northern (present-day coordinates) margin, the Tunguska Basin continued forming in a small, flat depression conjugate to the South Taimyr passive continental margin. The depression contains Devonian and Mississippian sulfate-carbonate rock and variegated clay-carbonate rock with salt horizons (Matukhin, 1989; Vaag and Matukhin, 1989).

(6) Rifting was widespread in the Verkhoyansk passive continental margin and the adjacent part of the North Asian craton in the Middle to Late Devonian and the Mississippian (Gaiduk, 1988). Several, three-branch rift systems are recognized. The failed branches of the systems die out within the North Asian craton and are recognized as aulacogens. Most of the rift basins occur in the Verkhoyansk passive continental margin and are filled with thick Middle to Late Devonian and Mississippian units, including highly alkaline basalt, red beds, coarse-clastics, evaporite, and basalt dike swarms that extend for hundreds of kilometers parallel to the rift basins.

(7) At the boundary of the North Asian craton and cratonal margin with the Paleo-Pacific Ocean the North Okhotsk continental-margin arc formed for which fragments are preserved as overlap assemblages in the Okhotsk, Avekova, and Omolon cratonal terranes. The arc units consist of Middle to Late Devonian and Mississippian calc-alkaline volcanic rocks and granodiorite plutons. The active continental margin changes along strike into an island arc that is preserved in the Oloy and Yarakvaam island-arc terranes.

(8) The North Okhotsk continental-margin is connected with the Norovlin continental-margin arc by a transform fault along which the Hangay-Daurian subduction- zone terrane occurs. The wedge contains Silurian through Pennsylvanian flysch with lenses of chert and mafic and intermediate volcanic rock (Geological structure of Chita oblast, 1991). The Devonian and Mississippian occurrence of volcanic rocks indicates that oblique subduction occurred along the continent margin.

(9) In the Late Mississippian, the South Mongol-Khingan collage was duplexed along the strike-slip faults and collided with the Bureya-Jiamusi superterrane and possibly with the Sino-Korean craton. The collision terminated the South Mongol-Khingan collage.

Metallogenesis

Metallogenic Belts Related to Island Arcs

Four metallogenic belts (the Edrengiin, Rudny Altai, Salair, and Tsagaan-suvarga belts) possess geologic units favorable for a wide variety of island-arc-magmatism-related deposits (fig. 8). The deposits types are volcanogenic Cu-Zn massive sulfide (Urals type), volcanogenic Zn-Pb-Cu massive sulfide, volcanogenic-sedimentary Mn, volcanogenic-sedimentary Fe, barite-vein, volcanic-hosted metasomatite, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, porphyry Cu-Mo (±Au, Ag), porphyry Cu (±Au), porphyry Cu-Au, and granitoid-related Au-vein. The fossil or isotopic ages of the deposits or hosting units range from Early Devonian through Early Carboniferous. The favorable geologic units are the Edren island-arc terrane, part of the South Mongolia-Khingan collage; the Rudny Altai island-arc terrane, part of the West Siberian collage; the Altai volcanic-plutonic belt, part of the South Mongolia-Khingan island arc; and the Gurvansayhan island-arc terrane, part of South Mongolia-Khingan collage.

Metallogenic Belts Related to Terrane Accretion

Five metallogenic belts possess geologic units favorable for a wide variety of major collisional granite-hosted deposits and related vein deposits (fig. 8)--the Bayangovi, Edren-Zoolon, Muiskiy, Ulziit, and Yaroslavka belts with granitoid-related Au-vein; Au in shear zone and quartz-vein; fluorite greisen; Sn-W greisen, stockwork, and quartz-vein; and carbonate-hosted Hg-Sb deposits. The fossil or isotopic ages of the deposits or hosting units range from Devonian through Early Carboniferous, or 440 to 396 Ma. The favorable geologic units and deposits are the Edren island arc and Zoolen subduction-zone terrane, both part of the South Mongolia-Khingan collage, granitoids and veins of the Barguzin-Vitim granitoid belt intruding the Baikal-Muya island arc and Muya metamorphic terrane, both part of the Tuva-Mongolia superterrane; granitoids intruding the Bureya-Jiamusi supterterrane, and vein replacements in the Govi-Altai continental-margin turbidite terrane, part of the South Mongolia-Khingan collage. These granitoids and veins are interpreted as having formed during regional metamorphism and vein emplacement associated with terrane accretion and generation of anatectic granitic plutons.

Metallogenic Belts Related to Transpressive Continental-Margin Arcs

Five metallogenic belts (the Deluun-Sagsai, Kizhi-Khem, and Korgon-Kholzun, Sorsk, and Teisk belts) possess geologic units favorable for a wide variety of major granite-hosted deposits (fig. 8). The major deposit types are polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite; polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite; polymetallic Pb-Zn ± Cu (±Ag, Au)-vein and stockwork; volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type); sediment-hosted Cu; volcanogenic-sedimentary Fe; porphyry Cu-Mo (±Au, Ag); Ag-Pb epithermal-vein; granitoid related Au-vein; W-Mo-Be greisen, stockwork, and quartz-vein; granitoid-related Au-vein; mafic-ultramafic related Ti-Fe (+V); porphyry Mo (±W, Bi); polymetallic (Pb, Zn, Ag); carbonate-hosted metasomatite; Fe-skarn; Zn-Pb (±Ag, Cu) skarn; and Ta-Nb-REE alkaline metasomatite. The host geologic units are the Deluun sedimentary-volcanic-plutonic belt (part of the transpressive South Siberian and Altai continental-margin arcs), replacements and granitoids related to the South Siberian volcanic-plutonic belt, and the Altai volcanic-plutonic belt. The isotopic ages of the deposits or hosting units range from Devonian through Early Carboniferous. The favorable geologic units and deposits are the South Siberian and Altai transpressive continental-margin arcs.

Metallogenic Belts Related to Transpressional Faulting

Two metallogenic belts (the Hongqiling and Mamsko-Chuisky belts) possess geologic units favorable for major vein deposits or plutonic-hosted deposits (fig. 8). The major deposit types are mafic-ultramafic related Cu-Ni-PGE, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, and muscovite pegmatite. The fossil ages of the deposits or hosting units are Devonian and Early Carboniferous and the isotopic ages range from 330 to 416 Ma. The favorable geologic units that host the tracts and deposits are: (1) mafic and ultramafic plutons intruding and overlapping the Zhangguangcailing superterrane and the Laoling terrane, part of the Bureya-Jiamusi supterterrane; and (2) veins and dikes in the Mamsky and Konkudero-Mamakansky complexes intruding the Chuja paragneiss terrane that is included in the Baikal-Patom cratonal margin. These units and deposits are interpreted as having formed during transpressional faulting and associated interplate rifting.

Metallogenic Belts Related to Rifting

Two metallogenic belts (the Sette-Daban and Udzha belts) possess geologic units favorable for a wide variety of rift-related deposits (fig. 8). The major mineral deposit types are sediment-hosted Cu, Basaltic native Cu (Lake Superior type), REE carbonatite, and carbonate-hosted Pb-Zn (Mississippi valley type). The fossil ages of the deposits or host units are Devonian and Early Carboniferous. The favorable geologic units and deposits are interpreted as having formed during rifting of the North Asian craton or cratonal margin.

Unique Metallogenic Belts

Two unique metallogenic belts (the Botuobiya-Markha and Daldyn-Olenyok belts) are hosted in Devonian diamond-bearing kimberlite intruding the North Asian craton (fig. 8). The origin of the diamond-bearing kimberlite deposits is not well known. The unique Edrengiin belt (fig. 8) (with volcanogenic Cu-Zn massive sulfide, volcanogenic-sedimentary Mn and Fe deposits) is hosted in the Edren island-arc terrane, part of the South Mongolia-Khingan collage, and is interpreted as having formed during island-arc marine volcanism.

Late Carboniferous through Middle Triassic (320 to 230 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Late Carboniferous through Middle Triassic (fig. 9) were as follows.

(1) In the northern North Asian craton, formation of the Tungus Plateau igneous province with widespread intrusive traps consisting of extensive belts of sills and rare dikes that intruded major fault zones.

(2) Starting of accretion of the Argun-Idermeg superterrane (Amur microcontinent composed of the Agun and Idermeg passive continental-margin terranes).

(3) Formation of the Gobi-Khankaisk-Daxing'anling continental-margin arc along the outboard edge of the accreted South Mongolia-Khingan collage and the Argun-Idermeg superterrane.

(4) Formation of the North Margin continental-margin arc along the edge of the Sino-Korean craton.

(5) Formation of the transform-continental-margin Hangay arc along the southern margin of the North Asian craton and accreted terranes.

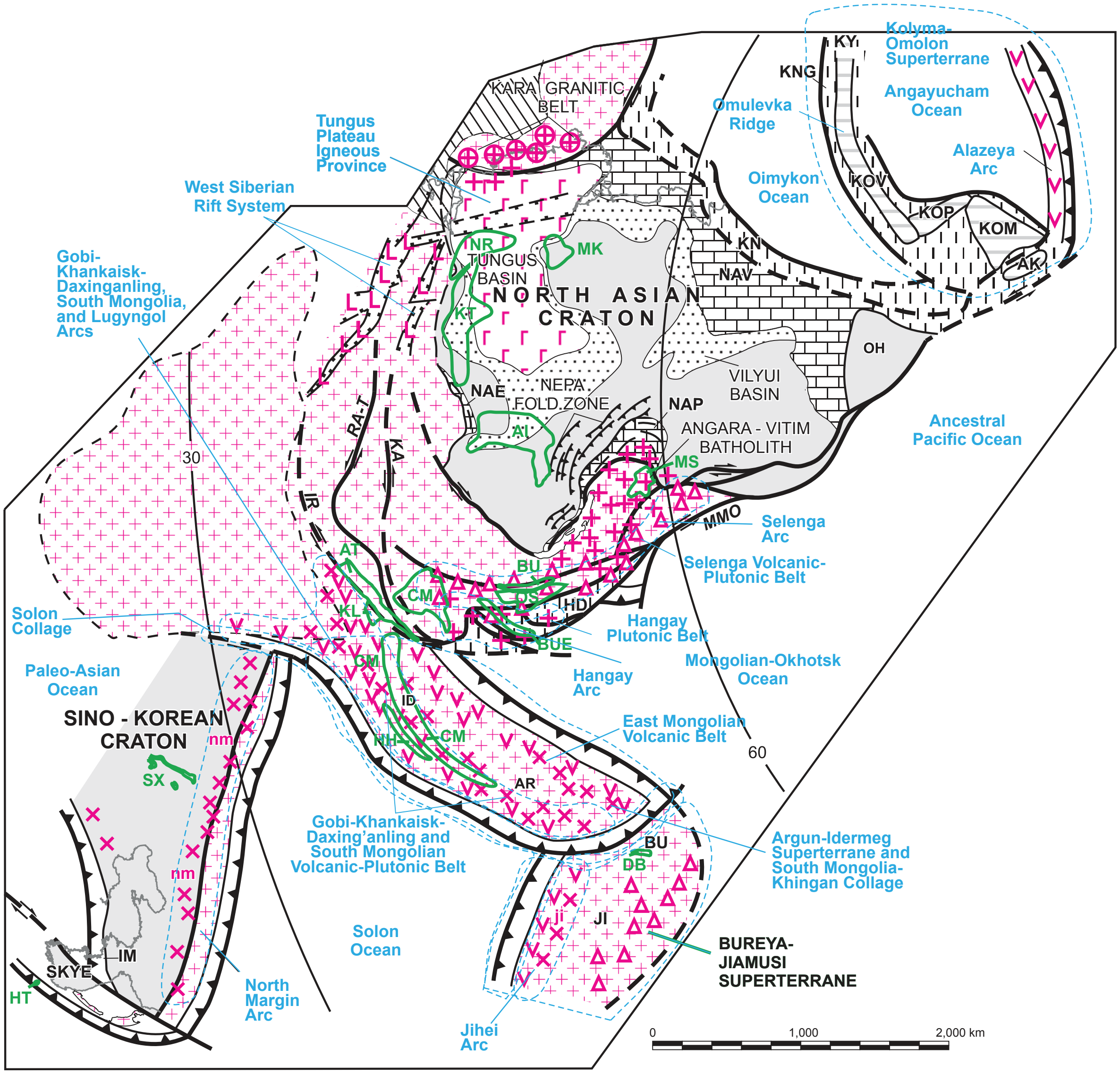
(6) Beginning of closure of the Mongol-Okhotsk Ocean and inception of an extensive, mainly right-lateral series of transform faults.

(7) Formation of the Jihei continental-margin arc along the margin of the Bureya-Jiamusi superterrane.

(8) Inception of the Alazeya island arc.

Important Geologic Details

(1) The Mongol-Okhotsk collage started to form with progressive eastward (present-day coordinates) accretion of the Argun-Idermeg superterrane (Zonenshain and others, 1990, including the Argun superterrane and the South Mongol-Khingan collage. Most of the displacement associated with accretion occurred along the Major Mongol-Okhotsk fault (MMP). Along with the Argun-Idermeg superterrane, the Solon collage commenced to form with left-lateral strike-slip displacement along the Kuznetsk-Altai and Kobdinsk faults, the Irtysh crush zone, and companion faults that are part of the Major Mongol-Okhotsk fault. In the West Siberian Lowlands these strike-slip faults are conjugate to Triassic longitudinal



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Terranes and Superterranes

AK - Avekov terrane
AR - Argunsky terrane
BU - Bureya terrane (Metamorphic)
ID - Idermeg terrane
IM - Imjingang terrane (Accretionary wedge, type B) (Devonian)
JI - Jiamusi terrane
KN - Kular-Nera terrane (Continental-margin turbidite) (Permian through Early Jurassic)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
ND - Nora-Sukhotin-Duobaoshan terrane (Island arc) (Neoproterozoic through Early Carboniferous)
OH - Okhotsk terrane
SKYE - Yeongnam terrane (Granulite-paragneiss) (Late Archean to Paleoproterozoic)

Overlap Continental-Margin Arcs and Granite Belts

ji -Jihei plutonic belt (Permian)
nm - North marginal plutonic belt Carboniferous and Permian)

Strike-Slip Fault and Shear Zone

IR - Irtysh shear zone
KA - Kuznetsk-Altai
MMO - Main Mongol-Okhotsk
RA-T - Rudny Altai - Taimyr

METALLOGENIC BELTS

AI - Angara-Ilim
AT - Altay
BU - Buteeliin nuruu
BUE - Battsengel-Uyanga-Erdenedalai
CM - Central Mongolia
DB - Duobaoshan
HH - Harmagtai-Hongoot-Oyut
HT - Hitachi
KL - Kalatongke
KT - Kureisko-Tungsk
MK - Maimecha-Kotuisk
MS - Muiskiy
NR - Norilsk
OS - Orhon-Selenge (185-240, 250)
SX - Shanxi

Figure 9. Early Permian (275 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

rifts. The progressive wes to teastward closing of the Mongol-Okhotsk Ocean starting in the Late Permian is supported by paleomagnetic data (Zhao and others, 1990).

(2) A subduction zone formed along the northern margin of the Argun-Idermeg superterrane and is tectonically linked to the Permian East Mongolian volcanic belt (Mossakovskiy, 1975; Yarmolyuk, 1983; Zonenshain and others, 1990; Kovalenko and Yarmolyuk, 1990). The belt is conjugate to the more northerly North Gobi forearc basin that contains Mississippian and Pennsylvanian flysch and Permian and Early Triassic shallow marine sedimentary units with volcanic horizons (Mossakovskiy and Tomurtogoo, 1976). In the Argun region are widespread Undinsk granitoids (with Rb-Sr ages of 250 to 276 Ma; Dril' and others, 2000) that formed along an active continental margins (Efremov and others, 1998). The Undinsk granitoids are interpreted as being a continuation of the East Mongolian volcanic-plutonic belt. The Borzja Basin in the East Transbaikal region contains Late Permian marine sandstone, siltstone, and conglomerate, with bands of siliceous tuff, and is probably a forearc basin.

(3) Triassic granitoids and fragments of a Pennsylvanian-Permian magmatic arc occur along the eastern margin of the Bureya-Jiamusi superterrane and are probably tectonically linked to an outboard subduction zone (Khanchuk and others, 1989; Sun Jiapeng and others, 2000) that is also a continuation of the active continental margin.

(4) Paleomagnetic data indicate that the width of the Mongol-Okhotsk Ocean was greater than 4,000 km in the Late Permian (Ziegler and others, 1996; Şengör and Natal'in, 1996; Kravchinskiy and others, 2002a). Paleomagnetic data also indicate that the Argun-Idermeg superterrane, that forms the southern margin of the Mongol-Okhotsk collage, was located at approximately 20° N. latitude in the Late Permian (Kravchinskiy and others, 2002a,b). The superterrane contains numerous remains of Late Permian boreal brachiopods, bivalves, crinoids, and bryozoans. (Amantov and others, 1966; Durante, 1976; Meyen, 1970).

(5) Zonenshain and others (1976, 1985, 1990) interpret that the Mongol-Okhotsk collage formed progressively from west to east towards the Paleo-Pacific Ocean, from the Pennsylvanian through Jurassic (Zonenshain and others, 1990). The ocean was bordered by the giant Altai orocline that consisted of a sharp bend in the strike of the early Paleozoic orogenic belts. At the core of the orocline occurs a western or so-called blind termination of the Mongol-Okhotsk orogenic belt. Confined to the core of the Altai orocline are Pennsylvanian-Early Permian granitoids that intrude older, deformed rocks in the western Mongol-Okhotsk collage and the older units of the western and northern rims of the belt.

(6) The Mongol-Okhotsk collage contains a typical boreal late Paleozoic and early Mesozoic fauna. However, puzzling inclusions of carbonate rocks with Early Permian fusulinids are reported from subduction- zone terranes in the Dzhagdy Range (Kirillova and Turbin, 1979) and the East Transbaikal region (Amantov, 1963).

(7) The Pennsylvanian through Early Triassic Selenga volcanic-plutonic belt formed along the northern margin of the Mongol-Okhotsk collage and extends for 2,000 km in northern Mongolia and the Transbaikal region (Mossakovskiy, 1975; Mossakovskiy, Tomurtogoo, 1976; Kozubova and others, 1982; Yarmolyuk, 1983; Gordienko, 1987; Derbeko, 1998; Yarmolyuk and others, 2001). The belt consists of calc-alkaline rocks in the lower part of the section grading upward into bimodal alkaline rocks (Mossakovskiy, 1975; Kozubova and others, 1982; Kovalenko and others, 1983; Gordienko, 1987). The Selenga igneous belt formed along a transform fault along the continent-ocean boundary at the early stage of its development and graded into subduction beneath the continental margin.

(8) To the north of the Selenga volcanic-plutonic belt is the giant Late Pennsylvanian and Early Permian (290 to 320 Ma) Angara-Vitim batholith (Yarmolyuk and others, 1997) that formed synchronously with the Selenga belt (according to recent, extensive U-Pb zircons ages). To the northwest of the Angara-Vitim batholith, on the margin of the Siberian platform, is the late Paleozoic Nepa folded zone (Malykh, 1997).

(9) Also in the late Paleozoic, the Solon Ocean existed to the south of the Argun-Idermeg superterrane as indicated by Mississippian ophiolites with Tethyan fauna and Permian island-arc formations in the Solonker collage (Wang and Liou, 1986; Ruzhentsev and others, 1989; Badarch and others, 2002). The Solon Ocean was wide because paleomagnetic and paleobiogeographic data indicate that the Sino-Korean craton occurred in subtropical latitudes in the late Paleozoic, whereas in the areas to the north (present-day coordinates), the Solon Ocean was in a boreal paleobiogeographic province (Pavlova and others, 1986; Popeko and others, 1993; Xu Guirong and Yang Weiping, 1994; Popeko, 1996). The closure of the Solon Ocean and formation of the Solon collage occurred during subduction beneath bounding continental blocks (Chen and others, 2000).

(10) Along the northern margin of the Solon Ocean was the South Mongolian arc that contained Pennsylvanian calc-alkaline basalt, andesite, dacite, rhyolite, and Permian subalkaline and alkaline basalt, trachyrhyolite, comendite, and pantellerite (Kovalenko, Yarmolyuk, 1990; Kovalenko and others, 1995; Munkhtsengel and Iizumi, 1999). Southward the South Mongolian belt changes into a Permian forearc flysch basin. In Northeast China, the South Mongolian arc merged into the Permian Djikhey plutonic belt with granodiorite, monzogranite, and diorite with isotopic ages of 244 Ma (K-Ar) and 241 Ma (U-Pb) (Li and Zhao, 1989; Zhao and others, 1996).

(11) To the south of the Solon Ocean was the Pennsylvanian-Permian North marginal plutonic belt that formed along the margin of the Sino-Korean craton and the associated Wenduermiao collage (Cheng and others, 1994). The Solon Ocean closed in the Late Permian through Early Triassic, as indicated by paleomagnetic data showing that terranes in southern Mongolia and in the Sino-Korean craton had a single paleomagnetic pole in the Late Permian (Zhao and others, 1990). The

position of the pole significantly differs from that for the North Asian craton, Kazakhstan, and Europe.

(12) In the late Mississippian, after Devonian rifting, a large block, including the Okhotsk and Omolon cratonal and the Prikolyma and Omulevka passive continental-margin terranes, was detached from the eastern margin of the North Asian craton with clockwise rotation. As a result, the minor Oimyakon Ocean was formed, and that was separated from the Angayucham Ocean by the Omulevka ridge (Nokleberg and others, 2000). Also as a result of thermal subsidence following rifting, the Pennsylvanian Vilyui and Tunguska Basins formed on the North Asian craton, ending in the Permian.

(13) In the Verkhoyansk passive continental margin, thick grey clastic units accumulated and graded towards the adjacent ocean basin into turbidite and hemipelagic continental slope and rise deposits.

(14) In the Late Permian, the Kara terrane accreted to the northern margin of the North Asian craton with boundary diagonally cut by the Kara granitoid belt with isotopic ages of 264 Ma (U-Pb) and 258 to 252 Ma (Rb-Sr and Ar-Ar) (Vernikovskiy, 1996; Vernikovskiy and others, 1995, 1998).

(15) A huge and unique basalt eruption ($2x10^6$ to $3x10^6$ km^3) (Campbell and others, 1992) occurred on the northwestern North Asian craton at the Permian-Triassic boundary. The basalts are known as Siberian traps and are widespread in the Tungus Basin. The total thickness of lava sheets and tuffs locally reaches 3,000 m. The eastern, western and southern margins of the Tungus Basin are dominated by intrusive traps represented by extensive sills and rare dikes that mark a huge superplume.

Metallogenesis

Metallogenic Belts Related to Superplume

Four metallogenic belts (the Angara-Ilim, Kureisko-Tungsk, Maimecha-Kotuisk, and Norilsk belts) possess geologic units favorable for a wide variety of major trapp-magmatism-related deposits. The major mineral deposit types are mafic-ultramafic related Cu-Ni-PGE, Fe-Ti and phlogopite carbonatite, metamorphic graphite, basaltic native Cu (Lake Superior type), porphyry Cu-Mo, Fe-skarn, and weathering crust carbonatite REE-Zr-Nb-Li deposits. The isotopic ages of the deposits or hosting units range from Devonian through Early Carboniferous. The favorable geologic units and deposits are interpreted as having formed in a continental-margin or island-arc, or in associated arc-margin terranes. The deposits are related to replacements associated with the Tungus plateau basalt, sills, dikes, and intrusions that intrude or overlie the North Asian craton. The isotopic ages of the deposits or hosting units range from Permian through Triassic (260 to 200 Ma). The belts are interpreted as related to widespread development of trapp magmatism on the North Asian craton that occurred during intrusion of a superplume. The Norilsk belt contains the famous mafic-ultramafic related Cu-Ni-PGE deposits in the Norilsk district in northern Siberia.

Metallogenic Belts Related to Selenga and South Mongolian Continental-Margin Arcs

Four metallogenic belts (the Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia and Orhon-Selenge belts) possess geologic units favorable for a wide variety of granitic magmatism-related deposits. The major mineral deposit types are Fe-Zn-skarn; Sn-skarn; Zn-Pb skarn; W-skarn; Cu-skarn; porphyry Cu-Mo; porphyry Mo; Au-skarn; granitoid related Au-vein; W-Mo-Be greisen, stockwork, and quartz-vein; peralkaline granitoid-related; REE-Li pegmatite; and basaltic native Cu (Lake Superior type) deposits. The belts are hosted in granitoids in the Selenga sedimentary-volcanic-plutonic belt that constitutes the Selenga continental-margin arc that formed on the Yenisey-Transbaikal and Tuva-Mongolia collages. The isotopic ages of the deposits or hosting units range from 240 to 285 Ma. The belts are interpreted as having formed during transform-faulting and oblique subduction of oceanic crust of the Mongol-Okhotsk Ocean plate under the southern margin of the North Asian craton and cratonal margin and previously accreted terranes.

The Harmagtai-Hongoot-Oyut metallogenic belt (with porphyry Cu-Mo and Au, granitoid-related Au, and Au-Ag epithermal Au deposits) is hosted in granitoids related to the South-Mongolian volcanic-plutonic belt and is interpreted as having formed in the South Mongolian continental-margin arc that formed along the northern margin (present-day coordinates) of the Mongol-Okhotsk Ocean.

Metallogenic Belts Related to Island Arcs

Three metallogenic belts (the Duobaoshan, Hitachi, and Kalatongke belts) possess geologic units favorable for a wide variety of granite- and mafic- plutonic-related deposits, and volcanogenic massive sulfide deposits. The major deposit types are porphyry Cu-Mo; granitoid-related Au-vein; mafic-ultramafic related Cu-Ni-PGE; and volcanogenic Zn-Pb-Cu massive sulfide deposits. The isotopic ages of the igneous rocks that host the deposits range from Pennsylvanian through Permian. The belts are interpreted as having formed in a chain of island arcs that formed south (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. The island arcs were in the Duobaoshan terrane (part of the South Mongolia-Khingan collage), the South Kitakami terrane (part of the Bureya-Jiamusi supterterrane), and the Waizunger-Baaran terrane (part of the Atasbogd collage).

Metallogenic Belt Related to Collision of Cratons

The Altai metallogenic belt (with REE-Li pegmatite, and muscovite pegmatite deposits) is hosted in veins, dikes, and replacements related to Late Carboniferrous granitoids in the Altai volcanic-plutonic belt that intrudes the Altai continental-margin turbidite terrane. The belt is interpreted as having formed during intrusion of collisional granite that formed during collision of the Kazakhstan and North Asian cratons, resulting in high-grade metamorphism with crustal melting and generation of anatectic granite

Metallogenic Belt Related to Weathering

The Shanxi metallogenic belt (with sedimentary bauxite deposits) is hosted in Pennsylvanian stratiform units in the upper part of the Sino-Korean Platform overlapping the Sino-Korean craton and the West Liaoning terrane. The belt is interpreted as having formed during weathering of metamorphic rocks of the Northern China Platform. Bauxite deposits are hosted in karst and lagoonal basins in a littoral-shallow sea.

Late Triassic through Middle Jurassic (230 to 154 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Late Triassic through Middle Jurassic (fig. 10) were as follows.

(1) Accretion of the Argun-Idermeg superterrane (Amur microcontinent composed of Agun and Idermeg passive continental-margin terranes), the Bureya-Jiamusi supterterrane, and the Sino-Korean craton.

(2) Continuation of closure of the Mongol-Okhotsk Ocean and continuation of an extensive, mainly right-lateral series of transform faults along the western, closed part of the ocean.

(3) Inception of the Uda-Murgal continental-margin and island-arc system.

(4) Continuation of the Alazeya island arc.

(5) Collision between the North Asian craton and the Kara superterrane with formation of post-collisional granitoid intrusions (with isotopic ages of about 223 to 233 Ma).

Important Geologic Details

(1) The Mongol-Okhotsk collage continued to form and was accompanied by left-lateral strike-slip faulting along the Major Mongol-Okhotsk and the Kuznetsk-Altai faults, Irtysh crush zone, and associated faults. In the late Middle Jurassic, the last part of the ocean closed in the east part of the collage, as indicated by paleomagnetic data (Zhao and others, 1990). However, recent paleomagnetic data indicate that the width of the Mongol-Okhotsk Ocean was about 3,000 km until the late Late Jurassic (Kravchinskiy and others, 2002a). The data contradict geological observations.

(2) In the Late Triassic, to the east of the eastern margin of the North Asian craton and cratonal margin, the Ancestral Pacific Ocean plate began migrating toward the margins of the North Asian craton and cratonal margin. As a result, a new system of subduction-related magmatic arcs formed along the continental margin (Parfenov and others, 1999a; Nokleberg and others, 2000).

(3) As a result of the migration of the Ancestral Pacific Ocean Plate, on the eastern margin of the the North Asian craton and cratonal margin, the Uda-Murgal arc and the Alazeya island arc formed. In the late Middle Jurassic, collision and amalgamation of the Alazeya island arc with the Omulevka Ridge and the Prikolyma and Omolon terranes produced the Kolyma-Omolon superterrane (Parfenov, 1991). From 180 to 135 Ma, convergence occurred between the northeastern margin of Asia and the northeastward moving Farallon plate (Engebretson and others, 1985), thereby resulting in oblique subduction beneath the active continental margin.

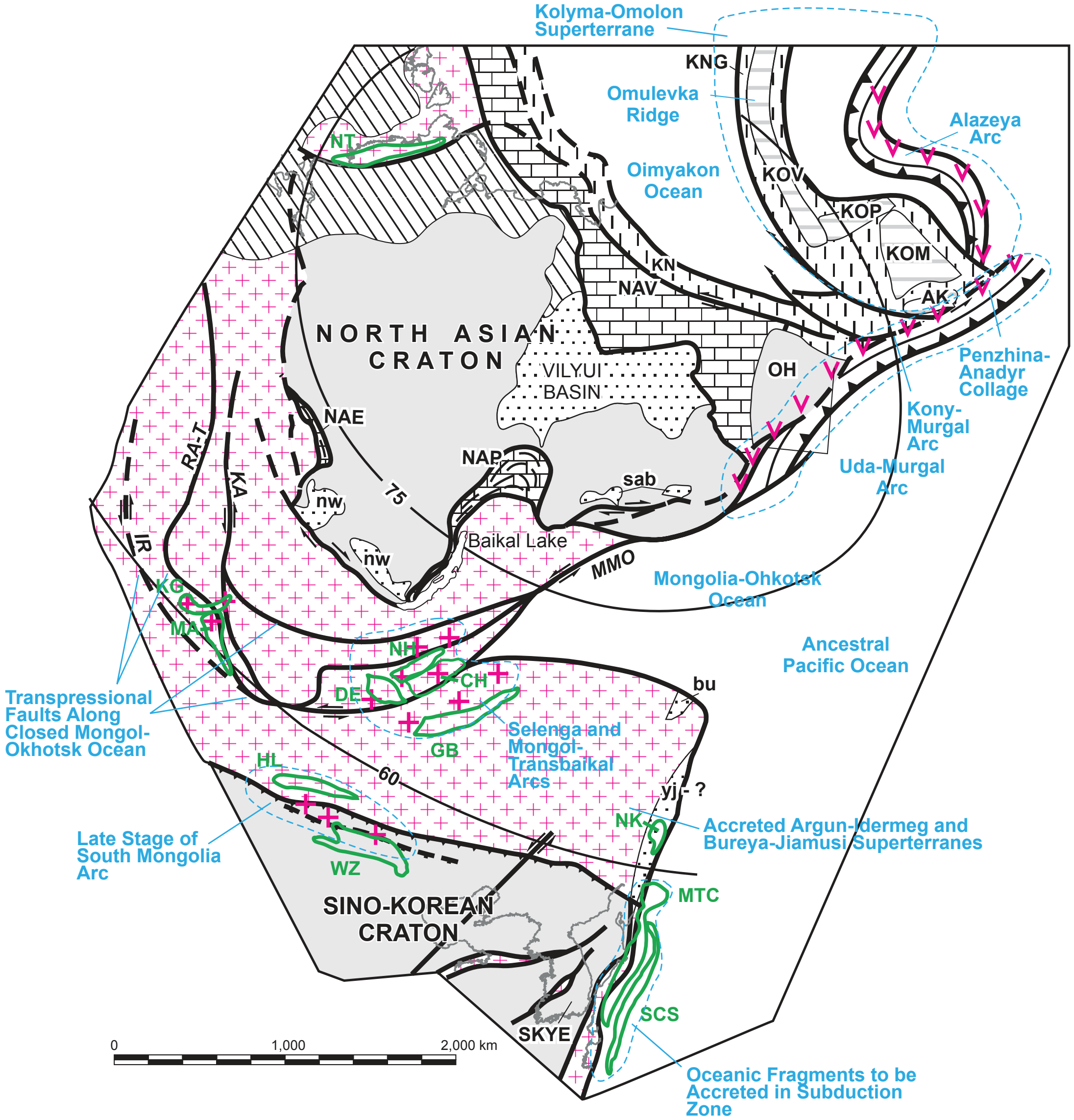
Major Late Triassic through Middle Jurassic Metallogenic Belts

Metallogenic Belts Related to Transpressional Arc and Faults Caused by Closure of Mongol-Okhotsk Ocean

Collision caused by the closure of the Mongol-Okhotsk Ocean resulted in the formation of the Late Triassic through Early Jurassic Mongol-Transbaikal volcanic-plutonic belt along with formation of numerous intraplate strike-slip fault zones and related transpression and transtension zones and related metallogenic belts.

In this area, (figs. 4, 10), five metallogenic belts (the Central Henti, Delgerhaan, Govi-Ugtaal-Baruun-Urt, Harmorit-Hanbogd-Lugiingol, and North Hentii belts) possess geologic units favorable for a wide variety of granite-related deposits. The major deposit types are porphyry Cu; granitoid-related Au; Au in shear zone and quartz-vein; Fe-Zn-skarn; Cu-skarn; Zn-Pb skarn; Sn-skarn; Sn-W greisen, stockwork, and quartz-vein; W-skarn; Ta-Nb-REE akaline metasomatite; REE carbonatite;peralkaline granitoid-related Nb-Zr-REE; and REE-Li pegmatite. The isotopic ages of the igneous rocks that host the deposits range from 199 to 242 Ma. The belts are hosted in the Late Triassic through Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt that constitutes a major part of the Mongol-Transbaikal transpressional arc that is interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.

Two more metallogenic belts (the Kalgutinsk and Mongol Altai belts) possess geologic units favorable for a wide variety



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Intracontinental Sedimentary Basin

bu - Bureya sedimentary basin (Early Jurassic to Early Cretaceous)
nw - Western Siberia sedimentary basins (Mesozoic and Cenozoic)
sab - South Aldan sedimentary basin (Jurassic)
yj - Yanji-Jixi-Raohe overlap sedimentary assemblage (Mesozoic and Cenozoic)

Terranes and Superterranes

AK - Avekov terrane
KN - Kular-Nera terrane (Continental-margin turbidite) (Permian through Early Jurassic)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
OH - Okhotsk terrane
SKYE - Yeongnam terrane (Granulite-paragneiss) (Late Archean to Paleoproterozoic)

Strike-slip Fault and Shear Zone

IR - Irtysh shear zone
KA - Kuznetsk-Altai
MMO - Main Mongol-Okhotsk
RA-T - Rudny Altai - Taimyr

METALLOGENIC BELTS

CH - Central Hentii
DE - Delgerhaan
GB - Govi-Ugtaal-Baruun-Urt
HL - Harmorit-Hanbogd-Lugiingol
KG - Kalgutinsk
MTC - Mino-Tamba-Chugoku
MA - Mongol Altai
NH - North Hentii
NK - North Kitakami
NT - North Taimyr
SCS - Sambagawa-Chichibu-Shimanto
WZ - Wulashan-Zhangbei

Figure 10. Late Triassic (210 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

of granite-related deposits. The major mineral deposit types are W-Mo-Be greisen, stockwork, and quartz-vein; Ta-Nb-REE alkaline metasomatite; and Sn-W greisen, stockwork, and quartz-vein deposits). The isotopic ages of the igneous rocks that host the deposits range from 183 to 204 Ma. The belts are hosted in small granitoids that intruded along major transpressional fault zones (Hovd regional fault zone and companion faults) with a combination of strike-slip, extensional, and compressional displacements. The transpressional fault zones strike northwest (present-day coordinates).

Metallogenic Belt Related to Superterrane Accretion

The North Taimyr metallogenic belt possesses geologic units favorable for granite-related deposits (W-Mo-Be greisen, stockwork, and quartz-vein; W-skarn; and porphyry Cu-Mo). The isotopic ages of the host granitoids range from 223 to 233 Ma (Vernikovskiy, 1996). The belt is interpreted as having formed during generation of granitoids during and after accretion of the Kara superterrane with the North Asian craton.

Metallogenic Belts Related to Oceanic Crust

The Sambagawa-Chichibu metallogenic belt possesses geologic units favorable for stratiform sediment-hosted deposits (Besshi Cu-Zn-Ag massive sulfide, volcanogenic-sedimentary Mn, Cyprus Cu-Zn massive sulfide) that are now preserved in younger subduction-zone terranes. These terranes are the Shimanto subduction-zone terrane (part of the Sakhalin-Hokkaido collage), the Mino Tamba Chichibu subduction-zone terrane (part of the Honshu-Sikhote-Alin collage), and the Sambagawa metamorphic terrane (part of the Honshu-Sikhote-Alin collage. The age of the host rocks for the deposits is interpreted as beinig Early Jurassic and younger. The Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor, and the Besshi (fig. 5) and Cyprus deposits are interpreted as having formed during submarine volcanism related to an ocean-spreading ridge.

The North Kitakami metallogenic belt possesses geologic units favorable for Besshi Cu-Zn-Ag massive sulfide, volcanogenic-sedimentary Mn, and Cyprus Cu-Zn massive sulfide deposits. The belt and deposits are hosted in the Mino Tamba Chichibu subduction-zone terrane, part of the Honshu-Sikhote-Alin collage. The Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor. The kuroko deposits formed in an island arc. The deposits were subsequently incorporated into the subduction zone.

The Mino-Tamba-Chugoku metallogenic belt (with volcanogenic-sedimentary Mn, podiform chromite, and Besshi massive sulfide deposits) is hosted in the Mino Tamba Chichibu subduction-zone terrane, part of the Honshu-Sikhote-Alin collage, that contains fragments of late Paleozoic and early Mesozoic oceanic crust in which these deposits originally formed.

Late Jurassic through Early Cretaceous (154 to 105 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Late Jurassic through Early Cretaceous (fig. 11) were as follows.

(1) Final closure of the Mongol-Okhotsk Ocean with resultant displacement of collisional processes eastward.

(2) Formation of the collisional Stanovoy granite belt, composed predominantly of granodiorite, granite, and granosyenite along the southern margin of the Aldan-Stanovoy shield of the North Asian craton and westward into the eastern Transbaikalia region.

(3) Continued formation of the Transbaikal volcanic-plutonic belt along the axis of the closed Mongol-Okhotsk Ocean in a transpressional-fault setting.

(4) Continued formation of transpressional fault zones along the axis of the closed Mongol-Okhotsk Ocean.

(5) Postcollisional transform faulting along within-plate transpression zones in northeast China.

(6) Accretion of the Kolyma superterrane and Okhotsk cratonal terrane against the Verkhoyansk (North Asian) cratonal margin and formation of collision-related granitoids and volcanic units.

(7) Formation of the Oloy continental-margin arc along the outboard edge of the accreted Kolyma-Omolon superterrane.

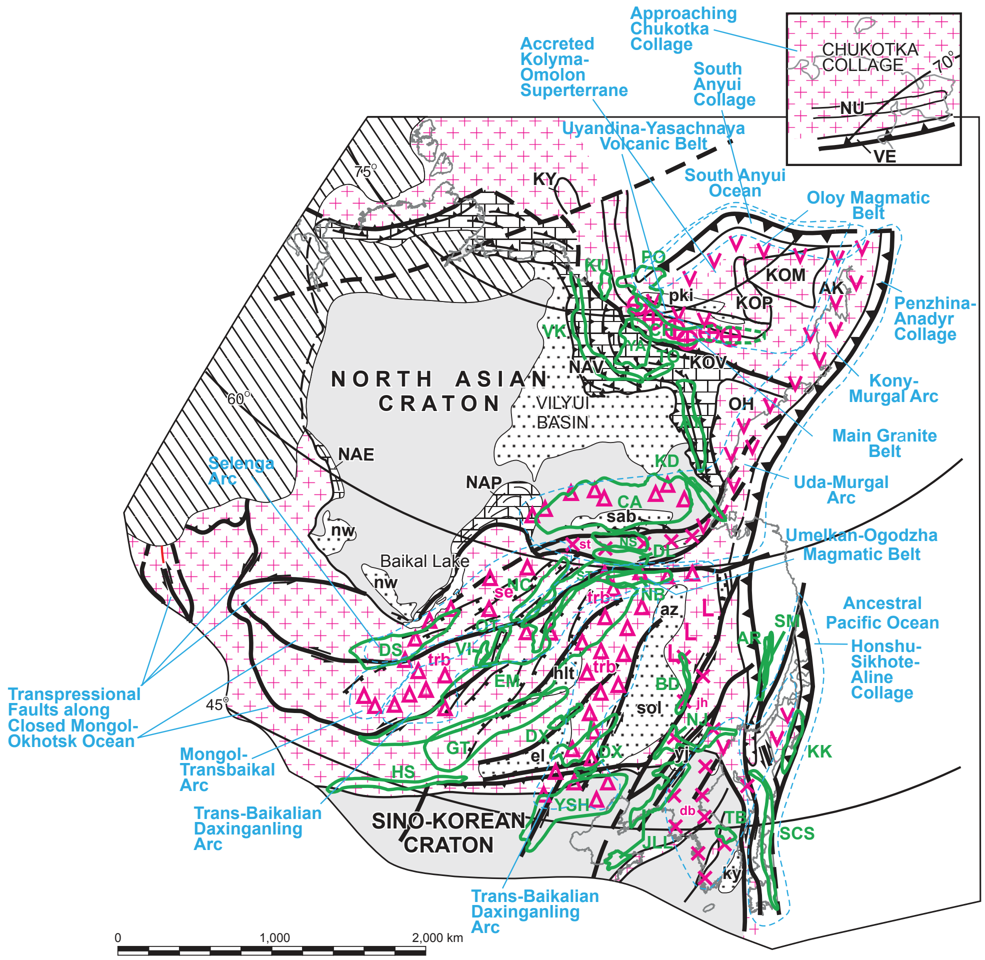
(8) Continued formation of the Uda-Murgal continental-margin arc and associated metallogenic belts.

(9) Beginning of underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along the Khingan transform continental margin in the Russian Far East.

(10) Formation of oceanic lithosphere that is now preserved as tectonic fragments in subduction-zone terranes.

Important Geologic Details

(1) The Kolyma-Omolon superterrane was accreted onto the Verkhoyansk cratonal margin. During convergence and accretion, the Uyandina-Yasachnaya arc was formed on the superterrane margin and was tectonically linked to the



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Intracontinental Sedimentary Basins

az - Amur-Zeya sedimentary basin (Late Jurassic to Quaternary)
el - Erlian sedimentary basin (Jurassic through Quaternary)
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
ky - Kyongsang sedimentary basin (Early Cretaceous)
nw - Western Siberia sedimentary basins (Mesozoic and Cenozoic)
pki - Ilin'-Tas back-arc basin (Late Jurassic)
sab - South Aldan sedimentary basin (Jurassic)
sol - Songliao sedimentary basin (Jurassic through early Tertiary)

Terranes and Superterranes

AK - Avekov terrane
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
NU - Nutesyn terrane
OH - Okhotsk terrane
VE - Velmay terrane

Overlap Continental-Margin Arcs and Granite Belts

db - Daebo granite belt (Early to Late Jurassic)
jh - Jihei volcanic and plutonic belt (Mesozoic)
se - Selenga sedimentary-volcanic plutonic belt (Permian through Jurassic)
st - Stanovoy granite belt (Jurassic and Early Cretaceous)
trb - Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt (Middle Jurassic through Early Cretaceous)

METALLOGENIC BELTS

AR - Ariadny
AY - Allakh-Yun'
BD - Bindong
CA - Chara-Aldan
CH - Chybagalakh
DL - Djeltulaksky
DS - Dzid-Selenginskiy
DX - Daxinganling
EM - East Mongolian-Priargunskiy-Deerbugan
GT - Govi-Tamsag
HS - Hartolgoi-Sulinheer
JLL - Jiliaolu
KD - Kondyor-Feklistov
KK - Kitakami
KU - Kular
NB - North Bureya
NC - Nerchinsky
NJ - North Jilin
NS - North Stanovoy
OT - Onon-Turinskiy
PO - Polousny
SCS - Sambagawa-Chichibu-Shimanto
SM - Samarka
ST - Shilkinsko-Tukuringrskiy
TB - Taebaegsan
TO - Tompo
VI - Verkhne-Ingodinsky
VK - Verkhoyansk
YA - Yana-Adycha
YSH - Yanshan

Figure 11. Late Jurassic (145 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

subduction of the Oimyakon Ocean Plate. Accretion of the Kolyma-Omolon superterrane ended in the latest Late Jurassic with formation of the Main granite belt that consists mainly of peraluminous collisional granitoids with $^{40}Ar/^{39}Ar$ isotopic ages of 135 to 145 Ma (Layer and others, 2001).

(2) After accretion of the superterrane, the northern margin of the North Asian craton and cratonal margin was defined by the Late Jurassic through Neocomian Oloy arc that was tectonically linked to subduction of the South Anyui Ocean Plate.

(3) The Uda-Murgal arc contined to form along the eastern margin of the Northeast Asia and was tectonically linked to subduction of the Ancestral Pacific Ocean Plate. This arc extended southwestward into the continent into the Stanovoy plutonic belt. In the back arc area, the South Aldan coal basin formed during the Jurassic-Early Neocomian. Also in this area, Jurassic-Neocomian subalkaline and alkaline magmatism occurred in the Aldan shield and Omolon cratonal terrane (Terekhov and others, 1984).

(4) From 145 to 135 Ma, the western Ancestral Pacific Ocean and Farallon Ocean Plates continued northeastward migration, and from 135 to 100 Ma, the Izanagi Plate migrated at an oblique angle to the continental margin (Engebretson and others, 1985; Maruyama and Seno, 1986). Consequently, the extensive Kema transform continental margin arc formed south and was tectonically linked to a Late Jurassic-Early Neocomian subduction zone that consisted of schistose turbidites with fragments of Pennsylvanian and Permian limestone with Tethyan fauna, Permian-Middle Jurassic jasper, and ophiolites (Shevelev and Kuzmin, 1990; Natal'in, 1991; Kemkin and Khanchuk, 1993; Kirillova and others, 1996; Isozaki, 1997; Kemkin and Filippov, 2002). In the Late Jurassic-Berriasian, a zone of mixing of Boreal and Tethyan faunas existed here (Zakharov and others, 1996, Kirillova, 2000).

(5) Also in the Late Jurassic-Early Cretaceous, left-lateral strike-slip faulting continued along the eastern segment of the Major Mongol-Okhotsk fault. Farther west in the Transbaikal region and Mongolia, the faulting graded into a zone of crustal extension. As a result, a series of one-sided and two-sided grabens, with east-west to northeast strikes, formed and were filled with Late Jurassic-Early Cretaceous bimodal volcanic and continental clastic units.

(6) Farther south, in the Mongol-Okhotsk collage, a system of large grabens formed and extended northeastward for 1500 km, roughly parallel to the continent-ocean boundary. The grabens contain Late Jurassic continental volcanic and sedimentary units and Cretaceous sedimentary rocks up to 3-10 km thick (Liu Li and others, 1994; Liu and others, 1996, Sun and others, 1997; Tian and Zhong, 1997). To the west, the Late-Jurassic-Early Cretaceous Bolshoy Khingan volcanic belt extended parallel to the grabens. This belt contains basalt, trachyandesite, trachydacite, and dacite with K-Ar isotopic ages of about 150 Ma (Xu Wenliang and others, 1994; Hung and others, 2000). This large zone of crustal extension, that grades into graben systems in the Transbaikal region and Mongolia is analogus to the late Cenozoic Basin and Range Province of the western USA. The extension zone is probably the result of subduction of a "slab window" that formed during subduction of an oceanic ridge beneath the eastern margin of Asia in the late Paleozoic through early Mesozoic. The detachment probably occurred in the Late Triassic through Middle Jurassic during the changing kinematics of the plate motions in the western Ancestral Pacific Ocean.

Metallogenesis

Metallogenic Belts Related to Trans-Baikalian-Daxinganling Transpressional Arc

Eleven metallogenic belts (the Daxinganling, Dzid-Selenginski, East Mongolian-Priargunskiy-Deerbugan, Govi-Tamsag, Hartolgoi-Sulinheer, Nerchinsky, Onon-Turinskiy, Shilkinsko-Tukuringrskiy, and Verkhne-Ingodinsky belts) possess geologic units favorable for a wide variety of siliceous igneous-rock related deposits. The major types of deposits are Au-skarn; Zn-Pb (±Ag, Cu) skarn; W±Mo±Be-skarn; Au-Ag epithermal; cassiterite-sulfide-silicate-vein and stockwork; fluorspar-vein; granitoid-related Au-vein; peralkaline granitoid-related Nb-Zr-REE; polymetallic metasomatite; polymetallic Pb-Zn-vein and stockwork; porphyry Au; porphyry Cu-Mo, Mo, and Au; sediment-hosted U; Sn-skarn; Sn-W greisen, stockwork, and quartz-vein; Ta-Nb-REE alkaline metasomatite; volcanic-hosted Au-base-metal metasomatite; carbonate-hosted Ag-Pb and Hg-Sb; volcanic-hosted zeolite; W-Mo-Be greisen, stockwork, and quartz-vein; W-skarn; and Zn-Pb-skarn. The isotopic ages of the igneous rocks that host the deposits range from 125 to 190 Ma. The belts are hosted in the major Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlaps terranes that were previously accreted to the southern (present-day coordinates) North Asian craton and cratonal margin. The host rocks and metallogenic belts are interpreted as having formed along the major Trans-Baikalian-Daxinganling transpressional arc that formed along the major Mongol-Okhotsk suture that cuts previously accreted terranes south of the southern margin (present-day coordinates) of the North Asian craton and cratonal margin. Displacement along the suture and arc formation occurred after the closing of the Mongol-Okhotsk Ocean

Metallogenic Belts Related to Accretion of Kolyma-Omolon Superterrane and Okhotsk Terrane

Eight metallogenic belts (the Allakh-Yun, Chybagalakh, Kular, Polousny, South Verkhoyansk, Tompo, Verkhoyansk, and Yana-Adycha belts) possess geologic units favorable for a wide variety of Au-vein deposits and collisional granite-related deposits. The major mineral deposit types are Au in shear zone and quartz-vein; granitoid-related Au-vein; Cu-skarn; Au in black shale; W-skarn; polymetallic Pb-Zn-vein and stockwork;

cassiterite-sulfide-silicate-vein and stockwork; Sn-W greisen, stockwork, and quartz-vein; W-Mo-Be greisen, stockwork, and quartz-vein; and Au-Ag epithermal-vein. The ages of the veins and associated granites range from Late Jurassic through Aptian. The belts and deposits are hosted in veins and granitoids (such as the South Verkhoyansk, Main, and Northern granite belts) that intrude the Verkhoyansk (North Asian) cratonal margin and/or the margin of the adjacent Kolyma-Omolon superterrane. The host rocks and metallogenic belts are interpreted as having formed during collision and accretion of the Kolyma-Omolon superterrane to the North Asian cratonal margin that resulted in regional metamorphism and generation of anatectic granitoids and related hydrothermal fluids. The Allakh-Yun and South Verkhoyansk metallogenic belts are interpreted as having formed immediately before the accretion of the Okhotsk terrane to the North Asian cratonal margin.

Metallogenic Belts Related to Uda-Stanovoy Continental-Margin Arc

Three metallogenic belts (the Chara-Aldan, Djeltulaksky, and North Stanovoy belts) possess geologic units favorable for granitoid-related deposits. The major mineral deposit types are granitoid-related Au-vein; Au-Ag epithermal-vein; Au-skarn; Au in shear zone and quartz-vein; Au potassium metasomatite; and charoite metasomatite. The isotopic ages for the granitoids hosting or related to the deposits range from Jurassic through Early Cretaceous. These metallogenic belts are interpreted as having formed during intrusion of granitoids of the Stanovoy granite belt that was part of the Uda-Stanovoy continental-margin arc. The arc is interpreted as having formed during subduction and closure of the Mongol-Okhotsk Ocean beneath the North Asian craton to the north (present-day coordinates).

Metallogenic Belts Related to Transpression

Four metallogenic belts (the Jiliaolu, North Jilin, Samarka, and Yanshan belts) possess geologic units favorable for a wide variety of transpressional granitoid-related deposits. The major mineral deposit types are Au-Ag epithermal-vein; Cu-skarn; W-skarn; fluorspar-vein; granitoid-related Au-vein;, polymetallic Pb-Zn-vein and stockwork; polymetallic volcanic-hosted metasomatite; porphyry Cu and Cu-Mo; W-skarn; and Zn-Pb-skarn. The isotopic ages for the granitoids hosting the deposits range from 110 to 186 Ma. The granitoids and veins intrude either overlap assemblages on the Sino-Korean craton or the Samarka subduction-zone terrane (part of Honshu-Sikhote-Alin collage). The metallogenic belts are interpreted as having formed during intrusion of granitoids along transpressional zones along microplate boundaries, underthrusting of the Kula oceanic ridge, and formation of bimodal igneous rocks along a transform continental margin, or during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic Plate beneath the Eurasian Plate.

Unique Metallogenic Belts

Six unique metallogenic belts formed during this time span. (1) The Kondyor-Feklistov belt, with zoned mafic-ultramafic Cr-PGE deposits, is hosted in mafic-ultramafic intrusions and is interpreted as having formed during intrusion of mafic-ultramafic plutons along a deep-seated fault that formed along the North Asian cratonal margin during collision and accretion of outboard terranes. (2) The North Bureya belt, with Au-Ag epithermal-vein and granitoid-related Au-vein deposits, is hosted in the Umlekam-Ogodzhin volcanic-plutonic belt. The belt is interpreted as having formed during formation of the Umlekan-Ogodzhin continental-margin arc that formed during subduction of part of the Ancestral Pacific Ocean plate. (3) The Ariadny belt, with mafic-ultramafic rock-related deposits, is hosted in Middle Jurassic and Early Cretaceous plutons intruding the Samarka subduction-zone terrane, part of the Honshu-Sikhote-Alin collage. The belt is interpreted as having formed during generation of ultramafic and gabbroic plutons during underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along a transform continental margin. (4) The Taebaegsan belt, with a wide assortment of granitoid-related deposits, is hosted in the Daebo granite and is interpreted as having formed during intrusion of granitoids associated with Late Jurassic through Early Cretaceous Daebo granite. The granitioid are interpreted as being part of a continental-margin arc that was linked to subduction of the Ancestral Pacific Ocean plate. (5) The Kitakami belt, with Cu-skarn and granitoid-related Au deposits, is hosted in the Early Cretaceous Hiroshima granite belt (with isotopic ages of 110 to 120 Ma) and is interpreted as having formed during intrusion of granitoids associated with a continental-margin arc and siliceous magmatism. (6) The Bindong belt, with Zn-Pb (±Ag, Cu) skarn and W±Mo±Be-skarn deposits, is hosted in small granitoids in the Mesozoic Jihei volcanic and plutonic belt and is interpreted as having formed during interplate extensional tectonism and generation of subalkaline to alkaline volcanism and related sedimentation along northeast and east-west regional faults.

Cenomanian through Campanian (97 to 74 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Cenomanian through Campanian (fig. 12) were as follows.

(1) Formation of granitoids along the the Khingan transform continental-margin arc in response to oblique subduction of the Ancestral Pacific Ocean Plate in the Russian Far East.

(2) After accretion of the Kolyma-Omolon superterrane and the Okhotsk terrane, and accretion of the Koryak collage (composed of Late Jurassic and Early Cretaceous island-arc and tectonically-linked subduction-zone terranes) in the Late Jurassic and Early Cretaceous, outboard stepping of subduction and formation of the major Late Cretaceous and early Tertiary Okhotsk-Chukotka continental-margin arc.

(3) After accretion of the Bureya-Jiamusi supterterrane and the Sino-Korean craton in the Late Jurassic through Early Cretaceous, and accretion of outboard terranes, outboard stepping of subduction and formation of the East Sikote-Alin continental-margin arc (containing the East Sikote-Alin volcanic-plutonic belt).

(4) Formation of major back-arc basins in the Russian Northeast behind the Okhotsk-Chukotka continental-margin arc and in northern China behind the East Sikhote-Alin continental-margin arc.

(5) Late-stage continuation of transpressional-fault zones along the axis of the closed Mongol-Okhotsk Ocean.

(6) Postcollisional transform faulting along within-plate transpression zones in northeast China.

(7) In the late part of this time span, in the area of the East Sikhote-Alin fault, formation of a major continental-margin transform-fault system in the Russian Southeast along with generation of granitic and volcanic rocks.

(8) Rifting and formation of the Eurasian Basin and formation of the Arctic Ocean.

(9) In the area to become Japan, accretion of the Honshu-Sikhote-Alin collage that is composed mainly of island-arc, continental-margin turbidite (flysch), and subduction-zone terranes.

Important Geologic Details

(1) After closure of the South Anyui Ocean, that led to the formation of the South Anyui and Penzhina-Anadyr orogenic belts, the large Eastern Asian active continental margin formed along the western margin of the Ancestral Pacific Ocean. This arc extended from South China through Korean peninsula and eastern Sikhote-Alin region to Chukotka and farther into western Alaska (Parfenov and others, 1999a; Nokleberg and others, 2000).

In eastern Northeast Asia, the East Asian active continental margin consists of the East Sikhote-Alin arc to the south and the Okhotsk-Chukotka arc to the north. Associated with the arcs are Late Cretaceous coal-bearing forearc basins--the Penzhina Basin to the north and the West Sakhalin-Ezo and Izumi Basins to the south.

(2) In the rear of the active continental margin, the Indigirka crust extension belt formed and extended from the Laptev Sea shelf southeastward to the Okhotsk-Chukotka arc. The belt contains a series of grabens that on the Laptev shelf and the adjacent area are filled with thick Aptian-Albian and the lowermost Late Cretaceous sedimentary units (Drachev and others, 1998; Drachev, 1999) and, to the south, contains linear and isometric magmatic zones with Aptian-Late Cretaceous and, presumably, Paleogene subalkaline and alkaline volcanic and plutonic rocks and anorogenic alkaline granitoids [Tectonics, geodynamics, and metallogeny of the territory of the Sakha Republic (Yakutia), 2001]. Formation of the Indigirka belt is related to crustal extension that predated the opening of the Eurasia Ocean in the Arctic.

(3) In the Late Cretaceous, onto the northern margin of this arc was accreted the Koryak collage (containing the Mainitskiy island arc, Alkatvaam turbidite, and Ekonay subduction-zone terranes). Similar accreted terranes may occur in the Sea of Okhotsk (Maruyama and others, 1997; Fujita and others, 1983).

(4) Opening of the Eurasian Basin along the margin of the North American cratonal margin (not shown in fig. 12) (Nokleberg and others, 2000).

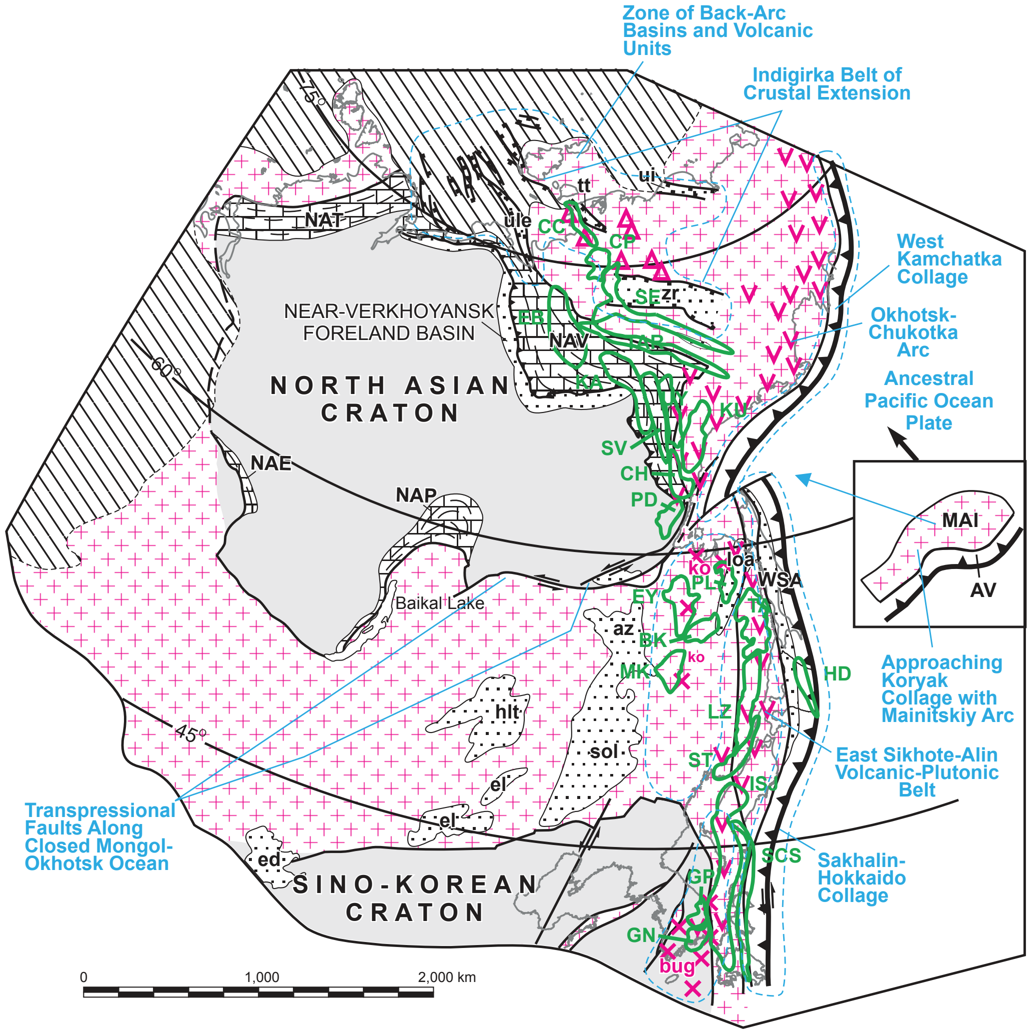
Metallogenesis

Metallogenic Belts Related to Okhotsk-Chukotka and East Sikhote-Alin Continental-Margin Arcs

Seven metallogenic belts (the Chelasin, Kukhtuy-Uliya, Luzhkinsky, Preddzhugdzhursky, Sergeevka-Taukha, Tumnin-Anyuy, and Upper Uydoma belts) possess geologic units favorable for a wide variety of granitoid-related deposits. The major mineral deposit types are Au-Ag epithermal-vein; boron (datolite) skarn; cassiterite-sulfide-silicate-vein and stockwork; granitoid-related Au-vein; polymetallic Pb-Zn-vein and stockwork; polymetallic volcanic-hosted metasomatite; porphyry Cu, Cu-Mo, and Mo; Cu-skarn; porphyry Sn; Sn-W greisen, stockwork, and quartz-vein; Sn-B-skarn; W-Mo-Be greisen, stockwork, and quartz-vein; and Zn-Pb-skarn. The ages of the associated granites range from mid-Cretaceous through Paleocene. The belts and deposits are hosted in granitoids in the Okhotsk-Chukotka volcanic-plutonic belt, or in the East Sikhote-Alin volcanic-plutonic belt. Both units are major overlap assemblages in the Russian Far East and are interpreted as part of the extensive, nearly coeval, and colinear continental-margin Okhotsk-Chukotka and East Sikhote-Alin arcs that overlie the North Asian craton and cratonal margin and previously accreted terranes to the east (present-day coordinates).

Metallogenic Belts Related to Opening of the Eurasin Basin

Four metallogenic belts (the Central Polousny, Chokhchur-Chekurdakh, Eckyuchu-Billyakh, Khandyga, and



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental Sedimentary Basins

az - Amur-Zeya sedimentary basin (Late Jurassic to Quaternary)
ed - Erduosi sedimentary basin (Triassic through Cretaceous)
el - Erlian sedimentary basin (Jurassic through Quaternary)
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
loa - Lower Amur overlap assemblage (Late early and early Late Cretaceous)
sol - Songliao sedimentary basin (Jurassic through early Tertiary)
tt - Tastakh Basin
ui -Ust-Indigirka Basin
ule - Ust-Lena Basin
zr - Zyryanka sedimentary basin (Late Jurassic through Cenozoic)

Terranes

AV - Alkatvaam terrane
MAI - Mainitskiy terrane
WSA - West Sakhalin terrane (Accretionary wedge, type A) (Cretaceous)

Overlap Continental-Margin Arcs and Granite Belts

ko - Khingan-Okhotsk volcanic-plutonic belt (Cretaceous)
bug - Bulgugsa granite (Late Cretaceous

METALLOGENIC BELTS

BK - Badzhal-Komsomolsk
CC - Chokhchur-Chekurdakh
CH - Chelasin
CP - Central Polousny
EB - Eckyuchu-Billyakh
EY - Ezop-Yam-Alin
GN - Gyeongnam
GP - Gyeongpuk
HD - Hidaka
ISJ - Inner Zone Southwest Japan
KA - Khandyga
KU - Kukhtuy-Uliya
LZ - Luzhkinsky
MK - Malo-Khingan
PD - Preddzhugdzhursky
PL - Pilda-Limuri
SCS - Sambagawa-Chichibu-Shimanto
SE - Selennyakh
ST - Sergeevka-Taukha
SV - South Verkhoyansk
TA - Tumnin-Anyuy
TAR - Taryn
UY - Upper Uydoma

Figure 12. Santonian (87 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

Selennyakh belts) possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits. The major mineral deposit types are Ag-Sb-vein; Au-Ag epithermal-vein; carbonate-hosted As-Au metasomatite; cassiterite-sulfide-silicate-vein and stockwork; clastic sediment-hosted Hg±Sb and Sb-Au; Hg-Sb-W-vein and stockwork; polymetallic Pb-Zn-vein and stockwork; carbonate-hosted Hg-Sb; volcanic-hosted Hg; and Sn-W greisen, stockwork, and quartz-vein. The isotopic ages for the vein deposits range from 97 to 120 Ma and the interpreted ages for the deposits range from Aptian through Late Cretaceous. The belts and deposits are hosted in units that intrude the Northern and Transverse granite belts, the Svyatoi Nos volcanic belt, and the Uyandina-Yasachnaya volcanic belt that intrude or overlie the Verkhoyansk (North Asian) cratonal margin and outboard accreted terranes. The belts are interpreted as having formed during extension related to the formation of the Eurasia Basin during initial opening of the Arctic Ocean.

Metallogenic Belts Related to the Khingan Continental-Margin Arc

Four metallogenic belts (the Badzhal-Komsomolsk, Ezop-Yam-Alin, Malo-Khingan, and Pilda-Limuri belts) possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits. The major mineral deposit types are Cu-skarn; porphyry Mo; granitoid-related Au-vein; polymetallic Pb-Zn; porphyry Sn; rhyolite-hosted Sn; Sn-W greisen, stockwork, and quartz-vein; cassiterite-sulfide-silicate-vein and stockwork; and W-Mo-Be greisen, stockwork, and quartz-vein. The isotopic ages for the granitoids hosting or associated with the deposits range from 75 to 100 Ma. The belts and deposits are hosted in granitoids related to the Khingan-Okhotsk volcanic-plutonic belt that is interpreted as having formed during the generation of granitoids along the Khingan continental-margin arc. The arc is related to oblique subduction of the Ancestral Pacific Ocean Plate and formation of the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes, part of the Honshu-Sikhote-Alin collage.

Unique Metallogenic Belts

Four unique metallogenic belts formed during this time span.

(1) The Gyeongpuk and Gyeongnam belts (with granitoid-related deposits) have isotopic ages of Cenomanian through Campanian and are hosted in the Cretaceous Bulgugsa granite that intrudes the Sino-Korean craton.

(2) The Hidaka belt (with Cyprus Cu-Zn massive sulfide deposits) is hosted in Middle Cretaceous through Eocene stratiform units that occur in tectonic fragments in the Shimanto subduction-zone terrane, part of the East Sakhalin collage.

(3) The Inner Zone Southwest Japan belt (with a wide variety of vein and replacement and granitoid-related deposits) is hosted in the Nohi rhyolite volcanic belt and coeval Hiroshima granitic belt that overlie previously-accreted terranes. The host rocks and deposits have isotopic ages of Cretaceous through Paleogene.

Maastrichtian through Eocene (72 to 33.7 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Maastrichtian through Eocene (fig. 13) were as follows.

(1) Migration of the Olyutorka-Kamchatka collage (and contained Olyutorka-Kamchatka island arc and subduction zone) toward the northeast margin of Northeast Asia.

(2) Slightly later, accretion of the Olyutorka-Kamchatka collage.

(3) Migration of the East-Sakhalin collage (and contained Terprniya-Nemuro island arc and subduction zone) toward the eastern margin of Northeast Asia.

(4) Continuation of transpressional-fault zones along the axis of the closed Mongol-Okhotsk Ocean and formation of associated metallogenic belts.

(5) Postcollisional, transform faulting along within-plate transpression zones in northeast China.

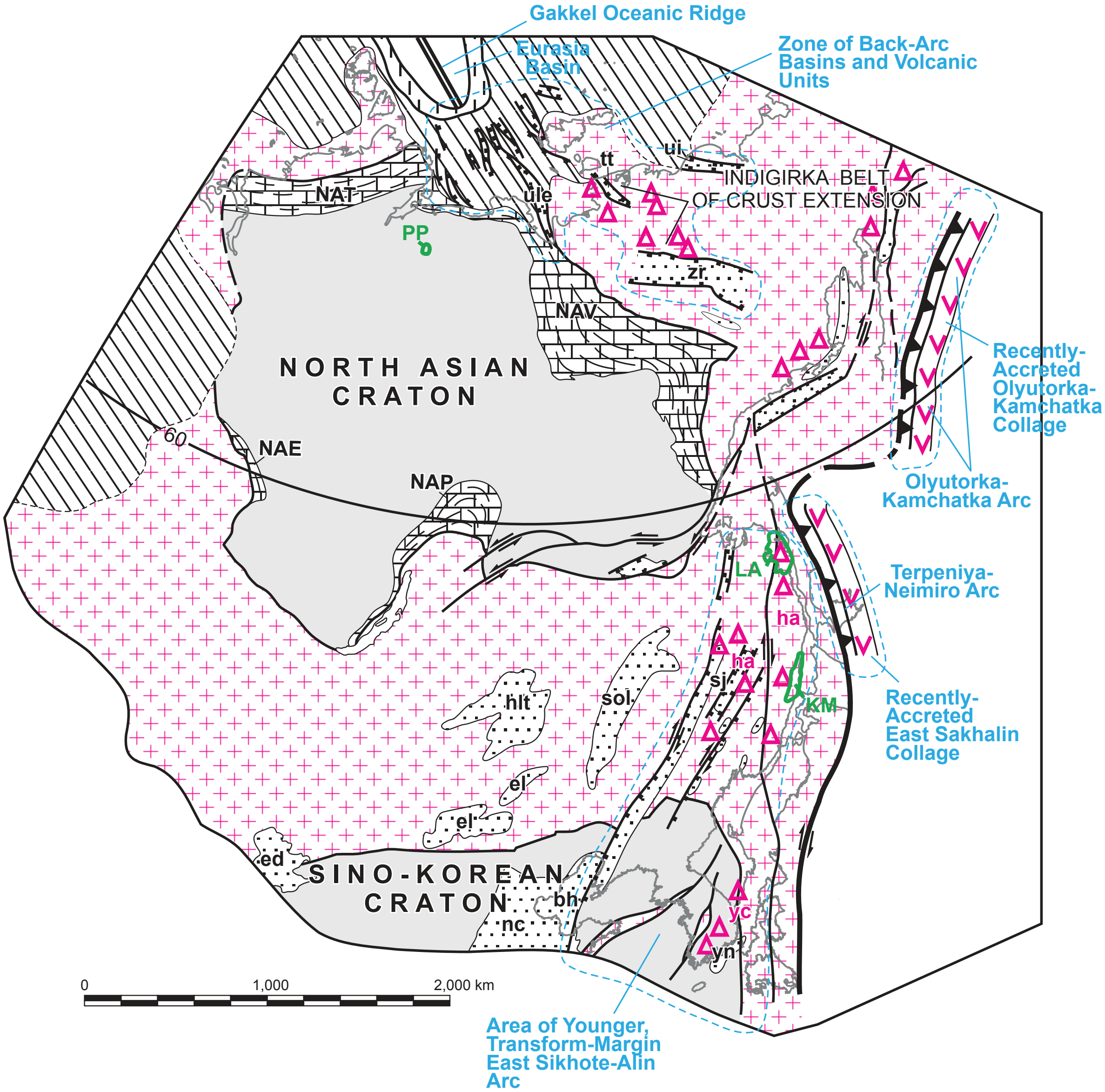
(6) Continued formation of a major continental-margin transform-fault system and generation of the younger part of the East Sikhote-Alin volcanic-plutonic belt (East Sikhote-Alin transform continental-margin arc) in the Russian Southeast and northeast China.

(7) Continued rifting and formation of the Eurasia Basin and opening of the Arctic Ocean.

Important Geologic Details

(1) Following the subduction of the Izanaga Plate, the Pacific Plate moved northward at a low angle to the continent margin and began plunging beneath it (Engebretson and others, 1985), thereby causing a transform boundary. This transform boundary is presently in the Sea of Okhotsk.

(2) At about 50 Ma, the Olyutorka-Kamchatka collage accreted to the continental margin (Zinkevich and Tsukanov, 1992), and subsequently, at about 40 Ma, the T East-Sakalin collage (and contained Terprniya-Nemuro island arc and subduction zone) accreted.



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental Sedimentary Basin

bh - Bohai sedimentary basin (Cenozoic)
ed - Erduosi sedimentary basin (Triassic through Cretaceous)
el - Erlian sedimentary basin (Jurassic through Quaternary)
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
nc - North China sedimentary basin (Cenozoic)
sj - Sanjiang sedimentary basin and Yishu graben (Mesozoic and Cenozoic)
sol - Songliao sedimentary basin (Jurassic through early Tertiary)
tt - Tastakh Basin
ui -Ust-Indigirka Basin
ule - Ust-Lena Basin
yn - Yonil Group (Cenozoic)
zr - Zyryanka sedimentary basin (Late Jurassic through Cenozoic)

Overlap Continental-Margin Arcs and Granite Belts

yc -Yucheon volcanic belt
ha - Hasan-Amurian volcanic-plutonic belt (Paleocene to early Miocene)

METALLOGENIC BELTS

KM - Kema
LA - Lower Amur
PP - Popigay

Figure 13. Eocene (50 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

(3) Around the margin of the Circum-North Pacific, major, right-lateral strike-slip faults formed and extended for thousands of kilometers. These faults are well-studied in Alaska and the Canadian Cordillera (Frasier, Straight Creek, Denali, Kaltag, and Tintina faults), where motions on them are estimated at hundreds and 1,500 to 2,000 km (Plafker and Berg, 1994; Monger and Nokleberg, 1996).

(4) During the Eocene, along the East Asia margin, extensive graben systems (Bohai, I-Shu, Pereyaslavskiy, Yama-Tuya) formed and accumulated thick lacustrine-alluvial deposits (Kirillova and others, 1996; Maruyama and others, 1997).

(5) The Eurasia Basin continued to open with detachment of a narrow linear strip from the margin of the Barents Sea shelf and formation of the intraoceanic Lomonosov Ridge (not shown on fig. 13) (Karasik, 1974; Karasik and others, 1983). The boundary between the Eurasian and North American plates is the Gakkel oceanic ridge, and it can be traced in a series of grabens on the Laptev Sea shelf and the onshore Zyryanka Basin to the southeast [Tectonics, geodynamics, and metallogeny of the territory of the Sakha Republic (Yakutia), 2001]. In the early Paleogene, the pole of rotation of the plates occurred north of Japan.

(6) With extension along the Gakkel ridge, the Northeast Asia lithosphere was extended.

Metallogenesis

Two metallogenic belts (the Kema and Lower Amur belts) possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits. The major mineral deposit types are Ag-Au epithermal-vein; porphyry Cu-Mo; porphyry Cu; porphyry Au; porphyry Mo; Au-Ag epithermal-vein; epithermal quartz-alunite; and Sn-W greisen, stockwork, and quartz-vein. The isotopic ages for the granitoids hosting or associated with the deposits range from Late Cretaceous through Paleocene. The belts and deposits are hosted in granitoids in the East Sikhote-Alin volcanic-plutonic belt that is a major overlap assemblage in the Russian Far East. The belt is interpreted to be part of an extensive continental-margin arc that formed along the eastern margin (present-day coordinates) of the North Asian craton and cratonal margin and previously-accreted terranes to the east. The arc is interpreted as having formed during subduction of the Ancestral Pacific Ocean Plate.

The unique Popigay metallogenic belt contains impact diamond deposits. Isotopic age from tagamite (impact melt rock) and impact glasses is 35.7 Ma. The belt is hosted in the Popigay ring structure and is interpreted as having resulted from meteoritic impact with formation of pseudotachylite, diamond, high-grade shock metamorphic minerals, and allogenic breccia.

Oligocene through Miocene (33.7 to 5.3 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Oligocene to Miocene (fig. 14) were as follows.

(1) Formation of the short-lived Central Kamchatka continental-margin arc along the outboard margin of northern Northeast Asia.

(2) Migration of the East Kamchatka collage (and contained Kronotskaya island arc and subduction zone) toward the northeast margin of Northeast Asia.

(3) Slightly later, accretion of the East Kamchatka collage outboard of the Central Kamchatka arc.

(4) Formation of the Japan continental-margin arc and back-arc spreading between the arc and the southern part of Northeast Asia.

(5) To the south, formation of the Izu Bonin continental-margin arc.

(6) Continued rifting and formation of the Eurasian Basin and formation of the Arctic Ocean.

Important Geologic Details

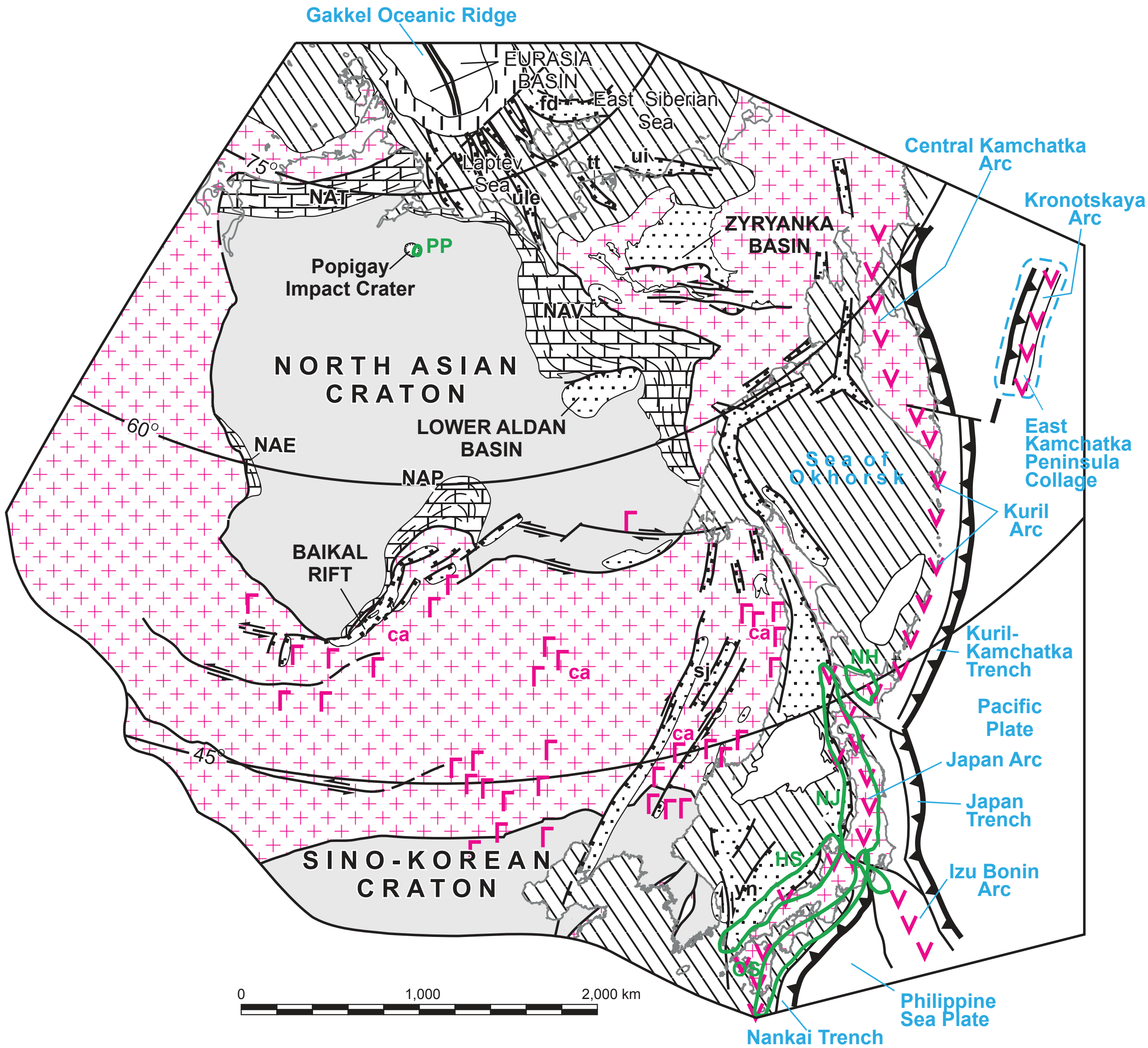
(1) The eastern margin of North Asia underwent a transition to the present-day shape. In the early Oligocene, the Pacific Plate moved northwestward at a high angle to the continental margin at a rate of about 10 cm/yr (Zonenshain and others, 1985; Engebretson and others, 1985).

(2) After accretion of the East Sakhalin collage, subduction stepped oceanward, and the Japan and Kuril island arcs formed. The Kuril and Central Kamchatka arcs, connected by a transform fault, were the northern continuation (Parfenov and others, 1979).

(3) The East Kamchatka collage (and contained Kronotskaya island arc and subduction zone) migrated towards Kamchatka as part of the Pacific Plate (Levashova and Bazhenov, 1997) and was accreted to the accreting continental margin in the late Miocene.

(4) After accretion of the East Kamchatka collage, subduction stepped oceanward, and in the Pliocene, the Kamchatka arc formed.

(5) Rifting and back-arc spreading occurred behind the island arcs. In the Sea of Okhotsk and the sea west of Japan, deep-water basins with oceanic crust as well as linear,



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

Intracontinental Sedimentary Basins

fd - Faddeevskiy Basin
sj - Sanjiang sedimentary basin and Yishu graben (Mesozoic and Cenozoic)
tt - Tastakh Basin
ui -Ust'-Indigirka Basin
ule - Ust'-Lena Basin
yn - Yonil Group (Cenozoic)

Plateau Basalt Belt

ca - Central Asian plateau basalt belt (Neogene and Quaternary)

METALLOGENIC BELTS

HS - Hokuriku-Sanin
NH - Northeast Hokkaido
NJ - Northeast Japan
OS - Outer Zone Southwest Japan
PP - Popigay

Figure 14. Miocene (10 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

rift-related sedimentary basins formed and were filled with Oligocene-Pliocene basalt and sedimentary rock (Kharakhinov, 1998, Ingle and others, 1990; Jolivet, 1992; Tamaki and others, 1992; Maruyama and others, 1997; Tectonic map of the Sea of Okhotsk, 2000). West of Japan, back-arc spreading occurred from 32 to 23 Ma and was marked by crustal extension and thinning, intense basalt magmatism, marine-rifting sedimentation, and thermal sinking of the crust at a rate of 150 mm/yr. The main rifting event occurred in the early Miocene. During back-arc spreading, a right-lateral strike-slip fault system formed and extends for about 2,000 km from central Japan to North Sakhalin Island.

(6) The Eurasian Basin continued forming in the Arctic. In the Oligocene, the pole of rotation of the Eurasian and North American Plates migrated to the area north of the New Siberian Islands (Drachev and others, 1998) caused compression in an area to the south. The result was onset of general uplift, formation of the arches of the Verkhoyansk, Chersky, and Moma Ranges. In addition, piedmont basins (Lower Aldan, Zyryanka) formed along the periphery of the arched uplift. In the late Miocene to early Pliocene, thrust systems with horizontal displacements of up to 20 km, as well as conjugate folded folds and strike-slip faults, formed along the sides of the arched uplifts [Tectonics, geodynamics, and metallogeny of the territory of the Sakha Republic (Yakutia), 2001]. These tectonic events correlate well with increased spreading rate in the Eurasian Basin (up to 1.2-1.5 cm/yr) (Drachev and others, 1998) that was the result of an increased convergence rate between the Eurasian and North American Plates.

(7) In the Oligocene-Miocene, the Baikal rift formed (Mats and others, 2001).

(8) During the Miocene, the extensive plateau basalts were erupted in Central Asian, including both solitary lava sheets and fields up to 3,000 km^2. The plateau-basalts occur from East Sayan and the Stanovoy Range in the north to the northern margin of the Sino-Korean craton in the south, and from northern and central Mongolia in the west to the shores of the Tatar Strait in the east. The volcanic units include high alkalinie basalts (Rasskazov, 1993; Yarmolyuk and others, 1997, 2000). This volcanic activity was initially related to local mantle plumes and was associated with grabens, as in the South-Khangai area (Yarmolyuk and others, 1997, 2000).

Miocene to Present Metallogenesis

The five major Miocene through Present metallogenic belts (the Kyushu, Northeast Hokkaido, Hokuriku-Sanin, Northeast Japan, and Outer Zone Southwest Japan belts) possess geologic units favorable for a wide variety of volcanic-rock-related deposits. The major mineral deposit types are Au-Ag epithermal-vein; cassiterite-sulfide-silicate-vein and stockwork; chemical-sedimentary Fe-Mn; clastic sediment-hosted Hg±Sb; clastic-sediment-hosted Sb-Au; Ag-Sb and Hg-Sb-W-vein and stockwork; limonite from spring water; Mn-vein; polymetallic Pb-Zn-vein and stockwork;, polymetallic volcanic-hosted metasomatite; Sn-skarn; Sn-W greisen, stockwork, and quartz-vein; sulfur-sulfide; volcanic-hosted Hg; Ag-Sb-vein; volcanogenic Zn-Pb-Cu massive sulfide; volcanogenic-sedimentary Mn; W-Mo-Be greisen, stockwork, and quartz-vein; and Zn-Pb-skarn. The isotopic ages of the igneous rocks hosting the deposits range from 0.3 to 15 Ma. The belts and deposits are hosted in the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that are interpreted as part of the modern-day Japan continental-margin arc. This arc is tectonically related to subduction of the Pacific Ocean and Philippine Sea Plates beneath the East Asia continental margin.

Pliocene through Present (5.3 to 0 Ma) Stage of Tectonic and Metallogenic Model

Major Tectonic Events

The major tectonic events in the Pliocene through the Present (fig. 15) were as follows.

(1) Continued formation of the Kuril-Kamchatka continental-margin arc along the eastern margin of Northeast Asia.

(2) Continued formation of the Japan continental-margin arc and back-arc spreading between the arc and the southern part of Northeast Asia.

(3) To the south, continued formation of the Izu Bonin continental-margin arc.

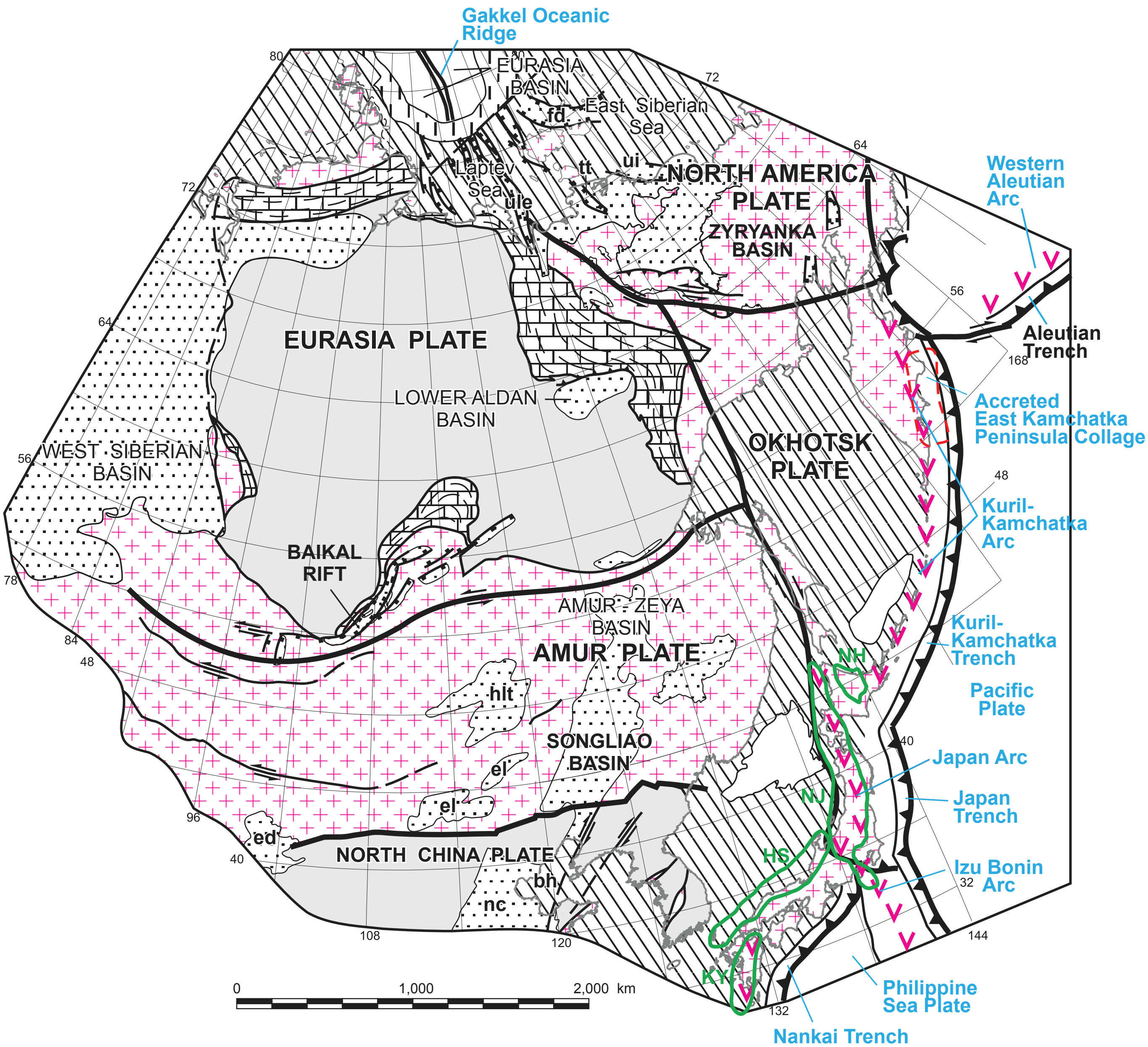
(4) Continued rifting and formation of the Eurasian Basin and formation of the Arctic Ocean; and on the basis of modern-day earthquake foci, formation of several new tectonic plates across the region (Nokleberg and others, 2000).

(5) Continued formation of the Baikal rift (Mats and others, 2001).

Conclusions

Major Tectonic Processes

New and fundamental processes in the tectonic evolution and formation of collages and orogenic belts are supported by this research. The major ancient ocean basins (Paleo-Asian, Mongol-Okhotsk, and Solon), that contain the major collages of Central and Northeast Asia, were major new units that



GEOLOGIC UNITS

Intracontinental Sedimentary Basins

bh - Bohai sedimentary basin (Cenozoic)
ed - Erduosi sedimentary basin (Triassic through Cretaceous)
el - Erlian sedimentary basin (Jurassic through Quaternary)
fd - Faddeevskiy Basin
hlt - Hailar-Tamsag sedimentary basin (Late Jurassic and Cretaceous)
nc - North China sedimentary basin (Cenozoic)
tt - Tastakh basin
ui -Ust'-Indigirka Basin
ule - Ust'-Lena Basin

METALLOGENIC BELTS

HS - Hokuriku-Sanin
KY - Kyushu
NH - Northeast Hokkaido
NJ - Northeast Japan

Figure 15. Present (0 Ma) time stage of tectonic and metallogenic model. See text for explanation of tectonic events and origins of major metallogenic belts and figure 3 for explanation of symbols and patterns.

exhibited common tectonic processes. Formation of variously aged collages (orogenic belts) along the margins of the North Asian and Sino-Korean cratons was controlled by the same processes that are still occurring along the periphery of the Pacific and Arctic Oceans.

In the northern, western, and southern margins of the North Asian craton, various independent, late Riphean, Vendian-Cambrian, and Silurian-Devonian island arcs formed and were separated from the cratons by large back-arc basins. The arcs are comparable to the modern-day island arcs offshore from Asia. Accretion of these ancient island arcs culminated in the formation of late Riphean, early Paleozoic, and middle Paleozoic collages. Formation of the late Paleozoic through early Mesozoic, Mongol-Okhotsk and Solon collages was also related to closure of major ocean basins.

The Mesozoic and Cenozoic collages along the eastern margin of Northeast Asia formed during convergence between the Paleo-Pacific and North Asian craton and cratonal margin. Convergence of the oceanic and continental plates was accompanied by rifting, opening, and subsequent closure of minor ocean basins behind active continental-margin and island arcs. In the Late Mississippian, after extensive Devonian rifting, a narrow linear strip of the shelf was detached from the eastern margin of the North Asian craton, and it became the intraoceanic Omulevka Range. The Omulevka Range and the Oimyakon Oceanic Basin are comparable to the present-day Lomonosov Ridge and the Eurasian Basin of the Arctic Ocean.

Formation of major orogenic belts was accompanied by large (hundreds and thousands of kilometers), longitudinal strike-slip motions that were subparallel to the continental margin. Large strike-slip motions were the result of oblique convergence between the oceanic plates and the continental margins.

Refinement of the Tectonic and Metallogenic Model

Our tectonic and metallogenic model is the first major interpretation for the region. The most important problems for future studies are (1) determining the age and nature of rifting events responsible for the break-up of the Proterozoic supercontinent Rodinia and formation of the North Asian craton; (2) establishing the nature of fragments of cratons and Riphean and early Paleozoic collages that occur in various, different-aged orogenic belts of Central Asia; and (3) clarifying the origin of late Paleozoic-early Mesozoic ocean basins that were eventually preserved in the Mongol-Okhotsk and Solon collages.

These problems can be solved with additonal isotopic-geochemical and geochronological data that will permit better understanding of the geodynamic nature of magmatic complexes, as well as the timing of geological events. For example, for the origin of the Mongol-Okhotsk collage, evidence needs to be found for magmatic units that formed during the early opening of the Mongol-Okhotsk Ocean. Such data will be very important for understanding the nature of the Mongol-Okhotsk Ocean. In addition, new isotopic and geochemical data on the formation of the early stages of the emplacement of the Selenga, East Mongolian, and South Mongolian volcanic-plutonic belts are needed. New data on the geodynamic nature and the age of Paleozoic granitoids of the Khangai-Daurian, West Stanovoy, and Argun terranes are also needed.

Finally, reliable reconstruction of the tectonic evolution of Northeast Asia is dependent on high-quality paleomagnetic data. The present data are limited and are available only for distinct stratigraphic horizons of various terranes. Paleomagnetic data for the entire stratigraphic section of each terrane are needed, as well as for overlap assemblages. In particular, new data are needed for the Argun-Idermeg superterrane. These data will assist solving major debates about the origin of the Mongol-Okhotsk region and are of prime importance for understanding the tectonic evolution of Northeast and East-Central Asia.

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Appendix A

Description of the Northeast Asia Project and Associated Products

By Warren J. Nokleberg [1], Leonid M. Parfenov [2], Alexander I. Khanchuk [3], Mikhail I. Kuzmin [4], Alexander A. Obolenskiy [5], Andrei V. Prokopiev [2], Sergey M. Rodionov [6], Alexander P. Smelov [2], Gombosuren Badarch [7], Hongquan Yan [8], Duk Hwan Hwang [9], and Masatsugu Ogasawara[10]

Introduction

This appendix provides an overview of the associated project on the Metallogenesis and Tectonics of Northeast Asia and lists the participating agencies and scientists and the extensive publications that have already been produced.

Project Area, Collaborating Agencies, Participants, and Purpose

The project area consists of eastern Russia (most of Siberia and most of the Russian Far East), Mongolia, Northeastern China, South Korea, Japan, and adjacent offshore areas (fig. 1), bounded by latitude 30-82° N. and longitude 75-144° E. Participating agencies in the project are the Russian Academy of Sciences, VNIIOkeangeologia and Ministry of Natural Resources of the Russian Federation; Mongolian Academy of Sciences; Mongolian University of Science and Technology; Mongolian National University; Jilin University, Changchun, People's Republic of China; the China Geological Survey; the Korea Institute of Geosciences and Mineral Resources; the Geological Survey of Japan/AIST; University of Texas Arlington; and the U.S. Geological Survey (USGS). Collaborating agencies are listed below in table 1. In addition to the numerous agencies and participants, several major Western organizations and universities have supported the project by inviting project-related talks and organizing symposia on the project at major and minor meetings, including the Colorado School of Mines; Stanford University; University of Alaska Fairbanks; University of Pittsburgh; the Alaska Miners Association; the Northwest Mining Association; and the Society of Economic Geologists.

This project extends and builds on data and interpretations from a previous project on Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera that was conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada.

The chapters in this volume and for the associated publications were compiled by a large group of international geologists, using new concepts and definitions for analyzing the metallogenesis and tectonics of a large and geologically complex region. Research was conducted over a 7-year period with large, end-of-year workshops in Northeast Asia. Each chapter should have major global significance. The information presented here will be useful for several purposes, including regional tectonic analysis, mineral resource and metallogenic analysis, mineral-resource assessment, petroleum-resource analysis and assessment, neotectonic analysis, and analysis of seismic and volcanic hazards.

The purpose of this project is to benefit participants and customers by (1) providing a comprehensive international database on the mineral resources of the region that will be the first, extensive knowledge available in English; (2) providing substantially new interpretations of the origin

[1] U.S. Geological Survey, Menlo Park, Calif.
[2] Russian Academy of Sciences, Yakutsk.
[3] Russian Academy of Sciences, Vladivostok.
[4] Russian Academy of Sciences, Irkutsk.
[5] Russian Academy of Sciences, Novosibirsk.
[6] Russian Academy of Sciences, Khabarovsk.
[7] Mongolian Academy of Sciences, Ulaanbaatar.
[8] Jilin University, Changchun, People's Republic of China.
[9] Korean Institute of Geosciences and Mineral Resources, Taejon.
[10] Geological Survey of Japan/AIST, Tsukuba.

and crustal evolution of mineralizing systems and their host rocks, thereby enabling enhanced, broad-scale metallogenic and tectonic reconstructions; and (3) promoting trade and scientific and technical exchanges between North America and Eastern Asia. With the numerous and detailed publications and presentations at important professional meetings (listed below), the project has provided vital data to a wide variety of customers for making sound economic planning and investment decisions and for increasing their geologic knowledge of the region, including (1) mining, petroleum, environmental, construction, investment, and information companies; (2) Federal and State government agencies in all countries; (3) professional organizations; (4) earth-science departments at universities; and (5) the news media.

Products of the Northeast Asia Project

Products for the project include (1) detailed mineral resource tables and location maps with data on 1,674 significant lode deposits and 91 selected placer districts in the project area, based on original, cited references; (2) regional geodynamics maps and detailed explanations that provide the geologic setting for mineral deposits and metallogenic belts; (3) mineral deposit location and metallogenic belt maps; and (4) metallogenic and tectonic interpretations, including a four-dimensional time-space model depicting the crustal origin and evolution of mineral deposits and host rocks. Publications are released in both hard copy (USGS publications and scientific journals), and digital format (CD-ROM, World Wide Web).

Figure 1. Regional summary geographic map of Northeast Asia showing majors regions and countries.

Table 1. Organizations and participants in international project on metallogenesis and tectonics of Northeast Asia.

Country	Organization	Participants
China	Geological Research Institute, Jilin University, Changchun	Yongsheng Dong Xujun Li Fengyue Sun Jiapeng Sun Weizhi Sun, Hongquan Yan Mao Ye Aihua Xi
Japan	Geological Survey of Japan/AIST, Tsukuba	Masatsugu Ogasawara Masakatsu Sasada Sadahisa Sudo Koji Wakita
Mongolia	Institute of Geology and Mineral Resources, Mongolian Academy of Sciences, Ulaanbaatar	Sodov Ariunbileg Gombosuren Badarch Demberel Orolmaa Onongin Tomurtogoo
	Mineral Resources Authority of Mongolia, and Ministry of Agriculture and Industry, Ulaanbaatar	Gunchin Dejidmaa Ayurzana Gotovsuren
	Mongolian University of Science and Technology, Ulaanbaatar	Ochir Gerel
	Department of Geology and Mineralogy, Mongolian National University, Ulaanbaatar	Jamba Byamba Dangindorjiin Dorjgotov
Russia	All Russia Research Institute for Geology and Mineral Resources of the World Ocean (VNIIOkeangeologia), Russian Ministry of Natural Resources, St. Petersburg	Boris I. Kim Eugeney A. Korago Mikhail K. Kos'ko Oleg I. Suprunenko
	Buryat Institute of Geology, Russian Academy of Sciences, Ulan-Ude	Alexander N. Bulgatov
	Buryat Scientific Center, Russian Academy of Sciences, Ulan-Ude	Ivan V. Gordienko
	Far East Geological Institute, Russia Academy of Sciences, Vladivostok	Alexander I. Khanchuk Marina Yu. Kapitanchuk Elena Koltunova Vera V. Naumova Mikhail I. Patuk Vladimir V. Ratkin
	Institute of Diamond and Noble Metal Geology, Russian Academy of Sciences, Yakutsk	Gennandiy B. Biryul'kin Yury V. Davydov Alexey V. Deikunenko Gennadiy N. Gamyanin Alexei V. Kostin Andrei V. Prokopiev Vladimir S. Oxman Leonid M. Parfenov Alexander P. Smelov Valeriy M. Supletsov Vladimir F. Timofeev Felix F. Tret'yakov Oleg A. Tyan

Table 1. Organizations and participants in international project on metallogenesis and tectonics of Northeast Asia.—Continued

Country	Organization	Participants
	Yakutian State University	Valeriy G. Vetluzhskikh Yakov.V. Yakovlev Alexander N. Zedgenizov Valeriy Yu. Fridovskiy Valeriy M. Nikitin Valeriy V. Stogniy Vladimir.I. Zhizhin
	Institute of Earth's Crust, Russian Academy of Sciences, Irkutsk	Valentina Belichenko Eugene V. Sklyarov Lydia M. Zorina
	Institute of Geochemistry, Russian Academy of Sciences, Irkutsk	TatianaV. Bounaeva Sergey I. Dril Mikhail I. Kuzmin Sergey A. Letunov Alexander M. Spiridonov
	Institute of Geology, Russian Academy of Sciences, Novosibirsk, Institute of Tectonics and Geophysics, Russian Academy of Sciences, Novosibirsk	Nikolay A. Berzin Elimir G. Distanov Alexander A. Obolenskiy Nikolay.V. Popov Sergey N. Rudnev Vitali I. Sotnikov Valery A. Vernikovsky Alexander G. Vladimirov Y.V. Yakovlev
	Irkutsk State Technical University	Anatoliy P. Kochnev Galina D. Malceva Zhan V. Seminskiy
	Institute of Tectonics and Geophysics, Russian Academy of Sciences, Khabarovsk	Galina L. Kirillova Lyudmila I. Popeko Sergey M. Rodionov
	Northeast Integrated Scientific Research Institute, Russian Academy of Sciences, Magadan	Nikolai A. Goryachev Vladimir D. Melnikov Vladimir I. Shpikerman
	ALROSA Joint Company, Mirnyi	Nikolay.N. Zinchuk
South Korea	Korea Institute of Geosciences and Mineral Resources, Taejon	Duk Hwan Hwang
U.S.A.	University of Texas, Arlington, Texas	Christopher R. Scotese
	U.S. Geological Survey, Menlo Park, California	Robert J. Miller Warren J. Nokleberg

Geodynamics maps and mineral-resource data and maps are compiled and published as Geographic Information Systems (GIS) spatial datasets. Following is a list of all project publications through the date of this publication.

Preliminary Publications, Book 1

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Digital Data Files for Northeast Asia Geodynamics, Mineral-Deposit Locations, and Metallogenic-Belt Maps, Stratigraphic Columns, Descriptions of Map Units, and Descriptions of Metallogenic Belts

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Appendix B

Description of Map Units for Northeast Asia Summary Geodynamics Map

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Introduction

The major geologic and tectonic units on the summary geodynamics map of Northeast Asia are cratons, cratonal margins, cratonal terranes, superterranes, tectonic collages (Archean and Proterozoic, Vendian through Cretaceous, Late Cretaceous and Cenozoic), overlapping continental-margin arcs (Devonian through early Tertiary), transform continental-margin arcs (Devonian through Early Cretaceous), active arcs (Miocene through Holocene), and active subduction zones (Miocene through Present). Units are listed in the order of abbreviations within each major map unit. The map units were previously described in Nokleberg and others (1994, 1997c, 2000, 2004), Greninger and others (1999), and Naumova (2006).

Cratons

NAC North Asian craton (Archean and Proterozoic)—Consists of Archean and Proterozoic metamorphic basement and nondeformed, flat-laying platform cover of late Precambrian thourgh Mesozoic sedimentary and volcanic rocks, locally as much as 14,000 m thick. Metamorphic basement is exposed in the Aldan-Stanovoy and Anabar shields near the southern and northern cratonal margins, respectively, and in a narrow band of basement rocks named the Near-Sayan uplift along the southwestern cratonal margin. Within these two shields and uplift are several terranes composed of early Precambrian crystalline rocks that vary in composition and structural style. The platform cover consists of Neoproterozoic, Vendian and early Paleozoic, middle Paleozoic, late Paleozoic, and Mesozoic sequences; each is characterized by a unique structural style and a unique suite of sedimentary and magmatic rocks, and each are separated from the others by regional discontinuities and unconformities related to major tectonic events.

SKC Sino-Korean craton (Archean and Proterozoic)—Consists of several major terranes and younger overlap units in northern China and the northern part of the Korean Peninsula. Archean and Proterozoic metamorphic basement composes various major terranes and first-overlapped units: (1) the Paleoproterozoic Alashan granulite-paragneiss terrane in northwestern China, (2) the Archean Erduosi granulite-paragneiss terrane in north-central China, (3) the Archean Yinshan granite-greenstone terrane and first overlapped Proterozoic and Mesoproterozoic rift-related Zhangbei-Bayan Obo-Langshan metasedimentary and metavolcanic rocks in north-central China, (4) the Archean Jilin-Liaoning-East Shandong tonalite-trondhjemite-gneiss terrane and Paleoproterozoic overlapped, metamorphosed and deformed rocks of East Shandong-East Liaoning-East Jilin rift or foreland basin in northeastern China, (5) the Archean West Liaoning-Hebei-Shanxi granulite-orthogneiss terrane and overlapped, Paleoproterozoic metamorphosed and deformed rocks of Hutuo rift basin in northern China, (6) the Archean and Paleoproterozoic Machollyong granulite-paragneiss terrane in the northern part of the Korean Peninsula. Overlap units consist of extensive Proterozoic

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[5] Russian Academy of Sciences, Vladivostok.
[6] Russian Academy of Sciences, Irkutsk.
[7] U.S. Geological Survey, Menlo Park, Calif.
[8] Geological Survey of Japan/AIST, Tsukuba.
[9] Russian Academy of Sciences, Khabarovsk.
[10] Jilin University, Changchun, People's Republic of China.

and Paleozoic continental-margin sedimentary rocks and lesser volcanic rocks; extensive Mesozoic and Cenozoic marine and terrigenous sedimentary rocks, and volcanic and plutonic arcarc-related rocks.

Craton Margins

BP Baikal-Patom cratonal margin (Riphean through Cambrian and older basement)—Consists of a fault-bounded basin containing Riphean carbonaceous and terrigenous sedimentary rocks, and Vendian and Cambrian sedimentary rocks that discordantly overly a fragment of pre-Riphean basement of the North Asian craton. Local detritus suggests derivation from ophiolite and island-arc complexes of the Bakal-Muya terrane during accretion to the craton. Local greenschist- and amphibolite-facies regional metamorphism is isotopically dated at about 800 Ma.

EA East Angara cratonal margin (Riphean and older basement)—Consists of late Riphean terrigenous carbonaceous sedimentary rocks (sandstone, siltstone, and mudstone with interlayered dolomite and limestone) that overlie a fragment of the North Asian craton. Metamorphosed up to greenschist facies. Unconformably overlapped by late Riphean and Vendian molasse and Vendian and Cambrian dolomite and limestone.

ST South Taimyr cratonal margin (Ordovician through Jurassic)—Consists chiefly of a thick wedge of cratonal margin and deep-basin deposits as much as 20,000 m thick. Composed chiefly of Ordovician through Jurassic clastic rocks, shallow-marine terrigenous and carbonaceous rocks, and mafic volcanic and volcaniclastic rocks. Late Carboniferous and Permian sedimentary rocks contain extensive sills and dikes of Early Triassic trapp subalkaline and alkaline diabase. Interpreted as a tectonically detached from crystalline basement of the North Asian craton that was subsequently accreted back onto the craton.

VR Verkhoyansk (North Asian) cratonal margin (Devonian through Jurassic)—Consists chiefly of a thick (maximum 20 km) wedge of cratonal margin deposits, mainly Carboniferous, Permian, Triassic, and Early and Middle Jurassic clastic rocks, and littoral-marine, deltaic, and shelf sedimentary rocks deposited on the Verkhoyansk passive continental margin of the North Asian craton, grading successively eastward into turbidite deposits and deep-water black shale. Includes (1) local Middle through Late Devonian and Early Carboniferous rift-related deposits similar to those on the Siberian platform, and (2) local Early Triassic through Early Jurassic alkalic basalt flows, dikes, and sills. The northern and southern parts of the cratonal margin contain Neoproterozoic and early Paleozoic thick shallow-marine carbonaceous and clastic deposits that fine and thicken eastward. Interpreted as tectonically detached from passive continental-margin and crystalline basement of the North Asian craton.

Cratonal Terranes

GY Gyenggi-Yeongnam cratonal terrane (Archean and Proterozoic)—Consists of two major parts: (1) the Mesoproterozoic, Neoproterozoic, and older Gyenggi granulite-paragneiss terrane in the southern part of the Korean Peninsula, and (2) the Late Archean and Paleoproterozoic Yeongnam granulite-paragneiss terrane in the southern part of the Korean Peninsula Peninsula. Locally overlain by extensive Paleozoic continental-margin sedimentary and lesser volcanic rocks, and extensive Mesozoic and Cenozoic marine and terriginous sedimentary rocks, and volcanic and plutonic arc-related rocks. Interpreted as a displaced fragment of the Sino-Korean craton, or possibly a fragment of the South China (Yangzi) craton.

JA Jiaonan cratonal terrane (Proterozoic)—Consists a Paleoproterozoic major high pressure metamorphic terrane, locally overlain by extensive Paleozoic continental-margin sedimentary and lesser volcanic rocks, extensive Mesozoic and Cenozoic marine and terriginous sedimentary rocks, and volcanic and plutonic arc-related rocks. Interpreted as a displaced fragment of the South China (Yangtzi) Craton.

OH Okhotsk cratonal terrane (Archean, Proterozoic, and early and middle Paleozoic)—Consists chiefly of large blocks of Archean and Paleoproterozoic gneiss and schist with a U-Pb zircon age of 3.7 Ga, overlain by (1) gently dipping shallow-marine Mesoproterozoic and Neoproterozoic clastic and carbonaceous rocks, (2) Early Cambrian limestone, marl, and sandstone, (3) Early Ordovician conglomerate, limestone, marl, and sandstone, (4) unconformable Middle Devonian limestone, sandstone, shale, and conglomerate and Late Devonian rhyolite, ignimbrite, andesite, dacite, and tuff that are interlayered with nonmarine sandstone, siltstone, and conglomerate, and (5) Carboniferous through Late Jurassic nonmarine and rare marine clastic rocks. Interpreted as a fragment of the North Asian craton and cratonal margin that was rifted in the Late Devonian or Early Carboniferous and accreted to the East Asian continental margin in the Late Jurassic.

Superterranes

AI Argun-Idermeg superterrane (Proterozoic through Cambrian; timing of accretion - late Neoproterozoic through Cambrian)—Consists of (1) the Paleoproterozoic through late Paleozoic Argunsky metamorphosed passive-continental-margin terrane (AR) (eastern Mongolia, northeastern China, Transbaikalia), and (2) the Proterozoic through Cambrian Idermeg metamorphosed passive-continental-margin terrane (ID) (eastern Mongolia).

BJ Bureya-Jiamusi superterrane (Proterozoic through Permian; timing of accretion, early Paleozoic)—Consists of an early Paleozoic tectonic collage of the following metamorphic, continental-margin-arc, subduction-zone, passive-continental-margin and island-arc terranes: (1) the Neoproterozoic through Triassic Bureya terrane (southern Russian Far East), (2) the Neoproterozoic and older and Early Cambrian Jiamusi terrane (northeastern China), (3) the Proterozoic Matveevka terrane (southern Russian Far East), (4) the Proterozoic Nakhimovka terrane (southern Russian Far East), (5) the Silurian through Permian(?) South Kitakami metamorphosed island-arc terrane (northern Honshu Island, Japan), and (6) the Late Carboniferous and Permian Laoyeling-Grodekov island-arc terrane (northeastern China, southern Russian Far East), (7) the Cambrian through Permian passive-continental-margin Voznesenka terrane (southern Russian Far East), (8) the Cambrian(?) and Ordovician(?) Sergeevka island-arc terrane (southern Russian Far East), (9) the Neoproterozoic through Devonian Zhangguangcailing continental-margin-arc terrane (northeastern China), (10) the Ordovician and Silurian Heilongjiang subduction zone, type B terrane (northeastern China), (11) the Archean through Middle Triassic Urmi passive-continental-margin terrane (northeastern China, southern Russian Far East), and (12) the Late Carboniferous and Permian Tumangang island-arc terrane (Korean Peninsula), all derived from a sequence of late Precambrian volcanic units, and late Precambrian through Ordovician shallow-marine clastic and carbonaceous rocks, locally metamorphosed tp amphibolite and granulite facies metamorphism dated at Early and Middle Ordovician (480 to 500 Ma). Intruded by Cambrian and Ordovician granitoids and unconformably overlain by Devonian rocks. Interpreted as a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during closure of the Mongol-Okhotsk Ocean, possibly a fragment of the Yenisey-Transbaikal orogenic belt that also contains early Paleozoic granulite facies metamorphic rocks and Cambrian and Ordovician granitoids.

KR Kara superterrane (Proterozoic through Ordovician; timing of accretion, early Paleozoic(?)—Consists of the late Neoproterozoic through Ordovician Kara continental-margin turbidite terrane (northern part of the Taimyr Peninsula), containing mainly late Riphean turbidites metamorphosed to amphibolite facies. Uppermost turbidites contain Cambrian and Early Ordovician fauna. Turbidites are unconformably overlain by Ordovician through Devonian littoral-marine and continental sedimentary rocks. Accreted to the North Asian craton with the genesis of Middle Permian two-mica and biotite-amphibole granite and granodiorite (with U-Pb, Rb-Sr, and incremental Ar isotopic ages of 252-264 Ma. Granitoids compose an extensive belt that obliquely cuts the superterrane and the margin of the late Riphean Circum-Siberian tectonic collage. Interpreted as a rift fragment of the North Asian craton that was reaccreted in the Jurassic.

KOM Kolyma-Omolon superterrane (Archean through Jurassic; timing of accretion, Late Jurassic)—Consists of a tectonic collage of cratonal, passive-continental-margin, island-arc, and ophiolite terranes, mainly the Alazeya (island arc), Aluchin (subduction zone), Argatass (turbidite), Beryozovka (turbidite), Kenkel'da (subduction zone), Khetachan (island arc), Munilkan (oceanic) including various small ophiolite fragments [Garbyn'ya, Indigirka, Kybytygas, Munilkan, Uyandina, Uvyazka], Nagondzha (turbidite), Oloy (island arc), Omolon (cratonal), Omulevka (continental-margin), Prikolyma (continental-margin), Uyandina (island arc), and Yarkvaam (island arc). Interpreted as having formed during accretion of terranes of cratonal, continental (Omulevka, Prikolyma, Omolon), and oceanic affinity to the Alazeya island arc, in association with obduction of oceanic crust and formation of small ophiolite fragments of the Munilkan terrane. Unconformably overlain by the Late Jurassic Uyandina-Yasachnaya superterrane marginal arc (uy), under which the Oimyakon Ocean basin was subducted during migration toward the North Asia (Verkhoyansk) cratonal margin. Accreted to the northeast Verkhoyansk (North Asian) cratonal margin in the Late Jurassic and Early Cretaceous, resulting in formation of collisional granites of the Main (mb) (Late Jurassic) and Northern (nb) (Early Cretaceous) granite belts (Yakutia).

TM Tuva-Mongolia superterrane (late Riphean and older; timing of accretion, late Neoproterozoic)—Consists many of fragments of: (1) the Archean and Paleoproterozoic Gargan cratonal terrane (North Huvsgol, Mongolia, eastern Sayan), (2) the Proterozoic Sangilen passive-continental-margin terrane (southwestern Siberia, Mongolia), (3) the Neoproterozoic and older Baydrag cratonal terrane (northwestern Mongolia), and (4) the Late Archean(?) and Paleoproterozoic(?) Muya metamorphic terrane (Transbaikalia). Includes various terranes of the Baikal-Muya island-arc system (Baikal-Muya, Barguzin, Dibinsky, Hug, Ilchir, Kuvai, Olokit-Delunuran, and Sarkhoy) that were amalgamated to form the Tuva-Mongolian microcontinent. Unconformably overlain by Vendian and Cambrian sedimentary and volcanic rocks.

Tectonic Collages Accreted between the North Asian and Sino-Korean Cratons (Proterozoic through Early Mesozoic)

AB Atasbogd collage (Ordovician through Permian; timing of accretion, Late Carboniferous or Early Permian)—Consists of (1) the Ordovician through Permian Waizunger-Baaran terrane, (2) the Devonian and Carboniferous Beitianshan-Atasbogd terrane, and (3) the Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin-arc terrane. Unconformably overlain by Permian volcanogenic and coal-bearing rocks. Accreted to the southern margin of the Siberian continent in the Late Carboniferous or Early

Permian (320 to 300 Ma). Interpreted as a southwestward continuation (present-day coordinates) of the South Mongolia-Khingan island arc.

AL Altai collage (Vendian through Ordovician; timing of accretion, Late Silurian)—Consists of the Vendian through Early Ordovician Salair island arc and fragments of arc-related turbidite and subduction-zone terranes, metamorphic terranes derived from arc-related rocks, and thick Cambrian and Ordovician overlap turbidites formed on the continental slope and rise, and fragments of originally adjacent oceanic terranes (Gorny Altai, West Sayan, Central and Northwestern Mongolia, and adjacent regions of northern China). Interpreted as an island-arc system that near the southwest margin (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. The Salair island arc (Vendian through Early Ordovician) is preserved in fragments in southwestern Siberia in: (1) the Early Cambrian through Early Ordovician Salair island-arc terrane, (2) the Cambrian Ulus-Cherga island-arc terrane, and (3) the Early and Middle Cambrian Sugash terrane. Tectonically linked subduction-zone and oceanic-crustal rocks are the Vendian and Early Cambrian Alambai subduction-zone terrane and the late Neoproterozoic and Early Cambrian Baratal subduction-zone terrane. The arc is also preserved in fragments in the Middle Silurian and older Angurep, the Late Permian and older Belokurikha, and Mesoproterozoic and Neoproterozoic Qinghe-Tsel metamorphic (arc-related) terranes. The arc is also preserved the Early to Late Paleozoic Anui-Chuya terrane; the Precambrian and Cambrian through Devonian Altai terrane; the Cambrian through Devonian Charysh terrane; the late Neoproterozoic through Devonian West Sayan terrane, and the Neoproterozoic through Silurian Hovd continental-margin turbidite terranes. The arc is also tectonically linked to the Early Paleozoic or older Kaitanak, Middle Devonian or older Maralikha, late Neoproterozoic through Early Cambrian Terekta, and late Neoproterozoic through Early Cambrian Baratal subduction-zone terranes. The arc is also tectonically linked to the late Neoproterozoic and Early Cambrian Mogen-Buren terrane, the Late Cambrian and Early Ordovician Zasurin terrane, and the late Neoproterozoic and Early Cambrian Saratan oceanic terranes. Timing of the accretion to the Siberian Continent is constrained by an angular unconformity at the base of the Upper Silurian or Devonian rocks and by orogenic granitoid magmatism of Early Devonian or older (pre-Emsian) age (435-415 Ma).

CS Circum-Siberia collage (Proterozoic; timing of accretion - Neoproterozoic)—Consists of the Baikal-Muya island-arc, the Near Yenisey Ridge island-arc, the Zavhan continental-margin-arc, Central and West Angara passive-continental-margin terranes, all of Neoproterozoic age, and small fragments of cratonal and metamorphic terranes of Archean and Proterozoic age. Interpreted as three separate Neoproterozoic island-arc systems that formed south (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. Unconformably overlain by Vendian and Cambrian sedimentary rocks, similar to coeval rocks of the Siberian platform but much thicker and containing more marine rocks. Accretion of the collage to the North Asian craton and cratonal margin occurred in the late Neoproterozoic. The Baikal-Muya island arc is preserved in fragments in the Paleoproterozoic through Early Cambrian Hamar-Davaa metamorphic terrane (metamorphosed forearc prism), the Neoproterozoic Baikal-Muya island-arc terrane, the late Neoproterozoic Barguzin metamorphic terrane (metamorphosed forearc prism), and (4) the late Neoproterozoic Sarkhoy island-arc terrane. Tectonically-linked subduction-zone terranes are the Paleoproterozoic through Neoproterozoic Olokit-Delunuran, the Neoproterozoic Hug, and the Neoproterozoic Kuvai. The Near Yenisey Ridge island arc is preserved in fragments in (1) the Neoproterozoic Isakov, the late Neoproterozoic Predivinsk, and the Neoproterozoic Chelyuskin island-arc terranes. The Zavhan continental-margin arc is preserved in fragments in northern Mongolia in the late Neoproterozoic Zavhan continental-margin-arc, and the Neoproterozoic Tasuul oceanic terranes. Cratonal and metamorphic terranes consist mainly of relatively small (tens of kilometers wide) fragments preserved in the Archean and Paleoproterozoic Gargan cratonal terrane, the Late Archean(?) and the Paleoproterozoic(?) Muya metamorphic terrane, and the Paleoproterozoic Kan cratonal terrane which are interpreted as fragments of the North Asian craton and that were rifted away during the breakup of the Rodinia supercontinent. These cratonal and metamorphic terranes formed a tectonic backstop for the accretion of Neoproterozoic island arcs to the Circum-Siberia collage.

MO Mongol-Okhotsk collage (Devonian through Late Jurassic; timing of accretion, late Paleozoic and early Mesozoic)—Consists mainly of the middle to late Paleozoic and early Mesozoic Selenga, Hangay, Uda-Murgal, and Stanovoy continental-margin arcs composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically linked outboard subduction-zone terranes. The arcs overlap the southern North Asian craton and cratonal margin and previously accreted terranes. Major continental-margin-arc overlap rocks are (1) the Permian through Jurassic Selenga sedimentary-volcanic plutonic belt, (2) the Late Carboniferous and Early Permian Hangay plutonic belt, (3) the Jurassic and Early Cretaceous Uda-Murgal and Stanovoy granite belts, (4) the Devonian through Triassic Lan continental-margin turbidite terrane, and (5) the Late Triassic through Middle Jurassic Ulban continental-margin turbidite terrane. Tectonically linked to the arc are the Cambrian through Early Carboniferous Galam, the Silurian through Permian Tukuringra-Dzhagdy, the Silurian through Late Carboniferous Hangay-Dauria, and the Paleozoic Ononsky subduction-zone terranes.

Interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean with the oblique; closure and accretion extend from the Permian through the Late Jurassic (140-90 Ma). After closure of the Mongol-Okhotsk Ocean, continuing left-lateral slip along the Mongol-Okhotsk Fault that bounded the former ocean resulted in formation of the Trans-Baikalian-Daxinganling bimodal igneous belt.

SL Solon collage (Carboniferous to Permian; timing of accretion - Late Paleozoic and Early Mesozoic)—Consists of the: (1) the Carboniferous and Early Permian North Margin, (2) the Late Carboniferous to Permian Solon, (3) the Devonian Imjingang, (4) the Paleozoic Ogcheon, and (5) the Silurian through Permian Sangun-Hidagaien-Kurosegawa subduction-zone terranes interpreted as fragments of the Solon Ocean plate. The terranes locally contain sedimentary rocks with mixed Tethyan and Boreal fossils. Some subduction-zone terranes were derived from underthrusting of the northern part of the Solon Ocean plate to form a composite continental-margin arc on the South Mongolia-Khingan collage and the Argun-Idermeg superterrane (Amur microcontinent composedm Carboniferous through Late Triassic South Mongolian volcanic-plutonic belt, (2) the Lugyngol arc, composed of Permian Lugyngol volcanic and sedimentary basin, (3) the Gobi-Khankaisk-Daxing'anling arc, composed of Permian Gobi-Khankaisk-Daxing'anling volcanic-plutonic belt, and (4) the Jihei arc, composed of Permian Jihei plutonic belt. Other subduction-zone terranes were derived from underthrusting of the southern part of the Solon Ocean plate and are tectonically linked to the North Margin continental-margin arc that formed on the Sino-Korean craton and is composed of the Carboniferous and Permian North Marginal plutonic belt of the North China platform. The various terranes were accreted to continental margins in the Permian and Triassic (290-203 Ma).

SM South Mongolia-Khingan collage (Ordovician through Carboniferous; timing of accretion, Late Carboniferous or Early Permian)—Consists mostly of the South Mongolia-Khingan island arc. Collage mainly composed of extensive local Ordovician, Silurian, Devonian, and Mississippian island-arc and turbidite terranes and tectonically linked subduction-zone terranes. Preserved in fragments in (1) the Neoproterozoic through Early Carboniferous Nora-Sukhotin-Duobaoshan island-arc terrane, the Devonian through Carboniferous Beitianshan-Atasbogd terrane, the Cambrian through Middle Devonian Dongwuzhumuqin-Nuhetdavaa terrane, the Middle Ordovician through Early Carboniferous Mandalovoo-Onor terrane, the Silurian through Early Carboniferous Gurvansayhan terrane, (6) the Devonian and Early Carboniferous Edren terrane, (7) the Cambrian through Devonian Govi Altai turbidite terrane, (8) the Ordovician through Devonian Bayanleg subduction-zone terrane, and (8) the Devonian through Permian Hegenshan terrane. Tectonically linked subduction-zone terranes are the Ordovician(?) and Devonian Zoolen, and the Devonian Mandan. The South Mongolia-Khingan island arc was separated from the North Asian craton by a large backarc basin now represented by fragments in the Ordovician through Devonian Bayanleg subduction-zone terrane and the Devonian Mandah subduction-zone terrane. The collages composing the arcs were accreted to the southern margin of the Siberian continent in the Late Carboniferous or Early Permian (320-300 Ma).

WD Wundurmiao collage (Mesoproterozoic through Silurian; timing of accretion, Late Silurian)—Consists of (1) the Late Ordovician and Silurian Laoling island-arc terrane, (2) the Mesoproterozoic through Middle Ordovician Wundurmiao subduction-zone terrane, and (3) the Neoproterozoic Seluohe subduction-zone terrane. Interpreted as having formed in the Laoling island-arc system that formed near Sino-Korean craton that was widely separated from the North Asian craton in the early Paleozoic. Intruded by granodiorite with a U-Pb age of 466 Ma and unconformably overlain by Silurian clastic rocks. Accreted to Sino-Korean craton in the Late Silurian (435-415 Ma) along a transform continental margin. Timing of accretion of the collage to the Siberian Continent is constrained by an angular unconformity at the base of the Upper Silurian or Devonian rocks and by orogenic granitoid magmatism of Early Devonian or older (pre-Emsian) age (about 435-415 Ma).

WS West Siberian collage (Ordovician through Carboniferous; timing of accretion, Late Carboniferous or Early Permian)—Consists of the Late Silurian through Early Carboniferous Rudny Altai island-arc terrane and the tectonically linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. Preserved in fragments in southwestern Siberia. Interpreted as a northwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc where it extends under Cenozoic and Mesozoic cover of southwestern Siberia.

YT Yenisey-Transbaikal collage (Vendian through Devonian; timing of accretion, Vendian through Early Ordovician)— Consists of Vendian through Middle Cambrian Kuznetsk-Tannuola, Dzhida-Lake island-arc terranes, tectonically linked backarc basins, and tectonically eroded subduction-zone terranes. Interpreted as a linear array of Vendian and Cambrian island-arc systems that formed south (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. Eastern part includes the West Stanovoy metamorphosed terrane, which may be a displaced fragment of the North Asian craton or another Unconformably overlain by Ordovician and Silurian flysch and molasse and contains local Early Ordovician metamorphic and granitoid complexes. Interpreted as having been accreted to the Siberian Continent in the Late Cambrian and Early Ordovician (500-460 Ma) during counterclockwise rotation of the Siberian continent that resulted in collision and duplexing of island arcs and closure of backarc basins. As a result, most of the island arcs and tectonically linked subduction-zones ceased activity in the Middle Cambrian. In the Late Cambrian and Early Ordovician, collisional granitoid batholiths were emplaced along with high-temperature metamorphic belts. The Kuznetsk-Tannuola island arc is preserved in fragments in southern Siberia and Mongolia in: (1) the Neoproterozoic through Devonian Telbes-Kitat island-arc terrane, (2) the late Neoproterozoic and Cambrian Kozhukhov island-arc terrane, (3) the late Neoproterozoic and Early Cambrian Kanim island-arc terrane, (4) the Cambrian and Ordovician Uimen-Lebed island-arc terrane, (5) the Early Cambrian Kurai island-arc terrane, (6) the Neoproterozoic through Devonian Ulgey Island arc terrane, (7) the Neoproterozoic through Early Cambrian North Sayan island-arc terrane, (8) the Cambrian Kizir-Kazir island-arc terrane, (9) the Cambrian Khamsara island-arc terrane, (10) the Early Cambrian Ulugo island-arc terrane, (11) the late Neoproterozoic through Ordovician Ondum island-arc terrane, (12) the Cambrian and older(?) Tannuola island-arc terrane, and (13) the late Riphean through Middle Cambrian Minusinsk-Tuva backarc basin. The tectonically linked subduction zone and oceanic-crustal rocks are: (1) the late Neoproterozoic Teletsk subduction-zone terrane, (2) the late Neoproterozoic and Early Cambrian Dzhebash subduction-zone terrane, (3) the Vendian and Early Cambrian Amil subduction-zone terrane, (4) the Early Cambrian Borus subduction-zone terrane, and (5) the late Neoproterozoic and Early Cambrian Kurtushiba subduction-zone terrane. Blueschist-facies rocks occur in the Borus and Kurtushiba subduction-zone terranes. Behind the Kuznetsk-Tannuola island arc were the Minusa and Tuva backarc molasse basins, consisting of the Altai-Sayan and East Tuva backarc basins. Units in the Altai-Sayan backarc basin are (1) the late Neoproterozoic and Cambrian Biya-Katun unit, (2) the late Neoproterozoic and Cambrian Kiya unit, and (3) the late Neoproterozoic Kizhikhem unit. The East Tuva backarc basin is late Neoproterozoic and Cambrian. The Minusa and Tuva backarc molasse basins, which formed over the Kuznetsk-Tannuola island-arc terranes, represent superposed structures related to the formation of Hercynian ocean basins. The Dzhida-Lake island arc is preserved in fragments in southern Siberia and Mongolia in (1) the late Neoproterozoic and Cambrian Lake island-arc terrane, (2) the late Neoproterozoic and Early Cambrian Eravna island-arc terrane, (3) the late Neoproterozoic through Silurian Orhon-Ikatsky island-arc terrane, and (4) the late Neoproterozoic and Early Cambrian Dzhida island-arc terrane. Behind the Dzhida-Lake island arc was the Transbaikal backarc basin, consisting of (1) the Ikatsky part of the late Neoproterozoic through Silurian Orhon-Ikatsky continental-margin-arc terrane, (2) part of the Paleoproterozoic through Early Cambrian Hamar-Davaa metamorphic terrane, and (3) part of the late Neoproterozoic Barguzin metamorphic terrane.

The West Stanovoy metamorphosed continental-margin terrane, which occurs at the east end of the collage in Transbaikalia and northern Mongolia, consists of the Early to Late Archean Nikitkinsky, and Paleoproterozoic schist, gneiss, quartzite-aluminous and carbonaceous subcomplexes, which are intruded by late Archean and Paleoproterozoic granitoid and lesser mafic plutonic rocks. The terrane, which is metamorphosed from greenschist to upper amphibolite to granulite facies, may be a displaced fragment of the North Asian craton or another craton.

Tectonic Collages Accreted onto the Eastern Margin of the North Asian and Sino-Korean Cratons (Mesozoic and Cenozoic)

BD Badzhal collage (Triassic through Early Cretaceous; timing of accretion, Late Cretaceous)—Consists of subduction-zone terranes composed of mainly Triassic and Jurassic turbidite, with fragments of Pennsylvanian and Permian limestone and chert containing Tethyan fauna, Late Triassic and Jurassic chert, and small basalt lenses. Preserved in fragments in the northern Russian Southeast in the Triassic through Middle Jurassic Badzhal and the Middle Triassic through Middle Jurassic Nadanhada subduction-zone terranes, which were subducted beneath the Siberian continental margin and previously accreted terranes, resulting in formation of the Umlekan continental-margin arc composed of the Cretaceous Umlekan-Ogodzhin volcanic-plutonic belt. The collage was amalgamated and accreted to the Siberian continental margin during subsequent strike-slip emplacement of outboard terranes in the Early Cretaceous. Unconformably overlain by the late Albian and Late Cretaceous Okhotsk-Chukotka volcanic-plutonic belt, which forms a major continental-margin arc.

CH Chukotka collage (Paleozoic through Triassic; timing of accretion, Late Jurassic and Early Cretaceous)—Consists of passive-continental-margin terranes that originally formed along the long-lived Neoproterozoic through early Mesozoic North American continental margin. Major units are Paleozoic and Triassic continental shelf and slope sedimentary rocks, Early Jurassic flysch, and unconformably overlying, flat-lying Late Jurassic and Early Cretaceous sedimentary overlap rocks. Interpreted as having formed during rifting of the North American continental margin in the Late Jurassic and Early Cretaceous and accretion of terranes to the northern North Asian cratonal margin in the Late Cretaceous.

EP East Kamchatka Peninsula collage (mainly Paleocene; timing of accretion, Pliocene)—Consists of Coniacian through Paleocene island-arc rocks with ophiolite fragments, which are unconformably overlain by flat-lying Quaternary volcanic rocks. Preserved mainly in the Late

Cretaceous to Paleocene Kronotskiy island-arc terrane and the mainly Cretaceous and Paleocene Kamchatskiy Mys oceanic terrane. Interpreted as a short-lived island arc and adjacent oceanic crust that were accreted to the East Asian continental margin during closure of an inboard ocean in the Pliocene.

ES East Sakhalin collage (Late Cretaceous to early Tertiary; timing of accretion, Early Tertiary)—Consists of Late Cretaceous through middle Eocene island-arc and tectonically linked subduction-zone terranes preserved in fragments in (1) the Late Cretaceous Terpeniy island-arc terrane, (2) the Late Cretaceous to middle Eocene Tokoro-Nemuro island-arc terrane, (3) the Late Jurassic through Late Cretaceous Shmidt island-arc terrane, (4) the Early Cretaceous through Miocene Shimanto subduction-zone terrane, and (5) probable subduction-zone terranes delineated by linear positive magnetic anomalies to the east of Sakhalin Island. Accretion to the East Asian continental margin occurred during closure of an inboard ocean and resulted in the formation of collision-related granitoids at about 40 Ma.

HS Honshu-Sikhote-Alin collage (Jurassic and Early Cretaceous; timing of accretion-Cretaceous)—Consists of fragments of subduction-zone, continental-margin turbidite (flysch), and island-arc terranes. Preserved in fragments in (1) the Permian through Early Cretaceous Mino Tamba Chichibu subduction-zone terrane, (2) the Carboniferous and Permian Akiyoshi-Maizuru subduction-zone terrane containing fragments of sedimentary rocks with Tethyan fossils, (3) the Cretaceous Sambagawa metamorphic terrane, (4) the late Early Cretaceous Kema island-arc terrane, (5) the Late Jurassic through Early Cretaceous Taukha subduction-zone terrane, (6) the Late Permian through Middle Jurassic Samarka subduction-zone terrane, (7) the early Paleozoic (?) Khor island-arc terrane, (8) the Jurassic and Early Cretaceous Kiselyovka-Manoma subduction-zone terrane, and (9) the Late Jurassic and Early Cretaceous Zhuravlevsk-Amur River continental-margin turbidite terrane. The Zhuravlevsk-Amur River continental-margin turbidite terrane and companion island-arc terranes are Interpreted as having formed along a Late Jurassic and Early Cretaceous continental-margin transform fault along which the older subduction-zone Mino Tamba Chichibu and Akiyoshi-Maizuru subduction-zone terranes were emplaced. Unconformably overlain by late Albian and younger flat-lying volcanic rocks of the East Sikhote-Alin volcanic-plutonic belt and its continuation onto Honshu Island. Interpreted as having formed along a transform continental margin.

KOR Koryak collage (Late Triassic through Cretaceous; timing of accretion, Late Cretaceous)—Consists of a Late Jurassic and Early Cretaceous island arc and tectonically linked subduction-zone terranes that are preserved in fragments in: (1) the Late Jurassic through mid-Cretaceous Mainitskiy island-arc terrane, (2) the Late Jurassic through Paleocene Alkatvaam subduction-zone terrane, (3) the Paleozoic Zolotogorskiy passive-continental-margin terrane, and (4) the Upper Paleozoic-Early Cretaceous Ekonay subduction-zone terrane.

OK Olyutorka-Kamchatka collage (Late Cretaceous and Paleocene; timing of accretion, Early Cenozoic)—Consists of island arc and tectonically linked subduction-zone terranes. Preserved in fragments in: (1) the Late Early Cretaceous and Paleocene Olyutorka-Kamchatka island-arc terrane, (2) the Late Cretaceous Iruneiskiy island-arc terrane, and (3) the Late Cretaceous through Oligocene Vetlovskiy subduction-zone terrane. Unconformably overlain by late Eocene, Oligocene, and Miocene sedimentary rocks. Interpreted as having been accreted to the East Asia continental margin during closure of an inboard ocean.

PA Penzhina-Anadyr collage (Late Jurassic and Early Cretaceous; timing of accretion, Late Cretaceous)—Consists of Late Jurassic-Neocomian subduction-zone terranes and a tectonically linked island-arc terrane that rim the eastern Kolyma-Omolon superterrane and Verkhoyansk-Kolyma collage. Preserved in fragments of: (1) the Ordovician through Middle Jurassic Penzhina Anadyr subduction-zone terrane that includes fragments of Devonian ophiolite, (2) the Middle and Late Jurassic Talovskiy subduction-zone terrane, (3) the Late Triassic through Early Cretaceous Kony-Murgal arc terrane, (4) the Triassic Velmay subduction-zone terrane, and (5) the West Pekulney island-arc terrane. Interpreted as the Uda-Murgal continental-margin and island arc and tectonically linked subduction-zone terrane, which formed in the Senomanian-Campanian following the closure of the outboard Mongol-Okhotsk Ocean. Unconformably overlain by the Late Albian and Late Cretaceous Okhotsk-Chukotka volcanic-plutonic belt that forms a major continental-margin arc.

SA South Anyui collage (Permian through Early Jurassic; timing of accretion, Late Cretaceous)—Consists of Late Jurassic through Neocomian subduction-zone terranes, and island and continental-margin-arc terranes that rim the northeastern Kolyma-Omolon superterrane and the Verkhoyansk-Kolyma collage. Preserved in fragments in (1) the mainly Late Jurassic-Early Cretaceous South Anyui subduction-zone terrane, (2) the Triassic and Early Jurassic Velmay subduction-zone terrane, (3) the Late Jurassic and Early Cretaceous Oloy and Late Jurassic Svyatov Nos volcanic belts along the northeastern margin of the Kolyma-Omolon superterrane, (4) the Late Jurassic and Early Cretaceous Nutesyn continental-margin-arc terrane that formed on the margin of the Chukotka collage during the closure of the South Anyui Ocean, and (5) the Permian and Triassic Shalaurov subduction-zone terrane. Interpreted as the Oloy island-arc and tectonically linked subduction-zone terranes. Unconformably overlain by the Late Albian and Late Cretaceous Okhotsk-Chukotka volcanic-plutonic belt (oc) that forms a major continental-margin arc. Interpreted as having accreted to the Russian Northeast continental margin during closure of the inboard South Anyui Ocean and was succeeded by formation of the Okhotsk-Chukotka continental-margin arc.

SH Sakhalin-Hokkaido collage (Cretaceous; timing of accretion, Eocene)—Consists of the Late Cretaceous flysch terranes of Sakhalin and Hokkaido Islands and tectonically linked subduction-zone terranes to the east that contain fragments of ophiolite, glaucophane schist, Late Jurassic and Early Cretaceous limestone with Tethyan reef corals, and island-arc terrane. Preserved in fragments in: (1) the Middle Triassic through early Late Cretaceous Aniva subduction-zone terrane, (2) the Jurassic through Paleogene Sosunay-Langeri subduction-zone terrane, (3) the Early Cretaceous through Miocene Shimanto subduction-zone terrane, (4) the Late Cretaceous and Paleogene Nabilsky subduction-zone terrane, and (5) the Late Jurassic through Late Cretaceous Kamyshovy island-arc terrane. The terranes were subducted beneath the East Asian continental margin resulting in formation of the East-Sikhote-Alin continental-margin arc composed of (1) the Late Cretaceous to Miocene East Sikhote-Alin volcanic-plutonic belt, and (2) the Early Cretaceous West Sakhalin turbidite basin terrane. Interpreted as a continental-margin forearc basin and tectonically-linked subduction-zone terranes associated with the East Sikhote-Alin continental-margin arc that were accreted to the Russian Southeast continental margin during closure of an inboard ocean, followed by the formation of outboard modern-day continental-margin arcs in the Russian Northeast, Kurile Islands, and Japan and tectonically-linked outboard subduction zone.

VK Verkhoyansk-Kolyma collage (Late Paleozoic through Early Jurassic; timing of accretion, Late Jurassic and early Early Cretaceous)—Consists of (1) the Permian through Early Jurassic Kular-Nera passive-continental-margin terrane (KN) that formed between the North Asian cratonal margin and the Kolyma-Omolon superterrane to the east in the Russian Northeast as distal formations of the Verkhoyansk passive continental margin, (2) the Middle and-Late Jurassic Polousny-Debin subduction-zone terrane, (3) the Carboniferous through Jurassic Viliga passive-continental-margin terrane, (4) the Debin ophiolite terrane, and (5) the late Neoproterozoic through Late Triassic Kotel'nyi passive-continental-margin terrane. Part of the Kular-Nera terrane, which was subducted beneath the Kolyma-Omolon superterrane in the Late Jurassic, resulting in formation of the Late Jurassic Uyandina-Yasachnaya island arc along the southern margin of the Kolyma-Omolon superterrane. Ophiolite terranes (Garbyn'ya, Indigirka, Kybytygas, Munilkan, and Uyhandina) derived from the collapsing ocean basin were obducted onto the superterrane. The Polousny-Debin terrane formed during the subduction of the Oimyakon oceanic crust beneath the southern margin of the Kolyma-Omolon superterrane. Interpreted as having formed during accretion of the outboard Kolyma-Omolon superterrane.

WK West Kamchatka collage (Mid-Cretaceous to early Tertiary; timing of accretion, Early Cenozoic)—Consists of (1) the Jurassic and Cretaceous West Kamchatka, (2) the Late Jurassic and Cretaceous Yanranay, and (3) the Jurassic Ekonay subduction-zone terranes in the Russian Northeast. Tectonically linked to the Okhotsk-Chukotka continental-margin arc (mid Cretaceous to early Tertiary, 96-50 Ma) that consists of the mid Cretaceous to early Tertiary Okhotsk-Chukotka volcanic-plutonic belt and the Albian and Late Cretaceous Penzhina sedimentary basin. Interpreted as having been accreted to the East Asian continental margin during outboard accretion of the Olyutoka-Kamchatka island arc.

Granite Belts and Overlapping Continental-Margin Arcs (Devonian through Early Tertiary)

at Altay continental-margin arc (Devonian and early Carboniferous, 381-290 Ma)—Occurs in southwestern Siberia, northwestern Mongolia, and northwestern China, where it consists of an extensive suite of mafic and intermediate-composition, and locally siliceous volcanic rocks, mafic and intermediate-composition intrusive rocks, and associated sedimentary rocks. Deposited under continental to marine conditions. Igneous rocks range from calc-alkaline through subalkaline to alkaline in composition. Interpreted as having formed along an active continental margin in an oblique-subduction-zone environment.

ea East Sikhote-Alin continental-margin arc (Late Cretaceous and early Tertiary, 96-55 Ma)—Occurs along the margin of southern Russian Far East, where it consists of Late Cretaceous and early Tertiary volcanic and plutonic rocks in the East Sikhote-Alin and West Sakhalin turbidite-basin terranes. Interpreted as having formed during subduction of the ancestral Pacific Ocean plate with formation of the older part of the Hidaka subduction zone, the younger part of the Aniva subduction-zone terrane, and the Nabilsky and Tokoro subduction-zone terranes.

gh Gobi-Khankaisk-Daxing'anling continental-margin arc (Permian, 295-250 Ma)—Occurs in northern China, Mongolia, and the Transbaikal region where it consists of the Gobi-Khankaisk-Daxing'anling volcanic-plutonic belt that overlies and intrudes the Argun-Idermeg superterrane and the South Mongolian and Solon collages. Volcanic and related sedimentary rocks are composed of basalt, andesite, dacite, rhyolite, tuff, sandstone, siltstone, conglomerate, sandstone, and minor limestone. Granitoid rocks are composed of adamellite, granite, granodiorite, monzonite granite, quartz monzonite, quartz diorite, gneissic granite, and two-mica granite. Interpreted as having formed during subduction of the northern part of the Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane.

ha Hangay continental-margin arc (Late Carboniferous and Early Permian, 320-272 Ma)—Occurs in central Mongolia, where it consists of large to medium-size multiphase rocks composed of granodiorite, tonalite, plagioclase granite, and minor gabbrodiorite, diorite, quartz diorite, and plagioclase leucogranite. Intrudes the Yenisey-Transbaikal and Mongol-Okhotsk collages. Interpreted as having formed during subduction of the northern part of Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously accreted terranes.

ji Jihei continental-margin arc (Permian, 295-250 Ma)— Occurs in eastern China, where it consists of granodiorite, monzonite, quartz diorite, quartz monzonite, diorite, syenite, and alkali-feldspar granite. Intrudes the Bureya-Jiamusi superterrane and the South Mongolia-Khingan collage. Interpreted as having formed during subduction of the northern part of the Solon Ocean plate under the southern margin (present-day coordinates) of the Bureya-Jiamusi supterterrane and adjacent rocks.

ko Khingan-Okhotsk continental-margin arc (Early Cretaceous and mid-Cretaceous)—Occurs in the Russian Southeast, where it consists of the Khingan-Okhotsk volcanic-plutonic belt that contains K-rich felsic volcanic rocks and coeval subvolcanic through plutonic granitoids. Tectonically paired with the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes (parts of the Honshu-Sikhote-Alin collage).

lg Lugyngol continental-margin arc (Permian, 295-250 Ma)— Occurs in southeastern Mongolia, where it consists of the Lugyngol volcanic-sedimentary basin composed of calk-alkalic andesite, dacite, rhyolite, conglomerate, sandstone, siltstone, and extensive flysch. Unit overlies and intrudes the South Mongolian and Solon collages. Interpreted as having formed during subduction of the northern part of the Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane.

ma Main granite belt (Late Jurassic, 144-134 Ma)—Occurs along adjacent sections of the North Asian cratonal margin and the Kolyma-Omolon superterrane, where it consists of Main amphibole-biotite granite, two-mica granite, and granodiorite. Interpreted as having formed during and immediately after collision of the Kolyma-Omolon superterrane with the North-Asian cratonal margin.

nb – Northern granite belt (Early Cretaceous, 138-120 Ma)— Occurs along the northwestern margin of the Kolyma-Omolon superterrane, where it consists of large, elongate plutons composed of quartz diorite, monzodiorite, and biotite granite, as well as amphibole-biotite granodiorite, biotite granite, and two-mica granite. Interpreted as having formed with subduction of oceanic crust during closure of a small oceanic basin in the late stage of accretion of the Kolyma-Omolon superterrane.

nm North Margin continental-margin arc (Late Carboniferous and Permian, 320-272 Ma)—Occurs in northern China, where it consists of the North marginal plutonic belt composed of calc-alkalic granodiorite, quartz monzonite, and granite. Intrudes northeastern margin (present-day coordinates) of the Sino-Korean Craton. Interpreted as having formed during subduction of the southern part of the Solon Ocean plate under the northeastern margin (present-day coordinates) of the Sino-Korean craton.

nr Norovlin continental-margin arc (Devonian and Early Carboniferous)—Occurs in northern Mongolia and the Transbaikal region, where it consists of a continental-margin arc formed on the Argun-Idermeg superterrane (Amur microcontinent and the Argunsky and Idermeg passive-continental-margin terranes). Preserved in Early and Middle Devonian calc-alkaline volcanic rocks and in Middle and Late Devonian volcaniclastic rocks, chert, and mudstone, and coeval granitoids that overlie or intrude superterrane and in Devonian through Early Carboniferous volcanic-sedimentary rocks fragments in the Ononsky subduction-zone terrane. Interpreted as having formed during subduction of the Mongol-Okhotsk Ocean plate beneath the northern margin (present-day coordinates) of the Argun-Idemeg superterrane (Amur microcontinent).

oc Okhotsk-Chukotka continental-margin arc (Late Cretaceous and early Tertiary, 96-53 Ma)—Occurs along the margin of the central and northern Russian Far East, where it consists of mid- and Late Cretaceous through early Tertiary volcanic and plutonic rocks in the Okhotsk-Chukotka volcanic-plutonic belt and the Penzhina sedimentary basin. Interpreted as having formed with subduction of the West Kamchatka, Ekonay, and Yanranay terranes during subduction of the ancestral Pacific Ocean plate

ol Oloy island arc (Late Jurassic, 154-135 Ma)—Occurs along the margin of the Kolyma-Omkolon superterrane, where it consists of the Late Jurassic-Neocomian Oloy volcanic belt, the Late Jurassic Svyatov Nos volcanic belt, and the Indigirka-Oloy sedimentary-volcanic-plutonic assemblage. Interpreted as having formed as an island arc on the Kolyma-Omolon superterrane during subduction of the South Anyui Ocean plate beneath the superterrane and formation of the South Anyui subduction-zone terrane.

se Selenga continental-margin arc (Permian through Jurassic, 295-135 Ma)—Occurs in Mongolia and the southern Transbaikal regions, where it consists of large volcanic fields and granite plutons. Volcanic rocks composed of rhyolite, trachyrhyolite, dacite, trachydacite, andesite basalt, trachybasalt, andesite flows, pyroclastic rocks, and local nonmarine sedimentary rocks. Granite plutons are composed of granodiorite, granite, granosyenite, and subordinate monzonite, diorite, and gabbrodiorite, REE granite, and leucogranite. Overlies and intrudes the Yenisey-Transbaikal collage and the Tuva-Mongolia superterrane. Interpreted as having formed during oblique subduction of the Mongol-Okhotsk Ocean plate under the North Asian cratonal margin and previously-accreted terranes.

sm South Mongolian continental-margin arc (Mid-Carboniferous through Triassic, 320-203 Ma)—Occurs in southern Mongolia, where it consists of the South Mongolian volcanic-plutonic belt composed of calc-alkalic basalt, andesite, basaltic andesite, dacite, rhyolite, and interbedded tuff and tuffaceous sandstone, granodiorite, granite, and leucogranite. Overlies and intrudes the South

Mongolian and the Atasbogd collages. Interpreted as having formed during subduction of the northern part of the Solon ocean under the Argun-Idermeg superterrane.

ss South Siberian volcanic-plutonic belt (Early Devonian)—Occurs in southern Siberia and the southern Transbaikal regions, where it consists of bimodal mafic and siliceous volcanic rocks with rare andesite, continental, red coarse-grained clastic rocks, diabase dikes and sills, and subalkaline to alkaline gabbro and granite, which occur in large intrusive massifs and small plutons in linear zones. Sedimentary and volcanic rocks range as far as 3,000 m or greater. Interpreted as having formed during rifting associated with a transition from a continental-margin transform margin to a convergent margin.

sv South Verkhoyansk granite belt (Late Jurassic through mid-Cretaceous, 157-93 Ma)—Occurs in the central Russian Far East, where it extends longitudinally along the central part of the South Verkhoyansk synclinorium on n the Verkoyansk (North Asian) cratonal margin. Occurs in batholiths, smaller granitoid plutons, and dikes composed of amphibole-biotite quartz diorite and granodiorite, adamellite, amphibole-biotite granite, and local melanocratic syenodiorite and locally in dikes of plagiogranite and granite aplite, leucocratic biotite granite, and Interpreted as having formed during the accretion of the outboard Okhotsk terrane.

tv Transverse granite belt (Early Cretaceous, 134-124 Ma)—Consists of several belts of granitic rocks that extend as far as a few hundred km and radiate outward from the southwestern bend in the Kolyma-Omolon superterrane. The belts taper out to the southwest and north and consist of fracture-related plutons and dikes swarms composed mainly of diorite, granodiorite, and granite. The belts crosscut, at a high angle, older folds and faults of the Verkhoyansk (North Asian) cratonal margin. Interpreted as having formed during the late stage of accretion of Kolyma-Omolon superterrane.

uo Umlekan-Ogodzhin continental-margin arc (Jurassic and Cretaceous, 135-65 Ma)—Occurs along the margin of the Kolyma-Omolon superterrane, where it consists of the Umlekan-Ogodzhin volcanic-plutonic belt and coeval Late Jurassic and Early Cretaceous granitic plutons. Tectonically linked to the Badzhal and Nadanhada subduction-zone terranes (parts of the Badzhal collage).

us Uda-Murgal and Stanovoy continental-margin arcs (Jurassic and Early Cretaceous, 203-96 Ma)—Occur in the central Russian Far East, where they consist of Late Jurassic and Early Cretaceous and lesser Late Triassic through Middle Jurassic igneous rocks preserved in the Uda volcanic-plutonic belt, the Uniya-Bom turbidite basin terrane, the Umlekan-Ogodzhin volcanic-plutonic belt, the Upper Amur sedimentary assemblage, and the Stanovoy granite belt. Intrude and overlie the southern margin of the North Asian craton. Interpreted as having formed during subduction of the Mongol-Okhotsk Ocean plate with formation of the Tukuringra-Dzhagd, Galam, and Ulban subduction-zone terranes.

uy Uyandina-Yasachnaya arc (Late Jurassic and Early Cretaceous, 154-120 Ma)—Occurs along the southern margin of the Kolyma-Omkolon superterrane and consists of the Uyandina-Yasachnaya volcanic belt, the Zyryanka sedimentary basin, the small Ainakhkurgen, Umkuveem, and Upper Penzhina basins, and the North Omolon basin, all parts of the Indigirka-Oloy sedimentary-volcanic-plutonic assemblage. Interpreted as having formed during subduction the Oimyakon Ocean plate between the North Asian cratonal margin and the Kolyma-Omolon superterrane, along the margin of which remnants of oceanic crust are preserved in small obducted ophiolites.

Plume-Related Igneous Province (Permian-Triassic Boundary)

tp Tungus Plateau (trapp) basalt, sills, dikes, and intrusions (Permian and Triassic)—Occurs in western part of eastern Siberia, where it consists of large volumes of basalt lava, tuffaceous-sedimentary rocks, sills and dikes, diatremes, diabase; gabbro, troctolite gabbro, anorthosite, and granophyre intrusions. Principal rocks intrusive rocks are diabase and gabbro-diabase. Geochronologic andpaleomagnetic studies indicate that trapp magmatism occurred at the Permian-Triassic boundary for a period of less than 1 Ma. Eruption of the Siberian trapps was among the largest surficial volcanic eruptions in the Phanerozoic history of the Earth Interpreted as forming in a mantle plume originating at the core-mantle boundary with no relation to lithosphere structures.

Transpressional Arcs (Devonian to Early Cretaceous)

mt Mongol-Transbaikal transpressional arc (Late Triassic through Early Cretaceous, 230-96 Ma)—Occurs in northern Mongolia and the southern Transbaikal region. Preserved in the Late Triassic through Early Cretaceous Mongol-Transbaikal volcanic-plutonic belt (mt) that consists of volcanic rocks in separate major basins, composed of trachyandesite, dacite, and trachyrhyolite flows, stocks, necks, and extrusive domes. Includes coeval granite plutons composed of grandiorite, alkaline gabbro-granite, granite, leucogranite, and Li-F granite. Interpreted as having formed with strike-slip faulting and rifting along the Mongol-Okhotsk Fault during and after closure of the Mongol-Okhotsk Ocean. Also referred to as the North Gobi arc.

ss South Siberian transpressional arc (Early Devonian, 415-400 Ma)—Occurs in the eastern Altai-Sayan region, where it consists of the South Siberian volcanic-plutonic belt. Volcanic rocks are composed of bimodal mafic and siliceous volcanic rocks, including andesite, olivine basalt, trachybasalt, essexite, phonolite, alkaline trachite, trachyandesite, and trachyrhyolite; plutonic rocks are composed of subalkaline to alkaline gabbro to granite, alkaline-syenite, granosyenite, leucogranite, and latite-bearing subalkaline gabbro, monzonite, and syenogranite. Interpreted as having formed along southern margin of the North Asian craton and cratonal margin during Early Devonian rifting that successively evolved into a continental-margin transpressive-fault margin and into a convergent margin.

tr Trans-Baikal-Daxinganling transpressional arc (Middle Jurassic through Early Cretaceous, 175-96 Ma)—Occurs in the Transbaikal region, Mongolia, and northeastern China, where it consists of the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt. Volcanic rocks are composed of shoshonite, latite, trachyte, trachyandesite, trachybasalt, trachyrhyolite, shoshonite, latite subalkaline basalt, and basalt andesite; plutonic rocks are composed of large calc-alkaline to subalkaline plutons of granite, leucogranite, quartz syenite, quartz monzonite, granodiorite, and biotite-amphibole diorite and small calc-alkaline subvolcanic bodies of dacite and rhyolite. Interpreted as having formed during strike-slip faulting and rifting along the Mongol-Okhotsk Fault during, and after closure of the Mongol-Okhotsk Ocean.

Active Continental-Margin Arcs (Miocene to Present)

ib Izu-Bonin continental-margin arc (Miocene through Holocene, 20-0 Ma)—Occurs south of southern Japan, where it consists of a volcanic arc composed chiefly of basalt to rhyolite, associated volcaniclastic rocks, and intercalated hemipelagic mudstone. Interpreted as having formed from subduction of the Philippine Sea plate during formation of Nankai subduction zone.

ja Japan continental-margin arc (Miocene through Holocene, 23-0 Ma)—Occurs along the Japan Islands, where it consists of extensive Quaternary volcanic rocks formed during subduction of the Pacific and Philippine Sea plates. Also contains associated volcanogenic forearc and backarc sedimentary basins. Volcanic rocks are mainly calc-alkaline basalt and andesite. Belt includes 83 active volcanoes and overlies all Japan terranes. Interpreted as having formed during subduction of the Pacific Ocean and Philippine Sea plates with formation of the Japan Trench and Nankai subduction zones.

kk Kuril-Kamchatka continental-margin arc (Miocene Holocene Present, 11-0 Ma)—Occurs along the Kamchatka Peninsula and Kuril Islands, where it consists of the Pliocene to Quaternary Central Kamchatka volcanic belt, the Central Kamchatka volcanic and sedimentary basin, and the East Kamchatka volcanic belt. Interpreted as having formed during subduction of the Pacific Ocean Plate during formation of the Japan Trench subduction zone.

Active Subduction Zones (Miocene to Present)

JT Japan Trench subduction zone (Miocene through Holocene; timing of accretion, 23-0 Ma)—Consists of the late Tertiary and Quaternary Japan and Kuril-Kamchatka Trench subduction-zone terranes. Tectonically linked to (1) the Miocene to Present Japan arc (ja), (2) the Miocene to Holocene Kuril-Kamchatka arc, and (3) the Paleogene through Quaternary Japan and Izu-Bonin forearc basins. Interpreted as having formed during active underthrusting of part of the western PacificOcean plate beneath the East Asian continental margin.

NN Nankai subduction zone (Miocene through Holocene; timing of accretion, 23-0 Ma)—Consists of (1) the Miocene through Quaternary Nankai subduction-zone terrane. Tectonically linked to (1) the Miocene to Holocene Japan arc, (2) the Miocene to Holocene Izu-Bonin volcanic belt, (3) the Paleocene Kyushu-Palau island-arc terrane, and (4) the Miocene through Quaternary Izu-Bonin island-arc terrane. Interpreted as having formed during active underthrusting of a fragment of the Pacific Ocean plate.

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Appendix C

Summary of Major Metallogenic Belts in Northeast Asia (the Russian Far East, Yakutia, Siberia, Transbaikalia, Northern China, Mongolia, South Korea, and Japan)

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Appendix C. Summary of Major Metallogenic Belts in Northeast Asia (the Russian Far East, Yakutia, Siberia, Transbaikalia, Northern China, Mongolia, South Korea, and Japan).

[Note: For each time span, metallogenic belts are listed from west to east, progressing from north to south. Adapted from detailed descriptions of metallogenic belts in Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006); detailed descriptions of major deposits adapted from Ariunbileg and others (2003)]

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
			Major Metallogenic Belts - Archean (> 2.5 Ga)		
Jidong (JD)	Banded iron formation (Shuichang, Sijiaying); Au in shear zone and quartz vein (Jinchangyu)	Northern China	Sino-Korean craton - West Liaoning-Hebei-Shanxi granulite-orthogneiss terrane.	Archean and Proterozoic. Archean deposits have Rb-Sr isotopic age greater than 3,500 Ma. Proterozoic or younger age for Au deposits in shear and retrograde metamorphic zones with isotopic ages of 2.5-2.6 Ga., 1.7-1.8 Ga., or younger.	Banded iron formation deposits are interpreted as having formed in a volcanic and sedimentation basin along an unstable proto-continental margin, or in a fragment of Archean craton. Au deposits are interpreted as having formed during retrograde metamorphism to greenschist facies.
Liaoji (LJ)	Banded iron formation (Gongchangling); Volcanogenic Zn-Pb-Cu massive sulfide (Hongtoushan); Au in shear zone and quartz vein (Jiapigou)	Northeastern China	Sino-Korean craton, Jilin-Liaoning-East Shandong terrane.	Late Archean. Metamorphic age of the Anshan Group hosting the banded iron formation deposits is 2.5-2.6 Ga. Isotopic age of the banded iron formation deposits units is probably older than 2.8 Ga. U-Pb zircon isotopic age for trondhjemite (mylonite) is 3,804 Ma.	Host greenstone belt in the Northern Liaoning (Hunbei) area is interpreted as having formed in an active continental margin whereasthe greenstone belts in the Anshan-Benxi and Jiapigou areas are interpreted as having formed in oceanic rifts along a continental margin. Au deposits are interpreted as having formed during retrograde metamorphism to greenschist facies. Because of the ancient geologic units and lack of detailed data, several mineral deposit types are combined into a composite belt.
Sharizhalgaiskiy (SH)	Banded iron formation; Talc (magnesite) replacement (Sosnov□ Baits, Baikalskoye, Savinskoye)	Russia, southern-eastern Siberia (East Sayan)	Sharizhalgay terrane (tonalite-trondhjemite gneiss, included in the North Asian craton) and Onot granite-greenstone terrane, derived from the North Asian craton).	Archean. Sharyzhalgay series has U-Pb, Rb-Sr, Sm-Nd isotopic ages of 2.42-3.12 Ga. Sedimentary rocks in the Onot terrane are Paleoproterozoic.	Some deposits (Kitoy group and the Baikalskoye deposit) are hosted in Archean sequences; others (Onot group – Sosnovy Baits deposits) are Proterozoic age. Layering in ferruginous quartzite and occurrence in two-pyroxene schists are interpreted as derived from ferruginous volcanic and sedimentary rock sequences.
Sutam (ST)	Banded iron formation (Olimpiyskoe)	Russia, southern Yakutia	Central Aldan superterrane (included in the North Asian craton).	Archean. Gneiss in the Sutam block has isotopic age of 2.5-3.0 Ga.	Two rock groups with banded iron formation deposits occur in the belt. (1) Magnetite-hypersthene and magnetite-pyroxene gneiss interlayered with amphibole-pyroxene and magnetite-pyroxene-plagioclase schist, which which the banded iron formation deposits consist of magnetite and hypersthene-magnetite quartzite occur in the outer part of an antiform. (2) Feldspar quartzite interlayered with garnet- and sillimanite-bearing schist with diopside calciphyre. Also occurring are magnetite-hypersthene and garnet-magnetite hypersthene layers.

West Aldan (WA)	Banded iron formation (Charskoye, Tarynnakh, Nelyuki, Dagda, Sulumatskoye, Severnoye and Yuzhnoye NizhneSakukan, Sakukannyrskoye and Oleng-Turritakhskoye); Au in shear zone and quartz vein (Lemochi, Olondo)	Russia, southern Yakutia	West Aldan terrane (included in the North Asian craton).	Archean through Paleoproterozoic. Metavolcanic and sedimentary rocks interlayered with banded iron formation deposits have isotopic ages of 2.7-3.2 Ga. Age of Au occurrences is Late Archean to Paleoproterozoic.	Belt is interpreted as having formed in a back-arc basin and (or) island arc. Au occurrences are mainly in shear zones cutting metabasalt, amphibolite, and ultramafic rock. Shear zones formed during amalgamation of terranes or during later tectonic events. Banded iron formation deposits (magnetite quartzite) form stratiform layers and lenses in metabasalt and amphibolite, and local siliceous metavolcanic rock and schist.
Wutai (WT)	Banded iron formation (Baizhiyan)	Northern China	Sino-Korean craton - West Liaoning-Hebei-Shanxi terrane (Granulite-orthogneiss)	Archean. Isotopic ages of >2.5 Ga.	Wutai greenstone belt and contained banded iron formation deposits deposits are interpreted as having formed in a non-mature to mature island arc.
			Major Metallogenic Belts, Paleoproterozoic (2.5-1.6Ga)		
Baydrag (BD)	Banded iron formation (Baydragiin Gol)	Central Mongolia	Baydrag cratonal terrane (part of the Tuva-Mongolia superterrane).	Paleoproterozoic. K-Ar phlogopite isotopic age for skarn is 1,900 Ma. U-Pb isochron and Pb-Pb zircon isochron ages range from 2.65-2.8 Ga for tonalite gneiss in the Baydrag metamorphic complex, and 2.4 Ga for charnokite in the Bombogor intrusive Complex	Banded iron formation deposits are hosted in Paleoproterozoic gneiss, amphibolite, schist, marble and quartzite derived from a volcanic and clastic sedimentary rock basin. Host rocks are intruded by Bombogor intrusive complex that is interpreted as a continental margin arc.
Jiliaojiao (JLJ)	Sedimentary-metamorphic borate (Wengquangou); Sedimentary-metamorphic magnesite (Xiafangshen); Talc (magnesite) replacement (Fanjiapuzi); Banded iron formation (Dalizi); Korean Pb-Zn massive sulfide (Qingchengzi); Metamorphic graphite (Nanshu); Au in shear zone and quartz vein (Baiyunshan, Nancha)	Northeastern China	East Shandong-East Liaoning-East Jilin rift basin overlying the Sino-Korean craton.	Late Paleoproterozoic. Metamorphism and intense deformation occurred at 1.9 Ga. Paleoproterozoic Dashiqiao Formation is with isotopic age of 1.7-1.5 Ga. Marble in the Proterozoic Liaohe group has isotopic age of 1.8 Ga.	Belt is interpreted as having formed in a passive continental margin, possibly as part of the Paleoproterozoic East Shandong-East Liaoning-East Jilin rift. Environment of formation and deposit controls are debated. Metallogenic belt is composite and includes several mineral deposit types.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
			Major Metallogenic Belts, Paleoproterozoic (2.5-1.6Ga)		
Kalar-Stanovoy (KS)	Au in shear zone and quartz vein (Ledyanoe, Namark, Pravokabaktanskoe)	Russia, southern Yakutia	Veins in the Kalar tectonic melange zone (included in the North Asian craton).	Paleoproterozoic (about 2.0 Ga)	Belt is interpreted as having formed during the collision between the Tynda and West Aldan terranes in the Aldan-Stanovoy region and during subsequent collapse of orogenic belt. Cause of collision was amalgamation of terranes during the formation of the North Asia craton. Au deposits occur in hear zones that cut metamorphosed mafic and ultramafic and plutonic rock.
Luliangshan (LL)	Banded iron formation (Yuanjiachun); Au in shear zone and quartz vein (Hulishan)	Northern China	Hutuo rift basin or foreland basin	Early Paleoproterozoic. Pb-Pb isotopic age of 2.23 Ga. U-Pb zircon isotopic age of 2.37 Ga.	Banded iron formation deposits iron and shear zone Au deposits are interpreted as having formed in a Paleoproterozoic Hutuo Basin that was superposed on the Archean Northern China craton. A composite metallogenic belt that includes several mineral deposit types.
Nimnyr (NM)	Apatite carbonatite (Seligdar)	Russia, southern Yakutia	Central Aldan superterrane (included in the North Asian craton).	Paleoproterozoic. Carbonatite pluton with isotopic age of 1.9 Ga.	Carbonatite is interpreted as having formed during interplate rifting. Deposits consist of apatite-carbonate, apatite-quartz-carbonate, martite-apatite-quartz-carbonate, and martite-apatite-carbonate and apatite-carbonate-quartz ores in a carbonatite in asymmetric stocks.
Qinglong (QL)	Banded iron formation (Zhalanzhangzhi); Clastic-sediment-hosted Sb-Au (Qinglonghe)	Northern China	Sino-Korean craton -West Liaoning-Hebei-Shanxi terrane.	Paleoproterozoic.	Banded iron formation deposits are hosted in marine volcaniclastic and clastic sedimentary rocks with minor conglomerate that are metamorphosed to amphibolite and greenschist facies. Belt is interpreted as having formed in a passive continental margin or aulacogen that was subsequently regionally metamorphosed and thrusted.
Tyrkanda-Stanovoy (TS)	Au in shear zone and quartz vein (Kolchedannyi Utyos)	Russia, southern Yakutia	Veins in the Tyrkanda tectonic melange zone (included in the North Asian craton).	Paleoproterozoic (about 2.0 Ga).	Belt is interpreted as having formed during collision between the Tynda composite terrane and the Central Aldan and East Aldan superterranes. The reason for collision is unclear. Au shear zone deposits cut metamorphosed mafic and utramafic bodies and plutonic rocks.
Uguy-Udokanskiy (UU)	Zoned mafic-ultramafic Cu-PGE (Chineyskoye;); Sediment-hosted Cu (Udokanskoye); Ta-Nb-REE alkaline metasomatite (Pravo-Ingamakit, Sakinskoye, Sulbanskoye, Katuginskoye)	Russia, southern Yakutia	West Aldan terrane (included in the North Asian craton).	Paleoproterozoic. Age of Cu sandstone in the Udokan deposit is 2.2-1.8 Ga. Ta, Nb, REE alkaline metasomatite deposits have an isotopic age of 2.0-1.6 Ga.	Cu and PGE deposits in zoned mafic-ultramafic plutons and Cu in the sedimentary rocks are interpreted as having formed along a passive continental-margin rift. Ta-Nb-REE alkaline metasomatite deposits are interpreted as having formed during later collision and formation of anatectic granite.

Major Metallogenic Belts, Mesoproterozoic (1.6-1.0 Ga)					
Darvi (DR)	Sedimentary bauxite (Alag Uul); Sedimentary Fe-V	Mongolia	Baydrag cratonal terrane (part of the Tuva-Mongolia superterrane).	Mesoproterozoic.	Belt is interpreted as having formed during bauxite sedimentation in a Lower to Middle Riphean sedimentary basin along a passive continental margin.
Langshan-Bayan Obo (LB)	Sedimentary exhalative Pb-Zn (SEDEX) (Huogeqi); Polygenic REE-Fe-Nb deposits (Bayan Obo)	Northwestern and North-Central China	Layers in the Zhangbei-Bayan Obo-Langshan rift-related metasedimentary and metavolcanic units deposited on the Sino-Korean craton.	Mesoproterozoic. Sm-Nd isochron ages for monazite, bastnaesite, and riebeckite are 1.2-1.3 Ga. Th-Pb and Sm-Nd ages of Ba-REE-F carbonates and aeschynite are 474-402 Ma.	Bayan Obo deposit is interpreted as a SEDEX deposit related to a carbonatite magma and associated hydrothermal activity. Belt is hosted in a Mesoproterozoic overlap sedimentary assemblages that formed in a rift along the passive continental margin of the Sino-Korean craton.
Yanliao (YL)	Chemical-sedimentary Fe-Mn (Wafangzi); Sedimentary exhalative Pb-Zn (SEDEX) (Gaobanhe)	Northern and Northeastern China	Jixian Group - sedimentary cover on Sino-Korea craton.	Mesoproterozoic. Age of the Jixian Group is 1.4-1.1 Ga.	Belt is interpreted as having formed in a shallow marine basin on the Sino-Korean craton.
Major Metallogenic Belts, Neoproterozoic (1,000-540 Ma)					
Angara-Pit (AP)	Sedimentary hematite Fe (Nizhne-Angarskoye); Volcanogenic-sedimentary Fe	Russia, eastern Siberia (Yenisei Ridge)	North Asian craton margin, East Angara fold and thrust belt.	Upper Riphean.	Belt is interpreted as having formed during pre-orogenic subsidence of the North Asian craton margin in a back-arc (interland) sedimentary basin.
Baikalo-Muiskiy (BM)	Volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn (±Cu); Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite; Serpentinite-hosted asbestos (Kholodninskoye, Lugovoye, Molodezhnoye)	Russia, Northern Transbaikalia	Baikal-Muya island arc terrane (part of the Circum-Siberia collage), and Muya metamorphic terrane (part of the Tuva-Mongolia superterrane), and Olokit-Delunuran craton-margin rift terrane.	Neoproterozoic.	Various deposits in the belt are interpreted as having formed in the Baikal-Muya island arc or during Riphean accretion of terrane with Muya metamorphic terrane and Olokit-Delunuran continental-margin rift terrane.
Bodaibin-skiy (BO)	Au in black shale (Sukhoy Log, Vysochaishi, Dogaldynskoye)	Russia, Northern Transbaikalia	North Asian craton margin, Patom fold and thrust belt.	Belt formation started in the Neoproterozoic with subsequent enrichment in the Devonian to Early Carboniferous. Age of gold from the Sukhoy Log deposit is about 320 Ma.	Initial gold deposition occurred during sedimentation and later metamorphism and hydrothermal activity. Subsequent Neoproterozoic postcollisional magmatic and hydrothermal activity formed economic deposits. Subsequent deposition of Au-Ag sulfosalt deposits during magmatic and hydrothermal activity in the middle and late Paleozoic.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
			Major Metallogenic Belts, Neoproterozoic (1,000-540 Ma)		
Bokson-Kitoiskiy (BK)	Sedimentary bauxite (Boksonskoye); Magmatic nepheline (Botogolskoye); Serpentine-hosted asbestos (Ilchirskoye); Au in shear zone and quartz vein (Zun-Kholba)	Russia, southern-eastern Siberia (East Sayan)	Layers in, and veins and plutons intruding or associated with the Belaya-Kitoy metamorphic, Hug subduction zone, and Tunka island arc terranes, the Tannuola plutonic belt, and Huvsgol-Bokson sedimentary overlap assemblage (all part of the Yenisey-Transbaikal collage).	Neoproterozoic through Silurian. Neoproterozoic sedimentary rocks with Cambrian through Silurian metamorphism, hydrothermal alternation, and plutonic intrusion. Younger of part of Sumsunur tonalite complex has U-Pb and Rb-Sr isotopics ages of 790 Ma.	Belt is hosted in metamorphic, oceanic, subduction zone, and tonalite-trondhjemite-gneiss terranes that underwent Cambrian through Silurian metamorphism, hydrothermal alternation, and plutonic intrusion. Deposits formed in multiple events. Metallogenic belt is a composite that includes several mineral deposit types.
Central-Yenisei (CY)	Au in black shale (Olympiada); Au in shear zone and quartz vein (Sovetskoye); Clastic-sediment-hosted Sb-Au (Udereiskoye)	Russia, eastern Siberia (Yenisei Ridge)	Central Angara passive continental margin terrane (part of the Central Siberia collage).	Late Neoproterozoic. K-Ar isotopic age for late-stage hydromica metasomatites in the Sb-Au deposit is 605 Ma-664 Ma. Rb-Sr isotopic age for the Tatarsk granitoid is 601 Ma.	Gold deposits are interpreted as having formed during collisional development of the late Riphean continental margin of the North Asian craton. Gold initially forming in black shale was subsequently concentrated and remobilized during collision-related metamorphism, granitoid intrusion, and hydrothermal activity.
Hovsgol (HO)	Sedimentary phosphate (Hubsugul); Volcanogenic-sedimentary Mn (Saihangol); Sedimentary Fe-V (Hitagiin gol)	Northern Mongolia	Huvsgol-Bokson sedimentary overlap assemblage deposited on the Tuva-Mongolia superterrane.	Vendian and Early Cambrian.	Belt is interpreted as having formed during sedimentation in a carbonate-dominated basin along a continental shelf.
Jixi (JX)	Banded iron formation (Shuangyashan); Homestake Au (Dongfengshan); Metamorphic graphite; (Liumao); Metamorphic sillimanite	Northeastern China	Jiamusi terrane (Metamorphic) terrane and Zhangguangcailing (Continental margin arc) superterrane	Neoproterozoic through Cambrian.	Belt is part of a khondalite that is interpreted as derived from Al-rich mudstone and carbonates of the Mashan and the Xingdong groups that were deposited in a shallow sea and isolated oceanic basin and lagoon.
Kyllakh (KY)	Carbonate-hosted Pb-Zn (Mississippi valley type) (Sardana)	Russia, Far East	Verkhoyansk (North Asian) craton margin.	Vendian.	Belt is interpreted as having formed on passive margin of the North Asian craton in the Vendian. Economic deposits occur in areas of facial thinning of dolomite.

Lake (LA)	Volcanogenic Cu-Zn massive sulfide (Urals type) (Borts uul); Volcanogenic-sedimentary Fe; Podiform Cr; Mafic-ultramafic related Ti-Fe (±V); Cu (±Fe, Au, Ag, Mo) skarn; Fe skarn; Granitoid-related Au vein (Khyargas); Cyprus Cu-Zn Massive Sulfide (Naran Davaa); Mafic-ultramafic related Cu-Ni-PGE (Tsagdaltyn Davaa)	Western Mongolia	Lake island arc terrane (part of the Yenisey-Transbaikal collage).	Late Neoproterozoic. Khantayshir ophiolite has an U-Pb zircon isotopic age of 568 Ma. Dariv ophiolite has an U-Pb zircon isotopic age of 573 Ma.	Various deposits in the belt are interpreted as having formed during sea floor spreading volcanism and related mafic-ultramafic magmatism, and in subduction-related island arc volcanism and mafic plutonism, and multiple-phase granitic magmatism.
Pribaikal-skiy (PB)	Carbonate-hosted Pb-Zn (Mississippi Valley type) (Barvinskoye)	Russia, East Sayan	Sheared margin between the Paleoproterozoic Akitkan volcanic-plutonic belt and the Verkhoyansk (North Asian) craton margin.	Riphean.	Belt is interpreted as having formed along shear zones and faults that occur between an ancient active continental margin along the North Asian craton margin.
Prisayan-skiy (PR)	REE (±Ta, Nb, Fe) carbonatite (Beloziminskoye); Mafic-ultramafic related Ti-Fe (±V)	Russia, southern-eastern Siberia (East Sayan)	Various units in the North Asia craton: Onot granite-greenstone and Sharizhalgay tonalite-trondhjemite gneiss terranes containing mafic-ultramafic plutons in the Ziminsky complex, and ultramafic alkaline plutonic rock.	Late Neoproterozoic. Rb-Sr isochron age for talc deposit is 633 Ma; Rb-Sr and ^{40}Ar-^{39}Ar age for REE carbonatite deposits is 547 Ma.	Belt occurs in the enderbite-gneiss, tonalite-trondjemite, anorthosite-paragneiss units in terranes that are fragments of Precambrian craton crystalline basement. Host terranes are uplifted parts of the North Asian craton.
Vorogovsko -Angarsk (VA)	Sedimentary exhalative Pb-Zn (SEDEX) (Gorevskoye); Carbonate-hosted Pb-Zn (Mississippi valley type) (Moryanikhinskoye); Fe skarn (Enashiminskoye)	Russia, eastern Siberia (Yenisei Ridge)	West Angara passive continental margin terrane (part of the Central Siberia collage).	Early Neoproterozoic. Model Pb-Pb isotopic age for Gorevskoye deposit is 834-852 Ma. Pb isotopic age of Moryanikhinskoye deposit is 740-849 Ma. Host rocks have an isotopic age of 950 Ma.	SEDEX deposits are interpreted as having formed along transcrustal block-bounding faults in the margin of the platform. Carbonate-hosted Pb-Zn deposits were hosted in the reefs. Fe skarn deposits formed during contact metasomatism of marine volcanic and sedimentary rocks.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
			Major Metallogenic Belts, Cambrian Through Silurian (540-410 Ma)		
Bedobinsk (BE)	Sediment-hosted Cu (Bedobinsk, Kurishskoye)	Russia, eastern Siberia (Yenisey Ridge area)	North Asian craton.	Middle and Late Cambrian.	Belt is interpreted as having formed in an inland-sea basin during post-saline stage of rock deposition. Main source of copper was weathered Riphean rocks as well as lode deposits in the Yenisei Ridge, and from hydrothermal activity along deep-fault zones related to rifting.
Bayanhon-gor (BH)	Au in shear zone and quartz vein (Bor Khairhan, Khan Uul, Dovont); Granitoid-related Au vein (Tsagaantsakhir Uul); Cu-Ag vein (Jargalant, Bayantsagaan, Burdiingol); Cu (±Fe, Au, Ag, Mo) skarn (Khokhbulgiin Khondii)	Central Mongolia	Veins in the Hangay-Dauria subduction-zone terrane, Orhon-Ikatsky continental margin arc terrane, and Zag-Haraa turbidite basin (all part of the Yenisey-Transbaikal collage).	Late Ordovician. K-Ar metamorphic isotopic ages of foliated and metamorphosed host mudstone (Vendian to Early Cambrian Olziitgol Formation in the Orhon terrane) are 447 and 453.9 Ma.	Belt is interpreted as having formed during regional metamorphism associated with accretion of the Bayanhongor and Baydrag terranes.
East Liaoning (EL**)**	Diamond-bearing kimberlite (Fuxian)	Northeastern China	Kimberlites intruding the Sino-Korean craton - Jilin-Liaoning-East Shandong tonalite-trondhjemite-gneiss terrane.	Ordovician(?). Isotopic age of kimberlite is about 340-455 Ma. Isotopic age of kimberlite on Shandong Peninsula is 460-490 Ma.	Kimberlite and associated intrusions occur along the northeast-trending regional Tanlu fault along northern margin of the Sino-Korean Platform.
Govi-Altai (GA)	Volcanogenic-sedimentary Fe (Uhin Ovoo); Volcanogenic-sedimentary Mn (Tahilgat Uul, Sharturuutiin gol)	Southwestern Mongolia	Govi Altai continental-margin turbidite terrane (part of the South Mongolia-Khingan collage).	Middle Cambrian through Early Ordovician.	Belt is interpreted as having formed during sedimentation along an early Paleozoic continental slope.
Hovd (HO)	Granitoid-related Au vein; Au skarn; Cu (±Fe, Au, Ag, Mo) skarn (Yolochka)	Western Mongolia	Replacements related to the Turgen granitoid complex that intrudes the Hovd continental-margin turbidite terrane (part of the Altai collage).	Ordovician through Late Silurian. K-Ar isotopic age of the Hovd complex is 426-456 Ma.	Belt is interpreted as having formed during subduction related granitic magmatism along a continental-margin arc.
Hunjiang-Taizihe (HT)	Evaporite sedimentary gypsum (Rouguan)	Northeastern China.	Platform sedimentary cover on the Sino-Korean craton.	Cambrian and Ordovician.	Gypsum is interpreted as having formed in a supertidal sabkha sedimentary environment.
Jinzhong (JZ)	Evaporite sedimentary gypsum (Taiyuan)	Northern China	Sino-Korean platform sedimentary cover	Cambrian and Ordovician.	Gypsum is interpreted as having formed in a large epicontinental marine basin.
Jixi (JX)			Started in the Neoproterozoic (1000-540 Ma)		

Kiyalykh-Uzen (KY)	Cu (±Fe, Au, Ag, Mo) skarn (Kiyalykh-Uzen, Juliya Mednaya); W±Mo±Be skarn (Tuim); Fe skarn (Samson); W-Mo-Be greisen, stockwork, and quartz vein (Verhne-Askizskoye, Turtek)	Russia, southern-eastern Siberia (Kuznetsk Alatau Mountains)	Replacements related to the Tannuola plutonic belt (part of the Yenisey-Transbaikal collage).	Early Ordovician through Early Silurian. ^{40}Ar/^{39}Ar host-rock isotopic age is 480-420 Ma.	Belt is related to early Paleozoic collisional granitoids that intrude a Vendian and Cambrian shelf carbonate and clastic-carbonate rocks during transpressive (dextral-slip) movement along the Kuznetsk Alatau fault.
Kizir-Kazyr (KK)	Fe skarn (Irbinskoye); Volcanogenic-sedimentary Fe (Belokitatskoye); Granitoid-related Au vein (Olkhovskoye)	Russia, southern-eastern Siberia (Eastern Sayan Ridge)	Replacements related to the Tannuola plutonic belt (part of the Yenisey-Transbaikal collage).	Cambrian and Ordovician. K-Ar isotopic age for deposit-related gabbro, diorite, and granodiorite plutons in the Irbinskoye district is 430 Ma.	Deposits are hosted in gabbro, diorite, and granodiorite in the collisional Tannuola plutonic belt, and in the volcanogenic-sedimentary rocks of the Kizir-Kazir island-arc terrane, part of the Yenisey-Transbaikal collage.
Martaiginsk (MT)	Granitoid-related Au vein (Sarala, Komsomolskoye); Au skarn (Natal'evskoye, Sinyukhinskoye, Komsomolskoye)	Russia, southern-eastern Siberia (Kuznetsk Alatau, Gorny Altai Mountains)	Granitoids and veins related to the Tannuola plutonic belt (part of the Yenisey-Transbaikal collage).	Late Ordovician and Early Silurian. ^{40}Ar/^{39}Ar isotopic age of 480-460 Ma for the Martaiginsk complex; K-Ar age of 445-427 Ma for the Lebed complex; Rb-Sr ages of 472 Ma, 458 Ma, 444 Ma, and 433 Ma for gangue minerals and metasomatite for the Gavrilovskoye, Centralnoye, Komsomolskoye, Sarala deposits.	Belt is related to early Paleozoic collisional granitoids that intrude Vendian and Cambrian shelf carbonate and clastic-carbonate rocks during transpressive (dextral-slip) movement along the Kuznetsk Alatau fault. Deposits clusters along fault and shear zones that are branches of the Kuznetsk Alatau fault.
Ozerninsky (OZ)	Volcanogenic-hydrothermal-sedimentary (metasomatic) massive sulfide Pb-Zn (±Cu); (Ozernoye); Volcanogenic-sedimentary Fe (Arishinskoye)	Russia, western Transbaikalia	Eravna island arc terrane (part of Yenisey-Transbaikal collage).	Cambrian through Silurian. Isotopic age of younger granitoids intruding terrane is 320-400 Ma.	Belt is interpreted as having formed in an island arc that was subsequently intruded by the Barguzin-Vitim batholith.
South Khingan (SK)	Banded iron formation (Yuzhno-Khingan, Kimkanskoe, Kostenginskoe)	Russia, Far East	Malokhingansk subduction-zone terrane, included in the Sino-Korean craton.	Neoproterozoic through Cambrian. Banded iron formation deposits intruded by granitic plutons with K-Ar isotopic ages of 604 and 301 Ma.	Belt is interpreted as having formed in a volcanic and sedimentation basin along an unstable proto-continental margin, or in a fragment of an Archean craton that was incorporated into an subduction-zone terrane.
Uda-Shantar (US)	Volcanogenic-sedimentary Fe (Gerbikanskoe); Volcanogenic-sedimentary Mn (Ir-Nimiiskoe-1); Sedimentary phosphate (North-Shantarskoe, Nelkanskoe, Ir-Nimiiskoe-2, Lagapskoe)	Russia, Far East	Galam subduction-zone terrane (part of the Mongol-Okhotsk collage).	Early Paleozoic.	Belt is interpreted as having formed during sea floor hydrothermal activity associated with basaltic volcanism that was accompanied by chert deposition in basins. Fe and Mn deposits occur in elongate beds and lenses. Sedimentary P deposits are interpreted as having formed in limestone caps that formed in two stages on accreted seamounts, atolls, and guyots. Units and deposits were subsequently incorporated into a subduction zone.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
			Major Metallogenic Belts, Devonian through Early Carboniferous (Mississippian)(410-320 Ma)		
Bayangovi (BG)	Au in shear zone and quartz vein (Bayangovi district)	Southern Mongolia	Replacements in the Govi Altai continental-margin turbidite terrane (part of the South Mongolia-Khingan collage).	Devonian.	Belt is interpreted as having formed regional metamorphism of the Govi-Altai terrane, part of the South Mongolia-Khingan collage, during collision with the Lake terrane.
Botuobiya - Markha (BM)	Diamond-bearing kimberlite (Mir, Internatsional'naya)	Russia, Central Yakutia	Kimberlite intruding the North Asian craton.	Devonian.	Tectonic environment unknown. Devonian kimberlite pipes intrude mostly Cambrian to Silurian carbonate sedimentary rocks of the North Asian craton.
Daldyn-Olenyok (DO)	Diamond-bearing kimberlite (Aikhal, Udachnaya, Ubileinaya, Sytykanskaya)	Russia, Northeast Yakutia	Kimberlite intruding the North Asian craton.	Devonian.	Tectonic environment unknown. Devonian kimberlite pipes intrude mostly Cambrian to Silurian carbonate sedimentary rocks of the North Asian craton.
Deluun-Sagsai (DS)	Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite (Burgedtas); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Nominy Am); Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type); Sediment-hosted Cu (Khatuugiin gol); Ag-Pb epithermal vein (Dulaan khar uul); Granitoid related Au vein	Western Mongolia	Granitoids and replacements related to the Deluun sedimentary-volcanic-plutonic belt (part of the Altai continental margin arc).	Early Devonian through Early Carboniferous.	Belt is interpreted as having formed along an active Andean-type continental margin.
Edrengiin (ED)	Volcanogenic Cu-Zn massive sulfide (Urals type) (Olgii nuruu); Volcanogenic-sedimentary Mn; Volcanogenic-sedimentary Fe (Olgiibulag)	Southwestern Mongolia	Edren Island arc terrane (part of the South Mongolia-Khingan collage).	Early Devonian.	Belt is interpreted as having formed during island arc volcanism. Deposits are hosted in pillow basalt and siliceous rocks.
Edren-Zoolon (EZ)	Au in shear zone and quartz vein (Edren, Nemegt)	Southern Mongolia	Veins in the Edren island arc terrane and Zoolen subduction-zone terrane (both part of the South Mongolia-Khingan collage).	Late Devonian through Early Carboniferous.	Belt is interpreted as having formed during regional metamorphism and vein emplacement associated with accretion of the Beitianshan-Atasbogd and Zhongtianshan terranes.

Hongqiling (HQ)	Mafic-ultramafic related Cu-Ni-PGE (Hongqiling); Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite (Guanma)	Northeastern China	Mafic and ultramafic plutons in the Hongqiling plutonic and the Guanma volcanic sedimentary complexes that intrude and overlap the Zhangguangcailing superterrane and the Laoling terrane (part of the Bureya-Jiamusi supterterrane).	Mississippian. Isotopic ages of 331-350 Ma.	Belt is interpreted as having formed during extension after accretion of the Zhangguangcailing superterrane and Laoling terrane. Belt is hosted in Mississipian or possibly Triassic mafic-ultramafic plutons, and in overlap volcanic assemblages in an extensional basin that formed after the accretion.
Kizhi-Khem (KZ)	W-Mo-Be greisen, stockwork, and quartz vein (Okunevskoye); Porphyry Cu-Mo (±Au, Ag) (Aksug, Dashkhemskoye); Ta-Nb-REE alkaline metasomatite (Aryskanskoye 1); Granitoid-related Au vein	Russia, southern-eastern Siberia (Northeast Tuva area)	Replacements and granitoids related to the South-Siberian volcanic-plutonic belt that overlies and intrudes the Khamsara island-arc terrane.	Devonian through Pennsylvanian. Estimated ^{40}Ar/^{39}Ar isotopic age for the Aksug Cu-Mo-porphyry deposit is 400-380 Ma. Alaskite and alkalic granite hosting W-Mo-Be deposits intrude Silurian-Devonian granite and have K-Ar isotopic ages of 305-280 Ma.	Belt is interpreted as having formed during granitoid magmatism associated with the South Siberian volcanic plutonic belt that formed during rifting associated with transpressional faulting.. Deposit-related plutons intrude Early Cambrian volcanic rocks of the Khamsara island-arc terrane and early Paleozoic granites of the Tannuola plutonic belt.
Korgon-Kholzun (KK)	Volcanogenic-sedimentary Fe (Kholzunskoye, Inskoye, Beloretskoye); Fe skarn, Mafic-ultramafic related Ti-Fe (±V) (Kharlovskoye); Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite (Charyshskoye)	Russia, southern-eastern Siberia (Gorny Altai area)	Deposits related to the Altai volcanic-plutonic belt that overlap and intrude the Altai and Charysh continental margin turbidite terranes.	Devonian and Carboniferous.	Belt is interpreted as having formed along the Altay continental margin arc.
Mamsko-Chuiskiy (MC)	Muscovite pegmatite (Vitimskoye, Lugovka, Kolotovka, Bolshoye Severnoye, Komsomolsko-Molodezhnoye, Sogdiondonskoye, and Chuyskoye)	Russia, northern Transbaikalia	Veins and dikes in the Mamsky and Konkudero-Mamakansky complexes intruding the Chuja paragneiss terrane (included in the Baikal-Patom craton margin).	Devonian and Early Carboniferous. Mamsky complex has an isotopic age of 350-300 Ma.	Interpreted as having formed during intrusion of alkaline granitoid of the Mamsky and Konkudero-Mamakansky Complexes into the Chuya paragneiss terrane that were part of a passive margin. The host granitoids are interpreted as having formed during post-accretionary magmatism in transpression zones related to transform microplate boundaries and within-plate (plume) environment.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
			Major Metallogenic Belts, Devonian through Early Carboniferous (Mississippian)(410-320 Ma)		
Muiskiy (MS)	Granitoid-related Au vein; Au in shear zone and quartz vein (Irokindinskoye); Carbonate-hosted Hg-Sb (Kelyanskoye); Porphyry Sn (Mokhovoye)	Russia, Northwestern Transbaikalia	Granitoids and veins related to the Barguzin-Vitim granitoid that intrudes the Baikal-Muya island arc terrane and Muya metamorphic terrane (both part of the Tuva-Mongolia superterrane).	Devonian and Early Carboniferous.	Belt is interpreted as having formed in granitoids and veins generation during Riphean collision of the Baikal-Muya terrane with the Muya terrane.
Rudny Altai (RA)	Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) (Korbalihinskoye, Stepnoye, Talovskoye, Rubtsovskoye, Zakharovskoye, Jubileinoye); Barite vein (Zarechenskoye, Zmeinogorskoye); Volcanic-hosted metasomatite	Russia, southern-eastern Siberia	Rudny Altai island arc, terrane (part of the West Siberian collage).	Middle and Late Devonian.	Belt is interpreted as having formed in an island arc. Belt is hosted in shallow marine shelf volcanic rocks
Salair (SL)	Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite (Salairskoye); Porphyry Cu-Mo (±Au, Ag) (Kamenushinskoye)	Russia, southern-eastern Siberia (Salair Range)	Porphyry intrusions and associated replacements related to the Altay volcanic-plutonic belt (Altay arc) that overlies and intrudes the Salair terrane.	Middle Devonian through Early Carboniferous for deposit-related quartz-porphyry intrusion.	Belt is interpreted as having formed in an active continental margin arc environment into which mafic dike swarms and small intrusions, and siliceous porphyries were intruded.
Sette-Daban (SD)	Sediment-hosted Cu (Kurpandzha); Basaltic native Cu (Lake Superior type) (Dzhalkan and Rossomakha); REE (±Ta, Nb, Fe) carbonatite (Gornoye Ozero, Povorotnoye); Carbonate-hosted Pb-Zn (Mississippi valley type) (Lugun , Segenyakh)	Russia, southern Yakutia	Verkhoyansk (North Asian) craton margin.	Middle Devonian through Early Carboniferous.	Cu deposits interpreted as having formed during Devonian rifting. REE and apatite deposits are hosted in alkali-ultramafic and carbonatite plutons are also interpreted as having formed during Devonian rifting.
Sorsk (SO)	Porphyry Mo (±W, Bi) (Sorskoye); Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite (Karasuk); Zn-Pb (±Ag, Cu) skarn (Julia Svintsovaya)	Russia, southern-eastern Siberia (Kuznetsk Alatau Mountains)	Granitoids and associated replacements related to the South Siberian volcanic-plutonic belt (South Siberian arc).	Early and Middle Devonian. ^{40}Ar-^{39}Ar isotopic age of deposits is 385-400 Ma. K-feldspar and albite metasomatite age is 400-380 Ma. Host volcanic rocks with K-Ar age of 396 Ma and Rb-Sr age of 416 Ma.	Belt is interpreted as having formed during Devonian subalkalic porphyry magmatism related to interplate rifting and transpressional faulting. Deposit-related porphyry intrusions intrude older early Paleozoic granitoid plutons. Skarn and metasomatic polymetallic deposits are hosted in Vendian and Cambrian shallow-water marine carbonate rocks.

Teisk (TE)	Fe skarn (Teiskoye, Khaileolovskoye); Mafic-ultramafic related Ti-Fe (±V) (Patynskoye, Kul-Taiga); Volcanogenic-Sedimentary Fe (Chilanskoye)	Russia, southern-eastern Siberia (Kuznetsk Alatau Mountains)	Plutonic rocks of the South Siberian volcanic-plutonic belt (South Siberian arc).	Early Devonian. K-Ar isotopic ages for syenite-diorite of the Malaya Kul-Taiga pluton are 411 and 438 Ma. K-Ar isotopic age of Devonian volcanic rocks is 396 Ma and Rb-Sr isotopic age is 416 Ma.	Belt is interpreted as having formed during interplate transpression and rifting that formed the South Minusa volcanic basin. Deposit is related to Early Devonian granosyenite plutons that occur along marginal faults of Devonian basins.
Tsagaan-suvarga (TsS)	Porphyry Cu-Mo (±Au, Ag) (Tsagaan suvarga; Oyutolgoi, Oyut, Bor Ovoo); Porphyry Cu (±Au) (Oyu Tolgoi); Porphyry Au; Granitoid-related Au vein (Alagtolgoi)	Southeastern Mongolia	Granitoids related to the Gurvansayhan island arc terrane (part of the South Mongolia-Khingan collage).	Late Devonian and Early Carboniferous. $^{40}Ar/^{39}Ar$ isotopic age for the Tsagaan suvarga porphyry Cu deposit is 364.9± 3.5 Ma.	Belt is interpreted as having formed in a mature island arc or continental-margin arc.
Udzha (UD)	REE (±Ta, Nb, Fe) carbonatite (Tomtor)	Russia, Northeast Yakutia	North Asian craton.	Devonian. Host rock Rb-Sr isotopic age is 810 Ma; K-Ar age is 240 Ma.	Belt is interpreted as having formed during intrusion of alkali-ultramafic rock and carbonatite associated with Devonian rifting.
Ulziit (UZ)	Au in shear zone and quartz vein (Olon Ovoot)	Southern Mongolia	Replacements in the Govi Altai continental-margin turbidite terrane (part of the South Mongolia-Khingan collage).	Devonian(?).	Belt is interpreted as having formed regional metamorphism of the Govi-Altai terrane during collision with the Idermeg terrane.
Yaroslavka (YA)	Fluorite greisen (Voznesenka-II); Sn-W greisen, stockwork, and quartz vein (Yaroslavskoe)	Russia, Far East	Granitoids intruding the Voznesenka passive continental margin terrane (part of the Bureya-Jiamusi supterterrane).	Late Cambrian though Devonian. Granitoids have K-Ar isotopic ages of 440-396 Ma.	Belt is interpreted as having formed in a collisional arc that formed in a fragment of Gondwanaland. Host leucogranite plutons are interpreted as having formed during early Paleozoic collision of the Voznesenka and Kabarga terranes. Deposit-related granitoids intrude Cambrian clastic rocks and limestone.

Major Metallogenic Belts, Late Carboniferous (Pennsylvanian) through Middle Triassic (320-230Ma)

Angara-Ilim (AI)	Fe skarn (Korshunovskoye); REE (±Ta, Nb, Fe) carbonatite (Chuktukonskoye); Weathering crust carbonatite REE-Zr-Nb-Li (Chuktukonskoye)	Russia, eastern Siberia	Replacements related to the Tungus plateau basalt, sills, dikes, and intrusions that intrude the North Asian craton.	Late Permian and Early Triassic(?). Isotopic ages of related igneous rock range from 260-200 Ma.	Belt is interpreted as related to widespread development of Trapp magmatism on the North Asian craton. Fe skarn deposits associated with Triassic explosive and intrusive basaltic complexes in diatremes. REE-Ta-Nb carbonatite deposits are associated with alkali-ultramafic intrusions.
Altay (AT)	REE-Li pegmatite; Muscovite pegmatite (Keketuohai, Ayoubulake)	Northwestern Mongolia; Northwestern China	Veins, dikes, and replacements related to granitoids in the Altai volcanic-plutonic belt that intrudes the Altai continental margin turbidite terrane.	Late Carboniferrous. Calc-alkaline anatectic granite with K-Ar isotopic age of 219 Ma.	Belt is interpreted as having formed during intrusion of collisional granite that formed during collision of Kazakhstan and North Asian cratons. Belt is interpreted as having formed during high-grade metamorphism with crustal melting and generation of anatectic granite.
Battsengel-Uyanga-Erdenedalai (BUE)	Granitoid-related Au vein (Mongot, Battsengel, Uyanga groups, Sharga Ovoo, Tsagaan Ovoo)	Central Mongolia	Small stitching plutons that formed in the early stage of intrusion of the Hangay plutonic belt that	Late Carboniferous and Permian.	Belt is interpreted as having formed along the Selenga continental margin arc that was adjacent to the Mongol-Okhotsk Ocean. Belt is hosted in gabbro, diorite, and granodiorite stocks and dikes.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Major Metallogenic Belts, Late Carboniferous (Pennsylvanian) through Middle Triassic (320-230Ma)					
			intrudes the Hangay-Dauria and Onon subduction-zone terranes (part of the Mongol-Okhotsk collage). Plutonic rocks are related to the Selenga sedimentary-volcanic plutonic belt (part of the Selenga arc).		
Buteeliin nuruu (BU)	Peralkaline granitoid-related Nb-Zr-REE (Bayangol); REE-Li pegmatite (Bayangol 1); W-Mo-Be greisen, stockwork, and quartz vein	Northern Mongolia	Granitoids related to the Selenga sedimentary-volcanic plutonic belt (Selenga arc) intruding the West Stanovoy terrane.	Early Permian(?) or Mesozoic(?). Early Permian according to a Pb-Pb zircon age of 275 Ma for strongly foliated granite-gneiss. K-Ar isotopic ages of 89-129 Ma for migmatite, gneissic granite, leucogranite, aplite, and pegmatite.	Belt is interpreted as related to an Early Permian core complex that consists of granitoids that intrude granite-gneiss and mylonite in the West Stanovoy terrane. Alternatively, the belt may be related collisional granitoids generated during Mesozoic closure of the Mongol-Okhotsk Ocean.
Central Mongolia (CM)	Fe-Zn skarn; Sn skarn, Zn-Pb (±Ag, Cu) skarn; W±Mo±Be skarn; Cu (±Fe, Au, Ag, Mo) skarn (Erdenekhairkhan); Porphyry Cu-Mo (±Au, Ag) (Zos Uul); Porphyry Mo (±W, Bi); Au skarn (Buutsagaan); Granitoid related Au vein; W-Mo-Be greisen, stockwork, and quartz vein; Basaltic native Cu (Lake Superior type)	Central Mongolia	Replacements and granitoids related to the Selenga sedimentary-volcanic plutonic belt (part of the Selenga arc).	Early and Late Permian.	Belt is interpreted as having formed along the Selenga continental margin arc along the northern margin of the Mongol-Okhotsk Ocean.
Duobaoshan (DB)	Porphyry Cu-Mo (±Au, Ag) (Duobaoshan)	Northeastern China	Granitoids related to the Nora-Sukhotin-Duobaoshan island arc, terrane (part of the South Mongolia-Khingan collage).	Pennsylvanian. K-Ar isotopic age for host batholith is 292 Ma.	Belt is interpreted as having formed in an island arc. Belt is hosted in a subduction-related granodiorite porphyry.
Harmagtai-Hongoot-Oyut (HH)	Porphyry Cu-Mo (±Au, Ag) (Nariinhudag, Hongoot, Kharmagtai); Porphyry Au; Granitoid-related Au vein (Uhaa hudag and Kharmagtai, Shine, Hatsar); Au-Ag	Southern Mongolia	Granitoids related to the South-Mongolian volcanic-plutonic belt (South Mongolian arc) that intrude the Mandalovoo-Onor island	Middle Carboniferous through Early Permian.	Belt is interpreted as having formed in the South Mongolian continental-margin arc.

	epithermal Vein Deposits (Shuteen)		arc terrane and Mandah subduction-zone terranes (both part of the South Mongolia-Khingan collage).		
Hitachi (Hit)	Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) (Hitachi)	Japan	South Kitakami island arc terrane (part of the Bureya-Jiamusi supterterrane).	Permian.	Belt is interpreted as having formed in an island arc.
Kalatongke (KL)	Mafic-ultramafic related Cu-Ni-PGE (Kalatongke); Granitoid-related Au vein (Alatasi)	Northwestern China	Waizunger-Baaran island arc terrane (part of the Atasbogd collage).	Pennsylvanian.	Belt is interpreted as having formed in an island arc.
Kureisko-Tungsk (KT)	Fe skarn (Suringdakonskoye); Mafic-ultramafic related Cu-Ni-PGE (Bilchany River); Metamorphic graphite (Noginskoye)	Russia, northern-Eastern Siberia	Replacements and plutons related to the Tungus plateau basalt, sills, dikes, and intrusions that intrude North Asian craton.	Permian and Triassic.	Belt is interpreted as related to mantle superplume magmatism that resulted in widespread development of Trapp magmatism on the North Asian craton along the long-lived West-Siberian rift system and the Yenisei sublongitudinal major fault.
Maimecha-Kotuisk (MK)	Fe-Ti (±Ta, Nb, Fe, Cu, apatite) carbonatite (Magan I, Bor-Uryach); REE (±Ta, Nb, Fe) carbonatite (Gulinskoye I); Phlogopite carbonatite (Odikhimcha)	Russia, Northeast Siberia	Alkali-ultramafic-carbonatite intrusions related to the Tungus plateau basalt that intrude the North Asian craton.	Late Permian and Early Triassic. ^{40}Ar/^{39}Ar isotopic ages of deposit-related intrusions range from 249-253 Ma.	Belt is interpreted as related to mantle superplume magmatism that resulted in widespread development of Trapp magmatism on North Asian craton. Magmatic rocks include tholeiite, diabase, trachybasalt, melanonephelinite volcanic rocks and intrusive rocks, and ijolite-carbonatite and kimberlite complexes.
Mino-Tamba-Chugoku (MTC)	Volcanogenic-sedimentary Mn (Hamayokokawa); Podiform chromite (Wakamatsu); Besshi Cu-Zn-Ag massive sulfide (Yanahara)	Japan	Mino Tamba Chichibu subduction-zone terrane (part of the Honshu-Sikhote-Alin collage).	Permian (or older) through Jurassic.	Belt is hosted in a subduction zone complex composed of marine sedimentary and volcanic rock, and fragments of oceanic crust with ultramafic rock. Besshi deposits are interpreted as having formed along a spreading ridge. Belt contains fragments of oceanic crust with podiform chromite deposits are hosted in ultramafic rocks, and chert-hosted Mn deposits. Deposits and host rocks were subsequently incorporated into a subduction zone.
Norilsk (NR)	Mafic-ultramafic related Cu-Ni-PGE (Norilsk I, II, Oktyabrskoye 3); Basaltic native Cu (Lake Superior type) (Arylakhskoye); Porphyry Cu-Mo (±Au, Ag) (Bolgochtonskoye)	Russia, northern-Eastern Siberia	Tungus plateau basalt, sills, dikes, and intrusions that intrude the North Asian craton.	Early Triassic. ^{40}Ar/^{39}Ar isotopic ages for mafic-ultramafic rocks in the Norilsk district are 241.0-245.3 Ma. Isotopic age for Cu-Mo deposits is 223.3 Ma	Belt is interpreted as related to mantle-derived superplume magmatism that resulted in widespread development of Trapp magmatism on the North Asian craton.
Orhon-Selenge (OS)	Porphyry Cu-Mo (±Au, Ag) (Erdenetiin Ovoo, Central, Oyut; Shand; Zuiliin gol)	Central Mongolia	Granitoids in the Selenga sedimentary-volcanic plutonic belt (Selenga arc).	Triassic. Quartz-sericite metasomatite of the Erdenetiin Ovoo deposit has K-Ar isotopic ages 210-190 Ma. Explosive breccia has age of 210 Ma. K-Ar ages of deposit-related granite	Belt is interpreted as having formed during oblique subduction of oceanic crust of the Mongol-Okhotsk Ocean plate under the southern margin of the Siberian continent. Basaltic Cu hosted in basalt and trachybasalt in mafic volcanic rock in the Permian Khanui Series.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Major Metallogenic Belts, Late Carboniferous (Pennsylvanian) through Middle Triassic (320-230Ma)					
				range from 185-240-250 Ma. $^{40}Ar/^{39}Ar$ isochron isotopic age of 207± 2 Ma for white mica from highest-grade part of the Erdenet mine.	
Shanxi (SX)	Sedimentary bauxite (Ke'er)	Northern China	Stratiform units in the upper part of the Sino-Korean Platform overlapping the Sino-Korean craton and the West Liaoning-Hebei-Shanxi terrane.	Pennsylvanian.	Belt formed during weathering of metamorphic rocks of the Northern China Platform. Bauxite deposits are hosted in karst and lagoonal basins in a littoral-shallow sea.
Major Metallogenic Belts, Late Triassic through Early Jurassic (230-175 Ma)					
Central Hentii (CH)	Sn-W greisen, stockwork and quartz vein (Modot, Tsagaan dabaa); REE-Li pegmatite; Ta-Nb-REE alkaline metasomatite (Janchivlan); W±Mo±Be skarn; Peralkaline peralkaline granitoid-related Nb-Zr-REE (Avdrant)	Mongolia	Replacements and granitoids related to the Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlaps the Hangay-Dauria terrane (part of the Mongol-Okhotsk collage, and adjacent units).	Late Triassic and Early Jurassic. Deposit-related granite with Rb-Sr isotopic age of 190.49 Ma and K-Ar age of 188-225 Ma.	Belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of the Mongol-Transbaikal arc. Small plutons hosting REE deposits intruded in a continental postcollisional event.
Delgerhaan (DE)	Porphyry Cu (±Au); Granitoid-related Au vein (Bayan Uul, Unegt)	Central Mongolia	Granitoids in the Mongol-Transbaikalia volcanic-plutonic belt that intrudes the Hangay-Dauria and, Onronsky terranes (part of the Mongol-Okhotsk collage and Gobi-Khankaisk-Daxinganling volcanic-plutonic belt and associated arc).	Late Triassic. $^{40}Ar/^{39}Ar$ isochron isotopic ages for plagioclase-biotite porphyry and biotite granodiorite from Bayan Uul ore-field are 220-223 Ma.	Belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of the Mongol-Transbaikal arc.
Govi-Ugtaal-Baruun-Urt (GB)	Fe-Zn skarn (Tomortiin Ovoo); Cu (±Fe, Au, Ag, Mo) skarn; Zn-Pb (±Ag, Cu) skarn; Sn skarn (Oortsog ovoo); Fe skarn; Porphyry Mo (Aryn nuur**)**	Central and eastern Mongolia	Replacements related to the Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlies the Argun-Idermeg superterrane and the Gobi-Khankaisk-Daxinganling volcanic-plutonic belt and associated arc.	Late Triassic and Early Jurassic.	Belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of the Mongol-Transbaikal arc. Belt is hosted in Late Triassic through Early Jurassic alaskite, granite, and alkaline granite.

Harmorit-Hanbogd-Lugiingol (HL)	Sn-W greisen, stockwork, and quartz vein (Khar morit); Ta-Nb-REE Alkaline Metasomatite (Khan Bogd); REE (±Ta, Nb, Fe) carbonatite (Lugiin Gol); Peralkaline granitoid-related Nb-Zr-REE; REE-Li pegmatite	Mongolia	Replacements and granitoids related to the South Mongolian volcanic-plutonic belt that intrudes and overlaps the Hutaguul-Xilinhot and Gurvansayhan terranes and the Lugyngol overlap volcanic-sedimentary basin (both part of the South Mongolia-Khingan and adjacent collages).	Middle Triassic through Early Jurassic. Rb-Sr whole-rock isochron age for the Lugiin gol nepheline syenite pluton is 244 Ma and whole rock-mineral isochron ages are 222 Ma and 180-199 Ma. K-Ar age is 228-242 Ma. The Khanbogd REE-Nb-Zr deposit is associated with late Paleozoic alkaline granite pluton with a Rb-Sr age isotopic of 277 Ma and a K-Ar age of 293 Ma.	Belt is interpreted as having formed in the late Paleozoic and early Mesozoic South Mongolian continental margin arc.
Kalgutinsk (KG)	W-Mo-Be greisen, stockwork, and quartz vein (Kalgutinskoye, (Urzarsaiskoye); Ta-Nb-REE alkaline metasomatite (Akalakhinskoye); Sn-W greisen, stockwork, and quartz vein (Baliktigkhem)	Russia, southern-eastern Siberia (Gorny Altai Mountains)	Granitoids and replacements related to the Belokurikha plutonic belt that intrudes the Altai and West Sayan terranes (both part of the Altai collage).	Early Jurassic. Rb-Sr isotopic age for the Chindagatui pluton is 201.0 Ma and 204.0 for Kalguta pluton. U-Pb isotopic ages for Ta spodumene granite in the Alakha stock are 183 and 188 Ma and a Rb-Sr age is 195 Ma. Rb-Sr age of Li-F granite-porphyry in the the Dzulaly stock is 188.0 Ma	Belt is interpreted as having formed during generation of REE granitoids along transpression zones (Hovd regional fault zone and companion faults) related to transform microplate boundaries and within-plate (plume) environment.
Mongol Altai (MA)	W-Mo-Be greisen, stockwork, and quartz vein (Ulaan Uul, Tsunheg)	Western Mongolia	Small bodies of leucogranite that intrude the Altai and Hovd Hovd terranes (both part of the Altai collage).	Late Triassic and Early Jurassic.	Belt is interpreted as having formed during Mesozoic intraplate rifting related to magmatism along transtensional zones (Hovd regional fault zone and companion faults) along transform microplate boundaries and within-plate (plume) environment.
North Hentii (NH)	Granitoid-related Au vein; Au in shear zone and quartz vein (Boroo, Sujigt, Narantolgoi)	Northern Mongolia	Granitoids related to the Mongol-Transbaikalia volcanic-plutonic belt.	Middle Triassic through Middle Jurassic. K-Ar isotopic ages of 166-235 Ma for deposit-related Yoroogol gabbro-granite.	Belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of the Mongol-Transbaikal arc. Belt is interpreted as having formed during granitoid intrusion related to extensional margin of the Khentii collisional uplift.
North Kitakami (NK)	Volcanogenic-sedimentary Mn (Nodatamagawa); Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) (Taro)	Japan	Mino Tamba Chichibu subduction-zone terrane (part of the Honshu-Sikhote-Alin collage).	Triassic and Early Cretaceous.	Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor. Kuroko deposits are interpreted as having formed in an island arc. Deposits were subsequently incorporated into a subduction zone.
North Taimyr (NT)	W-Mo-Be greisen, stockwork, and quartz vein (Kolomeitseva River); W±Mo±Be skarn (Morzhovoye); Porphyry Cu-Mo (±Au, Ag) (Mamont River)	Russia, northern-Eastern Siberia (Taimyr Peminsula)	Replacements associated with granitoids intruding Permian-Triassic volcanic and sedimentary rocks of the Lenivaya-Chelyuskin sedimentary assemblage, Central Taimyr superterrane, Kara superterrane.	Middle and Late Triassic. Age of deposit-related granitoids is about 223-233 Ma.	Belt is interpreted as having formed during generation of granitoids during and after collision between the North Asian craton and the Kara superterrane. Belt is hosted in intrusions in tectonic blocks which are bounded by post-orogenic faults.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
			Major Metallogenic Belts, Late Triassic through Early Jurassic (230-175 Ma)		
Sambagawa -Chichibu-Shimanto (SCS)	Besshi Cu-Zn-Ag massive sulfide (Besshi); Volcanogenic-sedimentary Mn (Ananai); Cyprus Cu-Zn massive sulfide (Okuki)	Japan	Shimanto subduction-zone terrane (part of the Sakhalin-Hokkaido collage), Mino Tamba Chichibu subduction-zone terrane (part of the Honshu-Sikhote-Alin collage), and Sambagawa metamorphic terrane (part of the Honshu-Sikhote-Alin collage).	Early Jurassic through Campanian. Age of submarine basaltic volcanism and related Besshi-type deposits is interpreted as between 200 and 140 Ma.	Mn deposits are interpreted as having formed in syngenetic setting on the ocean floor. Besshi and Cyprus deposits are interpreted as having formed during submarine volcanism related to spreading ridge. Deposits were subsequently incorporated into a subduction zone.
Wulashan-Zhangbei (WZ)	Alkaline complex-hosted Au; (Dongping); Au potassium metasomatite (Hadamen); Granitoid-related Au vein	Northwestern and North-Central China	Granitoids related to the Alashan-Yinshan Triassic plutonic belt (too small to show at 15 M scale) that intrudes the Sino-Korean craton - Erduosi terrane, Solon terrane, and adjacent units	Middle Jurassic or younger. ^{40}Ar-^{39}Ar isotopic ages of 327 Ma and 157-177 Ma for intrusion and deposit potassic feldspar, respectively.	Belt is interpreted as having formed in granitoids generated above a mantle plume in an extensional tectonic setting. Belt is related to Late Triassic through Early Jurassic alkaline to subalkaline granite.
			Major Metallogenic Belts, Middle Jurassic through Early Cretaceous (175-96 Ma)		
Allakh-Yun' (AY)	Au in shear zone and quartz vein (Yur, Nekur, Bular); Cu (±Fe, Au, Ag, Mo) skarn (Muromets); Au in black shale (Svetly)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins in the Verkhoyansk (North Asian) craton margin.	Late Jurassic through Early Cretaceous.	Belt is interpreted as having formed during accretion of the Okhotsk terrane to the North Asian craton margin. Belt occurs in the Minorsk-Kiderikinsk zone of highly deformed Late Carboniferous and Permian rocks in the western South Verkhoyansk synclinorium. Au quartz veins are slightly older than large anatectic granitic plutons of the South Verkhoyansk synclinorium.
Ariadny (AR)	Zoned mafic-ultramafic Cr-PGE (Katenskoe); Mafic-ultramafic related Ti-Fe (±V) (Ariadnoe, Koksharovskoe)	Russia, Far East	Plutons intruding the Samarka subduction-zone terrane (part of the Honshu-Sikhote-Alin collage).	Middle Jurassic through Early Cretaceous. K-Ar isotopic ages of about 160 Ma age	Belt is interpreted as having formed during generation of ultramafic and gabbroic plutons during underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along a transform continental margin.
Bindong (BD)	Zn-Pb (±Ag, Cu) skarn (Ergu-Xishan); W±Mo±Be skarn (Wudaoling); Fe skarn (Chuihongshan)	Northeastern China	Replacements related to small granitoids in the Mesozoic Jihei volcanic and plutonic belt that intrudes and overlies the Zhangguangcailing superterrane, Zhangguangcailing sedimentary overlap assemblage, and adjacent units.	Late Jurassic and Early Cretaceous. K-Ar isotopic age of 157.8 Ma for the Wudaoling quartz porphyry.	Belt is interpreted as having formed during interplate extensional tectonism along the Trans-Baikalian-Daxinganling transpressional arc with generation of sub-alkaline to alkaline volcanism and related sedimentation.

Chara-Aldan (CA)	Au potassium metasomatite (Kuranakh); Au skarn (Klin); U-Au (El'kon group); Au in shear zone and quartz vein (Krutoy); Charoite metasomatite (Murunskoye)	Russia, southern Yakutia	Replacements and granitoids related to the South Yakutian subalkaline and alkaline igneous belt (part of the Stanovoy plutonic belt) that intrudes the North Asian craton and the Central Aldan superterrane.	Jurassic and Early Cretaceous.	Belt is interpreted as having formed in the back-arc part of the Uda-Stanovoy continental-margin arc that was related to subduction and closure of the Mongol-Okhotsk Ocean beneath the North Asian craton to the north. Belt is hosted in subalkaline and alkaline plutonic rocks, including plutons, stocks, and sills of syenite, monzonite, granosyenite, alkali gabbro, and volcanic analogues, as well as zoned alkali-ultramafic plutons.
Chybaga-lakh (CH)	Cassiterite-sulfide-silicate vein and stockwork (Kere-Yuryakh); Sn-B (Fe) skarn (ludwigite) (Titovskoe); Granitoid-related Au vein (Chuguluk, Nenneli)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements in the Main granite belt that intrudes the southern margin of Kolyma-Omolon superterrane.	Late Jurassic through early Neocomian.	Belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton with associated regional metamorphism and generation of anatectic high-alumina granitoids.
Djeltu-laksky (DL)	Granitoid-related Au vein (Zolotaya Gora)	Russia, Far East	Granitoids related to the Stanovoy granite belt that intrudes the Tynda terrane (Stanovoy block) and Dzugdzur anorthositic belt (both part of the North Asian craton).	Early Cretaceous.	Belt is interpreted as having formed in the Uda-Stanovoy continental-margin arc that was related to subduction and closure of the Mongol-Okhotsk Ocean beneath the North Asian craton to the north.
Daxingan-ling (DX)	Zn-Pb (±Ag, Cu) skarn (Baiyinnuoer); Sn skarn; Cassiterite-sulfide-silicate vein and stockwork (Maodeng); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Meng'entaolegai, Aonaodaba); Peralkaline granitoid-related Nb-Zr-REE (Baerzhe); Au-Ag epithermal vein (Guandi)	Northeastern China (Great Xingan Mountains)	Veins, replacements, and granitoids related to to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt.	Late Jurassic and Early Cretaceous. Alubaogeshan granite porphyry has isotopic age of 149 Ma. Duerji granite complex has a U-Pb zircon age of 150 Ma. Rb-Sr age of 125 Ma for the Baerzhe pluton. Rb-Sr whole-rock isochron age of 148.31 Ma for the Aobaodaba granite porphyry.	Belt is interpreted as having formed during interplate extensional tectonism along the Trans-Baikalian-Daxinganling transpressional arc. The extension is interpreted as occurring during the Late Jurassic in a back-arc setting with formation a series of volcanic and sedimentary basins and sub-alkaline to alkaline granite. The basins and granitoids are controlled by northeast-north-northeast and east-west striking regional faults that reflect the pre-Mesozoic structures.
Dzid-Selenginskiy (DS)	W-Mo-Be greisen, stockwork, and quartz vein (Dzhida, Bulagtai); Granitoid-related Au vein; Au skarn (Tavt, Teshig 1); Porphyry Mo (±W, Bi); Fluorspar vein (Naranskoye); Magmatic and metasomatic apatite (Oshurkovskoye)	Russia, western Transbaikalia; northern Mongolia	Veins, replacements, and plutons related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Dzhid, Hamar-Davaa and the Orhon-Ikatsky terranes (both part of the Yenisey-Transbaikal collage).	Middle Jurassic through Early Cretaceous. Isotopic ages of 180-170 Ma and 145-140 Ma for Gudjir complex granitoids.	Interpreted as having formed during subalkaline and alkaline granitoid magmatism associated with transform-continental margin faulting (Mongok-Okhotsk and related faults) and associated Trans-Baikalian-Daxinganling transpressional arc during late-stage of closing and after closing of the Mongol-Okhotsk Ocean.
East Mongolian-Priargun-skiy-Deerbugan (EM)	Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite (Klichkinskoye, Vozdvizhenskoye); Zn-Pb (±Ag, Cu, W) skarn; Au skarn (Savinskoye-5, Bayandun);	Russia, eastern Transbaikalia; Central and eastern Mongolia; Northeastern China	Veins, volcanic complexes, replacements, and granitoids related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-	Middle Jurassic through Early Cretaceous. Gold deposits and occurrences with isotopic ages of 190-180 Ma and 165-175 Ma. K-Ar isotopic age for sericite at Ulaan Ag-Pb-Zn deposit is 161	Belt is interpreted as having formed during Middle Jurassic to Early Cretaceous extensional tectonism associated with generation of the Trans-Baikalian-Daxinganling transpressional arc. Belt is controlled by major, regional northeast-and northwest-trending faults.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Major Metallogenic Belts, Middle Jurassic through Early Cretaceous (175-96 Ma)					
	Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite (Tsav, Jiawula); Volcanic-hosted Au-base-metal metasomatite (Novo-Shirokinskoye); W-Mo-Be greisen, stockwork, and quartz vein (Tumentsogt); Porphyry Cu-Mo (±Au, Ag) (Wunugetushan); Porphyry Mo (±W, Bi) (Shakhtaminskoye); Granitoid-related Au vein (Urliin Ovoo); Carbonate-hosted As-Au metasomatite (Zapokrovskoye); Au-Ag epithermal vein (Noni, Tsagaanchuluut khudag II, Erentaolegai); Sedimentary siderite Fe; Sn-W greisen, stockwork, and quartz vein (Baga Gazar); Carbonate-hosted Hg-Sb; Fluorspar vein (Solonechnoye); Volcanic-hosted U		plutonic belt that overlies and intrudes Argun-Idermeg superterrane, and Gobi-Khankaisk-Daxinganling volcanic-plutonic belt and adjacent units.	Ma. K-Ar isotopic ages of mica at Dornot uranium deposit range from 141-143 Ma. K-Ar isotopic age of the granodioritic porphyry is 164 Ma.	
Govi-Tamsag (GT)	Sediment-hosted U (Haraat); Evaporite sedimentary gypsum (Shiree Uul, Taragt-2); Sedimentary celestite (Horgo uul); Volcanic-hosted zeolite (Tsagaantsav)	Southern Mongolia	Stratiform units in the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Dzhida, Govi Altai, Mandalovoo-Onor terranes (parts of the South Mongolia-Khingan and Yenisey-Transbaikal collages).	Late Jurassic and Early Cretaceous.	Belt is interpreted as having formed in Early Cretaceous (Aptian-Albian) and local Paleogene sedimentary rocks deposited in grabens and depressions that overlap the Mesozoic Eastern-Mongolian-Preargune continental rift belt that developed on the Idermeg passive continental margin, Govi-Altai turbidite, and Mandal-Ovoo island arc terranes. Units and structures part of the Trans-Baikalian-Daxinganling transpressional arc. The sedimentary U deposits and occurrences formed in the latest stage of a late Mesozoic continental rift. The gypsum deposits and occurrences formed in continental evaporite basins.
Hartolgoi-Sulinheer (HS)	Au-Ag epithermal vein (Biluut, Khoit Barjin); Ag-Pb epithermal vein (Biluut); Porphyry Mo; W±Mo±Be skarn (Qiyishan); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Harmorit, Khartolgoi);	Southern Mongolia; Northwestern China	Veins and replacements related to latite and lamprophyre dikes in the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that intrudes and overlies the Tsagaan	Late Jurassic and Early Cretaceous.	Belt is interpreted as having formed during interplate extensional tectonism along the Trans-Baikalian-Daxinganling transpressional arc.

	Carbonate-Hosted Ag-Pb (Hartolgoi); Carbonate-hosted Hg-Sb (Zuun Togoo Uul); Silica-carbonate (Listvenite) Hg		Uul-Guoershan (part of Atasbogd collage), and Solon terrane (part of Solon collage).		
Jiliaolu (JLL)	Zn-Pb (±Ag, Cu) skarn (Huanren); Cu (±Fe, Au, Ag, Mo) skarn (Huatong); Granitoid-related Au vein (Jiaojia); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Ermi); Volcanic-hosted Au-base metal metasomatite (Liujiapuzhi)	Northeastern China	Replacements and granitoids related to the Jilin-Liaoning-East Shandong volcanic-plutonic belt that overlies and intrudes Sino-Korean craton - Jilin-Liaoning-East Shandong terrane	Middle Jurassic and Early Cretaceous.	Belt is interpreted as having formed during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic plate beneath the Eurasian continental plate. Belt is hosted in twenty relatively large volcanic basins. Belt contains more than 200 granitoid-related vein Au deposits in a district of 23,000 km^2, some large and superlarge, that comprise one quarter of the proven Au reserve in China.
Kitakami (KK)	Cu (±Fe, Au, Ag, Mo) skarn (Kamaishi); Granitoid-related Au vein (Oya)	Japan	Replacements in the Early Cretaceous Hiroshima granitic belt intruding the South Kitakami terrane (part of the Bureya-Jiamusi supterterrane), and the Mino-Tamba-Chichibu terranes (part of the Honshu-Sikhote-Alin collage).	Early Cretaceous (Aptian through Albian). K-Ar isotopic ages of 120-110 Ma for deposit-related granitic rocks in the Kitakami Mountains.	Belt is interpreted as having formed during intrusion of granitoids associated with a continental-margin arc and siliceous magmatism.
Kondyor-Feklistov (KD)	Zoned mafic-ultramafic Cr-PGE (Kondyor)	Russia, Far East	Mafic-ultramafic intrusions intruded along a major fault cutting the North Asian craton and northeastern part of the Tukuringra-Dzhagdy terrane (part of the Mongol-Okhotsk collage).	Early Cretaceous. K-Ar isotopic ages for the zoned mafic-ultramafic intrusions in the Kondyor metallogenic belt range from 110-160 Ma. ^{40}Ar-^{39}Ar isotopic age of 127 Ma for the alkalic mafic and ultramafic igneous rocks at Ingagli.	Belt is interpreted as having formed during intrusion of mafic-ultramafic plutons along a deep-seated fault that formed along the North Asian craton margin during collision and accretion of outboard terranes.
Kular (KU)	Au in shear zone and quartz vein (Emelyanovskoye); Granitoid-related Au vein (Novoe); Sn-W greisen, stockwork, and quartz vein (Tirekhtyak district)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins in the Kular-Nera terrane (part of the Verkhoyansk-Kolyma collage).	Late Jurassic through Early Neocomian. Deposit-related granite has a ^{40}Ar-^{39}Ar isotopic age of 103 Ma.	Belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and associated regional metamorphism. Belt occurs in a complex fold and thrust structure with refolded recumbent isoclines. Host rocks are metamorphosed to the greenschist facies.
Nerchinsky (NC)	Granitoid-related Au vein (Darasunskoye); W-Mo-Be greisen, stockwork, and quartz vein (Muoklakanskoye); Fluorspar vein (Usuglinskoye)	Russia, eastern Transbaikalia	Granitoids and replacements related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that intrudes and overlaps the West Stanovoy terrane, Barguzin-Vitim granitoid belt, and Selenga sedimentary-volcanic plutonic belt.	Middle Jurassic thorugh Early Cretaceous.	Belt is interpreted as related to magmatism along transtensional zones along transform microplate boundaries and within-plate (plume) environment. Belt is related to granitoids in the Trans-Baikalian-Daxinganling transpressional arc.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Major Metallogenic Belts, Middle Jurassic through Early Cretaceous (175-96 Ma)					
			plutonic belt that intrudes and overlaps the West Stanovoy terrane, Barguzin-Vitim granitoid belt, and Selenga sedimentary-volcanic plutonic belt.		
North Bureya (NB)	Au-Ag epithermal vein (Pioneer); Granitoid-related Au vein (Pokrovskoe)	Russia, Far East	Veins and granitoids related to the Umlekam-Ogodzhin volcanic-plutonic belt that intrudes and overlaps the Malokhingansk and, Turan terranes (part of the Bureya superterrane), Gonzha terrane, and Nora-Sukhotin-Duobaoshan terrane (part of the South Mongolia-Khingan collage), and Tukuringra-Dzhagdy terrane (part of the Mongol-Okhotsk collage).	Early Cretaceous.	Belt is interpreted as having formed with the Umlekan-Ogodzhin continental-margin arc that formed during subduction of part of the ancestral Pacific Ocean plate that is now preserved as tectonically interwoven fragments of the Badzhal, Khabarovsk, and Samarka terranes.
North Jilin (NJ)	Zn-Pb (±Ag, Cu) skarn (Tianbaoshan); Granitoid-related Au vein; Porphyry Cu (±Au) (Xiaoxinancha); Porphyry Mo (±W, Bi) (Daheishan); Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite (Sanmen); Au-Ag epithermal vein (Ciweigou); Fluorspar vein	Northeastern China	Replacements related to Late Jurassic and Early granitoids intruding the North Margin plutonic belt that overlies the North China Platform and Laoling terrane (part of the Wundurmiao collage) and Zhangguangcailing superterrane.	Middle Jurassic through Early Cretaceous. Siliceous and mafic volcanic rocks at Ciweigou Au-Ag epithermal deposit have a Rb-Sr isochron age of 147.5 Ma.	Belt is interpreted as related to magmatism along transpression zones along transform microplate boundaries and within-plate (plume) environments.
North Bureya (NB)	Au-Ag epithermal vein (Pioneer); Granitoid-related Au vein (Pokrovskoe)	Russia, Far East	Veins and granitoids related to the Umlekam-Ogodzhin volcanic-plutonic belt that intrudes and overlaps the Malokhingansk terrane, the Turan terrane of the Bureya-Jiamusi superterrane, the Gonzha	Early Cretaceous.	Belt is interpreted as having formed with the Umlekan-Ogodzhin continental-margin arc during subduction of part of the ancestral Pacific Ocean plate that is now preserved as tectonically interwoven fragments of the Badzhal, Khabarovsk, and Samarka terranes.

			terrane, the Nora-Sukhotin-Duobaoshan terrane (part of the South Mongolia-Khingan collage), and the Tukuringra-Dzhagdy terrane (part of the Mongol-Okhotsk collage).		
North Stanovoy (NS)	Granitoid-related Au vein (Bamskoe); Au-Ag epithermal vein (Burindinskoe)	Russia, Far East	Granitoids related to the Stanovoy granite belt intruding the Tynda terrane (part of the North Asian craton).	Early Cretaceous.	Belt is interpreted as having formed in the Uda-Stanovoy continental-margin arc during subduction and closure of the Mongol-Okhotsk Ocean beneath the North Asian craton to the north.
Onon-Turinskiy (OT)	Granitoid-related Au vein (Lubavinskoye); Porphyry Au (Ara-Ilinskoe); Cassiterite-sulfide-silicate vein and stockwork (Khapcheranga, Tarbaldzheiskoe)	Russia, Central Transbaikalia; northern Mongolia	Veins, volcanic complexes, and replacements related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt that overlies and intrudes the Selenga sedimentary-volcanic plutonic belt, and the Ononsky terrane (part of the Mongol-Okhotsk collage).	Middle Jurassic through Early Cretaceous.	Belt is interpreted as having formed during interplate extensional tectonism along the Trans-Baikalian-Daxinganling transpressional arc. Belt and related host rocks occurs along the sub-meridional Onon-Tura fault.
Polousny (PO)	Cassiterite-sulfide-silicate vein and stockwork deposits (Ulakhan-Sala); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork deposits (Aragochan, Dalnee)	Russia, East-Central Yakutia (Verkhoyansk area)	Granitoids related to the Northern granite belt that intrudes the Kolyma-Omolon superterrane and adjacent units.	Middle Cretaceous (Neocomian to Aptian). ^{40}Ar-^{39}Ar isotopic age of 120-130 Ma.	Belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and associated regional metamorphism and generation of anatectic granitoids.
Samarka (SM)	Porphyry Cu-Mo (±Au, Ag) (Malakhitovoe); Porphyry Mo (±W, Sn, Bi); W±Mo±Be skarn (Vostok-2, Lermontovsky)	Russia, Far East	Replacements and granitoids in the Khungari-Tatibi granite belt that intrudes the Samarka terrane (part of the Honshu-Sikhote-Alin collage).	Early and mid-Cretaceous. K-Ar isotopic ages of 110-115 Ma for host granitoids.	Belt is interpreted as having formed during generation of S-type grantitoid plutons during underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along a transform continental margin.
Shilkinsko-Tukuringrskiy (ST)	Granitoid-related Au vein (Ukonikskoe); Porphyry Au; Au skarn; Au-Ag epithermal vein; Porphyry Mo (±W, Bi) (Zhirekenskoye); W-Mo-Be greisen, stockwork, and quartz vein; Cassiterite-sulfide-silicate vein and stockwork; Ta-Nb-REE alkaline metasomatite; Polymetallic Pb-Zn ± Cu (±Ag,	Russia, eastern Transbaikalia	Granitoids, volcanic rocks, and replacements related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt.	Middle Jurassic through Early Cretaceous.	Belt is interpreted as related to magmatism along transtension zones the Trans-Baikalian-Daxinganling transpressional arc. Belt occurs in basins with continental sedimentary rocks and alkaline magmatic plutonic and volcanic rocks that occur along the Mongol-Okhotsk suture that separates various terranes and the North Asian and the Sino-Korean cratons.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Major Metallogenic Belts, Middle Jurassic through Early Cretaceous (175-96 Ma)					
	Au) vein and stockwork (Berezitovoe); Au-Ag epithermal vein (Baleyskoe); Fluorite vein (Kalanguyskoye)				
South Verkho-yansk (SV)	Au in shear zone and quartz vein (Nezhdaninka); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Upper Menkeche); Granitoid-related Au vein; W-Mo-Be greisen, stockwork, and quartz vein; Au-Ag epithermal vein	Russia, East-Central Yakutia (Verkhoyansk area)	Veins related to mid-Cretaceous granitoids in the South Verkhoyansk granite belt intruding the Verkhoyansk (North Asian) craton margin	Aptian through Late Cretaceous.	Belt is interpreted as having formed during accretion of the Okhotsk terrane to the North Asian craton and resultant deformation of South Verkhoyansk belt. Au quartz veins are relatively older than large granitic plutons intruding the South Verkhoyansk synclinorium that have ^{40}Ar-^{39}Ar isotopic ages of 120-123 Ma.
Taebaegsan (TB)	Fe skarn (Kangwon, Dongnam, Susuk); Fe-Zn skarn (Yomisan); Zn-Pb (Ag, Cu, W) skarn; W±Mo±Be skarn (Wondong, Sangdong); REE-Li pegmatite; Au in shear zone and quartz vein (Seojom); polygenic REE-Fe-Nb (Bayan-Obo type) (Hongcheon-Jaun)	South Korea	Replacements and dikes related to Middle Jurassic through Early Cretaceous granitoids in the Daebo Granite intruding the Yeongnam Metamorphic Complex and Great Limestone Group (both part of the Sino-Korean craton).	Middle Jurassic through Early Cretaceous.	Belt is interpreted as having formed during intrusion of granitoids along a continental-margin arc that was linked to subduction of the ancestral Pacific Ocean plate. Granite consists of biotite granite, feldspar porphyry, and granite porphyry that intrude Precambrian metasedimentary rocks. Deposits formed during contact metasomatism of calcareous layers in metasedimentary rock.
Tompo (TO)	W±Mo±Be skarn (Agylky); Sn-W greisen, stockwork, and quartz vein (Erikag, Dzhuptagan)	Russia, East-Central Yakutia (Verkhoyansk area)	Replacements in the Northern and Transverse granite belt along the northwestern margin of the Kolyma-Omolon superterrane.	Neocomian.	Belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton with associated regional metamorphism and generation of anatectic granitoids. Belt occurs along sublatitudinal high-angle, probable strike-slip faults that cut Permian through Middle Jurassic sandstone and shale.
Verkhne-Ingodinsky (VI)	Cassiterite-sulfide-silicate vein and stockwork (Ingodinskoye, Levo-Ingodinskoye)	Russia, Central Transbaikalia	Veins, volcanic complexes, and replacements related to the Trans-Baikalian-Daxinganling sedimentary-volcanic-plutonic belt.	Middle Jurassic through Early Cretaceous.	Belt is interpreted as related to magmatism in transpression zones related to the Trans-Baikalian-Daxinganling transpressional arc.
Verkho-yansk (VK)	Au in shear zone and quartz vein (Djandi, Nikolaevskoe, Otkrytoe); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Sn-W greisen, stockwork, and quartz vein (Imtandzha); Au in black shale (Mangazeika 2)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements in the Verkhoyansk (North Asian) craton margin.	Late Jurassic through early Neocomian.	Belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and associated regional metamorphism.

Yana-Adycha (YA)	Cassiterite-sulfide-silicate vein and stockwork (Ege-Khaya, Ilin-Tas, Burgochan); Sn-W greisen, stockwork, and quartz vein (Kester)	Russia, East-Central Yakutia (Verkhoyansk area)	Replacements in the Transverse granite belt along the northwestern margin of the Kolyma-Omolon superterrane.	Mid-Cretaceous.	Belt is interpreted as having formed during collision of the Kolyma-Omolon superterrane and the North Asian craton and associated regional metamorphism and generation of anatectic granitoids.
Yanshan (YS)	Cu (±Fe, Au, Ag, Mo) skarn (Shouwangfen); W±Mo±Be skarn (Yangjiazhangzi); Porphyry Mo (±W, Bi) (Dazhuangke); Granitoid-related Au vein (Jinchanggouliang); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Caijiaying); Au-Ag epithermal vein (Niujuan)	Northeastern and northern China	Veins, replacements, and granitoids related to the Yanliao volcanic and sedimentary basin and plutonic belt that overlies and intrudes the northeastern Sino-Korean craton.	Middle Jurassic through Early Cretaceous. K-Ar isotopic age of Hongluoshan granite is of 178 to 186 Ma. K-Ar age for related dike at Jinchanggouliang deposit is about 120 Ma. Quartz diorite and quartz monzonite at Dazhuangke deposit have a K-Ar isotopic age of 146-168 Ma.	Belt is interpreted as having formed during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic plate beneath the Eurasian plate.

Major Metallogenic Belts, Cenomanian through Campanian (96-72 Ma)

Badzhal-Komso-molsk (BK)	Sn-W greisen, stockwork, and quartz vein (Pravourmiyskoe, Solnechnoe, Sobolinoye); Cassiterite-sulfide-silicate vein and stockwork; Cu (±Fe, Au, Ag, Mo) skarn; Porphyry Mo (±W, Sn, Bi)	Russia, Far East	Veins and replacements related to the Khingan-Okhotsk volcanic-plutonic belt.	Late Cretaceous. K-Ar isotopic ages of 75-86 Ma. Rb-Sr age of 95-83 Ma.	Belt is interpreted as having formed during generation of granitoids along the Khingan transform continental-margin arc consisting of the Khingan-Okhotsk volcanic-plutonic belt that related to oblique subduction of the ancestral Pacific Ocean plate.
Chelasin (CL)	Sn-B (Fe) skarn (ludwigite); Granitoid-related Au vein; Cu (±Fe, Au, Ag, Mo) skarn; Porphyry Cu (±Au) (Chelasin)	Russia, Far East	Replacements and granitoids related to the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies the North Asian craton and the Uda volcanic-plutonic belt.	Late Cretaceous and Paleocene.	Belt is interpreted as having formed during generation of granitoids in the Okhotsk-Chukotka continental margin arc that is related to subduction of the ancestral Pacific Ocean plate.
Central Polousny (CP)	Cassiterite-sulfide-silicate vein and stockwork (Ukachilkan); Sn-W greisen, stockwork, and quartz vein (Deputatskoe ; Takalkan)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements in the Northern granite belt along the northwestern margin of the Kolyma-Omolon superterrane.	Aptian through Late Cretaceous. Deputatskiy stock has a K-Ar isotopic age of 108 Ma.	Belt is interpreted as having formed during extension related to initiation of opening of Eurasia Basin in the Arctic Ocean. Belt associated with REE and subalkali granitoids that occur in small stocks.
Chokhchur-Chekur-dakh (CC)	Cassiterite-sulfide-silicate vein and stockwork (Churpunya, Chokurdakh)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements in the Svyatoi Nos volcanic belt that occurs along the southern margin of the Kolyma-Omolon superterrane.	Aptian through Late Cretaceous. Granitoids have ^{40}Ar-^{39}Ar isotopic ages of 105-106 Ma.	Belt is interpreted as having formed during extension related to initiation of opening of the Eurasia Basin in the Arctic Ocean. Belt occurs along the Yana fault. Belt is hosted in granodiorite, amphibole-biotite granite, and subalkali granite that form part of Svyatoy Nos magmatic arc.
Eckyuchu-Billyakh (EB)	Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Prognoz); Clastic-sediment-hosted Sb-Au; Hg-Sb-W vein	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements related to the Transverse granite belt that intrudes the Verkhoyansk (North	Aptian through Late Cretaceous. Granitoid stocks and dikes of various composition have ^{40}Ar-^{39}Ar isotopic ages of older than	Belt is interpreted as having formed during extension related to initiation of opening of the Eurasia Basin in the Arctic Ocean. Belt is hosted in granitoid stocks and dikes that occur at the terminations of the Transverse

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Major Metallogenic Belts, Cenomanian through Campanian (96-72 Ma)					
	and stockwork (Žvyozdochka); Ag-Sb vein vein; Au-Ag epithermal vein		Asian) craton margin.	120 Ma. Khoboyatu-Echiy granite pluton has a ^{40}Ar-^{39}Ar age of 97 Ma.	granitoid belt.
Ezop-Yam-Alin (EY)	W-Mo-Be greisen, stockwork, and quartz vein (Lednikovy-Sarmaka); Sn-W greisen, stockwork, and quartz vein; Cassiterite-sulfide-silicate vein and stockwork; Porphyry Mo (±W, Sn, Bi) (Ippatinskoe, Olgakanskoe, Shirotnoe)	Russia, Far East	Veins and replacements related to the Khingan-Okhotsk volcanic-plutonic belt.	Late Cretaceous. Sn granite has isotopic ages of 75-100 Ma.	Belt is interpreted as having formed during generation of granitoids along along the Khingan transform continental-margin arc that contains the Khingan-Okhotsk volcanic-plutonic belt and that is related to oblique subduction of ancestral Pacific Ocean plate.
Gyeongnam (GN)	Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite (Gwymyeong, Mulkum, Kuryong); Fe skarn Ulsan); W-Mo-Be greisen, stockwork, and quartz vein; Porphyry Mo (±W, Sn, Bi); Cu-Ag vein (Goseong, Tongyoung) Au in shear zone and quartz vein (Cheolma)	South Korea	Veins and replacements related to the Cretaceous Bulgugsa granite (biotite and feldspar porphyry) that intrudes Sino-Korean craton - Yeongnam terrane.	Cenomanian through Campanian (96-75 Ma).	Belt is interpreted as having formed in a continental-margin arc during subduction of the ancestral Pacific Ocean plate. Deposits occur along the fissures and shear zones.
Gyeongpuk (GP)	Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Darak, Chilgok); W-Mo-Be greisen, stockwork, and quartz vein (Kyeongju); Sn-W greisen, stockwork, and quartz vein (Wangpiri); Fe skarn; Polymetallic Ni vein (Samkwang).	South Korea	Veins and replacements related to the Cretaceous Bulgugsa granite (biotite granite and granodiorite) that intrudes the Sino-Korean craton - Yeongnam terrane.	Cenomanian through Campanian.	Belt is interpreted as having formed in a continental-margin arc during subduction of the ancestral Pacific Ocean plate.
Hidaka (HD)	Cyprus Cu-Zn massive sulfide (Shimokawa)	Japan, Hokkaido	Stratiform units in the Shimanto subduction-zone terrane (part of the East Sakhalin collage).	Middle Cretaceous through Eocene.	Belt is interpreted as having formed in basalt generated along the Kula-Pacific ridge. Subsequent structural incorporatation of host rocks and deposits into a subduction zone.
Inner Zone Southwest Japan (ISJ)	Zn-Pb (±Ag, Cu) skarn (Kamioka Tochibara); W-Mo-Be greisen, stockwork, and quartz vein (Otani); W±Mo±Be skarn; Cu (±Fe, Au, Ag, Mo)	Japan	Veins and replacements in the Nohi rhyolite volcanic belt and the Hiroshima granitic belt that overlie and intrude a large portion	Cretaceous and Paleogene. Cretaceous age of deposit-related granitic rocks in the Ryoke and Sanyo belts. Mainly a Paleogene age for Sanin belt.	Belt is interpreted as having formed during generation of granitoids along the East Asia continental margin arc related to subduction of the Kula and Pacific Ocean plates. East Asia arc is interpreted as the southern extension of the East Sikhote-Alin arc.

	skarn; Cu (±Fe, Au, Ag, Mo) skarn (Bandojima); Porphyry Mo (±W, Sn, Bi); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Ikuno); Fluorspar vein; Metamorphic graphite		and intrude a large portion of central and southern Japan.	age for Sanin belt.	extension of the East Sikhote-Alin arc.
Khandyga (KA)	Ag-Sb vein; Carbonate-hosted As-Au metasomatite; Clastic-sediment-hosted Sb-Au (Senduchen); Clastic sediment-hosted Hg±Sb (Seikimyan)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements in the Verkhoyansk (North Asian) craton margin.	Aptian through Late Cretaceous.	Belt is interpreted as having formed during post-accretionary extension related to initiation of opening of the Eurasia Basin. Belt occurs in veins and replacements in the southern Verkhoyansk fold and thrust along the Sette-Daban tectonic zone.
Kukhtuy-Uliya (KU)	Au-Ag epithermal vein (Khakandzha, Yurievka); Porphyry Mo (±W, Sn, Bi); Porphyry Sn; Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite	Russia, Far East	Veins related to the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies the Okhotsk terrane.	Late Cretaceous and Paleocene.	Belt is interpreted as having formed during generation of granitoids along the Okhotsk-Chukotka continental margin arc related to subduction of the ancestral Pacific Ocean plate.
Luzhkinsky (LZ)	Sn-W greisen, stockwork, and quartz vein (Tigrinoe, Zimnee, Arsenyevsky); Cassiterite-sulfide-silicate vein and stockwork (Vysokogorskoe); W-Mo-Be greisen, stockwork, and quartz vein; Porphyry Sn (Yantarnoe); Porphyry Cu (±Au); Porphyry Cu-Mo (±Au, Ag); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork	Russia, Far East	Veins, replacements, and granitoids related to the East Sikhote-Alin volcanic-plutonic belt that overlies and intrudes the Zhuravlevsk-Amur River terrane (part of the Honshu-Sikhote-Alin collage).	Mid-Cretaceous through early Tertiary isotopic ages that range form 100 to 50 Ma.	Belt is interpreted as having formed during generation of granitoids in the back-arc of the East-Sikhote-Alin continental-margin arc related to oblique subduction of the ancestral Pacific Ocean plate.
Malo-Khingan (MK)	Porphyry Sn (Khinganskoe); Rhyolite-hosted Sn	Russia, Far East	Granitoids related to the Khingan-Okhotsk volcanic-plutonic belt.	Late Cretaceous. Probable deposit-related to subalkaline potassium granite has K-Ar ages of 80-90 Ma and a Rb-Sr whole-rock isochron age of 78 Ma.	Belt is interpreted as having formed during generation of granitoids along the Khingan transform continental-margin arc that contained the Khingan-Okhotsk volcanic-plutonic belt. Arc is related to oblique subduction of the ancestral Pacific Ocean plate.
Pilda-Limuri (PL)	Sn-W greisen, stockwork, and quartz vein; W-Mo-Be greisen, stockwork, and quartz vein; Ag-Sb vein (Dyappe); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Uchaminskoye); Granitoid-related Au vein (Agnie-Afanasievskoye)	Russia, Far East	Veins, replacements, and granitoids related to the Khingan-Okhotsk volcanic-plutonic belt.	Late Cretaceous.	Belt is interpreted as having formed during generation of granitoids along the Khingan transform continental-margin arc that contained the Khingan-Okhotsk volcanic-plutonic belt. Arc is related to oblique subduction of the ancestral Pacific Ocean plate.
Preddzhug-dzhursky (PD)	Porphyry Cu-Mo (±Au, Ag_; Porphyry Cu (±Au); Au-Ag epithermal vein (Avlayakan); Granitoid-related Au vein; Cu (±Fe, Au, Ag, Mo) skarn	Russia, Far East	Granitoids related to the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies the East Aldan superterrane and adjacent units.	Late Cretaceous and Paleocene.	Belt is interpreted as having formed during generation of granitoids along Okhotsk-Chukotka continental margin arc related to oblique subduction of the ancestral Pacific Ocean plate.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Major Metallogenic Belts, Cenomanian through Campanian (96-72 Ma)					
Selennyakh (SE)	Carbonate-hosted Hg-Sb (Gal Khaya, Pologoye, Arbat); Volcanic-hosted Hg (Dogdo); Ag-Sb vein (Kysylga)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements in the Uyandina-Yasachnaya volcanic belt along the southern margin of Kolyma-Omolon superterrane.	Aptian through Late Cretaceous.	Belt is interpreted as having formed during post-accretionary extension related to initiation of opening of the Eurasia Basin.
Sergeevka-Taukha (ST)	Granitoid-related Au vein (Progress, Askold); Boron (datolite) skarn (Dalnegorsk); Zn-Pb (±Ag, Cu) skarn (Nikolaevskoe, Partizanskoe); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Porphyry Sn; Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite (Krasnogorskoye); Au-Ag epithermal vein; Porphyry Cu (±Au)	Russia, Far East	Veins and granitoids related to the East Sikhote-Alin volcanic-plutonic belt that overlies and intrudes the Sergeevka, Samarka, and Taukha terranes.	Late Cretaceous and early Tertiary. K-Ar ages of deposits range between 60 and 80 Ma.	Belt is interpreted as having formed during generation of granitoids along the East-Sikhote-Alin continental-margin arc related to subduction of the ancestral Pacific Ocean plate.
Tumnin-Anyui (TA)	Porphyry Sn (Mopau); Cassiterite-sulfide-silicate vein and stockwork; Au-Ag epithermal vein (Tumninskoye)	Russia, Far East	Veins and granitoids related to the East Sikhote-Alin volcanic-plutonic belt that overlies and intrudes the Kema, Luzhkinsky, and Samarka terranes.	Late Cretaceous and Paleocene.	Belt is interpreted as having formed during generation of granitoids along the East-Sikhote-Alin continental-margin arc related to oblique subduction of the ancestral Pacific Ocean plate.
Upper Uydoma (UY)	Cassiterite-sulfide-silicate vein and stockwork (Khoron); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Sn-W greisen, stockwork, and quartz vein; Porphyry Mo (±W, Sn, Bi)	Russia, East-Central Yakutia (Verkhoyansk area)	Veins and replacements related to the Okhotsk-Chukotka volcanic-plutonic belt that intrudes and overlies the Verkhoyansk (North Asian) craton margin.	Late Cretaceous.	Belt is interpreted as having formed during generation of granitoids along the Okhotsk-Chukotka continental margin arc that was related to oblique subduction of the ancestral Pacific Ocean plate.
Major Metallogenic Belts, Maastrichtian through Oligocene (72 to 24 Ma)					
Kema (KM)	Ag-Au epithermal vein (Glinyanoe, Tayozhnoe 1); Porphyry Cu-Mo (±Au, Ag) Sukhoi Creek; Porphyry Cu (±Au) Verkhnezolotoe); Porphyry Mo (±W, Sn, Bi)	Russia, Far East	Veins related to the East Sikhote-Alin volcanic-plutonic belt that intrudes and overlies the Kema terrane (part of the Honshu-Sikhote-Alin collage).	Early Tertiary.	Belt is interpreted as having formed during generation of granitoids along the East-Sikhote-Alin continental-margin arc that is related to subduction of ancestral Pacific Ocean plate.

Lower Amur (LA)	Au-Ag epithermal vein (Mnogovershinnoe); Epithermal quartz-alunite (Iskinskoe); Porphyry Au; Porphyry Cu (±Au); Sn-W greisen, stockwork, and quartz vein	Russia, Far East	Veins and granitoids related to the East Sikhote-Alin volcanic-plutonic belt that intrudes and overlies Amur River and Kiselyovka-Manoma subduction-zone terranes (both part of Honshu-Sikhote-Alin collage).	Late Cretaceous and Paleocene. K-Ar isotopic deposit ages are 49-69 Ma.	Belt is interpreted as having formed during generation of granitoids along the East-Sikhote-Alin continental-margin arc that is related to subduction of ancestral Pacific Ocean plate.
Popigay (PP)	Impact diamond (Popigay)	Russia, northern Yakutia	Astrobleme formed on North Asian craton.	Eocene. Tagamite and impact glasses have ^{40}Ar-^{39}Ar isotopic ages of 35.7 Ma.	Belt is hosted in the Popigay ring structure that is interpreted as resulting from meteoritic impact with formation of pseudotachylites, high-grade shock metamorphic minerals, and allogenic breccia.

Major Metallogenic Belts, Miocene through Quaternary (24-0 Ma)

Hokuriku-Sanin (HS)	Au-Ag epithermal vein (Omori); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Taishu); Ag-Sb vein; Clastic-sediment-hosted U	Japan	Veins and replacements related to the Neogene Japan sedimentary basin that overlies and intrudes the Hiroshima granitic plutonic belt, and the Akiyoshi-Maizuru and Mino-Tamba-Chichibu terranes (both part of the Honshu-Sikhote-Alin collage).	Miocene and Pleistocene.	Belt is interpreted as having formed along an island arc during back-arc rifting or axial part of the Japan arc that is tectonically related to subduction of Philippine Sea plate beneath the East Asia continental margin.
Kyushu (KY)	Au-Ag epithermal vein (Hishikari, Kushikino, Taio)	Japan	Veins and replacements related to the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that overlie and intrude the Akiyoshi-Maizuru, Shimanto, and Mino-Tamba-Chichibu terranes (both part of the Honshu-Sikhote-Alin collage).	Pliocene through Quaternary.	Belt is interpreted as having formed during hydrothermal activitiy along the Japan arc in either back-arc rifting or the axial part of the arc. Arc is tectonically related to subduction of the Pacific Ocean and Philippine Sea plates beneath the East Asia continental margin.
Northeast Hokkaido (NH)	Au-Ag epithermal vein (Konomai); Volcanic-hosted Hg (Itomuka); Hg-Sb-W vein and stockwork (Ryushoden); Clastic sediment-hosted Hg±Sb	Japan	Veins and replacements in the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that overlies and intrudes the Hidaka zone of the Shimanto accretionarry wedge terrane (part of the Honshu-Sikhote-Alin collage).	Miocene through Quaternary. Two ages of deposits: early stage (14.4-11.2 Ma); and late stage (8.1-0.3 Ma).	Belt is interpreted as having formed along the Japan arc that is tectonically related to subduction of the Pacific Ocean and Philippine Sea plates beneath the East Asia continental margin.

Name (symbol)	Mineral deposit types (major deposits)	Country, region	Unit or structure related to origin of belt	Age range	Tectonic event for origin of metallogenic belt
Northeast Japan (NJ)	Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) (Kosaka, Shakanai); Au-Ag epithermal vein (Sado, Hosokura, Toyoha); Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite; Sulfur-sulfide (S, FeS_2) (Horobetsu); Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork (Ashio); Mn vein; Volcanogenic-sedimentary Mn (Kinjo); Chemical-sedimentary Fe-Mn; Limonite from spring water (Gumma)	Japan	Layers and veins in the Quaternary Japan volcanic belt and Neogene Japan sedimentary basin that overlie and intrude the Hiroshima granitic plutonic belt, and the Mino-Tamba-Chichibu and South Kitakami terranes (both part of the Honshu-Sikhote-Alin collage).	Miocene through Quaternary. Many Kuroko-type deposits were formed in the middle Miocene, at about 13 Ma. K-Ar ages of vein deposits suggest two stages of formation: early stage (15-10 Ma); and late stage (8-2 Ma). Sulfur-sulfide (S, FeS_2) and limonite deposits formed on flanks of Quaternary volcanoes.	Volcanogenic massive sulfide deposits are interpreted as having formed in the back-arc and axial regions of the Japan arc that is tectonically related to subduction of the Pacific Ocean and Philippine Sea plates beneath the East Asia continental margin.
Outer Zone Southwest Japan (OS)	Sn skarn; Sn-W greisen, stockwork, and quartz vein; Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; Clastic-sediment-hosted Sb-Au; Au-Ag epithermal vein (Kishu); Volcanic-hosted Hg; Ag-Sb vein; Zn-Pb (±Ag, Cu, W) skarn (Chichibu); W-Mo-Be greisen, stockwork, and quartz vein; Hg-Sb-W vein and stockwork (Yamatosuigin); Cassiterite-sulfide-silicate vein and stockwork (Obira); Clastic-sediment-hosted Sb-Au	Japan	Veins and replacements related to the Neogene Japan sedimentary basin that overlies and intrudes the Hiroshima granitic plutonic belt, and Sambagawa, Shimanto, and Mino-Tamba-Chichibu terranes (both part of the Honshu-Sikhote-Alin collage).	Middle Miocene. Isotopic age of 15.5 Ma-13 Ma age for host siliceous igneous rocks.	Belt is interpreted as having formed in the back-arc rifting or axial part of the Japan arc that is tectonically related to subduction of the Pacific Ocean and Philippine Sea plates beneath the East Asia continental margin.

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