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 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 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

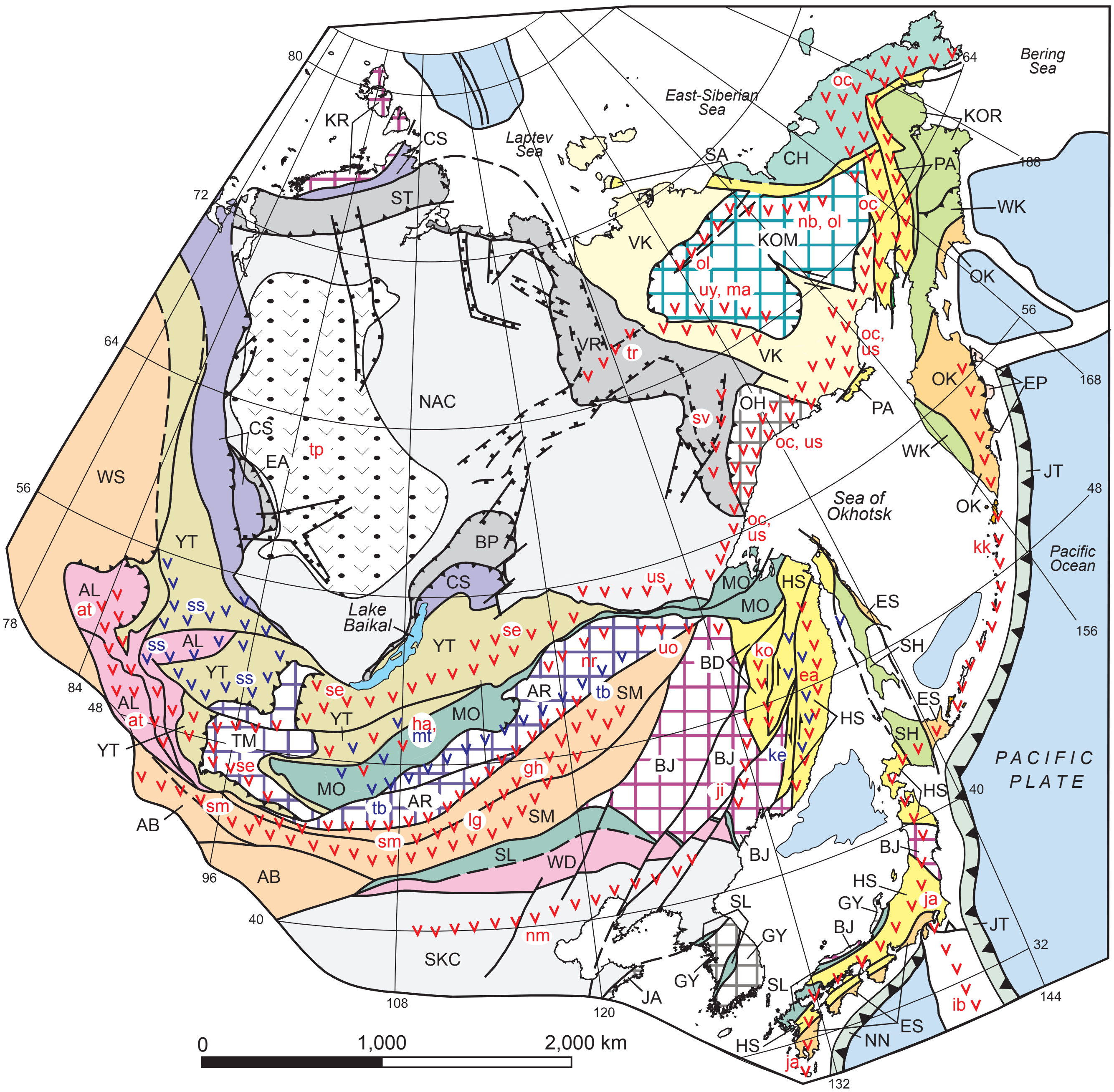


Figure 2. Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North 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

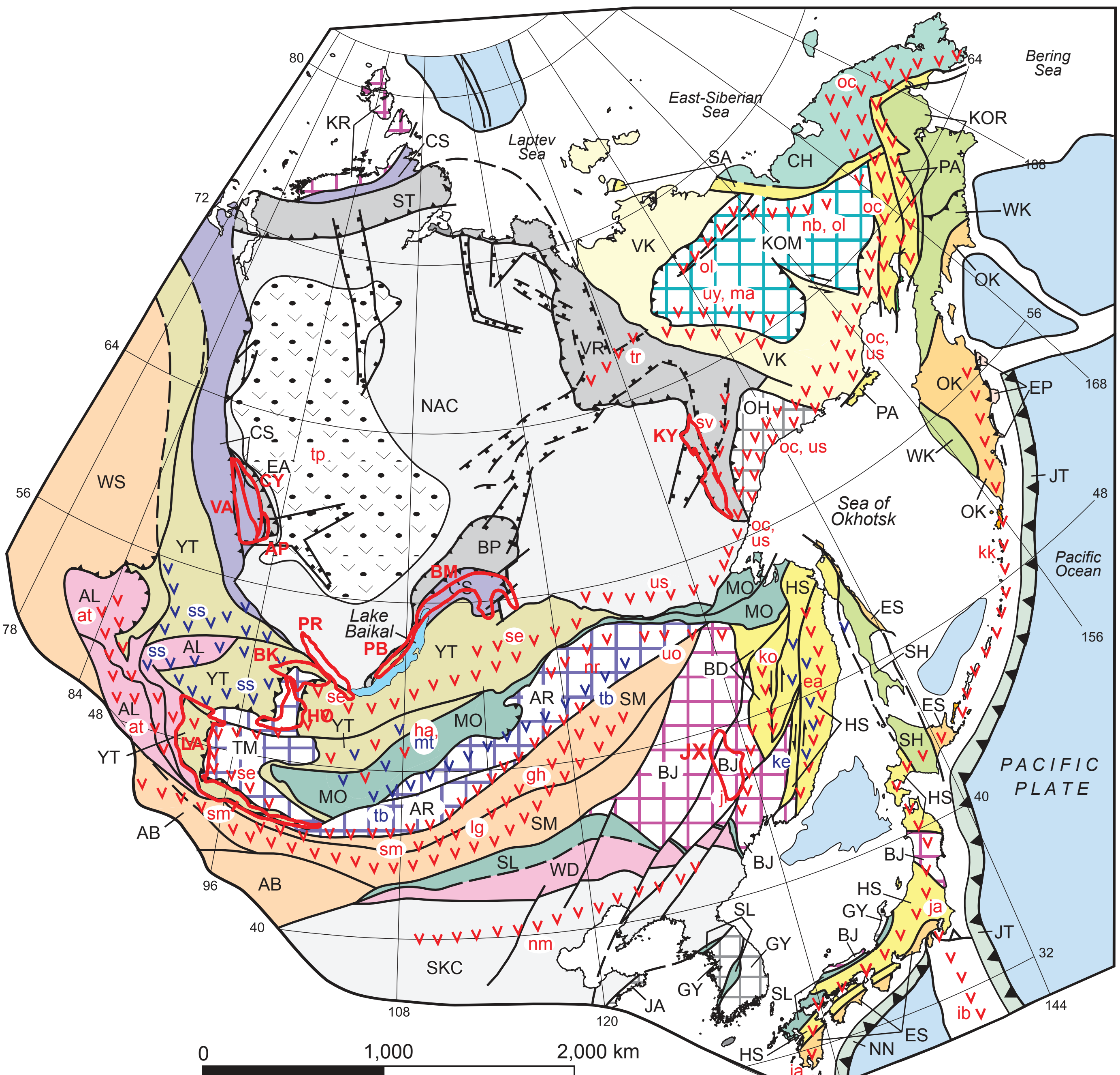


Figure 3. Generalized map of major Neoproterozoic metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 and table 1 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area east of 144° 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,

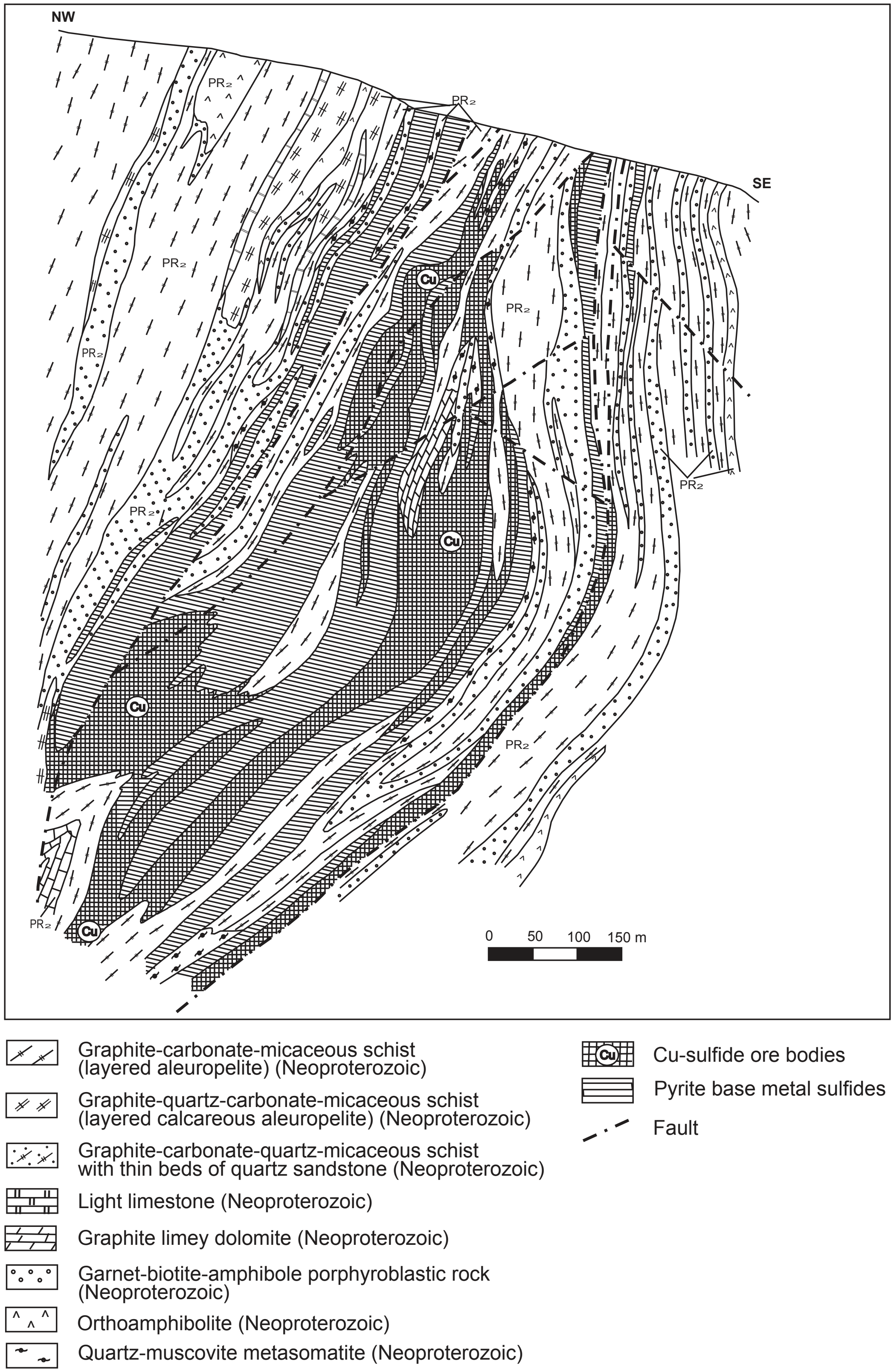


Figure 4. Schematic cross section of Kholodninskoe (volcanogenic-hydrothermal-sedimentary massive Pb-Zn sulfide deposit, Baikalo-Muiskiy metallogenic belt. Adapted from Distanov and others (1982).

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

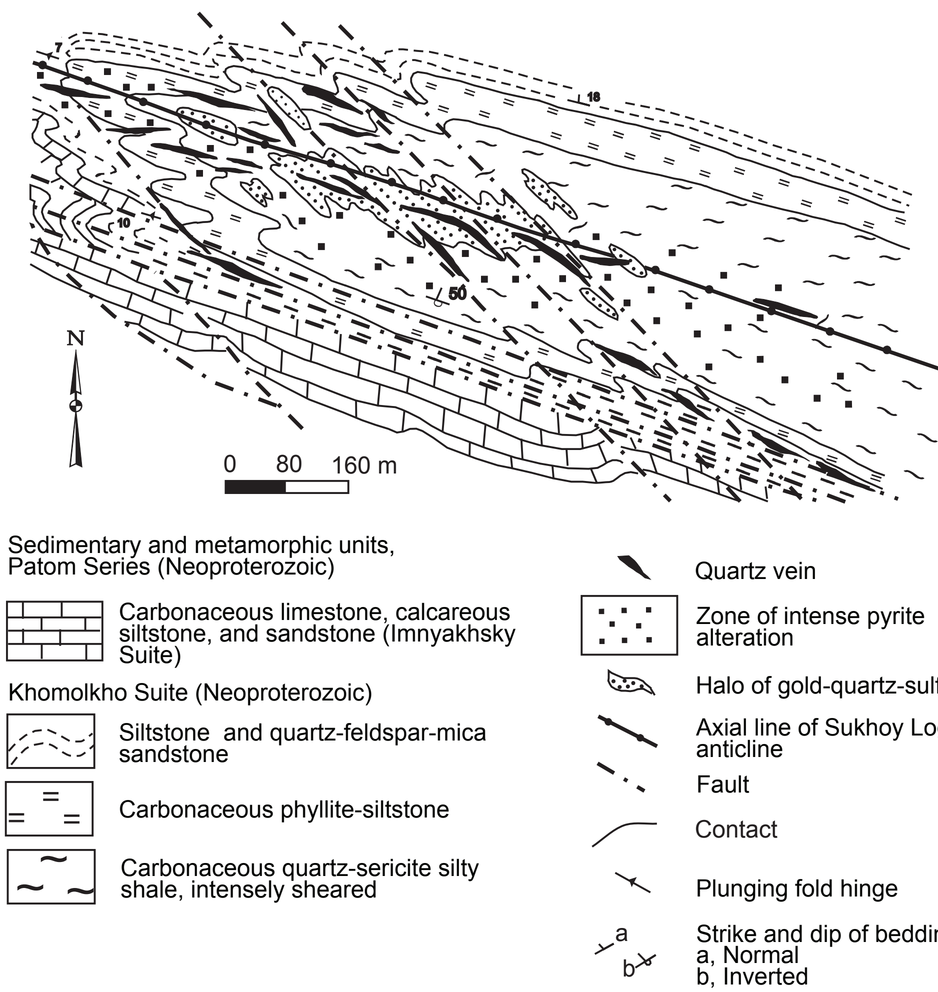


Figure 5. Generalized geologic map of Sukhoy Log Au in black shale deposit, Bodaibinskiy metallogenic belt. Adapted from Konovalov (1985).

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

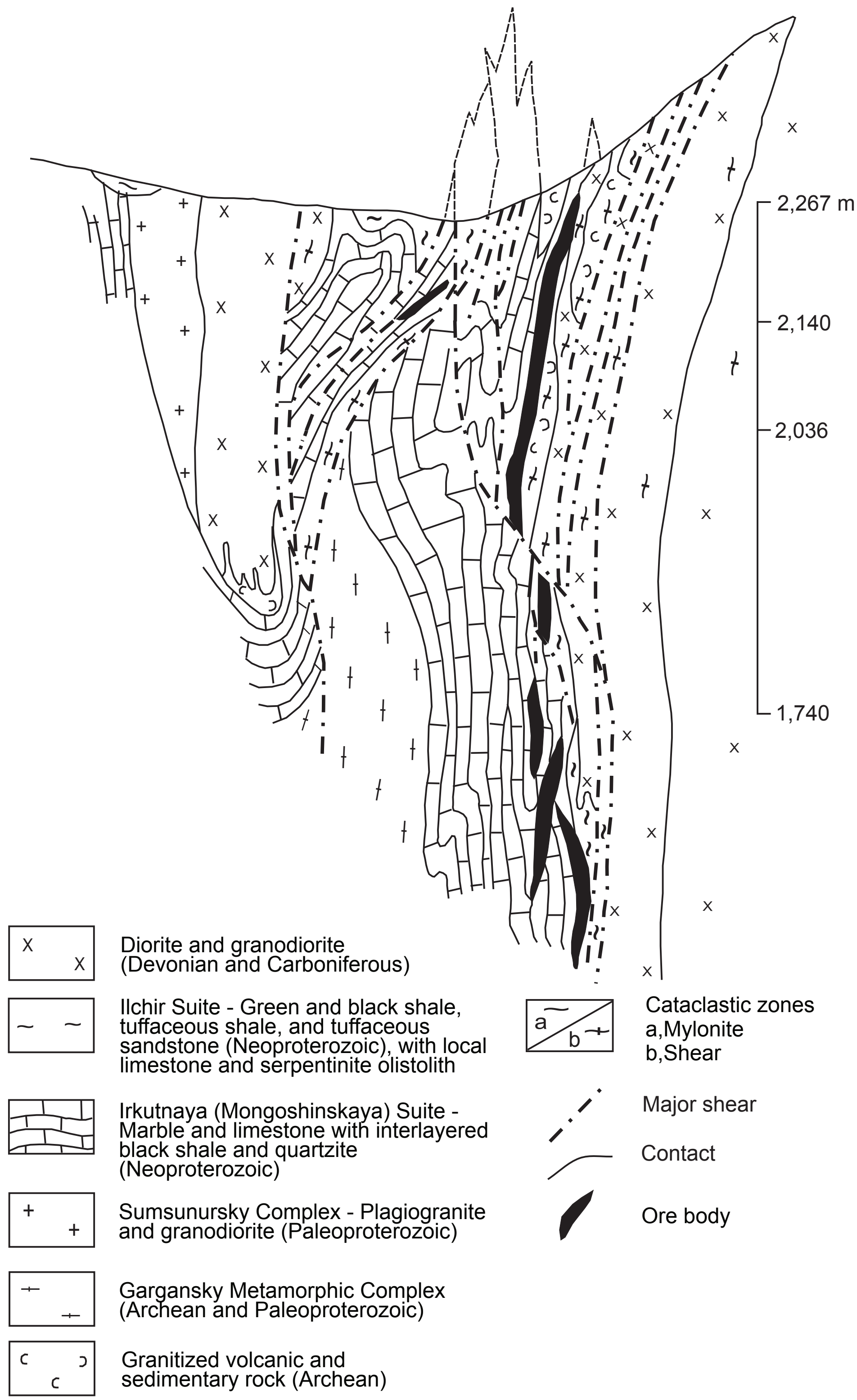


Figure 6. Schematic cross section of Zun-Kholba Au in shear-zone and quartz-vein deposit, Bokson-Kitoiskiy metallogenic belt. Adapted from Mironov and others (1995).6. Schematic cross section of Zun-Kholba Au in shear-zone and quartz-vein deposit, Bokson-Kitoiskiy metallogenic belt. Adapted from Mironov 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

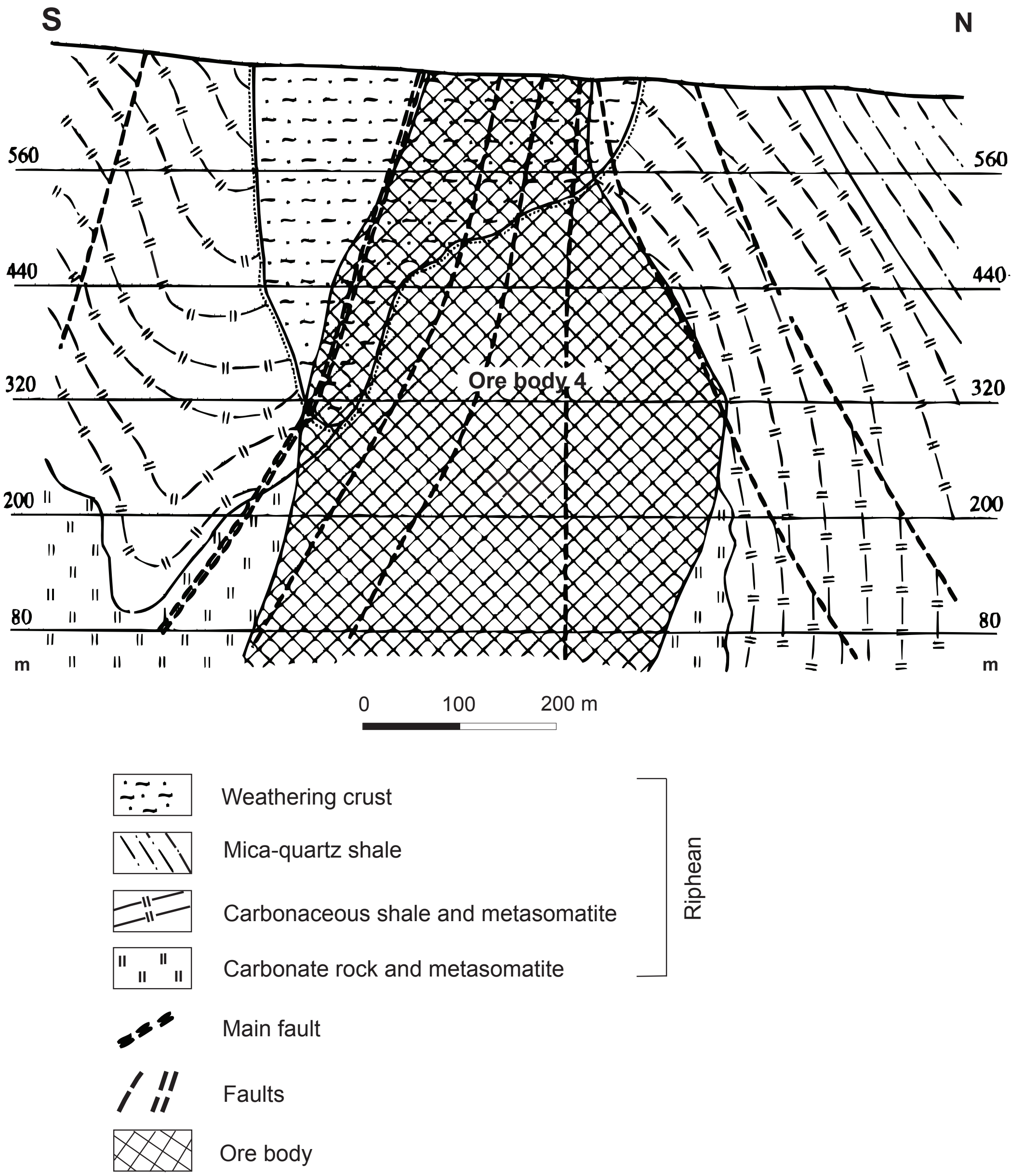


Figure 7. Schematic cross section of Olympiada Au in black shale deposit, Central-Yenisei metallogenic belt. Adapted from Genkin and others (1994).

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

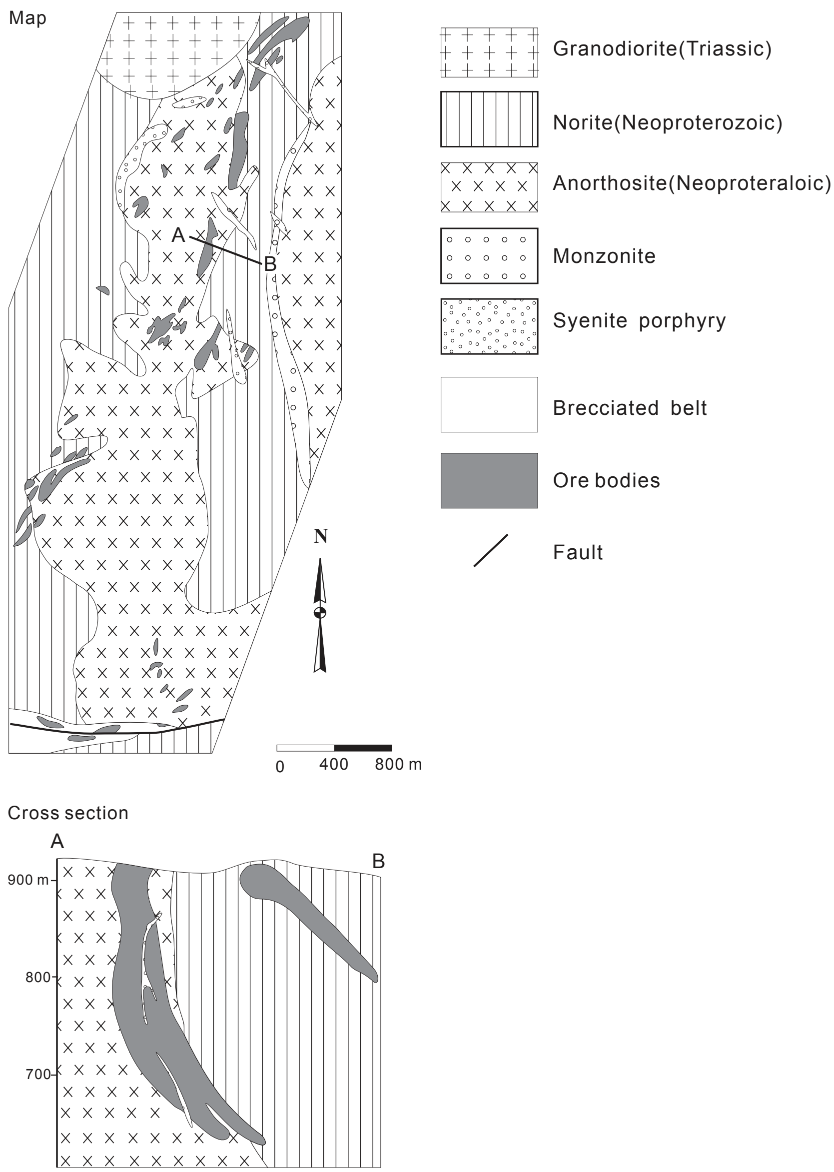


Figure 8. Generalized geologic map and cross section of Damiao mafic-ultramafic related Ti-Fe (V) deposit, Damiao metallogenic belt. Adapted from Dong (1993).

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

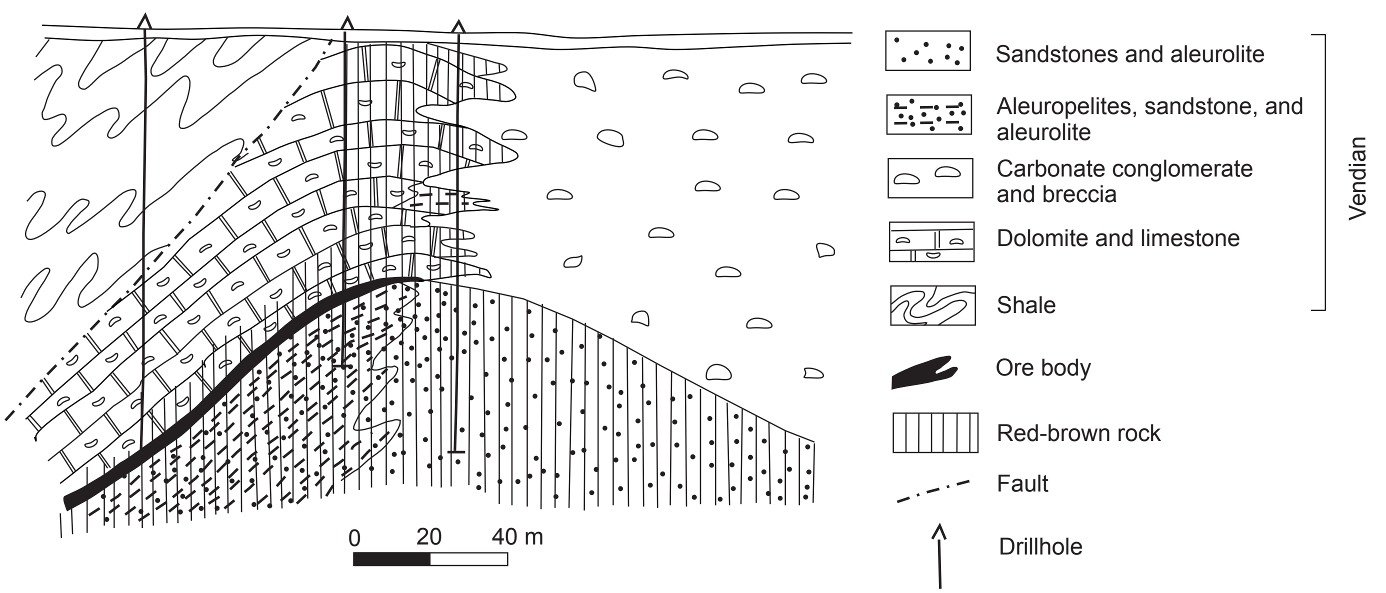


Figure 9. Schematic cross section of Graviiskoye sediment-hosted Cu deposit, Igarsk metallogenic belt. Adapted from Dyuzhikov and others (1988).

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);

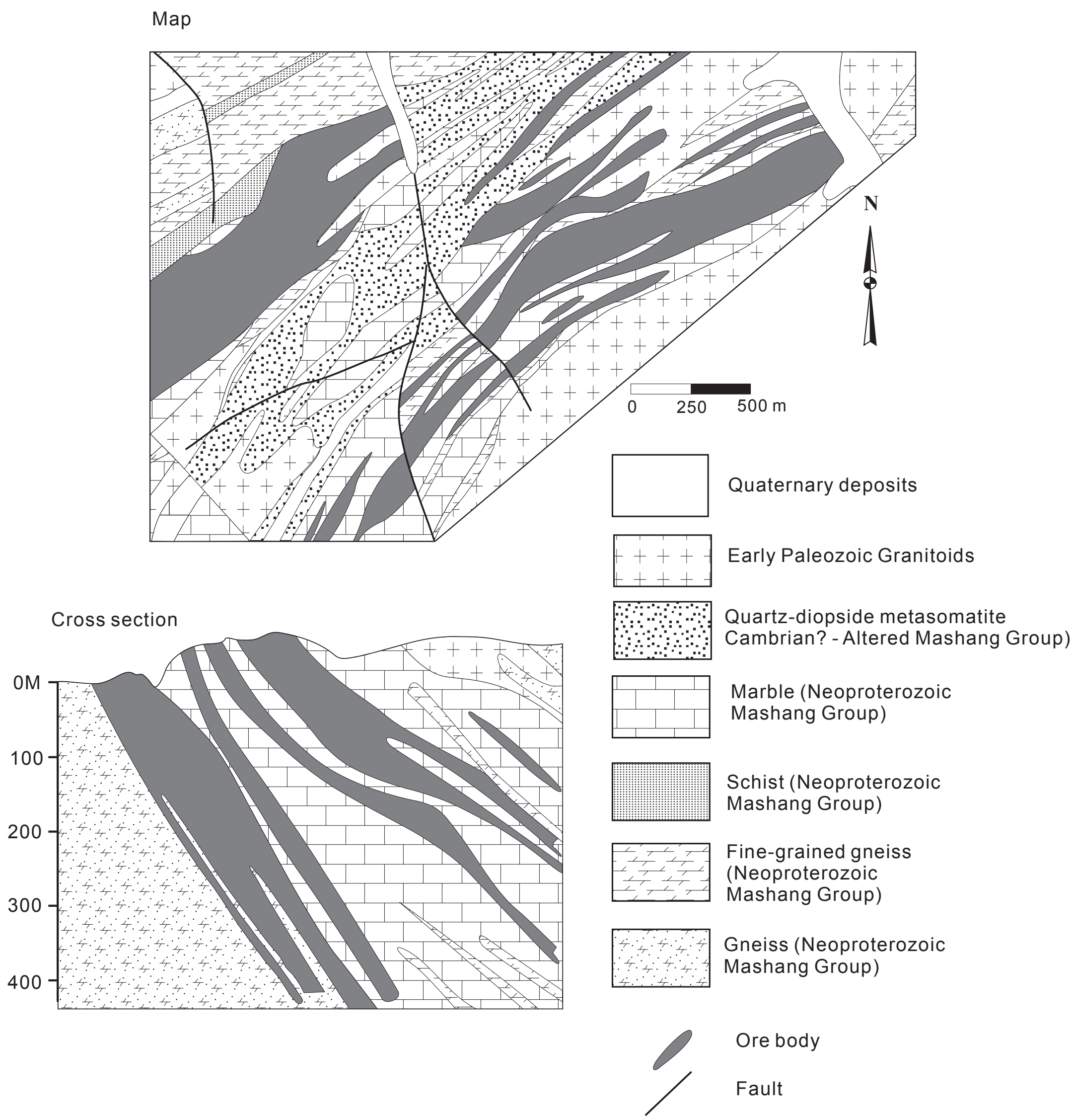


Figure 10. Generalized geologic map and cross section of Liumao metamorphic graphite deposit, Jixi metallogenic belt. Adapted afrom Zhang (1984).

(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 throughghtohiin 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

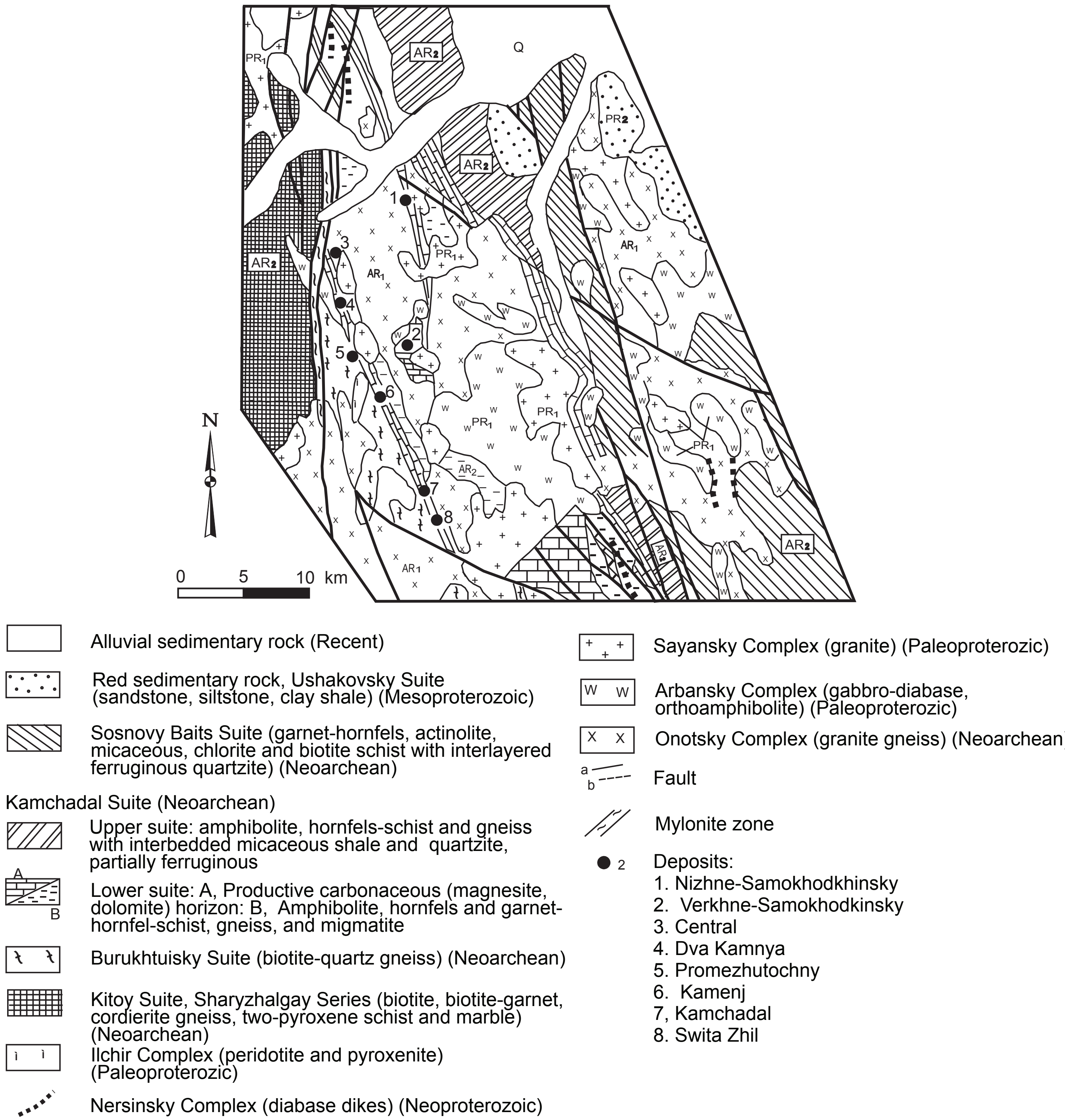


Figure 11. Generalized geologic map of Onotskoe talc (magnesite) replacement deposit, Prisayanskiy metallogenic belt. Adapted from Livitsky and others (1984).

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).

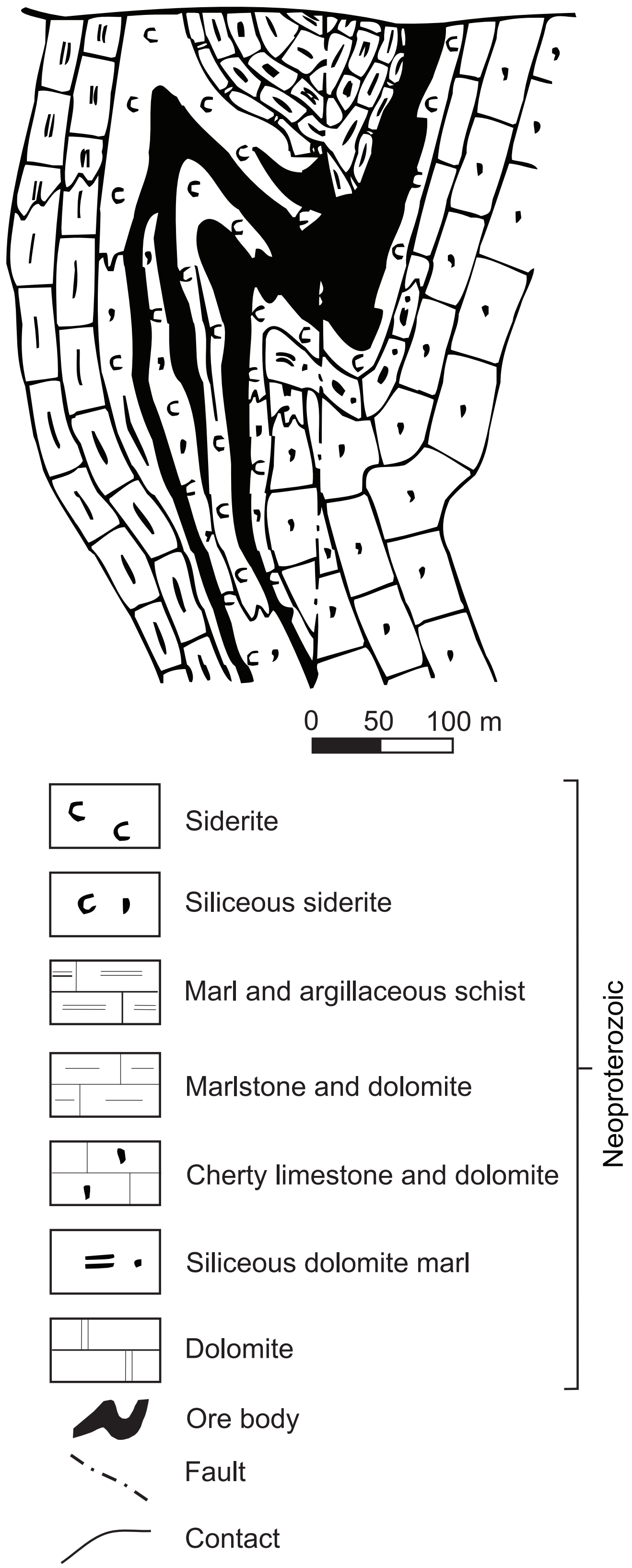
The main references on the geology and metallogenesis of the belt are Matrosov and Shaposhnikov (1988), Distanov (1985), Ponomarev and others (1991), and Obolenskiy and others (1999).

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

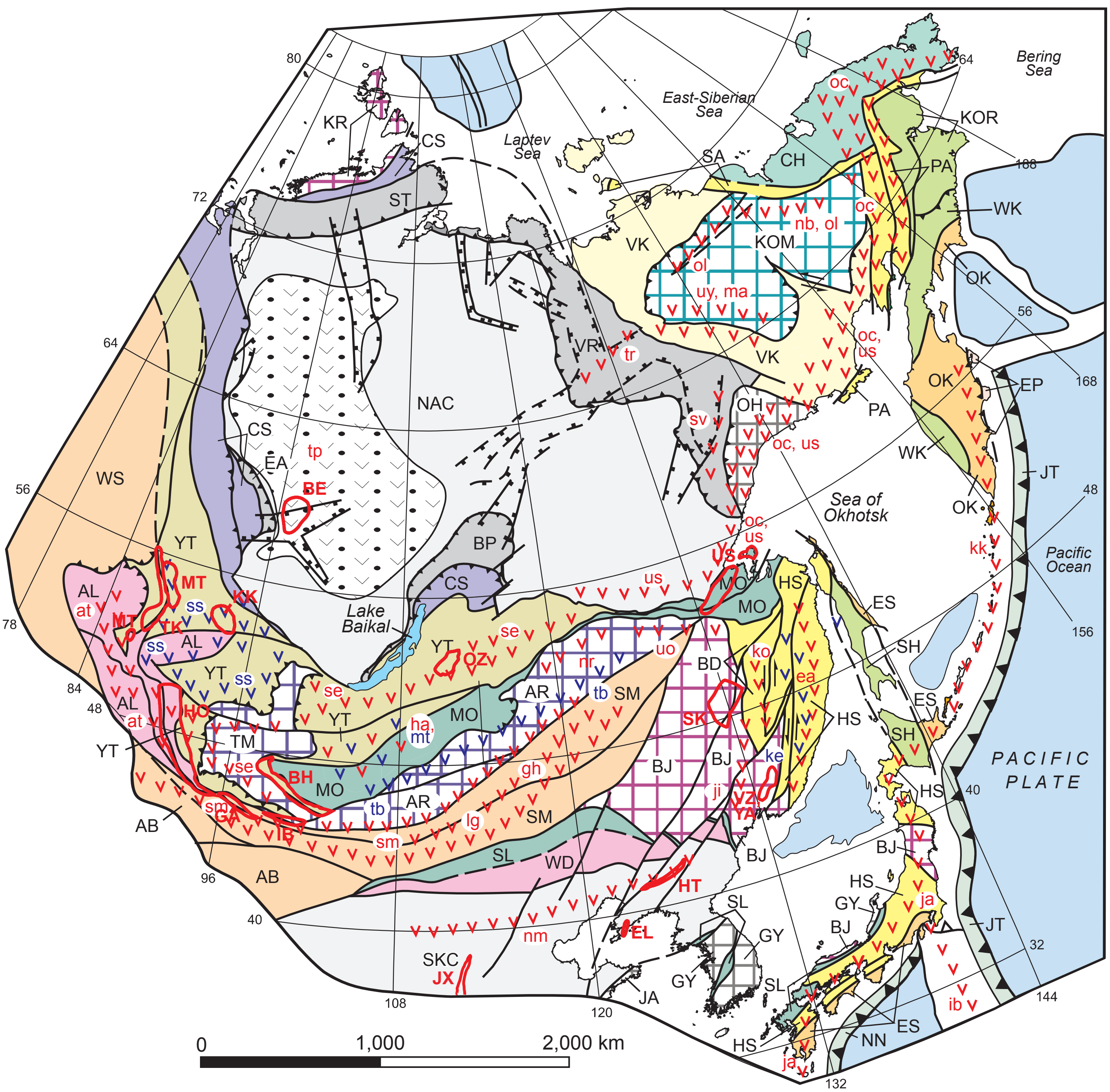


Figure 13. Generalized map of major Cambrian through Silurian metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (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.

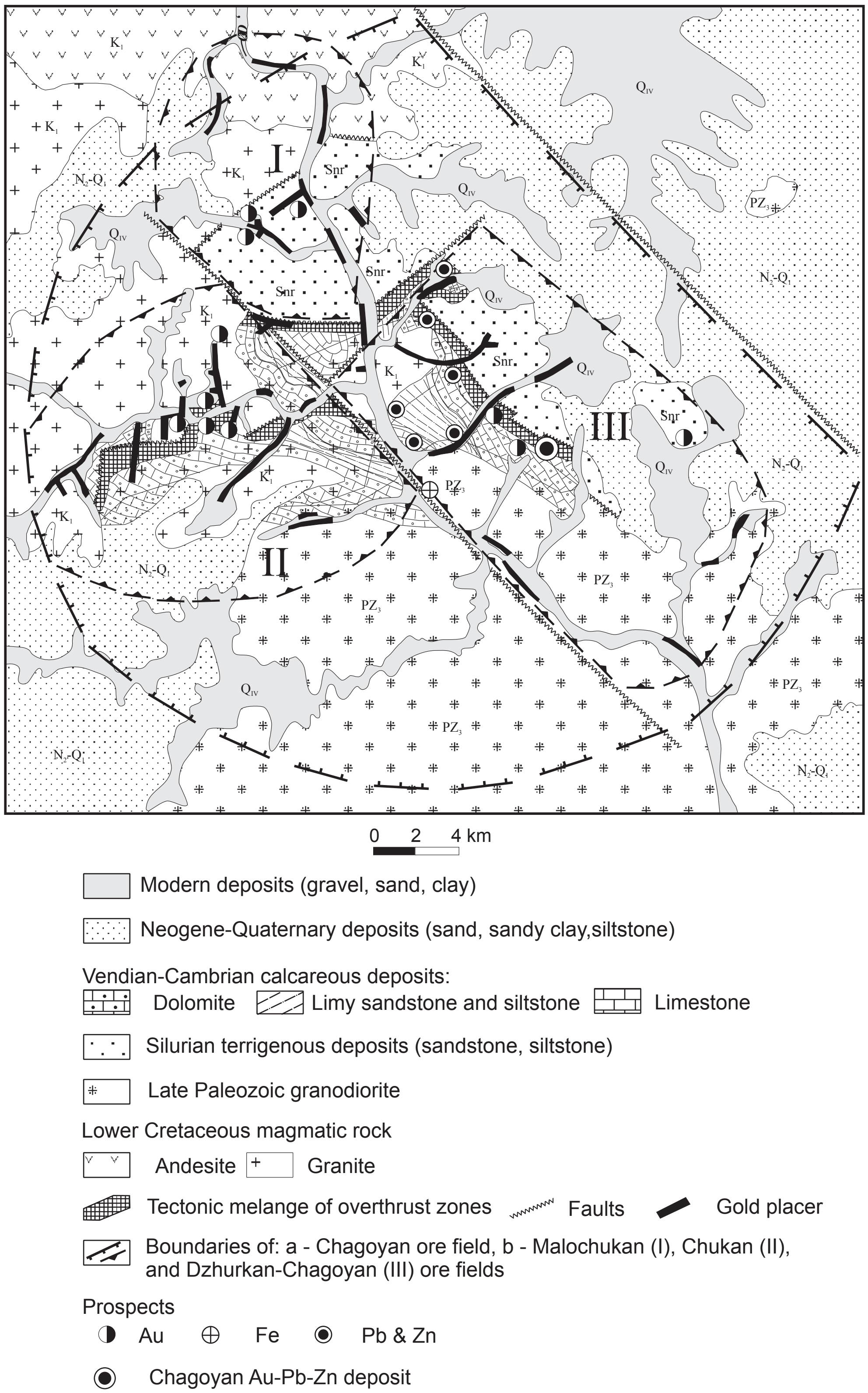
Govi-Altai Metallogenic Belt of Volcanogenic-Sedimentary Fe and Mn Deposits (Belt GAI) (Southwestern Mongolia)

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

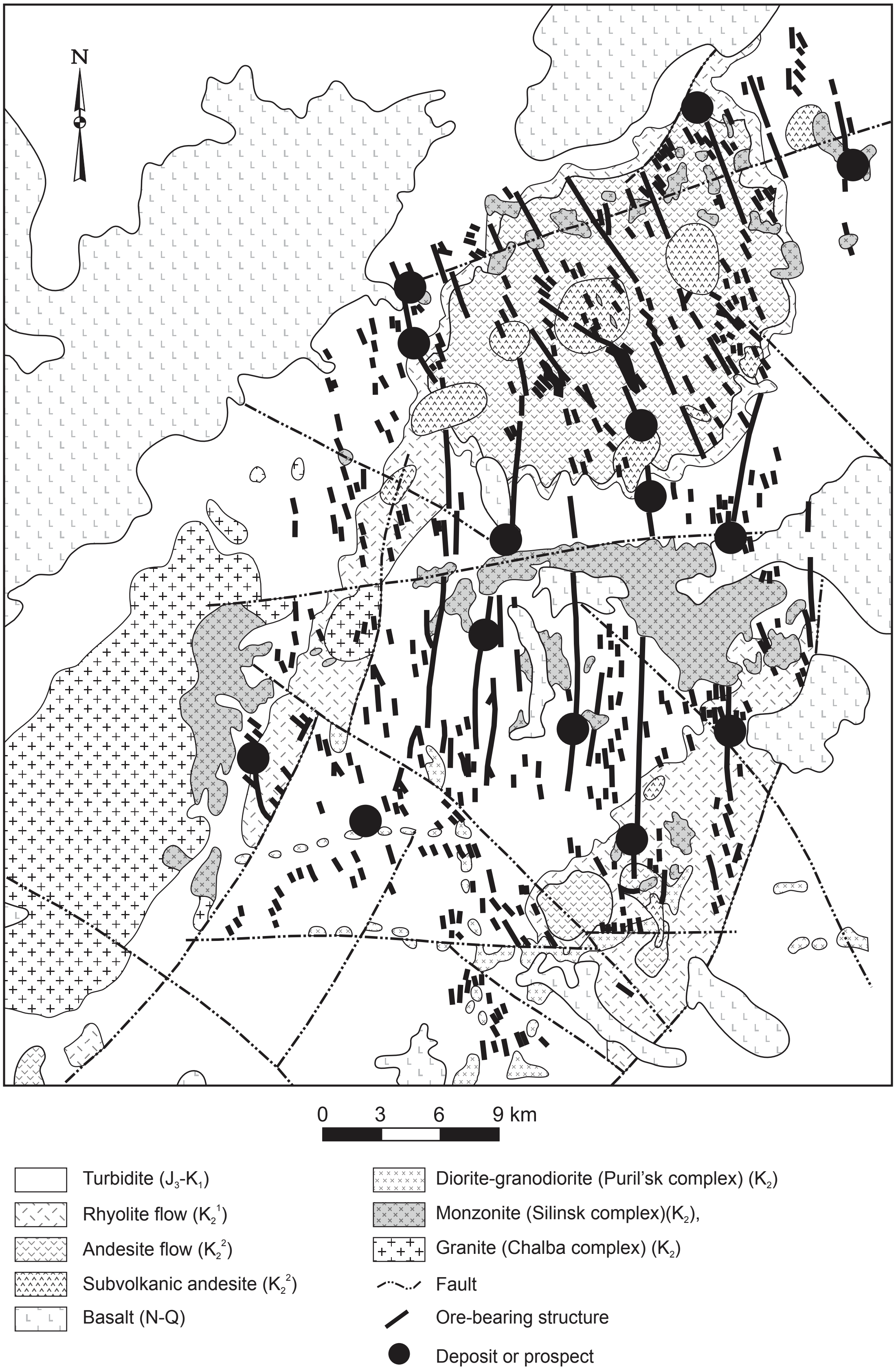


Figure 15. Generalized geologic map of Komsomolskoye Au district. Martaiginsk metallogenic belt. Adapted from Denisov (1968).

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.

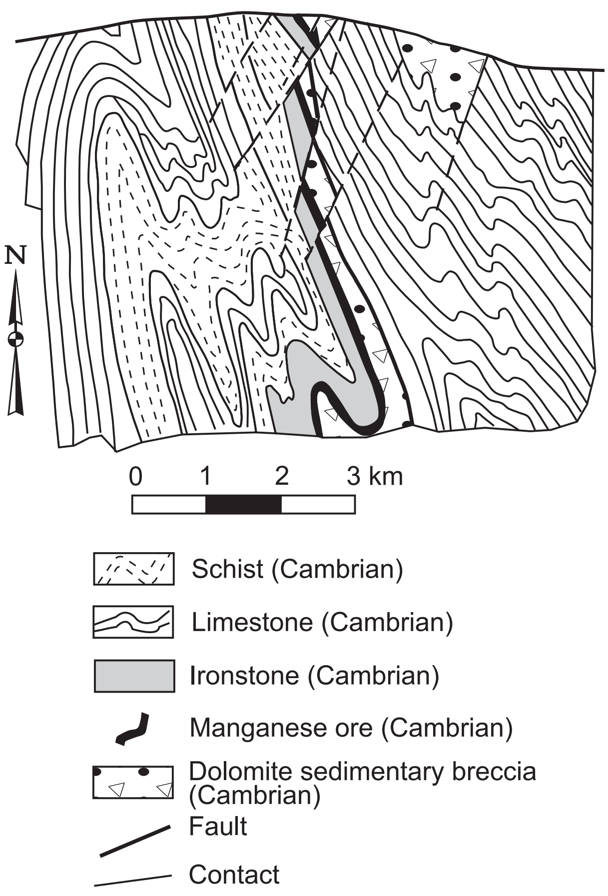


Figure 17. Schematic cross section of South Khingan banded iron formation deposit, South Khingan metallogenic belt. Adapted from V.A. Yarmolyuk and A.P. Glushkov (written commun., 1966)

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.

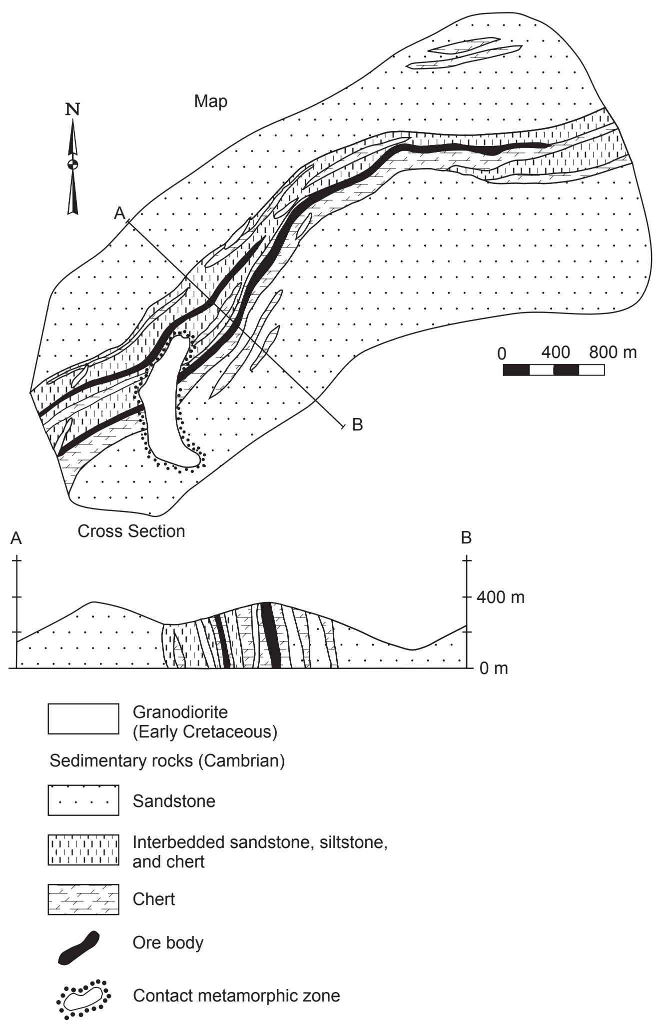


Figure 18. Generalized geologic map and schematic cross section of Gerbikanskoe volcanogenic-sedimentary Fe deposit, Uda-Shantar metallogenic belt. Adapted from Shkolnik (1973).

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.

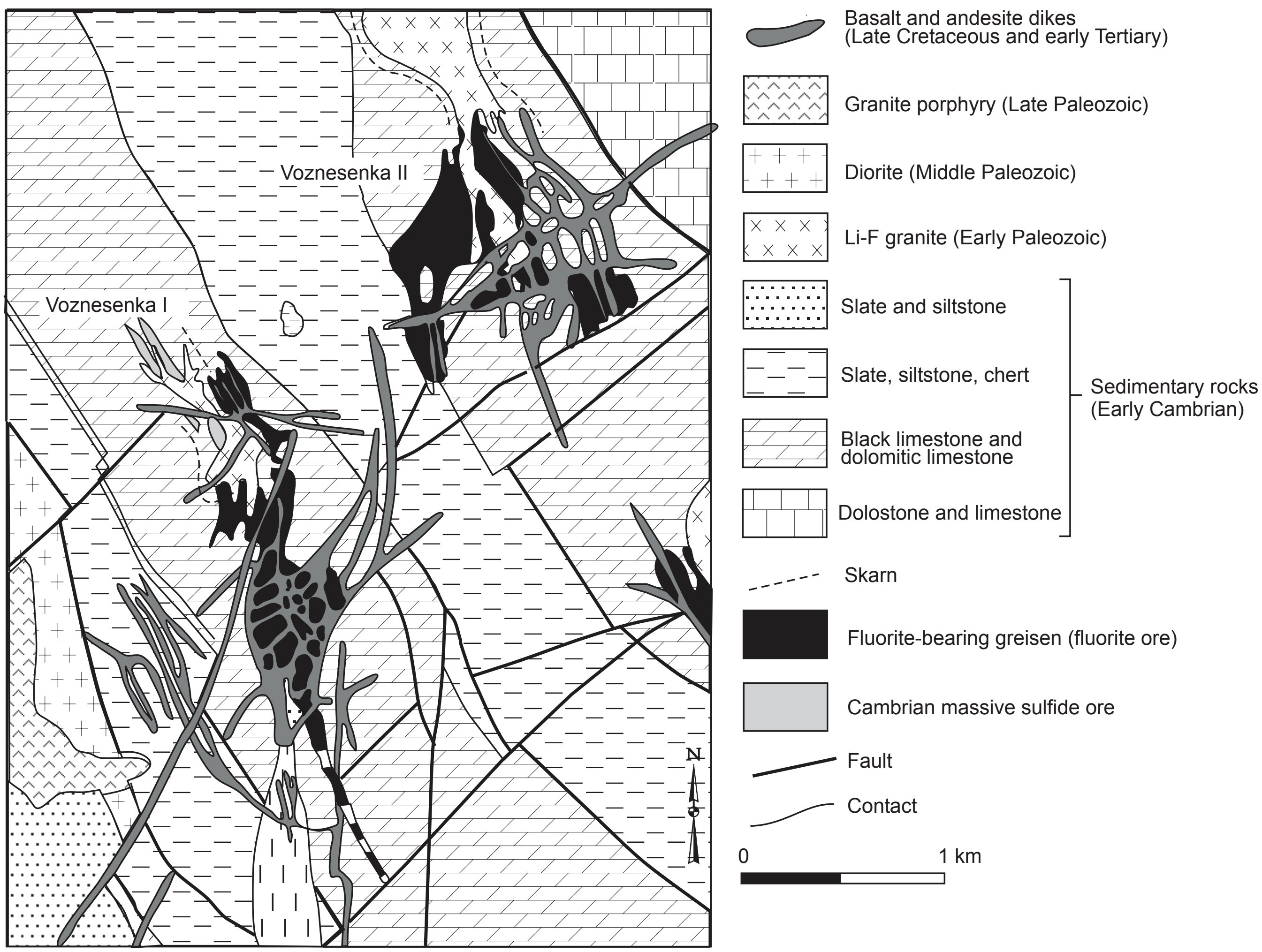


Figure 19. Generalized geologic map of Voznesenka-1 Korean Pb-Zn massive sulfide deposit, Voznesenka metallogenic belt. Adapted from Ratkin (1995).

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.

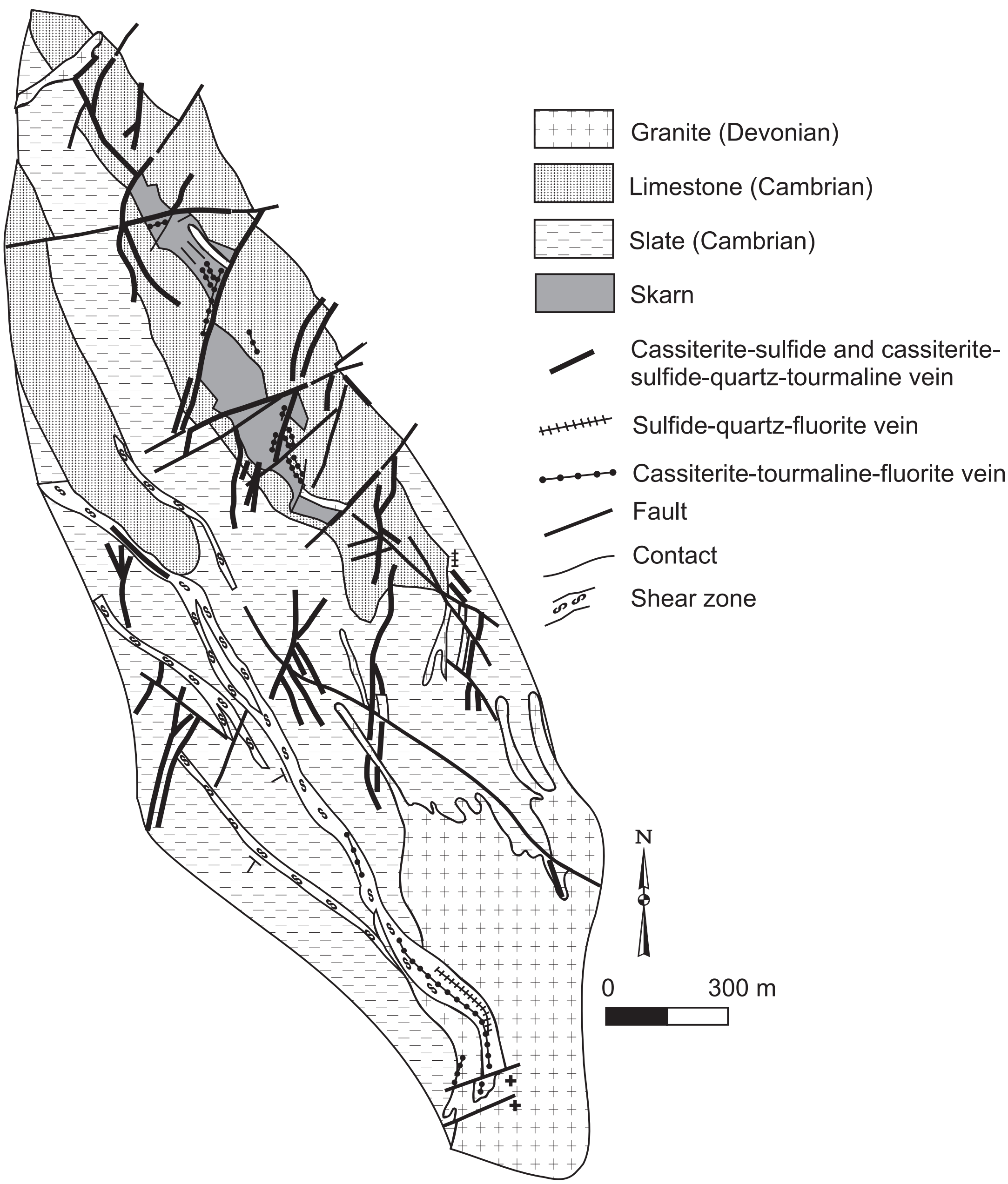


Figure 20. Generalized geologic map of Yaroslavskoe Sn-W greisen, stockwork, and quartz-vein deposit, Yaroslavka belt. Adapted from Govorov (1977) and Ryazantzeva (1998).

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).

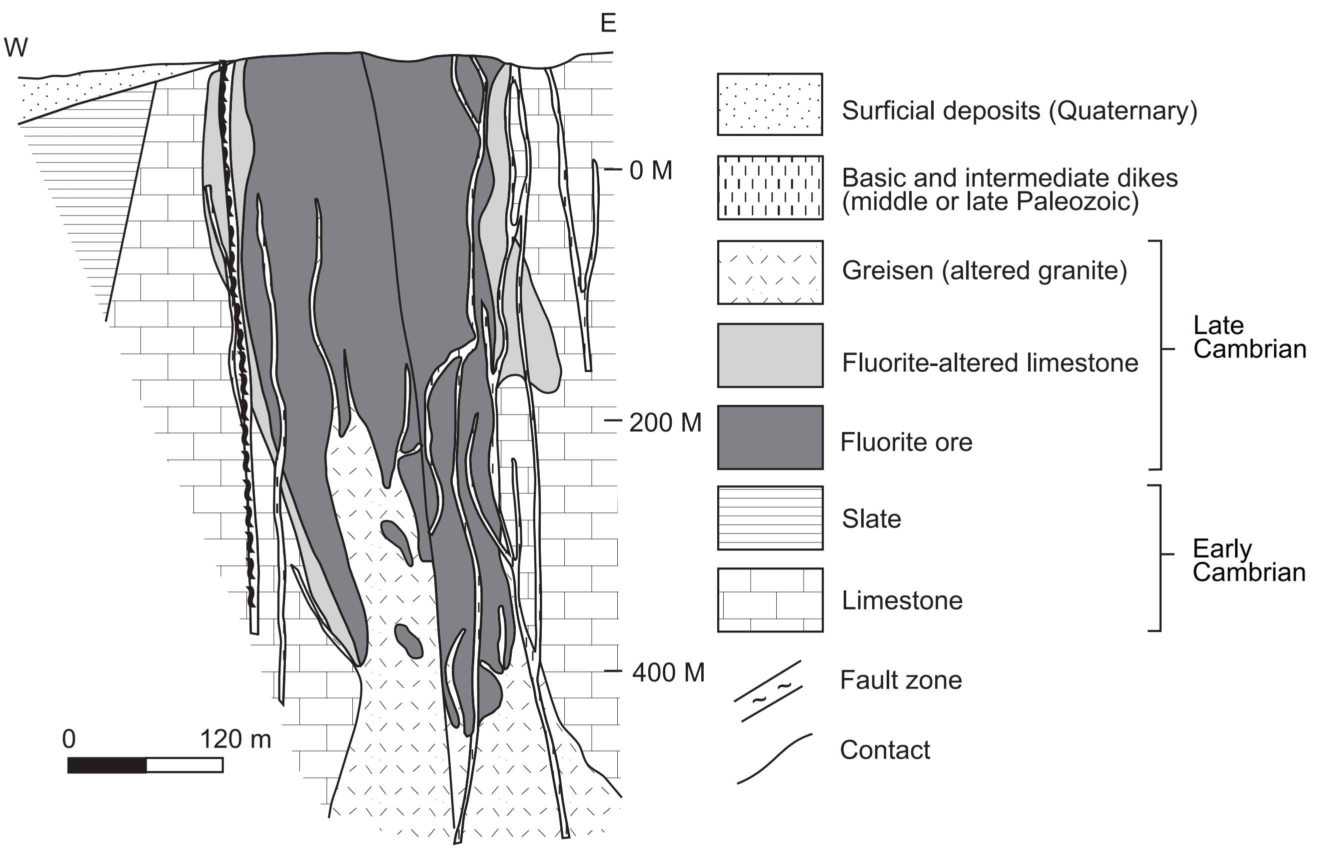


Figure 21. Schematic cross section of Voznesenka-2 fluorite fluorite greisen deposit, Yaroslavka belt. Adapted from Androsov and Ratkin (1990) and Ryazantzeva (1998).

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.

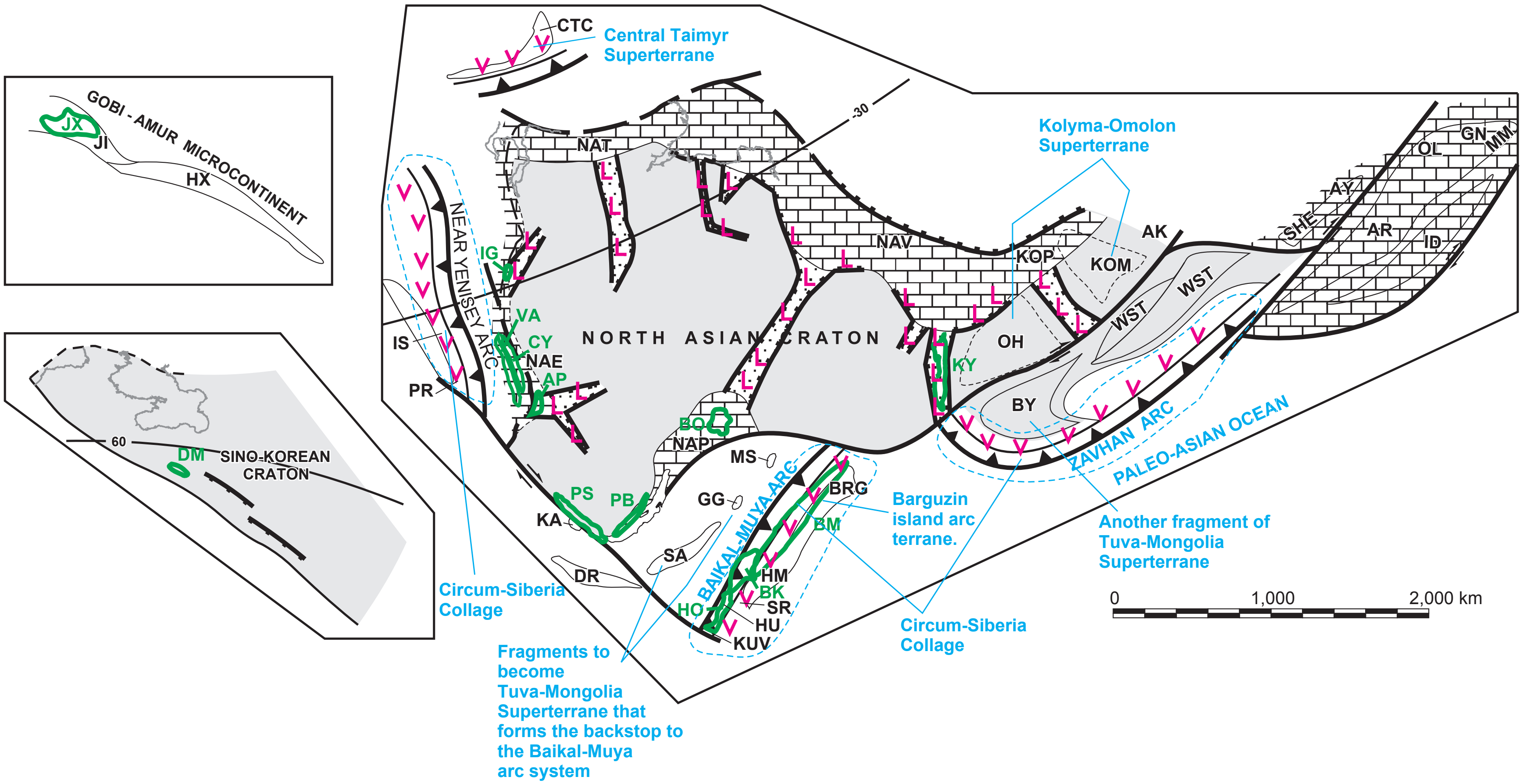
The Baikalo-Muiskiy belt (BM, figs. 3, 22; appendix C) is hosted in the Yenisey-Transbaikal collage and Tuva-mongolia superterrane, and it contains volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn (±Cu), polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite, and serpentinite-hosted asbestos 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

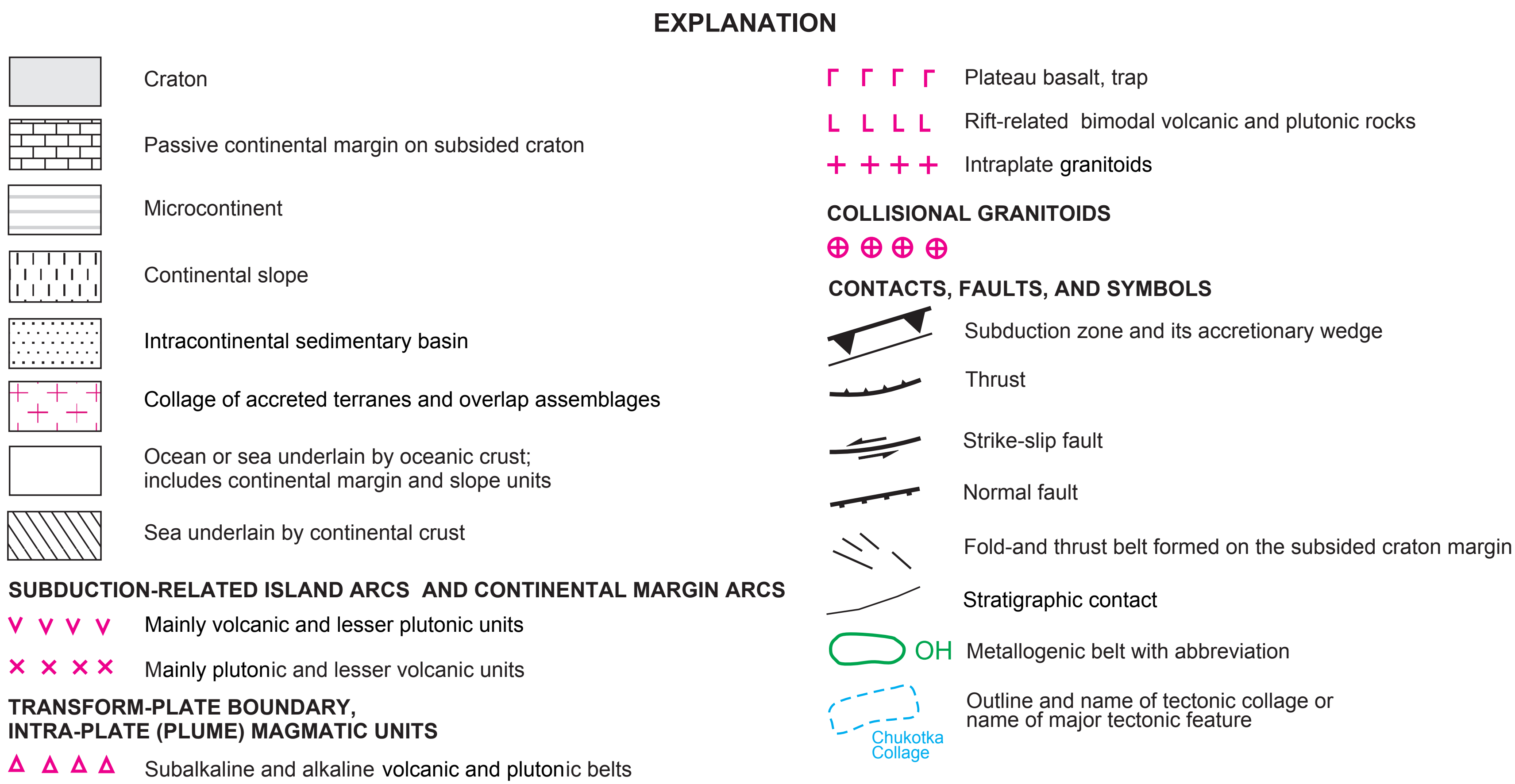


Figure 22. Neoproterozoic (850 Ma) metallogenic and tectonic model for Northeast Asia. Model and Explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

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.

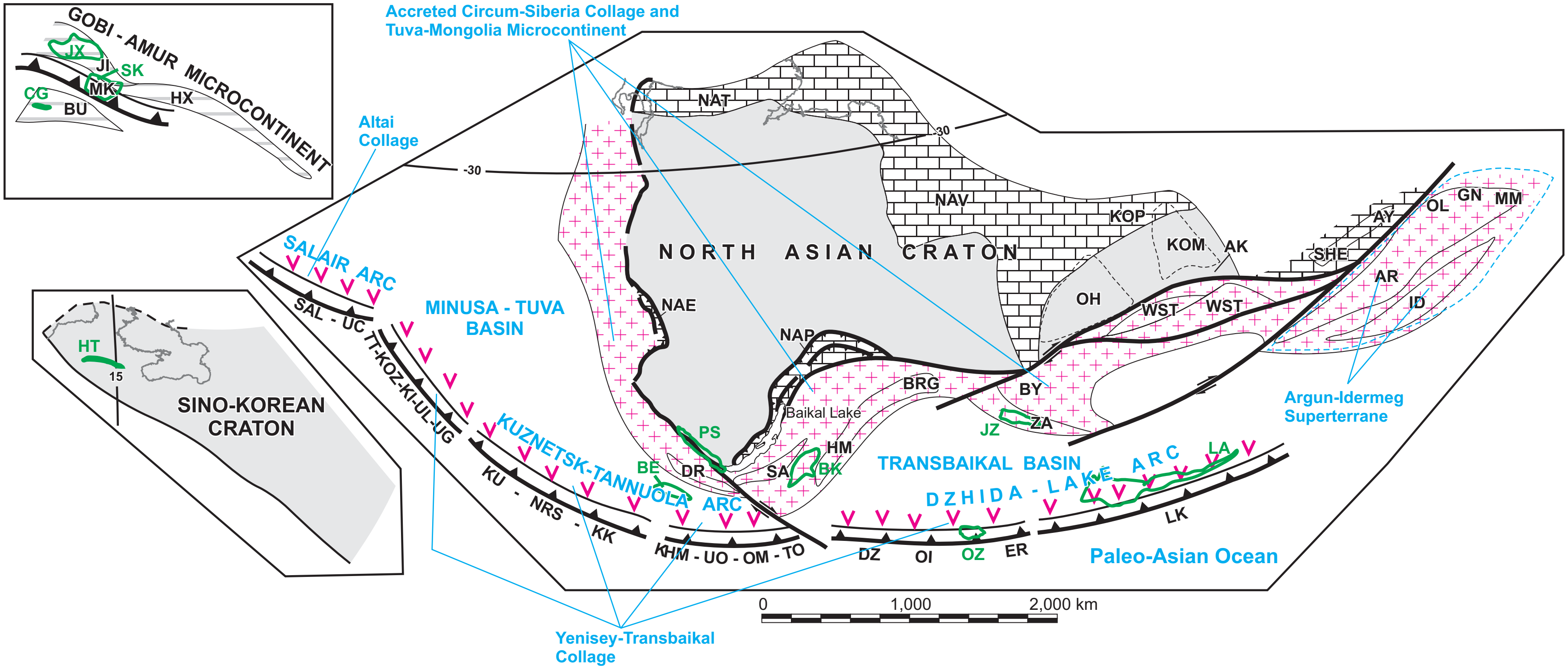
1. Completion of Neoproterozoic accretion of several major island-arc systems and tectonically linked subduction zones onto the North Asian craton, including the Near-Yenisey, Baikal-Muya, and Zavhan magmatic arcs.
2. Formation of new island-arc systems, including the Salair, Kuznetsk-Tannuola and Dzhida-Lake 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.

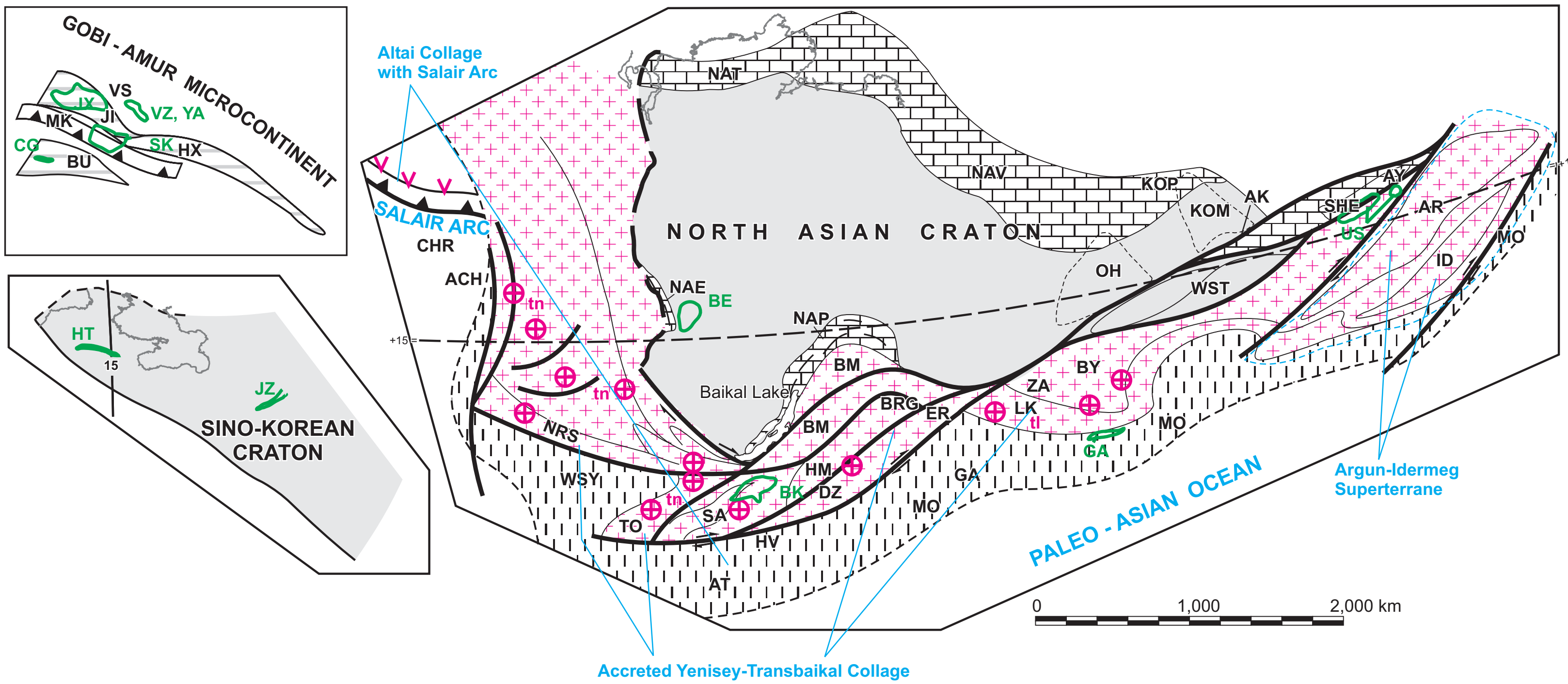
The Chagoyan belt (CG, figs. 13, 23, 24; appendix C) contains sedimentary exhalative Pb-Zn (SEDEX) deposits that are hosted in metasedimentary units in Bureya metamorphic terrane that is interpreted as part of the Gobi-Amur microcontinent. The belt is interpreted as having formed during rifting and submarine 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

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 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.

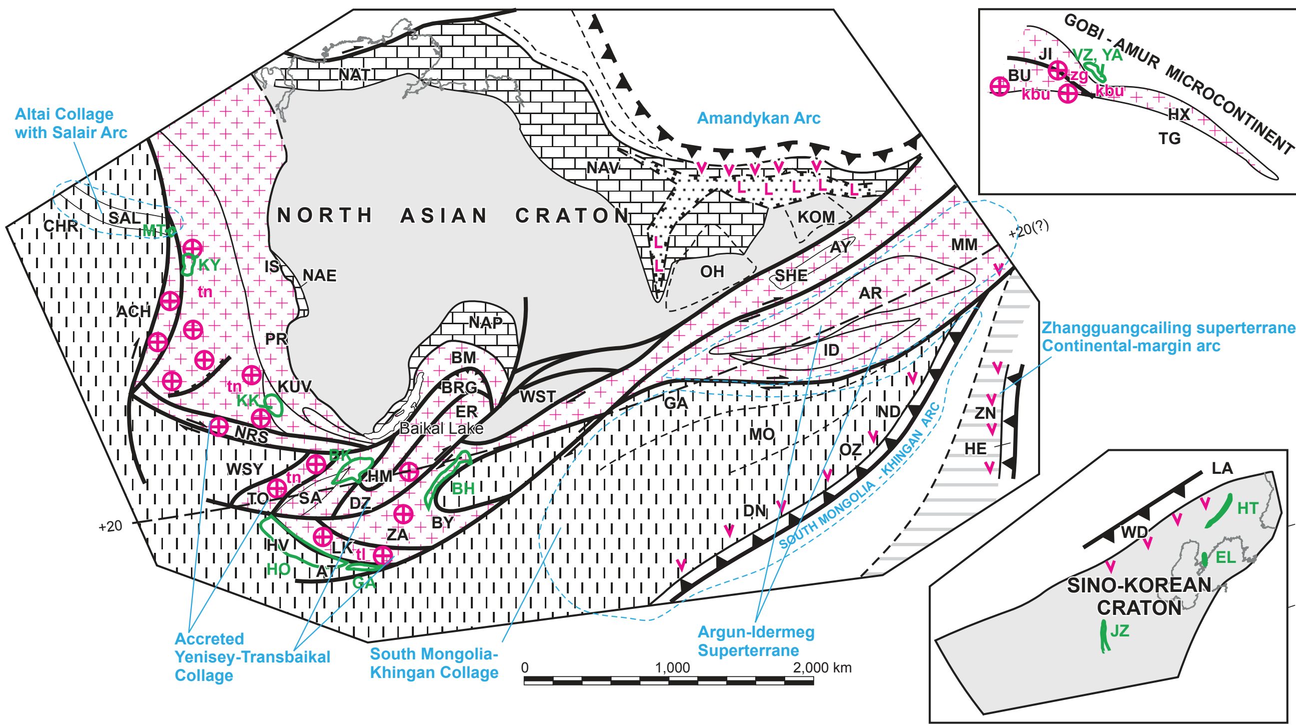
Metallogenesis

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.



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)

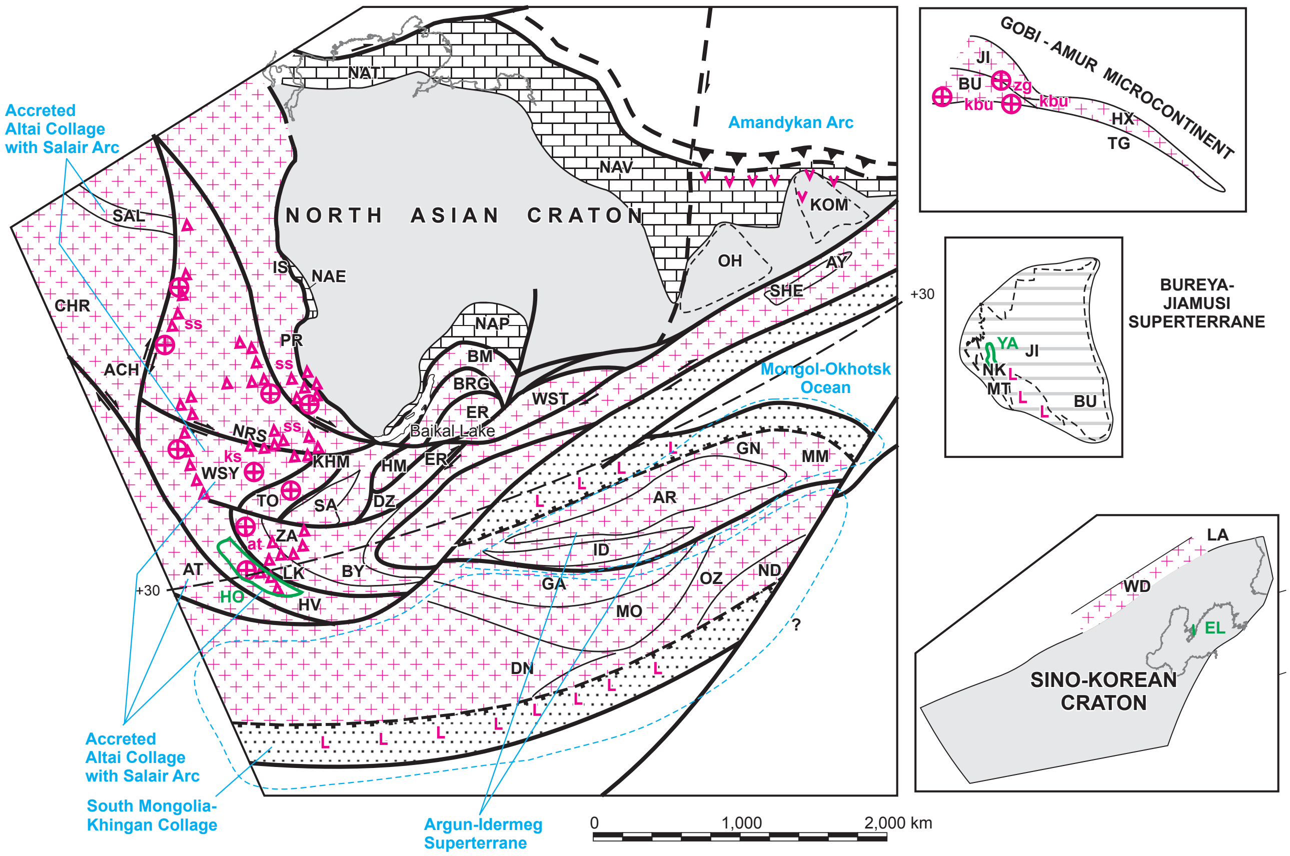
Overlap Continental Margin Arcs and Granite Belts

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 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).



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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
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KHM - Khamsara terrane (Island arc) (Cambrian)
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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)
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OZ - Orogen-Zalantun terrane (Metamorphic) (Proterozoic)
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SHE - Shevli terrane
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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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