Chapter 7

Late Carboniferous through Early Jurassic Metallogenesis and Tectonics of Northeast Asia

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Introduction

This paper presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia for the Late Carboniferous (Pennsylvanian) to Early Jurassic (320 to 175 Ma) and provides a detailed summary of these features for readers who are unfamiliar with Northeast Asia. Several parts of this book on Northeast Asia provide background information. An overview of the regional geology, metallogenesis, and tectonics of the region, and other materials, such an employed geologic time scale and standard geologic definitions, are provided in Chapter 1. The methodology for the metallogenic and tectonic analysis of this region is provided Chapter 2. Descriptions of mineral deposit models are provided in Chapter 3. Additional information on project publications, descriptions of major geologic units, and summaries of metallogenic belts are provided in appendixes A through C.

Compilations Employed for Synthesis, Project Area, and Previous Study

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

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

The Northeast Asia project extends and builds on data and interpretations from a previous project on the *Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera* (below figure) that was conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys,

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and the Geological Survey of Canada. A summary of the major products of this project are available online at: http://pubs.usgs.gov/of/2006/1150/PROJMAT/ and in appendix A.

Major Geologic Units

The major Late Carboniferous (Pennsylvanian) to Early Jurassic geologic and tectonic units of Northeast Asia are cratons, craton-margins, tectonic collages, superterranes (microcontinents) and terranes, and overlap sedimentary basins and intrusive belts, including the Tungus Plateau unit of basalt, sills, dikes, and intrusions (fig. 2, table 1). Short descriptions of map units are given in appendix B. Summary descriptions of the major units are provided in descriptions of metallogenic belts (below), and detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004), and Parfenov and others (2004b).

Major Cratons, Cratonal Margins, and Cratonal-Margin Terranes

The backstop or core units for the region of Northeast Asia are the Archean and Proterozoic North Asian craton and Sino-Korean craton and their cratonal margins (Baikal-Patom, East Angara, South Taimyr, and Verkhoyansk (North Asian).

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

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

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

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

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

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

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

Superterrane

The major Proterozoic through Permian Bureya-Jiamusi supterterrane (BJ) occurs along the margins of the North Asian and Sino-Korean cratons (fig. 2). The superterrane consists of a collage of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin, and island arc terranes. The superterrane is interpreted as a fragment of Gondwana that was accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic during final closure of the Mongol-Okhotsk Ocean.

Tectonic Collages between North Asian and Sino-Korean Cratons

The North Asian and Sino-Korean cratons are a series of accreted Devonian through Early Carboniferous tectonic collages. These tectonic collages were accreted successively from north to south during closures of the Paleo-Asian and Solon Oceans. Most of the tectonic collages contain one or more island arcs and tectonically-linked subduction zones. Because of successive accretions from north to south, the ages of collages are generally young from north to south. However, this pattern is locally interrupted because some collages, or parts of collages, were interspersed because of subsequent strike-slip faulting.

The tectonic collages are described in alphabetical order as follows (fig. 2). More detailed descriptions of terranes in each tectonic collage are provided in appendix B and in Parfenov and others (2003, 2004a,b).

(1) The Atasbogd collage (AB) (Ordovician through Permian age and accreted in Late Carboniferous or Early Permian) consists of: the Ordovician through Permian Waizunger-Baaran terrane, the Devonian through Carboniferous Beitianshan-Atasbogd terrane, and (2) the Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. The collage consists of the Rudny Altay island arc and tectonically-linked subduction zones, including the Zoolen terrane.The collage is interpreted as a northwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and margin and previously accreted terranes. The collage was initially separated from North Asian craton by the large back-arc basin.

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

(3) The South Mongolia-Khingan collage (SM) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the South Mongoia-Khingan arc (now a related series of related Early and Middle Paleozoic arc terranes), subduction-zone terranes, and backarc basins. Tectonically linked to the South Mongolia-Khingan island arc was a subduction zone now preserved in the discontinuous collage of the Kalba-Narim and Zoolen subduction-zone terranes that occur outward (oceanward) of, and parallel to, the South Mongolia-Khingan island arc. Also tectonically linked to the South Mongolia-Khingan island arc was an elongate backarc basin now preserved in a discontinuous and disrupted collage of terranes in Southern Mongolia. These terranes are the Bayanleg (BL) and Mandah (MN) subduction-zone terranes. The South Mongolia-Khingan arc is interpreted as having formed during the Devonian through Early Carboniferous subduction of the Paleoasian ocean basin. The collage formed southwest and west (present-day coordinates) of the North Asian craton and previously accreted terranes.

(4) The Solon collage (SL) (Carboniferous through Permian age and accreted in Late Paleozoic through Early Mesozoic) consists of several subduction-zone terranes (1) Carboniferous and Early Permian North Margin terrane, (2) Late Carboniferous through Permian Solon terrane, (3) Devonian Imjingang terrane, (4) Paleozoic Ogcheon terrane, and (5) Silurian through Permian Sangun-Hidagaien-Kurosegawa terrane. Parts of the collage are interpreted as fragments of the Solon Ocean plate that were subducted to form the South Mongolian, Lugyngol, Gobi-Khankaisk-Daxing'anling, and Jihei continental-margin arcs. Other parts of the collage are interpreted as fragments of the Solon Ocean plate that were subducted to form the North Margin continental-margin arc on the Sino-Korean craton.

(5) The West Siberian collage (WS) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the Late Silurian through Early Carboniferous Rudny Altai island arc, and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane.

The collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage.

Late Carboniferous through Early Jurassic Continental-Margin Arcs Occurring Along Southeastern Margin of the North Asian Craton and Adjacent Accreted Terranes

Three major major continental-margin arcs occur along the southeastern margin of the North Asian craton or on adjacent

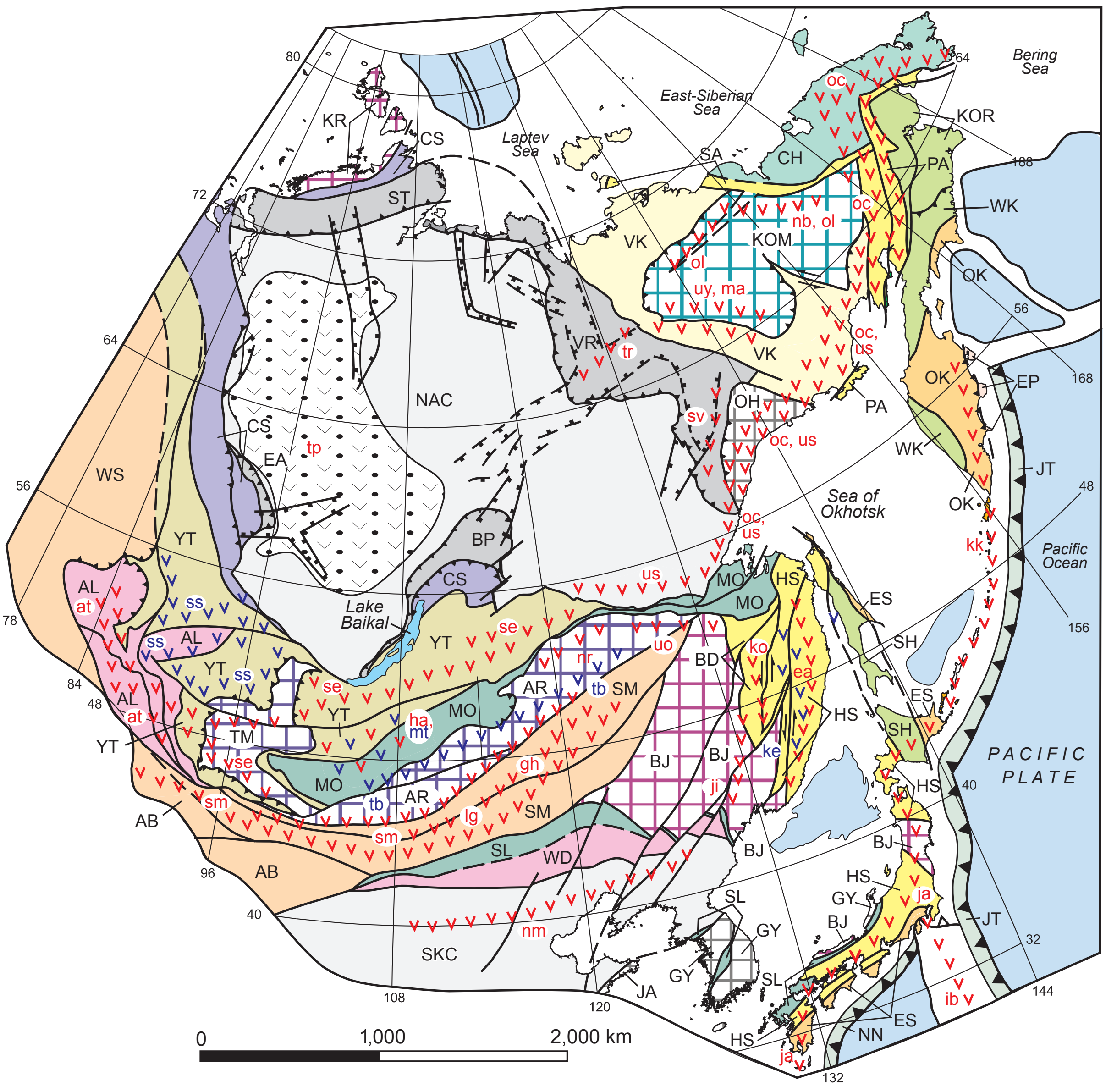


Figure 2. Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004a,b); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North Pacific tectono-stratigraphic terrane map at 10 million scale (Nokleberg and others, 1997). Map shows locations of major geologic and tectonic units including cratons and cratonal margins; cratonal terranes and superterranes; tectonic collages; overlap and transform continental-margin arcs; island arcs, and sea and ocean units. Refer to table 1 and text for unit descriptions.

EXPLANATION

Cratons and Cratonal Margins

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

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

Tectonic Collages Between the North Asian and Sino-Korean Cratons

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

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

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

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

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

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

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

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

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

EP - East Kamchatka Peninsular (Mainly Paleocene)

Active Subduction Zones

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

Cratonal Terranes and Superterranes

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

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

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

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

Pelagic and Oceanic Rocks

Surficial deposits

Oceanic crust

Overlap Continental-Margin Arcs and Igneous Belts

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

Plume-Related Igneous Province

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

Active Arcs

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

Transpressional Arcs

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

Symbols, Faults, and Contacts

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

Figure 2.—Continued

Table 1. Summary of major Late Carboniferous (Pennsylvanian) to Early Jurassic (320 to 175 Ma) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).

[Major units are listed from west to east, progressing from north to south. Units arranged in alphabetical order of map symbol in each major section on figure 2]

Name of unit, map symbol	Type of unit (craton, terrane, overlap assemblage)	Age range	Tectonic environment	Tectonic linkage
		NORTHEAST ASIA CRATONS		
North Asian, NAC Sino Korean, SKC	Craton	Archean through Mesozoic	Cratonal and passive continental margin	Primary units.
		NORTH ASIAN CRATONAL-MARGIN UNITS		
Baikal-Patom, BP East Angara, EA South Taimyr, ST Verkhoyansk, VR	Overlap assemblages	Neoproterozoic through Mesozoic	Passive continental margin	Original overlap assemblages on North Asian craton that were subsequently transformed into fold and thrust belts and terranes.
		SUPERTERRANE		
Bureya-Jiamusi	Superterrane	Proterozoic through Permian	Composite	Consists of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island-arc terranes. Interpreted as a fragment of Gondwana. Accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic.
		TECTONIC COLLAGES		
Atasbogd, AB	Collage	Ordovician through Permian	Composite	Consists of: (1) the Ordovician through Permian Waizunger-Baaran terrane, (2) Devonian through Carboniferous Beitianshan-Atasbogd terrane, and (3) Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. Collage is interpreted as a southwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and margin and previously accreted terrane. Accreted in Late Carboniferous or Early Permian.
Mongol-Okhotsk, MO	Collage	Devonian through Late Jurassic	Composite	Consists mainly of the Permian through Jurassic Selenga, Late Carboniferous and Early Permian Hangay, and Uda-Murgal and Stanovoy continental-margin arcs. Composed of continental-margin igneous overlap assemblages, continental-margin turbidite terranes, and tectonically-linked, outboard subduction-zone terranes. Interpreted as having formed during long-lived closure of the Mongol-Okhotsk Ocean with oblique subduction of terranes beneath of the southern North Asian cratonal margin and previously-accreted terranes.

Table 1. Summary of major Late Carboniferous (Pennsylvanian) to Early Jurassic (320 to 175 Ma) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).—Continued

South Mongolia-Khingan, SM	Collage	Ordovician through Carboniferous	Composite	Consists of the South Mongolia-Khingan arc and tectonically-linked subduction-zone terranes. The collage is interpreted as a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian craton and margin and previously accreted terranes. Collage was separated from the North Asian craton by a large back-arc basin. accreted in Late Carboniferous or Early Permian.
Solon, SL	Collage	Carboniferous through Permian	Composite	Consists of several subduction-zone terranes and terranes derived from the Solon Ocean plate.
West Siberian, WS	Collage	Ordovician through Carboniferous	Composite	Consists of the Late Silurian through Early Carboniferous Rudny Altai island arc, and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. Collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage. Accreted in Late Carboniferous or Early Permian.
CARBONIFEROUS AND PERMIAN ISLAND ISLAND ARCS				
Gobi-Khankaisk-Daxing'anling, gh	Overlap assemblage	Permian	Complex island-arc system	Complex island-arc system formed during subduction of Solon Ocean under Argun-Idermeg superterrane and South Mongolian and Atasbogd collages during final accretion to southern margin of North Asian craton.
Lugyngol. ji	Overlap assemblage	Permian		
South Mongolian, sm	Overlap assemblage	Middle Carboniferous through Late Triassic		
Jihei, ji	Overlap assemblage	Permian	Island arc	Occurs on the the southern margin of the Bureya-Jiamusi supterterrane. Interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin of the superterrane..
North Margin, nm	Overlap assemblage	Late Carboniferous through Permian	Island arc	Occurs on the northeastern margin of the Sino-Korean craton. Interpreted as having formed during subduction of the southern part of Solon Ocean plate under the northeastern margin of Sino-Korean craton.
LATE CARBONIFEROUS THROUGH EARLY JURASSIC CONTINENTAL-MARGIN ARCS				
Hangay, ha	Overlap assemblage	Pennsylvanian through Early Permian	Subduction-related continental-margin arc	Interpreted as having formed along the margin of the North Asian craton as a continental-margin transform system.
Selenga, se	Overlap assemblage	Permian through Jurassic	Transform continental-margin arc	Interpreted as having formed along the margin of the North Asian craton as a continental-margin transform system.
Uda-Murgal, us	Overlap assemblage	Jurassic through Early Cretaceous	Subduction-related continental-margin arc	Interpreted as having formed along the margin of the North Asian craton and cratonal margin during subduction of Ancestral Pacific Ocean.
LATE PERMIAN THROUGH EARLY TRIASSIC TRAP BASALT PROVINCE				
Tungus Plateau Igneous Province -- basalt, sills, dikes, and intrusions	Overlap assamblage	Permian through Triassic boundary (248.31 to 246.92 Ma)	Flood basalts and associated intrusions in an intraplate tectonic setting	Indicator of intraplate plume activity within North Asian Craton.

accreted terranes (fig. 2). The arcs are interpreted as beingrelated to subduction of the late Paleozoic and early Mongol-Okhotsk Ocean plate beneath the North Asian craton and margin. This ocean occurred between the North Asian craton to the north and the Argun-Idermeg superterrane to the south (present-day coordinates).

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

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

(3) The Uda-Murgal arc (us) (Jurassic through Early Cretaceous) occurs on the southern margin of the North Asian craton. The arc is interpreted as having formed during subduction of the Ancestral Pacific Ocean plate beneath the eastern margin of the North Asian craton and cratonal margin.

Carboniferous and Permian Island Arcs Occurring South of North Asian Craton and on Sino-Korean Craton

Several major island arcs occur on migrating superterranes (microcontinents) or cratons. Three arcs are part of an extensive linear array that occurs along the southern (present-day) coordinates of the South Mongolian and Atasbogd collages (Argun-Idermeg superterrane) and Solon collage (fig. 2). This linear array of arcs are interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Argun-Idermeg superterrane. (1) The Gobi-Khankaisk-Daxing'anling arc (gh) (Permian) occurs on the Argun-Idermeg superterrane, South Mongolian collage, and Solon collage. (2) The Lugyngol arc (lg) (Permian) occurs on the South Mongolian and Solon collages. (3) The South Mongolian arc (sm) (Middle Carboniferous through Triassic) overlies and intrudes the South Mongolian and Atasbogd collages.

Two other island arcs were active in the Carboniferous through Permian. (1) The Jihei arc (ji) (Permian) occurs on the the southern margin (present-day coordinates) of the Bureya-Jiamusi supterterrane. The arc is interpreted as having formed during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the superterrane and adjacent units. (2) The North Margin arc (nm) (Late Carboniferous through Permian) occurs on the northeastern margin (present-day coordinates) of the Sino-Korean craton. The arc is interpreted as having formed during subduction of the southern part of Solon Ocean plate under the northeastern margin (present-day coordinates) of Sino-Korean craton.

Tungus Plateau Igneous Province of Basalt, Sills, Dikes, and Intrusions Occurirng in Northern and Central Siberia

The Tungus Plateau igneous province consists mainly of massive basalt flows that formed on the North Asian Craton at the Permian-Triassic boundary. The unit is also named the Siberian trapps and is most widespread in the Tunguska Basin, with a total thickness of the lava sheets and tuff ranging as much as 3,000 m. In the eastern part of the platform are widespread intrusive traps consisting of extensive belts of sills and rare dikes that intruded major fault zones on the eastern margin of the Tunguska Basin and on the southwestern and northeastern slopes of the Anabar shield. Age of trap magmatism is late Permian and early Triassic. Special geochronologic investigation of the Siberian traps involving dating of their zircons and paleomagnetic studies indicate that trap magmatism occurred at the Permian-Triassic time boundary and continued for less than 1 Ma from from 248.31 to 246.92 Ma. This type of magmatism is best interpreted as having formed in a mantle plume originating at the core-mantle boundary with no relation to lithosphere structures. The eruption of the Siberian traps was among the largest surficial volcanic eruptions throughout the Phanerozoic history of the Earth. The total volume of the igneous material is estimated to be 2.106 to 3.106 km^3.

Summary of Late Carboniferous through Early Jurassic (320 to 175 Ma) Metallogenesis

Major Late Carboniferous through Middle Triassic Metallogenic Belts

The major Late Carboniferous through Middle Triassic metallogenic belts are the Angara-Ilim, Altay, Barlaksk, Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia, Duobaoshan, Harmagtai-Hongoot-Oyut, Hitachi, Kalatongke, Kolyvansk, Kureisko-Tungsk, Maimecha-Kotuisk, Mino-Tamba-Chugoku, Norilsk, Orhon-Selenge, and Shanxi belts (fig. 3, appendix C).

Metallogenic Belts Related to Superplume

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

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

Four metallogenic belts possess geologic units favorable for a wide variety of granitic magmatism-related

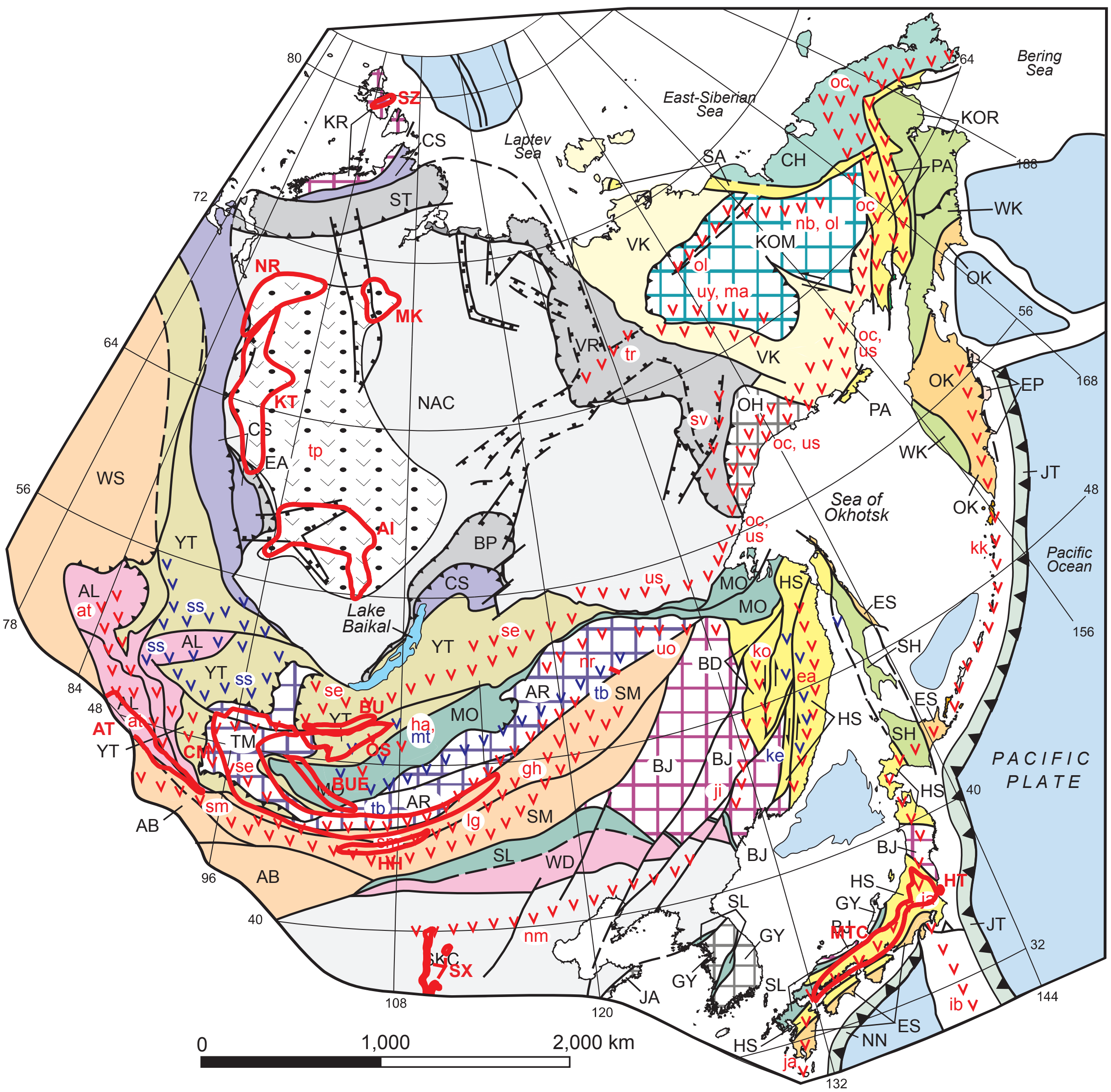


Figure 3. Generalized map of major Late Carboniferous through Middle Triassic metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outline adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004a,b). Metallogenic belts for areas to the east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

deposits, including the Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia and Orhon-Selenge belts [with Fe-Zn skarn, Sn-skarn, Zn-Pb skarn, W-skarn, Cu-skarn, porphyry Cu-Mo, porphyry Mo, Au-skarn; granitoid-related Au vein, W-Mo-Be greisen, stockwork, and quartz vein, peralkaline granitoid-related, REE-Li pegmatitem and basaltic native Cu (Lake Superior type) deposits]. The belts are hosted in granitoids in the Selenga sedimentary-volcanic plutonic belt that constitutes the Selenga continental-margin arc that formed on the Yenisey-Transbaikal and Tuva-Mongolia collages. The isotopic ages of the deposits or hosting units range from 240 to 285 Ma. The belts are interpreted as having formed during transform-faulting and oblique subduction of oceanic crust of the Mongol-Okhotsk Ocean plate under the southern margin of the North Asian craton and cratonal margin and previously-accreted terranes.

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

Metallogenic Belts Related to Island Arcs

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

Metallogenic Belt Related to Collision of Cratons

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

Metallogenic Belt Related to Weathering

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

Metallogenic Belt Related to Oceanic Crust

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

Major Late Triassic through Early Jurassic Metallogenic Belts

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

Metallogenic Belts Related to Transpressional Arc and Faults Caused by Closure of Mongol-Okhotsk Ocean

Collision caused by closure of Mongol-Okhotsk Ocean resulted in the formation of the Late Triassic through Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt along with formation of numerous intraplate strike-slip fault zones and related transpression and tranextension zones and related metallogenic belts.

In this area, (figs. 4), five metallogenic belts possess geologic units favorable for a wide variety of granite-related deposits, including the Central Henti, Delgerhaan, Govi-Ugtaal-Baruun-Urt, Harmorit-Hanbogd-Lugiingol, and North Hentii belts (with porphyry Cu; granitoid-related Au; Au in shear zone and quartz vein; Fe-Zn skarn; Cu-skarn, Zn-Pb-skarn; Sn-skarn; Sn-W greisen, stockwork, and quartz vein, W-skarn; Ta-Nb-REE akaline metasomatite; REE carbonatite; peralkaline granitoid-related Nb-Zr-REE; and REE-Li pegmatite deposits). The isotopic ages of the igneous rocks that host the deposits range from 242 to 199 Ma. The belts are hosted in the Late Triassic through Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt that constitutes a major part of the Mongol-Transbaikal transpressional arc that is interpreted as having formed during strike-slip faulting and rifting along the

Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.

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

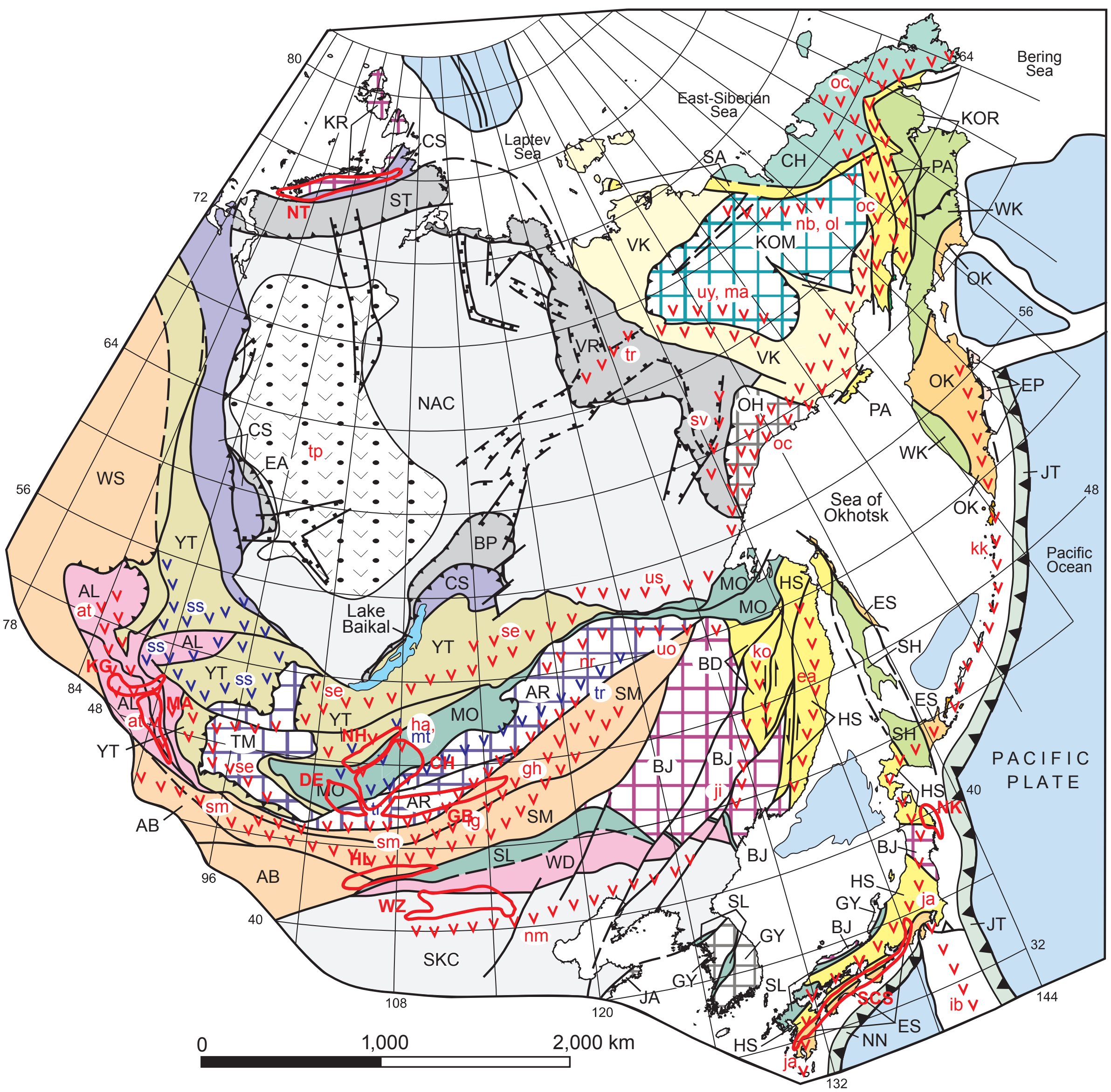


Figure 4. Generalized map of major Late Triassic through Early Jurassic metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004a,b). Metallogenic belts for areas to the east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

Metallogenic Belt Related to Superterrane Accretion

The North Taimyr metallogenic belt possesses geologic units favorable for granite-related deposits (W-Mo-Be greisen, stockwork, and quartz vein, W-skarn, and porphyry Cu-Mo). The isotopic ages of the host granitoids range from 233 to 223 Ma (Vernikovsky, 1996). The belt is interpreted as having formed during generation of granitoids during and after accretion of the Kara superterrane with the North Asian craton.

Metallogenic Belts Related to Oceanic Crust

The Sambagawa-Chichibu metallogenic belt possesses geologic units favorable for stratiform sediment-hosted deposits (Besshi Cu-Zn-Ag massive sulfide, volcanogenic-sedimentary Mn, Cyprus Cu-Zn massive sulfide) that are now preserved in younger subduction-zone terranes. These terranes are the Shimanto subduction-zone terrane (part of the Sakhalin-Hokkaido collage), Mino Tamba Chichibu subduction-zone terrane (part of Honshu-Sikhote-Alin collage), and Sambagawa metamorphic terrane (part of the Honshu-Sikhote-Alin collage. The age of the host rocks for the deposits is interpreted as Early Jurassic and younger. The Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor, and the Besshi (fig. 5) and Cyprus deposits are interpreted as having formed during submarine volcanism related to an ocean-spreading ridge.

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

Major Late Carboniferous (Mississippian) to Early Jurassic (320 to 175 Ma) Metallogenic Belts and Host Units

Angara-Ilim Metallogenic Belt of Trap-Related Fes-Skarn (Angara-Ilim type), REE (±Ta, Nb, Fe) Carbonatite, and Weathering Crust Carbonatite REE-Zr-Nb-Li Deposits (Belt AI) (Southwestern North Asian Craton, Russia)

This Late Permian through Early Triassic(?) metallogenic belt is related to replacements associated with the Tungus plateau basalt, sills, dikes, and intrusions that overlie and intrude the southern part of the North Asian craton. The belt forms a wide and elongated band about 40,000 km^2 at the southern closure of the Tungussk syncline. Fe-skarn deposits are associated with with Triassic explosive, intrusive basalt trapp complexes in central type diatremes (Fon-der-Flaas, 1981). The deposits occur mainly along exocontacts of subalkalic diabase intrusions and rarely in adjacent Early Cambrian through Early Triassic wall rock. Lithological factors control deposit distribution and include favorable composition of host clastic, carbonate (dolomite), and evaporite rock, and the screening effect of mafic trapp rock. REE (±Ta, Nb, Fe) carbonatite deposits are related to central-type alkalic ultramafic intrusions that are exposed on the slopes of the uplifted basement as at the Chadobetsk uplift (Lapin, 1992; Lapin and Tolstov, 1993).

The main references on the geology and metallogenesis of the belt are Fon-der-Flaas (1981), Seminsky (1985), Lapin (1992), Lapin and Tolstov (1993), and Dobretsov (1997).

Korshunovskoye Trap-Related Fe-Skarn (Angara-Ilim type) Deposit

The deposit (Antipov and others, 1960; Vakhrushen and Vorontsov, 1976; Momdzhi, 1976; Strakhov, 1978; Fon-der-Flaas, 1981; Seminsky and others, 1994) occurs in southwestern North Asian craton in the southern closure of the Tungussk syncline. The deposit consists of a stockwork (with plan dimensions of 2,400 by 700 m) composed of four partly merged layers that contain variable amount of hematite and martite in upper layers, calcite and magnetite in middle layers, and halite and magnetite in lower layers. In the first type of deposit, the major minerals are magnetite, pyroxene, chlorite, and minor epidote. Lesser minerals are amphibole, serpentine, calcite, and garnet, and rare quartz, apatite, and sphene. Ore minerals occur in oolites, druses, masses, and disseminations. In the second type of deposit, the calcite increases to 20 to 30 percent, and ore minerals occur in nets, streaks, disseminations, and layers. In the third type of deposit, halite, amphibole, Mn magnetite are more abundant and the ore minerals occur in incrustates and streaks. All deposits contain pyrite, chalcopyrite, and pyrrhotite. Magnetitite-rich deposits are polygenic-hydrothermal-metasomatic deposits and are associated with magmatic intrusion, and rare metamatite-martite deposits are hypergenic. Host rocks are Early Carboniferous limestone, Ordovician salt-bearing rock, and Permian through Triassic tuffaceous sandstone. The deposit is large, with resources of 637 million tonnes ore grading 26 percent Fe to a depth of 1,200 m.

Chuktukonskoye REE (±Ta, Nb, Fe) Carbonatite and Weathering Crust Carbonatite REE-Zr-Nb-Li Deposit

This deposit (Lapin, 1992, 1996; Lapin and Tolstov, 1993) consists of Nb-REE minerals and phosphate minerals that occur in weathered carbonatite that is part of the

Chadobetsk alkalic ultramafic complex. The carbonatite contains mainly calcite and dolomite and has an isotopic age of 260 to 200 Ma. The weathered crust varies from 70 to 100 to 350 m and more thick. Minerals in the crust are of goethite, hematite, psilomelane, pyrolusite, barite, monacite, florensite, gorceixite, cerianite, and pyrochlore. At the bottom of the crust is francolite, quartz, and hydromica. Nb-REE minerals occur in residual lateritic ochre that formed in a leach zone and contains from 1 to 1.5 percent Nb_2O_5, 3 to 6 percent TR_2O_3 (0.1 to 0.3 percent Y_2O_3). Phosphatic and Nb-phosphate minerals occur in francolite rocks in a cemented zone and contain from 10 to 30 percent P_2O_5 (average of 17 to 20 percent). Ore minerals formed in an epigenetic-altered weathered crust at the top of the deposit in a bleached horizon that is depleted in Fe and Mn and rich in Nb (as much as 3 to 5 percent Nb_2O_5) and REE (as much as 15 to 20 percent TR_2O_3). Thickness of this horizon ranges from 3 to 12 m. Ore minerals are monazite, florensite, crandallite, pyrochlore, anatase, pyrite, and goethite. The deposit is medium size.

Origin and Tectonic Controls for Angara-Ilim Metallogenic Belt

The belt is interpreted as being related to widespread development of trapp magmatism on the North Asian craton. Fe-skarn deposits associated with Triassic explosive and intrusive basaltic trapp complexes in diatremes. REE-Ta-Nb carbonatite deposits are associated with alkalic ultramafic intrusions. The deposits are interpreted as having formed during intrusion of mantle-derived mafic magma and are mainly controlled by the major sublongitudinal and sublatitudinal

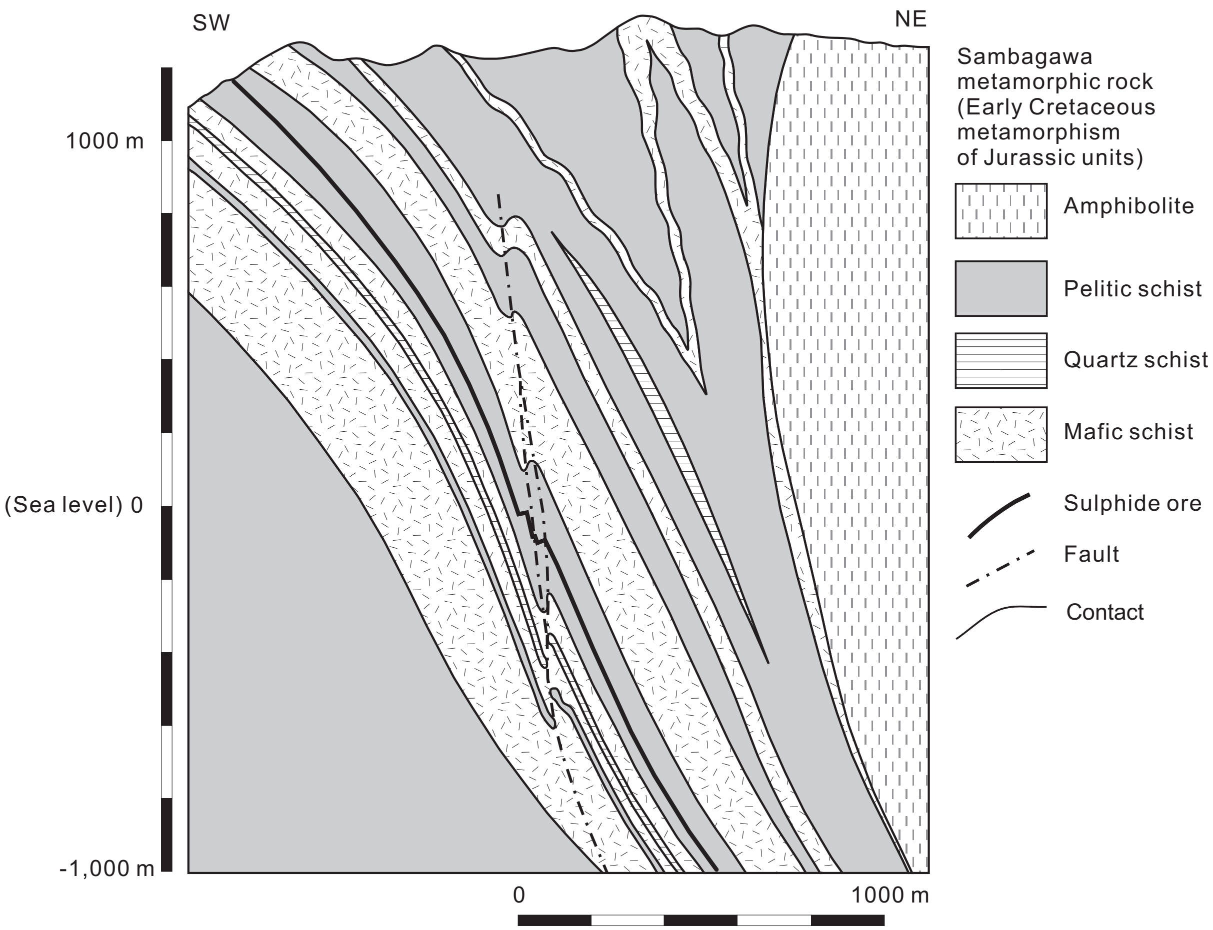


Figure 5. Schematic geologic cross section of Besshi Cu-Zn-Ag massive sulfide deposit, Sambagawa-Chichibu-Shimanto metallogenic belt. Adapted from Sumitomo Metal Mining Company (written commun., 1981).

regional faults. The belt occurs in two bow-shaped bands along the northern and southern boundaries of the Priangara syncline (Seminsky, 1985). The origin of the metallogenic belt is related to development of Permian and Triassic trapp magmatism in the Tungussk. Ancient, long-lived interblock basement fault zones were magmatic channels. Various districts occur in melanocratic and mesocratic igneous blocks in Platform basement rocks along local uplifted blocks. The widespread Permian and Triassic trapp magmatism is interpreted as being related to a mantle superplume (Dobretsov, 1997). The K-Ar isotopic age of alkalic ultramafic rock of the Chadobetsk Uplift ranges from 263 to 229 Ma.

Altay Metallogenic Belt of REE-Li Pegmatite, Muscovite Pegmatite, and Sn-W Greisen, Stockwork, and Quartz Vein Deposits (Belt AT) (Southwestern Mongolia)

This Late Carboniferrous metallogenic belt is related to veins, dikes, and replacements related to granitoids in the Pennsylvanian Altai volcanic-plutonic belt that intrudes the Paleoproterozoic Altai passive continental margin turbidite terrane in the Altay Mountain Range. More than 10,000 pegmatite veins occur in the metallogenic belt, and the belt contains numerous large and superlarge Li-, Be-, Nb-, Ta-pegmatite deposits and several tens of moderate to large muscovite pegmatite deposits. Muscovite reserves comprise more than 60 percent of the reserves for Mongolia. The belt trends northwest and is more than 450 km long and 70 to 80 km wide. The significant deposits are at Keketuohai and Ayoubulake.

The main references on the geology and metallogenesis of the belt are Rui and others (1993) and Tao and others (1994).

Keketuohai Li-REE Pegmatite Deposit

This deposit (fig. 6) (Lin and others, 1994; Editorial Committee of the Discovery History of Mineral Deposits, 1996) consists of (1) mitriform-pegmatite bodies that extend for 250 m, 250 m deep, and 150 m wide; and (2) gently dipping pegmatite veins that 2,000 m long, 1,500 m deep, and 40 m wide. The zoning of the mitriform pegmatite bodies from the margin to the center is: (1) graphic and graphic-like pegmatite; (2) sucrosic albite; (3) massive microcline; (4) muscovite-quartz; (5) cleavelandite-spodumene; (6) quartz-spodumene; (7) muscovite-lamella albite; (8) lamella albite-lepidolite; (9) central massive microcline and quartz zone. The pegmatite veins are divided into seven zones. The main alterations are biotite, Li-muscovite, Cs-biotite, Li-glaucophane, and fluorite alterations. The average grade in pegmatite is 6.5 percent muscovite, 0.05 percent lepidolite, 4.15 percent spodumene, 0.49 percent beryl, 0.05 percent pollucite. The mitriform pegmatite contains an average of 3,650 ppm LiO_2, 1,080 ppm Rb_2O, 190 ppm Cs_2O, 630 ppm BeO, 78 ppm Nb_2O_5, and 91 ppm Ta_2O_5. REE content is variable. The pegmatite bodies are related to Hercynian biotite microcline granite that is widespread and Ordovician biotite schist, staurolite schist, glaucophane schist that occur as relics in the granite intrusion. The granite also intrudes Paleozoic gabbro with an isotopic age of 330 Ma. The Keketuahai pegmatite no. 3 is a world class Be-Ta-Li pegmatite deposit. The deposit is large and has reserves of 244 tonnes Ta_2O_5. The average grade is 0.024 percent Ta_2O_5, 0.051 percent BeO, and 0.982 percent Li_2O.

Ayoubulake Muscovite Pegmatite Deposit

This deposit (Nie and others 1989; Ge and others, 1994) consists of 34 muscovite-pegmatite veins that range from 15 to 490 m long, extend several tens of meters downdip, and range from 0.5 to 15 m thick. Muscovite and quartz occurs in masses mainly in intermediate coarse-grained pegmatite. The host rocks are Ordovician staurolite schist, sillimanite schist, gneiss, and Hercynian biotite granite. An associated alteration zone is about 1 m wide and consists of muscovite, biotite, and toumaline. The deposit is large.

Origin and Tectonic Controls for Altay Metallogenic Belt

This belt is interpreted as having formed in during intrusion of anatectic granite that formed during collision of the Kazakhstan and North Asian cratons and resultant occurrence of high-grade metamorphism with crustal melting and generation of granite. The belt is hosted in postaccretionary mafic and ultramafic plutons that intrude along major east-west-trending faults. The host granite is mainly calc-alkaline and has a K-Ar isotopic age of 219 Ma. The granite intrudes both early Paleozoic metamorphic rock and Devonian through Early Carboniferous volcanic rock and turbidite that are regionally metamorphosed at moderate to low pressure and high temperature (Rui and others, 1993, Tao and others, 1994).

Battsengel-Uyanga-Erdenedalai Metallogenic Belt of Granitoid-Related Au Vein Deposits (Belt BUE) (Central Mongolia)

This Late Carboniferous through Permian metallogenic belt is related to small stitching plutons in the early stage of intrusion of the Hangay plutonic belt that intrudes Hangay-Dauria and Onon subduction-zone terranes. The metallogenic belt strikes northwest and is related Permian(?) granitoids, that from northwest to southeast intrude (1) the Hangay Dauria accretionary-wedge terrane, (2) the Onon accretionary-wedge terrane, and (3) the Permian Predhentey continental basin (part of Late Permian North Gobi overlapping assemblage) (Tomurtogoo and others, 1999) into which small Late Permian stocks and dikes of gabbro, diorite, granodiorite, and granite intrude coarse-grained sedimentary rock. Dejidmaa and others (1993) and Dejidmaa (1996) first studied and named this Au metallogenic belt as the Eastern Hangay belt that surrounds the Hangay Mountain Range to the northeast. The belt contains the Battsengel, Uyanga-Taragt, and Erdenedalai Au-bearing districts.The major deposits are at Mongot, Battsengel, Uyanga, Sharga Ovoo, and Tsagaan Ovoo.

The granitoid-related Au-vein occurrences consist of simple quartz veins and complicate metasomatitic zones with quartz veins and extend northwest. The occurrences are closely related to late Paleozoic diorite and granodiorite dikes and stocks. The occurrences are the sources for associated placer Au deposits The belt is bounded by the Orhon regional fault to northeast. The granitoid-related Au deposits are similar to those of the Ordovician Bayanhongor metallogenic belt described above. However, the age of granitoids hosting Au deposits in the Battsengel-Uyanga-Erdenedalai belt is not

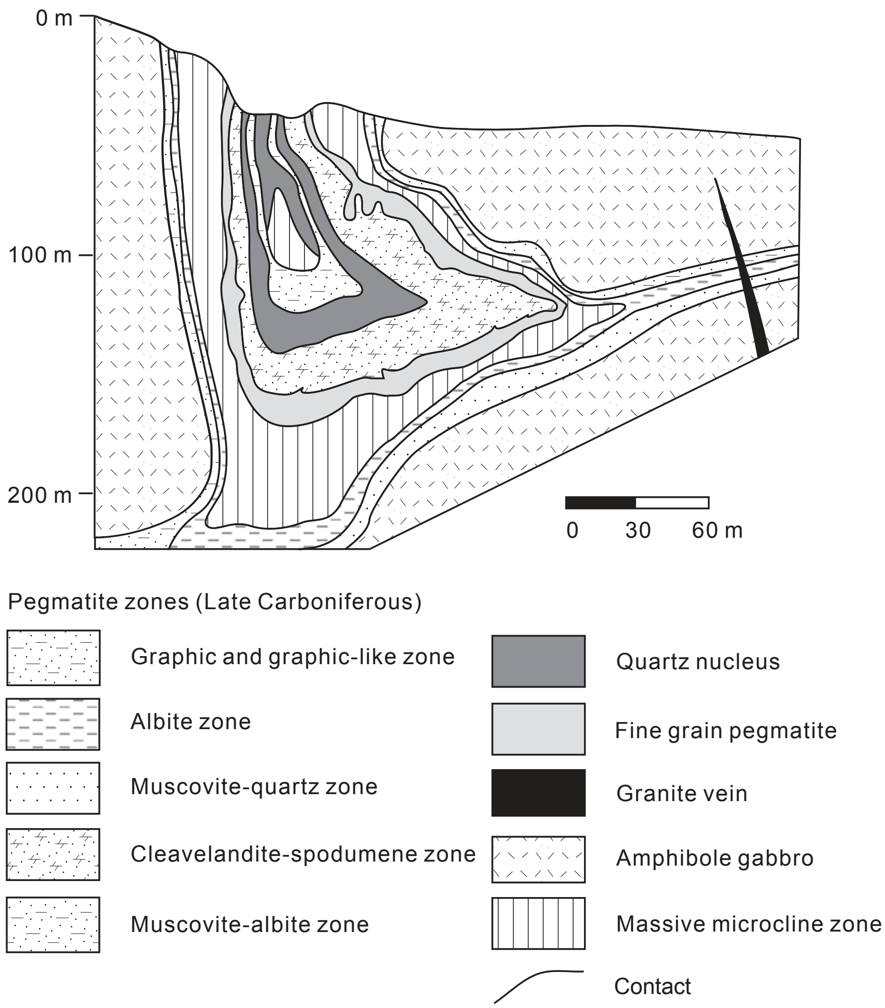


Figure 6. Geologic sketch map and cross section of Late Carboniferrous Keketuohai REE-Li pegmatite deposit, Altay metallogenic belt. Adapted from Lin and others (1994).

older than Late Permian as determined for the Sharga Ovoo and Tsagaan Ovoo Au occurrences in the southeastern part of the metallogenic belt. The Tsagaan Ovoo quartz-vein occurrence is in Permian sedimentary rock and is closely associated with an intruding diorite and granodiorite stock and dikes. Placer Au occurrences mined in ancient, small open pits are long known (Blagonravov and Shabalovskii, 1977).

The main references on the geology and metallogenesis of the belt are Blagonravov and Shabalovskii (1977), Dejidmaa and others (1993), Dejidmaa (1996), and Tomurtogoo and others (1999).

Sharga Ovoo Granitoid-Related Au-Vein Deposit

The deposit (O. Jamyandorj and others, written commun., 1972) is hosted in early Paleozoic gneissic granite and granodiorite that are intruded by granodiorite porphyry and diorite porphyry dikes and quartz veins. The quartz veins dip steeply, form a stockwork, occur along a northwest-trending weak shear zone, and form an en-echelon pattern. The stockwork consists of eight quartz veins, quartz veinlets, and local breccia, and varies from 40 to 300 m wide and 0.5 to 4.0 m thick. The host granite is silicified and cut by quartz stringers. The width of altered host rock varies from 1.0 to 20 m. Veins are white-grey, and contain coarse-grained quartz with pyrite, limonite, and rare gold. Gold is as much as 2 mm and is mostly fine-grained. Local visible gold occurs along selvages, especially in lower selvages. Channel samples contain from 0.1 g/t to 5.6 g/t Au, and rock-chip samples contain as much as 14.0 to 56.0 g/t Au.

Origin and Tectonic Controls for Battsengel-Uyanga-Erdenedalai Metallogenic Belt

The belt is interpreted as having formed along the Selenga transform continental-margin arc along the margin of the Mongol-Okhotsk Ocean with intrusion of subduction-related gabbro, diorite, and granodiorite stocks and dikes along the North Govi active continental-margin arc.

Buteeliin Nuruu Metallogenic Belt of Peralkaline Granitoid-related Nb-Zr-REE, REE-Li Pegmatite, W-Mo-Be Greisen, Stockwork, and Quartz-Vein Deposits (Belt BU) (North Mongolia)

This Early Permian metallogenic belt is related to high-alkaline granitic rock of the Selenga sedimentary-volcanic plutonic belt that intrudes the West Stanovoy terrane and to associated regional metamorphism. The belt extends 200 km and is about 30 km wide. The belt includes various deposits related to highly alkaline early Mesozoic granite stocks and associated rocks including U-Zr-REE, Ta-Nb-REE metasomatite, granitoid-related vein Bi, granitoid-related vein and stockwork U-Mo, Nb-Zr-REE peralkaline granite-hosted, Sn-W greisen, stockwork, and quartz-vein deposits. Many of these deposits occur in the northeastern late Paleozoic North Hangai REE metallogenic belt (Kovalenko and others, 1988, 1990; Kovalenko and Yarmolyuk, 1990) along the east-west trending Hangai regional fault. The early Permian age for the host granitic rocks is based on a U-Pb zircon isotopic age of 275 Ma for strongly foliated to mylonitized granite-gneiss. Contrasting K-Ar isotopic ages of 129 to 89 Ma exist for migmatite, gneissic granite, leucogranite, aplite, and pegmatite. The younger ages are herein interpreted as having formed during Late Mesozoic uplift and granitization. The major deposits are at the Bayangol district, Zelter Bi occurrences, and Arshivert occurrence.

The main references on the geology and metallogenesis of the belt are Luchitsky (1983), Kovalenko and others (1988), Kovalenko and Yarmolyuk (1990), Tsyba (1990), Kovalenko and others (1990), and Tomurtogoo and others (1999).

Bayangol District of Peralkaline Granitoid-related Nb-Zr-REE and REE-Li Pegmatite Occurrences

This district (Tsyba, 1990) occurs in the southwestern margin of the Buteeliinnuruu belt and is hosted in a granite-gneiss cupola with diameter of 12 km. The occurrence consists of quartz-K-feldspar-albite and albite metasomatite with high U, Th, REE, Zr, Ta, and Nb. The metasomatite occurs in weak fracture zones. The Gunondoriin Tsohio district is similar to the Bayangol deposit, occurs in the middle part of the belt, and consists of quartz-K-feldspar-albite metasomatite veins with high content of U, Th, Y, Yb, Nb, Ta, Zr, Ce, La, Hf, and Gd. This district forms an east-west-trending zone with surface dimensions of 3 by 13 km.

Bayangol 1 REE-Li Pegmatite Deposit

This deposit (Kudrin and Kudrina, 1959) consists of two spodumene pegmatite veins that are 100 to 200 m long and 10 to 20 m thick that cut Mesoproterozoic marble. The veins are composed of quartz, albite, spodumene, apatite, muscovite, beryl, columbite, pyrite, fergusonite, cassiterite, zircon, and lepidolite. Spodumene pegmatite occurs for 400 m along strike. The deposit is small.

Origin and Tectonic Controls for Buteeliinnuruu Metallogenic Belt

The belt is interpreted as having formed along the Selenga transform continental-margin arc along the margin of the Mongol-Okhotsk Ocean. The belt is hosted in an Early

Permian core complex containing granitoids of the Selenga sedimentary-volcanic plutonic belt that intrude granite-gneiss and mylonite in the West Stanovoy terrane. Alternatively, the belt may be related collisional granitoids generated during late Mesozoic closure of Mongol-Okhotsk Ocean.

Central Mongolia Metallogenic Belt of Fe-Zn Skarn, Sn-Skarn, Zn-Pb (±Ag, Cu) Skarn, W±Mo±Be Skarn, Cu (±Fe, Au, Ag, Mo) Skarn, Porphyry Cu-Mo (±Au, Ag); Porphyry Mo (±W, Bi), Granitoid-Related Au Vein, Cu-Ag Vein, W-Mo Greisen, Stockwork and Quartz Veins, and Basaltic Native Cu Deposits (Belt CM) (Central Mongolia)

This Early to Late Permian metallogenic belt is related to replacements and granitoids in the Selenga sedimentary-volcanic plutonic belt, occurs around the Hangay Mountain Range, and forms a large sickle shape in central Mongolia. The Selenga assemblage overlaps parts of the Late Archean and Paleoproterozoic Baydrag cratonal, Vendian through Middle and Late Cambrian Lake island arc, and Neoproterozoic through early Cambrian Idermeg passive marginal terranes (Tomurtogoo and others, 1999). The Central Mongolian metallogenic belt is dominated by skarn and porphyry deposits (Dejidmaa and others, 1996).

The major deposits are Menget and Sharain hudeg Fe-Zn skarn occurrences; Buyant group Fe-Sn skarn occurrences; Uzuur tolgoi, Berh Zn-Pb (±Ag, Cu) skarn occurrences; Chandmani Uul group and Buutsagaan Fe (Cu, Au) skarn occurrences; Buyant group W-skarn, Khohbulgiin hondii and Buutsagaan Au-Cu skarn occurrences; Saran uul porphyry Cu (±Au)-Au deposit, Tsahir hudag and Beger porphyry Cu (±Au) (Au, Ag) occurrences; Arynnuur porphyry Cu deposit, Naranbulag and Zost Uul porphyry Mo (±W, Bi) occurrences; Tsahir hudag and Chandmani uul group of granitoid-related vein and stockwork Cu occurrences; Oortsog, Olziit and Delgereh group of granitoid-related-vein and stockwork Au occurrences; Hatanbulag and Baga Bogd vein and stockwork Mo occurrences; and Buutsagaan group Cu basalt occurrences.

The skarn deposits are related to highly alkaline granitoids. Vein and stockwork Mo occurrences, as at Baga Bogd and Hatanbulag, occur in the central part of the belt in the Ih Bogd and Baga Bogd areas and are interpreted as having formed during intrusion of Permian subalkaline leucogranite stocks. Various porphyry Mo deposits and occurrences are related to granite porphyry stocks that are concentrated in the central part of the belt and are related to Late Carboniferous or Permian granodiorite and monzonite porphyry stocks. Granitoid-related vein and stockwork Cu occurrences are more extensive in the northern and central parts of the belt. Various basalt native-Cu occurrences in the Buutsagaan area are closely related to Permian basalt in the Hureemaral Formation.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Luchitsky (1983), Podlessky and others (1984), Sotnikov and others (1984, 1985), Dejidmaa and others (1996), and Tomurtogoo and others (1999).

Buutsagaan Au-Skarn Deposit

This deposit (Filippova and Vydrin, 1977; Podlessky and others, written commun., 1988; A.A. Rauzer and others, written commun., 1987) consists of magnesium skarn formed along the contact of Proterozoic schist and carbonate with a Permian granite massif. The deposit contains magnetite lenses and veins in an area of 0.25 by 0.75 km. The lenses and veins range from 6 m to 300 m long and 0.3 m to 4.5 m thick. Tourmaline, plagioclase, and quartz stringers also occur. Magnesium skarn is zoned intrusive to host metamorphic rocks with the following zones: granite replaced by pyroxene-plagioclase skarn; pyroxene-spinel skarn; pyroxene-spinel-forsterite skarn; forsterite-calcic skarn; and dolomite marble. Most magnetite is deposited in magnesium skarn. During calcic- skarn formation spinel-pyroxene skarn overprinted magnesium skarn and grossular-vesuvianite-salite-sulfide skarn along the endocontact of the granite massif. In Cu-sulfide skarn, the grade ranges as much as 150.0 g/t Au. Grab samples is as much as 2.0 percent Cu, 30.0 g/t Cd, 1.0 to 1.5 percent Zn, and 50.0 g/t Ag.

Zos Uul Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Bayandorj and others, written commun., 1980; Sotnikov and others, 1981, 1985a,b) consists of Late Permian and Early Triassic granitoids that intrude Paleoproterozoic metamorphic rock Early Proterozoic granite;, Cambrian gabbro; granodiorite; and granite; ; Early Devonian volcanic rocks; and Permian granosyenite and granite. The Late Permian and Early Triassic granitoids consist of a granodiorite and granite massif and porphyry in stocks and dikes. The porphyry stock and dikes and host rocks are intensively altered to silica, sericite, and pyrite. Quartz-sulfide vein and stockwork occur in altered rocks. The size of the stockwork is 2.0 by 2.2 km. Quartz-sulfide vein and veinlets are extensive in the western, eastern, and southern margins of the granite porphyry stock. The quartz-sulfide vein and stockwork contain rare molybdenite, quartz-molybdenite, and quartz-pyrite-chalcopyrite-molybdenite stringers and disseminations. Extensive hydrothermal alteration with quartz-sericite and quartz replacements in bodies ranging as much as 20.0 by 40.0 m also occur. Relicts of early-stage potassium feldspar alteration that is intensively developed in a granite-porphyry stock also occur. Also occurring are rare quartz-potassium feldspar veinlets with pyrite, garnet-epidote skarn that is overprinted by pyrite-chalcopyrite stringers. The deposit developed in the following stages: K feldspar-quartz, quartz-magnetite, quartz-sericite-chalcopyrite-molybdenite, quartz-polymetallic (sphalerite and galena), and post-ore chlorite-epidote-carbonate. Ore minerals are more abundant in quartz-sericite replacement. The deposit is small amd has a resource of 100,000 tonnes of Mo and average grades of 0.2 percent Cu and 0.01 percent Mo.

Erdenekhairkhan Cu (±Fe, Au, Ag, Mo) Skarn Deposit

This deposit (A. Enkhbayar and others, written commun., 1982; B.A. Samozvantsev and others, written commun., 1982) is hosted in Vendian and early Paleozoic carbonate rocks of the Tsagaanolom Formation that is intruded by a Permian syenite stock. According to a magnetic anomaly, the skarn is 600 m long and 300 to 400 m wide. The skarn is cut by two northeast-trending, steeply dipping faults that define three blocks. The central block is uplifted and more eroded; the northern and the southern blocks are downdropped. Three small openpits of size with surface dimensions of 2 by 70-80 m to 4 by 200 m occur in the central block. The deposit consists of disseminations and stringers of chalcopyrite and bornite. Host carbonate rock is locally altered to serpentinitie and recrystallized. Ore minerals are magnetite-hematite (5 to 70 percent), Fe oxides (as much as 7 percent), and minor chalcopyrite, bornite, chalcocite, malachite, native copper, covellite, native silver(?) and pyrrotite. Channel samples contain 0.89 to 2.34 percent Cu, and core-samples contain 0.2-1.0 percent Cu, as much as 1.8 g/t Au, and 0.4 g/t Ag . Grab samples grade from 0.1 to 1.0 percent to 7.88 percent Cu, 10.0 to 50.0-100.0 g/t Ag. Extensive northeast-trending quartz-carbonate veins occur in the eastern and south-eastern parts of the deposit and range from 0.2-0.5 m thick, and 20.0-100.0 m long. A Au soil anomaly occurs in an area 300 by 350 m, close to skarn. The average grades of the deposit are 1.3 to 1.4 g/t Au, 0.2 to 1.0 percent Cu, and 10.0 to 50.0 g/t Ag.

Origin and Tectonic Controls for Central Mongolia Metallogenic Belt

The belt is interpreted interpreted as having formed along the Selenga transform continental margin arc along the northern margin of the Mongol-Okhotsk Ocean. However, Tomurtogoo and others (1999) interpret the host Selenge assemblage as an intercontinental volcanic belt. Herein, the assemblage is herein interpreted as an overlapping Late Carboniferous through Late Permian continental margin arc that was tectonically linked to a subduction zone on the margin of Mongol-Ohotsk Ocean. Remnants of the ocean occur in a narrow band that extends for 3,000 km from central Mongolia to the Ohotsk Sea (Obolenskiy and others, 1999).

Duobaoshan Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag) Deposits (Belt DB) (Northeastern China)

This Pennsylvanian metallogenic belt is related to granitoids in the Nora-Sukhotin-Duobaoshan island-arc terrane, part of the South-Mongolia collage in the western Heilongjiang Province. The belt trends northeast and is about 130 km long and 30 km wide. The Nora-Sukhotin-Duobaoshan terrane is composed of (1) Cambrian metasandstone, and phyllite with the intercalation of the lenticulars of limestone; (2) Ordovician and Silurian metabasalt, metaandesite, metadacite and volcanic breccia with intercalated marble; (3) Early Devonian mudstone and tuff spilitic keratophyre; (4) Middle to Late Devonian sandstone, mudstone, and limestone; and (4) Late Carboniferous and Permian granite. The significant deposit is at Duobaoshan.

The main references on the geology and metallogenesis of the belt are Du (1980), Ge and others (1989), and Nei (2000).

Duobaoshan Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Ge and others, 1994) consists of disseminations, veinlets, and breccias in granodiorite and late Ordovician andesitic porphyry and tuff in the Duobaoshan Formation. The granodiorite forms a composite batholith with a surface exposure of 8 km^2. In the western part of the batholith is a granodiorite porphyry with a surface area of 0.16 km^2. Circular zonal alteration occurs around the silicified porphyry and consists of K-feldspar, sericite, and propylitic alteration zones from core to periphery. Main ore minerals are pyrite, chalcophyrite, and bornite, with minor molybdenite, chalcocite, magnetite, sphalerite, pyrrhotite, tetrahedrite, and galena. A K-Ar isotopic age for the batholith is 292 Ma and the ratio of K_2O/Na_2O is 0.5. The deposit occurs in a transitional uplift between the Daxinganling Mountain Range and the Songliao Basin. The deposit is large and has reserves of 2.37 million tonnes grading 0.45 percent Cu.

Origin and Tectonic Controls for Duobaoshan Metallogenic Belt

The belt is interpreted as having formed in a subduction-related Pennsylvanian granodiorite porphyry that formed in the Ordovician through Late Devonian Nora-Sukhotin-Duobaoshan island-arc terrane as part of the South-Mongolia-Khingan island arc. The subduction-type granodiorite porphyries that host the porphyry Cu-Mo (±Au, Ag) deposit and adamellite are Late Carboniferous. The Middle Ordovician andesite volcanic rock may also host part of the deposit (Du, Qi, 1980; Nei, Zhong-yao, 2000). Major faults strike northwest and are an important control for the Duobaoshan metallogenic belt.

Harmagtai-Hongoot-Oyut Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag), Porphyry Au, Granitoid-Related Au Vein, and Au-Ag Epithermal Vein Deposits (Belt HHO) (Southern Mongolia)

This Middle Carboniferous through Early Permian metallogenic belt is related to granitoids of the Mandah intrusive complex that form part of in the southern part of the South Mongolian volcanic-plutonic belt that intrudes the Mandalovoo-Onor island-arc and Mandah subduction-zone terranes. The Harmagtai-Hongoot-Oyut belt extends southwest-northeast for 450 km and ranges from 30 km to 60 km wide. Yakovlev (1977) first defined the Mandah Cu district. Subsequently, Shabalovskii and Garamjav (1984) and Sotnikov and others (1984, 1985a,b) defined the South Mongolian porphyry Cu (±Au) metallogenic belt.

The Mandah intrusive complex consists of monzodiorite, granodiorite, granite, and deposit-hosting diorite porphyry and granodiorite porphyry stocks and dikes. The complex is coeval with andesite, dacite, and rhyolite volcanic rock of the Doshiin ovoo Formation. The Mandah complex was described as Late Carboniferous and Early Permian (Goldenberg and others, 1978) or as Middle and Late Carboniferous (Tomurtogoo, 1999). Geological and isotopic-age data indicate that plutons (South Mandah, Hongoot and others) in the eastern belt are Late Carboniferous (Sotnikov and others, 1984), whereas (Harmagtai and others) in the western belt are Late Carboniferous and Early Permian.

From east to west the belt contains the Oyut, Nariin hudag, Hongoot, and Kharmagtai districts. Special features of the belt are high Au in porphyry Cu-Mo (±Au, Ag) deposits and occurrences and a close spatial and genetic relation of porphyry Cu-Mo (±Au, Ag) and vein and stockwork Au-Ag-Cu deposits. The major deposits are the Hongoot porphyry Cu-Mo (±Au, Ag) occurrence, the Nariinhudag porphyry Cu (±Au) deposit, the Shuteen porphyry Cu-Au deposit, and the Uhaa hudag and Kharmagtai 2 porphyry Au occurrences, and the Shine, Hatsar, and other Au-Ag-Cu occurrences.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Goldenberg and others (1978), Luchitsky (1983), Shabalovskii and Garamjav (1984), Sotnikov and others (1984, 1985a,b), Tomurtogoo (1999), Tomurtogoo and others (1999), and Bignall and others (2005).

Shine Granitoid-Related Au Vein Occurrence

The occurrence (A.E. Shabalovskii and others, written commun., 1978; Sotnikov and others, 1985a,b) is related to the Oyut granitoid massif in Middle to Late Carboniferous Mandakh Complex at a distance of 400 to 1500 m from the contact. The deposit contains stringers and disseminations of epidote, pyrite, molybdenite, and chalcopyrite grading 0.3 to 3.38 percent Cu and average 0.008 percent Mo. The deposit is located in zone that dips northwest, and ranges from 100 to 120 m wide and 350 to 400 m long. The zone is hosted in Devonian brecciated andesite is altered to K feldspar, epidote, sercite, and chorite. The ore and replacement minerals are formed in following sequence: K-feldspar-epidote; molybdenite; chlorite-sericite; pyrite-chalcopyrite; calcite. The occurrence probably formed in the upper part of a magmatic system. Drill cores reach a depth of 82 m and contain 0.3-1.0 percent Cu, 0.01 to 1.0 g/t Au, and trace to 0.003 percent, Mo.

Kharmagtai 2 Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Yakovlev, 1977; Sotnikov and others, 1985a,b; Kerwin and others, 2005) is hosted in Late Carboniferous and Early Permian diorite and granodiorite that intrudes Devonain tuff, andesite, and tuffaceous sandstone and siltstone. The ore minerals are chalcopyrite, covellite, bornite, and molybdenite. Oxidation minerals are malachite, azurite, and cuprite. Associated minerals are pyrite and magnetite and peripheral sphalerite, galena, and gold. The deposit is related to subvolcanic bodies of diorite and granodiorite porphyry in two stocks and bodies explosive breccia. The bodies ranges from 200 to 400 m wide amd are 900 m long. Surface grades are 0.05 to 0.4 percent Cu and 0.003 to 0.03 percent Mo over an area of 400 by 900 m. A zone 100 by 300m contains >0.3 percent Cu. The deposit extends at least to a depth of 250 m and is defined by stockwork veinlets of quartz with chalcopyrite and molybdenite that occur across the breccia pipe. Hydrothermal alteration minerals are weakly developed silica, sericite, K feldspar, chorite, epidote, and tourmaline. Sericite, potassic, and silicic alterations occur in the center of alteration zone, and chlorite and epidote alteration occurs along the periphery. Potassic alteration occurs mainly in the deeper part of deposit. The deposit is not well studied. The deposit is small with resources of 0.8 million tonnes Cu grading 0.35 percent Cu.

Origin and Tectonic Controls for Harmagtai-Hongoot-Oyut Metallogenic Belt

The belt is interpreted as having formed in the South Mongolian continental margin arc. The volcanic-plutonic belt formed a continental margin arc overlapping the Mandalovoo-Onor island-arc terrane and Mandah subduction-zone terranes.

Hitachi Metallogenic Belt of Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposits (Belt Hit) (Japan)

This Permian metallogenic belt is related to stratiform units in the South Kitakami terrane (probably part of Sino-Korean craton) and it occurs in the southern end of the Abukuma Mountains in Northeast Japan. The belt is 15 by 10 km and the western margin of the belt is the Tanakura tectonic line. The metallogenic belt occurs in metamorphic rock (Paleozoic Hitachi Formation). Cretaceous granitoid occur north of the belt, and contact metamorphosed rocks occur in the northern belt. The eastern margin of the belt is covered by Neogene sedimentary rock. The metallogenic belt contains the Hitachi deposit, a Kuroko type Cu-Zn deposit. Tsuboya and others (1956) first defined this belt as the Abukuma metallogenic province. The Hitachi Formation consists mainly of mafic to siliceous volcanic rock, slate, and limestone. The formation strikes generally northeast, and metamorphic grade increases from east to west, as much as amphibolite facies grade (Tagiri, 1971).

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956), Tagiri (1971), and Minato and others (1979).

Hitachi Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type) Mine

This mine (Omori and others, 1986) consists of eight stratiform ore bodies that occur in the Fujimi and Fudoutaki groups according to stratigraphic position. Bodies are hosted in greenschist, biotite-quartz schist, sericite-quartz schist, and siliceous schist of Paleozoic Hitachi Metamorphic Rock. The Fujimi ore bodies occur at, or near the contact between siliceous schist and overlying mafic to intermediate schist. The Fudoutaki bodies occur in mafic and intermediate schist. Geochemical studies suggest an origin of basalt in a marginal basin. The presence of calc-alkaline rock also indicates an island-arc setting. The ore bodies extend about 3,000 m along strike and about 700 m down dip. Individual ore body range from 150 to 600 m along strike and are 10 to 80 m thick. The main ore minerals are pyrite and chalcopyrite. Other ore minerals are pyrrhotite, sphalerite, galena, magnetite, marcasite, cubanite, and valleriite. Gangue minerals are quartz, barite, biotite, chlorite, sericite, calcite, gypzum, and cordierite. Contact metamorphism adjacent to a Cretaceous granite is also recognized. Mining started in 1591 and ceased in 1981. The mine is medium size and has produced 440,000 tonnes of Cu and 40,000 tonnes of Zn grading 1.5 percent Cu.

Origin and Tectonic Controls for Hitachi Metallogenic Belt

The belt interpreted as having formed in a subduction-related island arc along the margin of the Sino-Korean craton.

Kalatongke Metallogenic Belt of Mafic-Ultramafic Related Cu-Ni-PGE and Granitoid-Related Au-Vein Deposits (Belt KL) (Northwestern China)

This Pennsylvanian metallogenic belt is related to mafic-ultramafic and granitic plutonic rocks in the Waizunger-Baaran island-arc terrane, part of the Atasbogd collage that contains the South Mongolia-Khingan island arc. The belt occurs in the Ertix and Ulungur River areas south of the Altay Mountains, trends northwest, is 500 km long, and is as much as 70 km wide. The mafic-ultramafic plutons host Cu-Ni-PGE sulfide deposits, and the granite plutons contain Au deposits. The significant deposits are at Kelatongke and Alatasi.

The main references on the geology and metallogenesis of the belt are Tang and Li (1991), Rui and others (1993), and Kong (1994).

Kalatongke Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Wang and others, 1992; Editorial Committee of The Discovery History of Mineral Deposits, 1996) consists of nine Carbonaceous mafic-ultramafic intrusions with the number 1 intrusion being the largest. The intrusion is lenticular in plan view, and is 640 m long and 35 to 350 m wide, trends northwest, and dips 20 to 28° NE. In cross section, the pluton is wedge-shaped with a wide upper part and narrow lower part. The margin of the upper part consists of biotite diorite, gabbro, and contains sparse sulfide. The center of the upper part is gabbro and norite facies consisting mainly of biotite amphibole norite, gabbro, and quartz-bearing amphibole norite and contains lean Cu-Ni sulfides at the base. The center of the lower part is biotite-amphibole norite, biotite-olivine norite, and peridotite with more abundant sulfides at depth. The marginal part of the lower part is biotite-amphibole diabase and gabbro, olivine-amphibole diabase and gabbro and contains lean sulfides. The intrusion is ultramafic with a Mg/Fe ratio of 2:3. Ore minerals are mainly pyrrhotite, chalcopyrite, pentlandite, pyrite, and magnetite and 60 other lesser sulphides and oxide minerals. Ore minerals occur in masses and and disseminattions. Autometamorphism is widespread with formation of serpentinite, talc, bioitite, and uralite. The deposit formed during intrusion of magma, injection of magma with subsequent hydrothermal and weathering. The deposit is large with reserves of 410,800 tonnes of Cu, 1.740 tonnes of Pt, and 2.161 tonnes of Pd. The average grade is 0.58 to 0.88 percent Ni, 1.40 percent Cu, 0.07 g/t Pt, and 0.09 g/t Pd.

Alatasi Granitoid-Related Au Vein Deposit

This deposit (Rui, 1993) trends northwest for about 70 km in the metallogenic belt and contains several tens of veins and altered zones that vary from 1 to 3 km long and 0.05 to 0.4 km wide. These zones, veins, and lenses are concordant to host strata, or crosscut host strata at low angles of 5 to 15°. The ore minerals occur in veinlets, disseminations, and stockworks with idiomorphic-hypidiomorphic and caulking textures. The main ore minerals are pyrite, galena, native Au, and magnetite. Alterations are pyrite, bericite, silica, carbonate, hydromica alterations. The host rocks are Middle Devonian andesitic and basalt tuff and tuffeous breccia; Late Devonian sandstone, siltstone, and mudstone; and local andesite, rhyolite, and trachyte. The host rocks and Au deposits are related biotite granite, granodiorite, potassic granite, granite porphyry, quartz porphyry, diorite, and diorite porphyry. The deposit is medium size.

Origin and Tectonic Controls for Kalatongke Metallogenic Belt

The belt is interpreted as having formed in the Waizunger-Baaran island-arc terrane, part of Atasbogd collage and the

South Mongolia-Khingan island arc. The Waizuger island-arc terrane consists of (1) Ordovician limestone with intercalated andesite, clastic rock, tuff, mafic and siliceous volcanic rock, and muddy limestone; (2) Silurian sandstone, conglomerate, limestone, pyroclasic rock; (3) Devonian mafic and intermediate and mafic volcanic rock that consist mainly of siliceous volcanic rock and tuff, fine-grained sandstone, siltstone, and limestone, (4) Carboniferous clastic rock; and (5) Permian continental volcanic and clastic rock with local coal. The calc-alkalic granite related to the Au deposits and the mafic-ultramafic volcanic-plutonic complex related to Cu-Ni sulfide deposits are interpreted as being part of the island arc that was tectonically linked to a subduction zone to the south in Wulungu River area (Kong, 1994 and Rui and others, 1993). Some authors interpreted the Cu-Ni sulphide deposits and related mafic-ultramafic plutonic rocks as having formed in an extensional basin controlled by major faults along the southern margin of the Altay continent with lithosphere thinning and upwelling of upper mantle rocks resulting in emplacement of the mafic-ultramafic plutons into shallow crust (Tang and Li, 1991).

Kureisko-Tungsk Metallogenic Belt of Fe-Skarn, Mafic-Ultramafic Related Cu-Ni-PGE, and Metamorphic Graphite Deposits (Belt KT) (Western North Asian Craton, Russia)

This Permian through Triassic metallogenic belt is related to replacements and plutons in the Tungus plateau basalt, sills, dikes, and intrusions and occurs in a wide band along the western margin of North Asian craton for more than 900 km (Malich and others, 1987). The belt contains Fe skarn deposits, Cu-Ni-PGE sulfide deposits related to mafic-ultramafic rock, and metamorphic graphite deposits. The belt is controlled by the area of the Triassic trapp magmatism and the major Yenisei sublongitudinal fault zone that occurs along the western border of the Tungussk syncline. The metallogenic belt is conjugated with the Norilsk metallogenic belt to the north. Fe-skarn deposits occur along exocontacts of subalkalic diabase and are rarely farther removed (Pavlov, 1961). The age of host rocks ranges from Early Cambrian through Early Triassic. Cu-Ni-PGE deposits are hosted in dunite, gabbro, troctolite, and diabase intrusions (Kavardin, 1976; Dyuzhikov and others, 1988). The graphite deposits occurs in areas of contact metamorphism of Permian coal-bearing sequences by Triassic trapp intrusions (Malich and others, 1987).

The main references on the geology and metallogenesis of the belt are Pavlov (1961), Malich and others (1974), Kavardin (1976), Dyuzhikov and others (1988), Surkov (1986), and Dobretsov (1997).

Suringdakonskoye Fe-skarn Deposit

This deposit (Pavlov, 1961; Kalugin and others, 1981) consists of a steeply-dipping magnetite body in Late Devonian limestone and Permian clastic rock of age intruded by trapp magma. The deposit is 1.9 km long and varies from 35 to 40 m thick. Along strike, massive ore grades into streaks and disseminations in a zone that extends for 1.5 km and ranges from 50 to 350 m thick. Host rock for streaks and disseminations is garnet-chlorite-carbonate metasomatite. Masses grade 58.43 percent Fe, and disseminations grade 20.39 to 47.07 percent Fe. The deposit is large and has resources of 600 million tonnes grading 20 to 59 percent Fe.

Bilchany River Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Kavardin and others, 1967; Kavardin, 1976.) consists of Cu-Ni sulfides in a Triassic dolerite intrusive. The sulfides occur in nests and disseminatons. Ore minerals are pyrrhotite, pentlandite, chalcopyrite, and pyrite. The deposit is small.

Noginskoye Metamorphic Graphite Deposit

This deposit (Malich and others, 1974, 1987) consists of beds of amorphous (cryptocrystalline) graphite in an Early Jurassic coal-bearing sedimentary sequence that is intruded by a stratified trapp Triassic intrusion. Host rock consist of graphite and contact metamorphosed and graphite shale. Two beds of high-quality graphite occur, a lower bed that ranges as much as 6.7 m thick and an upper bed that is 1.7 m thick. The beds extend for 1.2 km. Graphite occurs in crystalline form and comprises as much as 40 percent by volume. Small amounts of hydrothermal graphite occur in carbonate veinlets with sulfides. Graphite ores occur in columns, layers, masses, and breccia. The deposit is large and has average grades of 71.33 to 90.56 percent C, 8.53 to 24.34 percent ash, and 0.28 to 3.06 percent volatiles. The deposit was abandoned.

Origin and Tectonic Controls for Kureisko-Tungsk Metallogenic Belt

The belt is interpreted as being related to mantle-derived superplume magmatism that resulted in widespread development of trapp magmatic rocks on North Asian craton along the long-lived West-Siberian rift and major Yenisei sublongitudinal fault (Surkov, 1986; Dobretsov, 1997). This belt occurs in the intersection of two lithospheric plates, the oceanic West-Siberian plate and continental Siberian plates. The Priyeniseisk deep-fault zone contains numerous Triassic diabase intrusions and ore occurrences, mainly Fe-skarn (of Angara-Ilim type). The majority of deposits occur along intersections of sublongitudinal and sublatitudinal faults (Malich and others, 1987). Graphite deposits formed as a result of thermal metamorphism of the late Paleozoic coal-bearing sedimentary rock during intrusion by numerous diabase intrusions (Malich and others, 1974).

Maimecha-Kotuisk Metallogenic Belt of Fe-Ti (±Ta, Nb, Fe, Cu, apatite) Carbonatite, REE (±Ta, Nb, Fe) Carbonatite, and Phlogopite Carbonatite Deposits (Belt MK) (Northwest of the North-Asian Craton, Russia)

This Late Permian through Early Triassic metallogenic belt is related to volcanic flows of the Tungus plateau basalt that occurs in the northwestern North Asian craton. The eastern boundary is the western border of the Anabar Shield. Varied Permian and Triassic magmatic rocks are widespread in the belt and consist of tholeiite, diabase, trachybasalt, picrite, and melanonephelinite extrusive and intrusive rock, and ijolite, carbonatite, and kimberlite complexes (Egorov, 1970; Malich and others, 1987). More than twenty, central-type, alkalic ultramafic plutons with carbonatite occur in the belt. The largest of these are the Gulinskoe pluton (about 500 km^2), Odikhincha pluton (56 km^2), Magan pluton (42 km^2), Bor-Uryach pluton (17 km^2), Kugda pluton (16.5 km^2), Essey pluton (6 km^2), and Irias pluton (6 km^2). Ijolite and carbonatite are most prevelant rock types. Most alkalic ultramafic carbonatite intrusions contain magnetite, titano-magnetite, perovskite, REE, phlogopite, apatite, and nepheline deposits (Malich and others, 1987). Several groups of deposits occur in the belt (1) large-and average-size Fe-Ti carbonatite (Gulinskoye I), Magan I, Bor-Uryach and others; (2) large REE (±Ta, Nb, Fe) carbonatite (Gulinskoye I); and (3) medium-size phlogopite-carbonatite (Odikhimcha I and others).

The main references on the geology and metallogenesis of the belt are Egorov (1970), Samoilov (1977), Yaskevich and others (1980), Malich and others (1987), Basu and others (1995), and Zolotukhin (1997).

Gulinskoye 1 Fe-Ti (±Ta, Nb, Fe, Cu, apatite) Carbonatite Deposit

This deposit (Kalugin and others, 1981; Sinyakov, 1988) consists of titanomagnetite in the Gulinsk alkalic central type ultramafic pluton. Titanomagnetite occurs in pyroxenite and peridotite in a half-ring zone that is 30 km long and 100 m wide. Titanomagnetite occurs as dissemination and locally in veins, nests, lenses, and large deposits that comprise as much as 25 to 30 percent pyroxenite bodies by volume. Dimensions of discrete concentrations range from 100 to 200 m to 5 km along strike and from 10 to 30 to 600 m thick. The deposit is large. Resources are 1.8 billion tonnes to a depth of 100 m, and has an average grade of 22.4 percent Fe.

Gulinskoye 2 REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (Kavardin and others, 1967) consists of REE in alkalic ultramafic carbonatite plutons. Two carbonatite plutons, with outcrop areas of 3 km^2 and 5 km^2, occur around the Gulinskoye phlogopite deposit. The plutons consist of vertically-dipping, isometrical bodies of mainly ankaratrite, picrite, peridotite, and melilite. The deposits consist of irregular, fine-grained disseminations of ore minerals in calcite, calcite-magnetite, calcite-dolomite, and dolomite carbonatite. Pyrochlore occurs with magnetite, serpentine, and REE minerals. Perovskite occurs in nests with magnetite and melanite, and is more abundant in micaceous melanite and pyroxenite in the Gulinskii pluton. The deposit is large and world class.

Odikhincha 1 Phlogopite Carbonatite Deposit

This deposit (Prochorova and others, 1966; Dyadkina and Orlova, 1976; Malich and others, 1987) consists of phlogopite deposits in the central type Odikhincha alkaline-ultramafic pluton. Phlogopite formation occurred in the ijolite and carbonatite stages of the pluton. The major phlogopite concentrations occur in dunite and and along contacts with ijolite-melteigite. Dunite contains as much as 10 to 30 percent phlogopite. Monomineral phlogopite veins occur in fissure zones in dunite. The veins are as much as several tens of meters long and as much as 1.5 to 2 m thick. Veins also contain olivine, titanomagnetite, calcite, and perovskite. Diopside-phlogopite veins occur near the contact of the pluton with wallrock. Phlogopite also occurs in garnet-nepheline-pyroxene and nepheline-melilite pegmatite veins. The deposit is medium size.

Origin and Tectonic Controls for Maimecha-Kotuisk Metallogenic Belt

The belt is interpreted as being related to mantle-derived superplume magmatism that resulted in widespread development of trapp magmatism on the North Asian craton. Magmatic rocks include tholeiite, diabase, trachybasalt, and melanonephelinite volcanic and intrusive rock, and ijolite-carbonatite and kimberlite complexes. The belt occurs at intersection of the trans-Asian longitudinal Taimyr-Baikal lineament and the major Yenisei-Kotuisk sublatitudinal fault belt. The distribution of the plutons of alkalic and ultramafic rock is determined by intersections of the major faults. Abyssal differentiation of mantle olivine-melilite magma was a crucial factor in multistage development of deposit-hosting plutons. Their compositions were complicated by superimposed metasomatic processes (Egorov, 1970; Samoilov, 1977). According to the $^{40}Ar/^{39}Ar$ data, the age of deposit-hosting intrusions ranges from 253.3 to 249.88 Ma (Basu and others, 1995) that corresponds to the Early Triassic stage of development of trappean magmatism at the North Asian craton (Zolotukhin, 1997). The origin of alkalic ultramafic-carbonatite plutons and accompanying deposits is geodynamically related to continental rifting occurring above a hot spot in the southern flank of the Yenisei-Khatanga rift (Yaskevich and others, 1980).

Mino-Tamba-Chugoku Metallogenic Belt of Volcanogenic-sedimentary Mn, Podiform Chromite, and Besshi Cu-Zn-Ag Massive Sulfide Deposits (Belt MTC) (Japan)

This Permian (or older) to Jurassic metallogenic belt is hosted in structural units in the Mino-Tamba-Chichibu and Akiyoshi-Maizuru subduction-zone terranes. The belt occurs in the western part of Honshu Island in the Inner Zone of southwestern Japan, trends east-northeast to west-southwest for more than 900 km, and is as much as 150 km wide. The eastern margin of the belt is the Tanakura tectonic line. Tsuboya and others (1956) named the belt the Chichibu geosyncline Fe-Mn metallogenic province. The North Kitakami metallogenic belt is interpreted as being an eastern extension of this belt. The Mino-Tamba belt contains a large number of various types of deposits. Mn deposits are hosted in the Mino-Tamba-Chichibu terrane, and podiform chromite and Besshi Cu-Zn-Ag massive sulfide deposits are hosted in in the Akiyoshi-Maizuru terrane. The Mino-Tamba-Chichibu terrane is a Jurassic accretionary complex and Mn deposits are associated with Triassic and Jurassic chert. Podiform Cr deposits occur in ophiolite in the prePermian Sangun metamorphic complex. Massive sulfide deposits occur in the Permian forearc Maizuru group. The significant deposit is at Awano.

The main reference on the geology and metallogenesis of the belt is Tsuboya and others (1956).

Wakamatsu Podiform Chromite Mine

This deposit (Tsuboya and others, 1956) occurs in serpentinite derived from dunite of the Tari-Misaka ultramafic body in the Sangun belt. The ultramafic body is mostly composed of massive harzburgite and dunite. The ultramafic rocks are contact metamorphosed by a Cretaceous granite. The mine contains three main ore bodies. Main number 7 body is 190 m long, 60 m wide, and 30 m thick and yielded 1 million tonnes ore. The ore mineral is refractory grade chromite. Serpentine and olivine occur in ore. The deposit was discovered in 1899, and the mine closed in 1994. The deposit is medium size and produced 780,000 tonnes of ore grading 32 percent Cr_2O_3.

Yanahara Besshi Cu-Zn-Ag Massive Sulfide Mine

This mine (Mining and Metallurgical Institute of Japan, 1965; Dowa Mining Corporation, 1981) consists of the main Yanahara ore body and nine smaller ore bodies. The ore bodies are stratiform and lenticular, and occur in an area 4.5 by 2 km. The main Yanahara ore body contains the upper, lower, and lowest ore bodies. The upper body is 350 m long along strike, extends 1000 m down dip, and is as much as 100 m wide. The lower ore body is similar. The main ore mineral is pyrite; minor ore minerals are pyrrhotite, magnetite, chalcopyrite, and sphalerite. Gangue minerals are quartz, sericite, and chlorite. The deposit is hosted in rhyolite pyroclastic rock and mudstone of the Paleozoic Maizuru Group. The deposit occurs immediately above the basalt of the Yakuno Group. The mine started in 1916 and closed in 1991. The mine is medium size and has reserves of 3.7 million tonnes grading 44 percent Fe, 47 percent S, 0.2 percent Cu, and 0.3 percent Zn.

Hamayokokawa Volcanogenic-Sedimentary Mn Mine

This mine (Mining and Metallurgical Institute of Japan, 1968; Uemura and Yamada, 1988) is located in the Yokokawa (Shiojiri) Mn deposit district that contains 17 deposits. The Hamayokokawa deposit is the largest and contains six main ore bodies. The largest ore body is 50 m long, 8 m thick, and extends 120 m down dip. The ore bodies occur in Paleozoic and Mesozoic chert and slate of the Mino belt. The ore minerals are rhodochrosite, hausmannite, manganosite, rhodonite, tephroite, and braunite. The mine closed in 1984. The mine is medium size and produced 260,000 tonnes of ore grading 33 to 42 percent Mn.

Origin and Tectonic Controls for Mino-Tamba-Chugoku Metallogenic Belt

The belt is hosted in tectonic fragments in a subduction-zone complex that formed along the margin of the Sino-Korean craton. The subduction zone composed of marine sedimentary and volcanic rock and fragments of oceanic crust with ultramafic rock. Besshi deposits are interpreted as having formed along a spreading ridge. In the oceanic crustal fragments are podiform chromite deposits hosted in ultramafic rocks and chert-hosted Mn deposits. The deposits and host rocks were subsequently incorporated into an accretionary wedge of the Mino-Tamba-Chichibu subduction-zone terrane.

Norilsk Metallogenic Belt of Mafic-Ultramafic Related Cu-Ni-PGE, Basaltic Native Cu, and Porphyry Cu-Mo (±Au, Ag) Deposits (Belt NR) (Northwestern North Asian Craton, Russia).

This Early Triassic metallogenic belt is related to the Tungus plateau basalt, sills, dikes, and intrusions that extend sublongitudinally to the west and sublatitudinally to the east. The belt is about 600 km long and varies from 60 to 150 km wide. The belt occurs in the area of trapp magmatism. The shape of the belt is controlled by fault zones related to the West-Siberian and Yenisei-Khatanga rifts (Dodin and others, 1985; Dyuzhikov and others, 1988). The belt contains major Cu-Ni-PGE deposits. The largest Cu-Ni-PGE deposits (Norilsk, Talnakh, and Oktyabrskoye) are the very important for the mineral industry of Russia (Dodin and others, 1998, 1999). The deposit-hosting intrusions are differentiated, stratiform plutons that range from 80 to 400 m thick and composed of variable rock sequences that range from plagioclase dunite to gabbro and diorite. Cu-Ni-PGE sulfides occur both in magmatic rocks and Paleozoic host rocks adjacent to exocontacts. Basalt native-copper deposits (Arylakhskoye deposit) occur in the upper part of a Triassic welded tuff sequence. Cu deposits generally occur in basalt flows and in breccia. The Bolgochtonskoye porphyry Cu-Mo (±Au, Ag) deposit occurs in the endocontact and exo-contact zones of a granitoid stock that intrudes a Silurian and Devonian argillaceous carbonate sequence.

The main references on the geology and metallogenesis of the belt are Zolotukhin and Vasiliev (1976), Dodin and others (1985, 1998, 1999), Dyuzhikov and others (1988), Dalrymple and others (1991, 1995), and Dobretsov (1997).

Norilsk I Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (fig. 7) (Godlevskiy, 1959; Ivanov and others, 1971; Smirnov, 1978) consists of Cu-Ni sulfide deposits hosted in the Triassic Norilsk differentiated mafic-ultramafic intrusive. The intrusive has a layered bed-like form that extends for 12 km and ranges from from 30 to 350 m thick (130 m average). The intrusive is composed of gabbro, diabase, and norite that intrude Permian sedimentary rock, trachydolerite, trachybasalt, andesite, and basalt. Sulfides occur in disseminations and nests of pyrrhotite, pentlandite, and chalcopyrite mainly in the lower olivine-rich picrite and diabase, and to a lesser extent in bands in diabase near the bottom of intusive. Veins of massive sulfides occur in the lower part of intrusive and in underlying rocks and consist of streaks and disseminations in wall rocks. These veins form an interrupted aureole around the intrusive

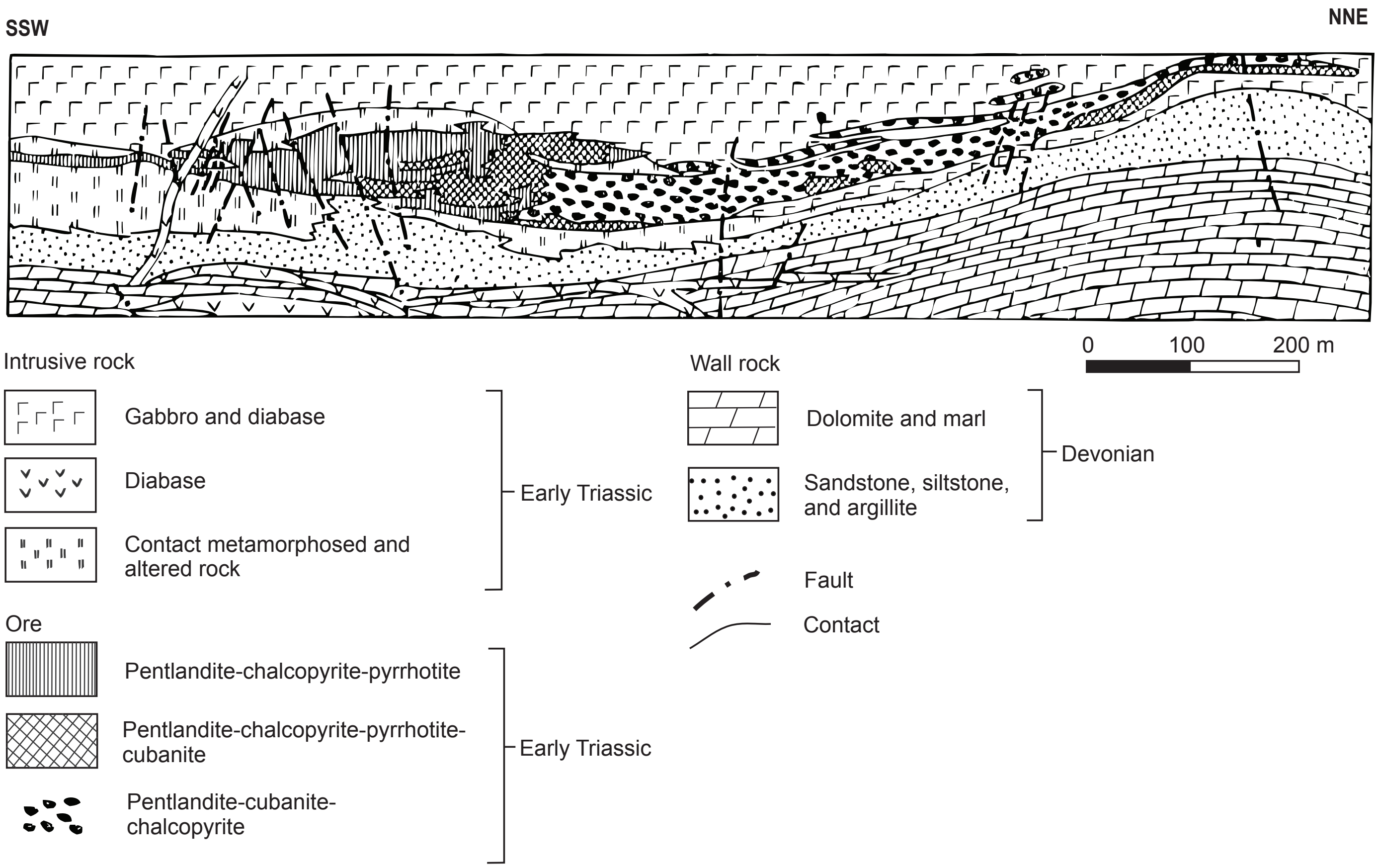


Figure 7. Schematic geologic cross section of Early Triassic Norilsk 2 mafic-ultramafic related Cu-Ni-PGE deposit, Norilsk metallogenic belt. Adapted from Smirnov (1978).

and extend for 15 km and range from 3 to 8 m thick. The sulfides mainly comprise form a stable layer that is concordant in plan view with the intrusive outline. The main mineral assemblages are pyrrhotite, chalcopyrite-pyrrhotite with pentlandite, cubanite-pentlandite-chalcopyrite, bornite-chalcocite, and millerite-pyrite. Elevated Pt in sulfides is characteristic. The oldest Cu-Ni sulfides are overprinted by low-temperature hydrothermal replacement with development of carbonate, chlorite, galena, and sphalerite. The deposit is large.

Norilsk II Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Zolotukhin and Vasil'ev, 1967) consists of Cu-Ni sulfides in a differentiated mafic-ultramafic intrusive that has a honolithe form, extends for 7 km, ranges from 100 to 300 m thick, and ranges from 100 to 800 m wide in plan view. The intrusion is layered and consists of gabbro and diabase at the top and olivine-biotite and picritic at the bottom. An irregular sulfide horizon occurs near the base of the intrusive, but often occurs in the footwall. The principal ore minerals are pyrrhotite, pentlandite, cubanite, and chalcopyrite; bornite, chromite, valleriite, pyrite, and PGE-minerals also occur. The ores are enriched in PGE. The deposit is a large and world-class.

Oktyabrskoye 3 Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Zolotukhin and others, 1975; Smirnov, 1978) consists of Cu sulfides-Ni deposits in differentiated mafic-ultramafic Talnakh intrusive. Intrusive composed of gabbro, non-olivine- and olivine-biotite gabbro, and diabase. The role of olivine-rich rocks increases to the intrusive floor. The deposit-hosting intrusive is at the 600 to 1,400 m depth and is hosted in metamorphosed rocks of Middle Devonian age. Three types of Cu sulfides-Ni ore are distinquished: massive, disseminated in intrusive rocks, and disseminated essentially Cu ores in host rocks. Massive sulfide ores compose a low-dipping deposit with area of about 4 km^2 and from 1 to 46 m thick. Disseminated ores compose some horizons at the base of intrusive having total thickness as much as 40 m. Disseminated essentialy Cu ores occur in the contact zone of the intrusive and are from 2 to 10 m thick. Principal ore minerals are: pyrrhotite, pentlandite, chalcopyrite, cubanite. Secondary minerals are magnetite, ilmenite, chromite, valleriite, bornite, and pyrite. The ores are by PGE-enriched. The deposit is large and world class.

Arylakhskoye Basaltic Cu (Lake Superior type) Deposit

This deposit (Dyuzhikov and others, 1976, 1977, 1988) consists of stratiform layers of native copper in Permian and Triassic carbonaceous breccia, in overlying basalt, and in underlying tuff. Ore minerals are native copper, cuprite, tenorite, chalcocite, and covellite. Gengue minerals are calcite, zeolite, chlorite, adularia, and quartz. The deposit and host rocks are regionally metamorphosed and exhibit carbonate, chlorite, and zeolite alteration. The Cu-bearing horizon is 2 to 10 m thick and extends for 40 km along the flank of the trapp basins. The highest concentration of native copper is in brecciated carbonate rocks. Native Cu occurs along the contacts of fragments in a carbonaceous matrix. Coarse grains (as much as 0.7 to 1 cm) and dendrite (as much as 3 to 5 cm) are widespread. The native copper occurs in veinlets, nests, fine disseminations, and amygdules. In tuff, Cu occurs as fine disseminations. Large aggregates (15 by 20 cm) and dendrite-like crystals (5 to 10 mm) of native copper occur in large amygdules and carbonate veins. The deposit is medium size.

Bolgokhtonskoye Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Matrosov and Shaposhnikov, 1988; Dyuzhikov and others, 1988) consists of Cu-Mo sulfides in veinlets and disseminations in hydrothermally-altered rock along contact of Bolgokhtokh granite pluton andin both the pluton and in adjacent intrusive rock. The granite-pluton stock intrudes Silurian and Devonian limestone, marl, and siltstone and Permian and Triassic volcanic rock and diabase. Metasomatite consists of calc-silicate-skarn, quartz-feldspar, quartz-sericite and quartz-calcite-chlorite rock. Two main districts occur. A Southern district occurs at depth and consists of streaks and lesser disseminations and nests. Thickness ranges as much as 0.8 to 1 cm. A Western zone crops out at the surface and consists of streaks and disseminations. Ore minerals are magnetite, molybdenite, chalcopyrite, sphalerite, pyrite, scheelite, bornite, fahl orewolframite, and galena. Gangue minerals are quartz, sericite, K-feldspar, and carbonate. Polymetallic sulfides increase in the propylite in the exterior part of the deposit. The deposit is medium size.

Origin and Tectonic Controls for Norilsk Metallogenic Belt

The belt is interpreted as being related to mantle-derived superplume magmatism that formed widespread of trapp magmatism on North Asian craton. The major Cu-Ni-PGE deposits occur in an area of orthogonal intersection of the Mesozoic Yenisei-Khatanga rift basin and the West-Siberian rift system. The deposits in the Norilsk district occur along ongitudinal linear structures that coincide with the major faults and axial zones of volcanic-tectonic basins. The major Norilsk-Kharaelakh fault is interpreted to be the major magmatic and deposit-controlling structure (Dyuzhikov and others, 1988). Magma generation is interpreted as being related to the mantle-derived superplume that resulted in widespread trapp magmatism on the North Asian craton (Dobretsov, 1997). Initial picrite magma is interpreted as being a source of mafic-ultramafic host for the Norilsk metallogenic belt (Zolotukhin and Vasil'iev, 1976; Dyuzhikov and others, 1988). $^{40}Ar/^{39}Ar$

isotopic age for basalt of the Norilsk ore district is 241.0 to 245.3 Ma, and the age for mafic-ultramafic intrusions is 248.7 to 248.9 Ma (Dalrymple and others, 1991, 1995). The $^{40}Ar/^{39}Ar$ isotopic age for Bolgokhtonsk granitoid that hosts the porphyry Cu-Mo (±Au, Ag) deposits is 223.3 Ma (Zolotukhin, 1997). The granitoid magmatism is interpreted as having resulted from evolution of the magmatic system during rifting (Dyuzhikov and others, 1988). Basalt native copper deposits formed later than the Ni-bearing mafic-ultramafic plutons (Dyuzhikov and others, 1988).

Orhon-Selenge Metallogenic Belt of Porphyry Cu-Mo (±Au, Ag) Deposits (Belt OS) (Central Mongolia)

This Triassic metallogenic belt is hosted in granitoids in and stratiform layers in the Selenga sedimentary-volcanic plutonic belt. The belt occurs in northeastern half of the North Mongolian metallogenic belt of porphyry Cu-Mo (±Au, Ag) (Sotnikov and others, 1984, 1985a,b) in the northeastern part of North Mongolian volcanic belt that was named the Orhon-Selenge Basin (Mossakovskii and Tomurtogoo, 1976) The metallogenic belt contains the major Late Triassic through Early Jurassic Erdenet porphyry district (Sotnikov and others, 1985a,b) that is coeval with trachyandesite volcanic rock. In this part of Mongolia, the Selenge sedimentary-volcanic-plutonic belt consists of Precambrian metamorphic rock, Permian volcanic rock in the Hanui Group, Late Permian gabbro, granodiorite, granosyenite, and granite in the Selenge complex, Late Permian and Early Triassic trachyandesite, Late Triassic and Early Jurassic gabbro, diorite, and granite stocks, and the Erdenet porphyry complex. Porphyry stocks and dikes developed in Erdenet disrict are called the Erdenet complex (Sotnikov and others, 1985a,b).

The following districts occur from northeast to southwest in the metallogenic belt (Dejidmaa and others, 1996) (1) Darhan district with porphyry Cu-Mo (±Au, Ag) occurrences; (2) Baruunburen district with porphyry Cu (±Au) occurrences; (3) Erdenet districts with porphyry Cu-Mo (±Au, Ag) deposits and occurrences; and (4) Bulgan district with porphyry Cu-Mo (±Au, Ag) and basalt Cu occurrences. Most porphyry Cu-Mo (±Au, Ag) deposits and occurrences are in the Erdenet district. The major deposits are at Erdenetiin Ovoo, Central, Oyut Cu-Mo deposits; the Shand Cu-Mo deposit; and the Zuiliin gol Cu-Mo occurrence.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Luchitsky (1983), Gavrilova and others (1984, 1989), Sotnikov and others (1985), Dejidmaa andi Naito (1998), and Lamb and Cox (1998).

Erdenet Porphyry Cu-Mo (±Au, Ag) District

This district (fig. 8) (Khasin, and others, 1977; Gavrilova, and others, 1984; Sotnikov and Berzina, 1989; Gerel and Munkhtsengel, 2005) contains the world's largest porphyry Cu-Mo (±Au, Ag) deposit at Erdenetiin Ovoo. This and the Central, Zavsryn, and Oyut deposits occur along the northwest-striking Buhaingol fault zone into which are intruded porphyry stocks and dikes of the Erdenet Complex. Erdenet Complex contains two phases of granodiorite porphyry stocks and dikes of diorite porphyry, plagiogranite porphyry, dacite porphyry, syenite porphyry, and andesite porphyry. Syenite porphyry and andesite porphyry occur in post-ore dikes. Quartz-sericite metasomatite at the Erdenetiin Ovoo deposit has a K-Ar isotopic age of 210 to 190 Ma and an explosive breccia has a K-Ar isotopic age of 210 Ma K-Ar (Late Triassic through Early Jurassic) (Sotnikov and others, 1985a,b). Younger K-Ar isotopic ages for three porphyrytic stages are 250 to 240 Ma for the deposit-hosting stage. K-Ar and Rb-Sr ages are 220 Ma for a younger stage with less extensive deposits. A K-Ar isotopic age is 185 Ma for a post-ore stage (Sotnikov and others, 1984). A $^{40}Ar/^{39}Ar$ isochron age of 207±2 Ma is reported for white mica from the highest grade part of the Erdenet mine (Lamb and Cox, 1998). The major deposit is at Erdenetiin Ovoo, which consists of the north-eastern or the Erdenetiin Ovoo, the central, and the Zavsryn and the Qyut parts. The small Shand deposit occurs south of the Erdenetiin Ovoo. Besides the Shand deposit, most porphyry Cu-Mo (±Au, Ag) occurrences in this belt constitute potential for concealed deposits at depths of 200 to 300 m.

Erdenetiin Ovoo Porphyry Cu-Mo (±Au, Ag) Mine

This deposit (Sotnikov and others, 1985; Koval and Gerel, 1986; Gerel, 1989; Dejidmaa, 1996; Gerel and Munkhtsengel, 2005) consists of stockwork veinlets and veins of quartz, chalcopyrite, and molybdenite in or near the granodiorite porphyry of the Selenge Complex. The size of the stockwork at the surface is 2,800 m by 300 to 1300 m and the primimary ore dimensions are 1,000 by 600 m. The deposit is related to intensive hydrothermal alteration of host rocks. A quartz-sericite zone is strongly developed in the center of the stockwork and grades outward into sericite-chlorite and carbonate-epidote-chlorite zones. In the upper part of the stockwork argillite alteration occurs, and K-feldspar alteration, locally with hydrothermal biotite and tourmaline, occurs. Altered quartz-sericite rock is called a secondary quartzite. In the eastern part of the deposit, the porphyritic rock and alteration zone is cut by a central meridian fault. This mine contains numerous supergenic halos. The northwest trending fault zone is important for the ore location process. The host rocks for the deposit are Precambrian basement composed of amphibolite, schist, and volcanic and edimentary rocks.

Five stages of mineralization correspond to five phases of porphyry intrusion. The stages are (1) magnetite, quartz-pyrite, (2) molybdenite-quartz, (3) chalcopyrite-pyrite-quartz, (4) pyrite metacrystals, (5) pyrrotite (cubanite)-chalcopyrite, (6) chalcocite-bornite, (7) galena-sphalerite-tennantite, and (8) zeolite-gypsum-carbonate in both primary and secondary enrichment zones. The main minerals in the oxide zone are malachite, azurite, cuprite, iron oxides, and native copper. A vertical zonation consists of (1) oxidized and leached ore (from 10 to 90 m thick); (2) secondary sulphide-enrichment zone (from 60 to 300 m thick); and (3) primary ore (to a depth 1,000 m). Cu grade varies from 0.8 percent to 7.6 percent Cu in secondary sulphide zone in the central part of the deposit and decreases to the periphery. Mo grade varies from 0.001 to 0.76 percent Mo in the econdary sulphide zone. Cu grade in primary ore decreases from the centre of stockwork (0.4 to 0.5 percent Cu) to 0.2 to 0.3 percent Cu at the periphery and to 0.2 to 0.25 percent Cu from 500 to 1000 m. Mo grade is variable and is somewhat antithetic to Cu grade. The secondary enrichment zone has 85 percent of the reserves. From 0.8 percent to 7.6 percent Cu and from 0.001 percent to 0.76 percent Mo occurs in the secondary enrichment zone, and 0.2 to 0.5 percent Cu and 0.025 percent Mo occurs in primary ore. The highest grade part is a chalcocite blanket composed of quartz, white mica, pyrite, and chalcopyrite with a well-developed quartz-vein stockwork. Secondary chalcocite forms coatings on both pyrite and chalcopyrite. Potassic alteration occurs mainly in the deep part of deposit. The deposit is large

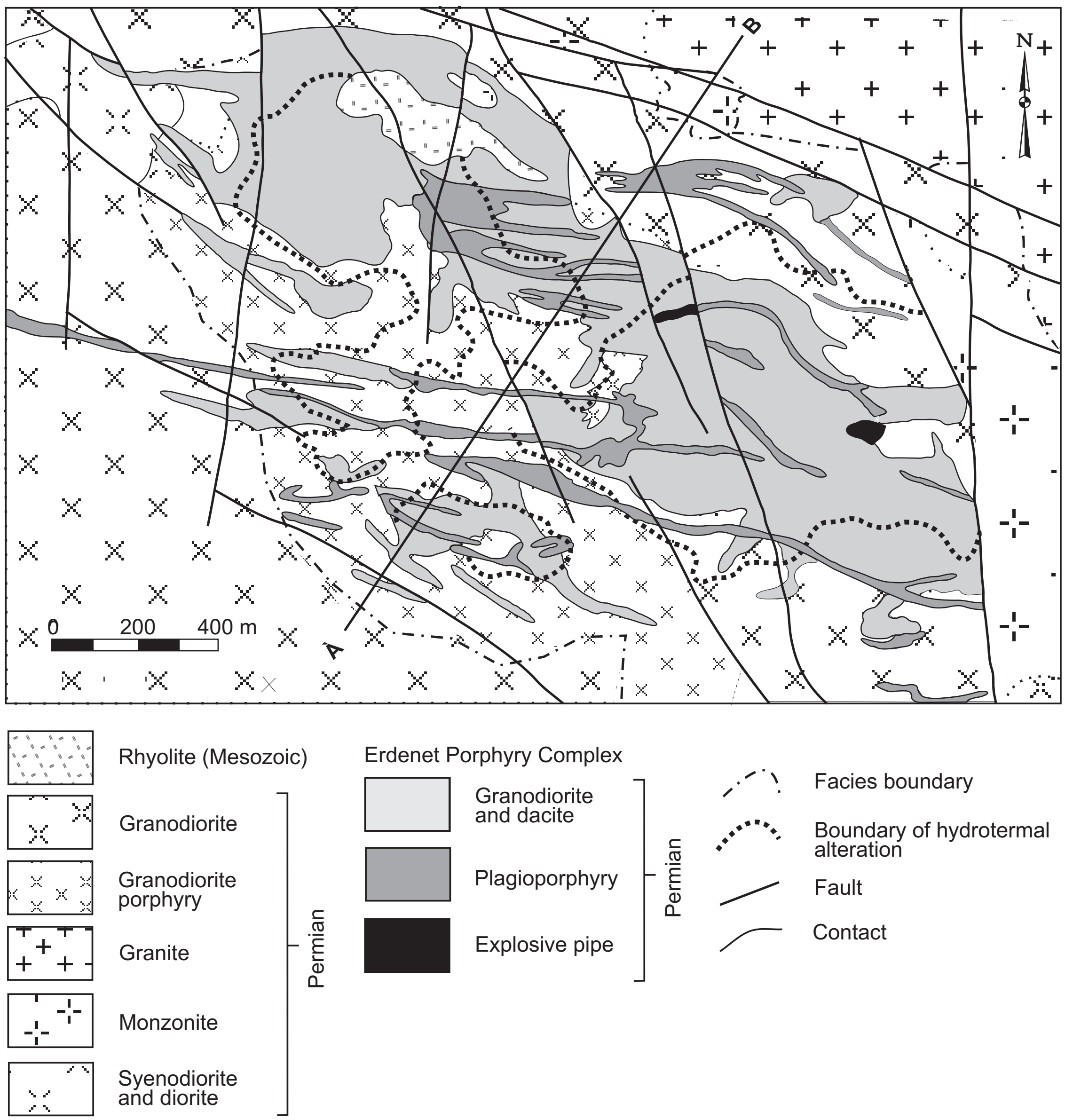


Figure 8. Geologic sketch map and cross section of Triassic Erdenet porphyry Cu-Mo deposit, Orhon-Selenge metallogenic belt. Adapted from Gavrilova and others (1989) and Gerel and Munkhtsengel (2005).

and has reserves of 10,851,000 tonnes of Cu and 167,073 tonnes of Mo.

Shand and Zuiliingol Porphyry Cu-Mo (±Au, Ag) Occurrence

This occurrence (V.P. Arsentev and others, written commun., 1985) consists of a Cu sulfide zone with surface dimensions of 350 by 1,100 m. The zone occurs along the contact of a granodiorite porphyry stock. Ore minerals are: chalcopyrite, molybdenite, sphalerite, galena, magnetite, and hematite. Grab grade from 0.1 to 1.0 percent Cu, and from 0.001 to 0.015 percent Mo, and as much as 0.001 percent Ag. Core samples grade from 0.1 to 0.4 to 0.5 percent, Cu and from 0.0001 to 0.1 percent Mo. The deposit is small with probable reserves of 500,000 tonnes of Cu and an average grade of 0.1 to 0.5 percent Cu and 0.0001 to 0.1 percent Mo. This occurrence at Shand and another at Zuiliingol have the potential for small concealed deposits at depths of 200 to 300 m.

Origin and Tectonic Control for Orhon-Selenge Metallogenic Belt

The belt is interpreted interpreted as having formed along the Selenga transform continental margin arc along the northern margin of the Mongol-Okhotsk Ocean. The transform margin consisted of oblique subduction of oceanic crust of the Mongol-Okhotsk Ocean plate under the southern margin of the Siberian continent. The Late Permian through Early Jurassic plutonic rocks of the Orhon-Selenge metallogenic belt are part of the mainly Permian Selenga sedimentary-volcanic plutonic belt (Tomurtogoo and others, 1999). Remnants of this ocean are preserved in a narrow band that extends 3000 km from central Mongolia to the Okhotsk Sea (Obolenskiy and others, 1999).

Shanxi Metallogenic Belt of Sedimentary Bauxite and Evaporate Sedimentary Gypsum Deposits (Belt SX) (North China)

This Pennsylvanian metallogenic belt is related to stratiform units in the upper part of the sedimentary platform cover for the Sino-Korean craton. The belt is hosted in Pennsylvanian sedimentary assemblages overlapping the West Liaoning-Hebei-Shanxi Archean terrane. The belt occurs along the Fanhe River and the middle reaches of the Yellow River in West Shanxi Province. The bauxite deposits occur in the lower part of the Pennsylvanian Benxi Formation. The belt trends north-south, is 300 km long, and ranges from 30 to 50 km wide. The belt contains 55 bauxite deposits of moderate or large size, with a reserve (1997) of 941 million tones that comprise 50 percent of China's bauxite reserve (Chen and others, 1997). The most significant deposit is at Keer. A minor evaporate sedimentary gypsum deposit occurs at Lingshi.

The main references on the geology and metallogenesis of the belt are Wang (1985), Jiang and others (1987), and Chen and others (1997).

Ke'er Sedimentary Bauxite Deposit

This deposit (Editorial Committee, Discovery History of Mineral Deposits of China, Shanxi volume, 1996; Chen and others, 1997) consists of stratiform and lenticular layers that are as much as 1800 m long and 400 m wide. Individual bauxite layers range from 0.5 to 11.7 m thick. From bottom to the top, the host rocks consists of a volcanogenic-sedimentary Fe deposit (hematite), allite, bauxite, refractory clay, shale, carbonaceous shale, and coal seams. The sequence is 8 to 20 m thick and occurs in the lower member of the Benxi Formation. The underlying strata are Middle Ordovician limestone. The lower boundary of the bauxite layer is 2 to 5 m above an ancient weathering-surface of the Ordovician limestone. In the mine, the strata are monoclinal and dip gently at 3 to 5 degrees. Oblique bedding occurs in the ores that are massive, rough, and oolitic. The ore minerals are mainly diaspore (98 percent) and local gibbsite (5 to 7 percent). Minor minerals are kaolinite, dickite, and hydromica and rare zircon, oysanite, tourmaline, quartz, and barite. Below the bauxite layer is hematite claystone and hematite shale, and local abundant intercalated limonite lenses. The bauxite probably formed during allochthonous surface accumulation on a weathering crust of carbonate and not by mechanical sedimentation. The Carbonaceous and Permian units of the North China Platform contain seven bauxite layers. The layer in the Late Carboniferous Benxi Formation is the most extensive. The deposit is large and has reserves of 62,656 thousand tonnes grading 64.43 percent Al_2O_3.

Origin and Tectonic Controls for Shanxi Metallogenic Belt

The belt is interpreted as having formed during weathering of metamorphic rock of the Northern China Platform. The bauxite deposits were deposited in karst and lagoonal basins in a littoral-shallow sea. The entire North China Platform, including the bauxite metallogenic belt, was uplifted, weathered, and eroded during the Middle Ordovician. During the Pennsylvanian, the platform subsided with formation of a littoral shallow sea (Wang, 1985). Bauxite deposits formed in local favorable karst and lagoon basins. The bauxite was derived from weathered metamorphic rock of the North China Platform and not from weathered Ordovician limestone that underlies the bauxite sequence (Chen and others, 1997). However, some authors advocate derivation of bauxite deposits from the weathering of the underlying limestone (Jiang and others, 1987).

Major Late Triassic through Early Early Jurassic (230 to 175 Ma) Metallogenic Belts and Host Units

Central Hentii Metalogenic Belt of Sn-W Greisen, Stockwork, and Quartz Vein, REE-Li Pegmatite, Ta-Li Ongonite, Ta-Nb-REE Alkaline Metasomatite, Peralkaline Granitoid-Related Nb-Zr-REE, W-Mo-Be Greisen, Stockwork, and Quartz Vein, and W±Mo±Be Skarn Deposits (Belt CHE) (Mongolia)

This Late Triassic through Early Jurassic metallogenic belt is related to replacements and granitoids in the Mongol-Transbaikal volcanic-plutonic belt that intrudes and overlaps Hangay-Dauria terrane and adjacent units. The Sn-W deposits and occurrences are hosted in a Late Triassic and Early Jurassic granodiorite and granite belt that forms the Hentii megadome that is 600 km long, as much as 200 to 220 km wide, and trends northeast. This dome is the Mongolian part of the Hentii-Daurian megadome that has been uplifted from the early Mesozoic through the Recent. The Hentii megadome contains Devonian and Carboniferous turbidite intruded by Paleozoic and Mesozoic granitoids. The major deposits are at Modot, Tsagaan dabaa, Gorkhi, Zuunbayan, Janchivlan, and Avdrant.

Various Sn-W greisen, stockwork, and quartz-vein deposits, at at Tsagaan Davaa, Modot, and Janchivlan, occur mainly in the upper part of evolved granite and rarely in host rocks. The host granite has a K-Ar isotopic age of 190.49±4.7 Ma and a Rb-Sr isotopic age of 225 to 188 Ma, and consists of three types: (1) coarse-grained porphyritic biotite granite and rare amphibole-biotite granite, (2) medium-grained two-mica granite, and (3) K-feldspar biotite granite (alaskite) and Li-F granite including microcline-albite, amazonite-albite, lepidolite-albite granite. Many granites are S-type granite higher alkalinity than typical. Li-F granite is A2 type (after Eby, 1992) and formed in post-collisional setting (Gerel, 1995; Gerel and others, 1999). First granite type contains many unique miarolic pegmatites (as at Gorkhi, Zuunbayan, and Janchivlan) with piezoelectrical quartz. The second granite type contains W-Sn veins (as at Modot, Bayan Mod, and Khujihan) and rare scheelite-skarn. The third granite type contains Ta-bearing granite deposits (as at Urt Gozgor, Buural Khangai, Borkhujir) and W-Sn vein and Be greisen deposits (as at Tsagaan Davaa). Numerous Sn placers, including the very large Tsenkher Mandal Sn placer deposit, occur nearby. Greisen bears biotite and contains topaz-quartz, tourmaline-quartz, and muscovite-quartz zones.

The main references on the geology and metallogenesis of the belt are Gerel (1995, 1998), Koval (1998), Gerel and others (1999), Gerel and others (1999), and Tomurtogoo (2001).

Modot Sn-W Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Khasin, 1977; Jargalsaihan and others, 1996) consists of Sn-W quartz veins related to Mesozoic granite pluton with a K-Ar isotopic age of 199 to 175 Ma. The pluton intrudes Vendian and Early Cambrian metamorphic rock, Paleozoic granitoids and Permian molasse. The deposit occurs along the pluton margin in the pluton, or in adjacent hornfels. The veins dip gently and strike northwest to north. Some veins dip steeply. The ore minerals are cassiterite, wolframite, arsenopyrite, pyrite, galena, sphalerite, and chalcopyrite. Greisen alteration occurs. The deposit is small and has produced 300 tonnes of WO_3.

Tsagaan dabaa W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (fig. 9) (Khasin, 1977; Jargalsaihan and others, 1996) consists of quartz-wolframite veins and zones that occur in a multistage Late Triassic-Early Jurassic granite pluton. Veins mainly occur in the central elevated part of pluton that consists of fine- to medium-grained biotite and leucocratic granite. The veins are 2 km long, 200 to 500 m wide, and occur at different hypsometric levels. The veins form subhorizontal bodies dip gently south, southeast, and southwest, parallel with pluton roof. Ore minerals are wolframite, cassiterite, molybdenite, and beryl, and rare chalcopyrite and pyrite. Gangue minerals are garnet, fluorite, and biotite. Associated greisen and silica alteration is common. Assemblage of biotite and fluorite is characteristic of the deposit. The deposit is medium size and has a resource of 3,497 tonnes. Grade ranges from 0.1 to 12.6 percent WO_3.

Janchivlan Ta-Nb-REE Alkaline Metasomatite Deposit

This deposit (Kovalenko and others, 1971; Ivanov and others, 1996) is hosted in albite-lepidolite and amazonite-albite granite that occurs along the southwest contact of a Mesozoic Janchivlan pluton that occurs along the northwest trending Ulaandavaa fault. Associated with the granite and deposit are microcline alteration, quartz-lepidolite greisen, albite metasomatite, and quartz-muscovite greisen, and quartz veins. Granites are composed of albite, quartz, lepidolite, amazonite and microcline, and topaz. Accessory minerals are fluorite, columbite, monazite, Pb-pyrochlore, zircon, and cassiterite. Grade from surface to depth of 100 m is 60 g/t Ta (Ta/Nb= 1.2), 600 g/t Li, 800 g/t Rb, and 50 g/t Sn. The average grade is 0.001 to 0.011 percent Ta.

Avdrant Peralkaline Peralkaline Granitoid-Related Nb-Zr-REE Deposit

This deposit (Kovalenko and others, 1971) is hosted in an albite amazonite granite that occurs in the upper part of a

Mesozoic granite pluton with a K-Ar isotopic age of 222 to 172 Ma and in dikes in adjacent host rock. The albite-amazonite granite occurs in a rim of alaskiteor in the core of the pluton, is medium-grained, and composed of amazonite, albite, quartz and zinnwaldite. The amazonite-albite granite contains 330 to 1400 g/t Li, 6 to 75 g/t Ta, and 76 to 350 g/t Nb. The average grade is 0.007 percent Ta and 0.008 percent Nb.

Origin and Tectonic Controls for Central Hentii Metallogenic Belt

The Sn-W greisen, stockwork, and quartz vein in the belt are interpreted as having formed during generation of collisional granitoids of the Mongol-Transbaikal volcanic-plutonic belt during final closure of the Mongol-Okhotsk Ocean (Zonenshain and others, 1990; Kovalenko and others; 1995; Koval, 1998). The REE deposits are related to small plutons that are interpreted as having formed during a continental post-collisional event. The margins of this metallogenic belt are northeast-trending faults that may also be favorable for epithermal Au deposits and intrusion-related sedimentary-hosted deposits (Gerel and others, 1999).

Delgerhaan Metallogenic Belt of Porphyry Cu (±Au) (Au, Ag) and Granitoid-Related Au Vein Deposits (Belt DE) (Central Mongolia)

This Late Triassic metallogenic belt is related to granitoids in the Mongol-Transbaikalia volcanic-plutonic belt that intrudes Hangay-Dauria terrane, Ononsky terrane, and the Gobi-Khankaisk-Daxinganling volcanic-plutonic belt. $^{40}Ar/^{39}Ar$ isochron ages for two samples of plagioclase-biotite porphyry and for one sample of biotite granodiorite from Bayan Uul ore-field are 220 to 223 Ma (Lamb and Cox, 1998). The major deposits are the Bayan Uul district with porphyry Cu (±Au) vein and Au-Ag-Cu and explosive pipe occurrences, and the Unegt district with Au-Ag-Cu vein and Cu vein and explosive pipe occurrences. Porphyry Cu (±Au), granitoid-related Au and Cu occurrences occur at the junction of the Ovorhangai, Tov, and Dundgovi provinces. The main deposit is at Bayan uul 2.

The main references on the geology and metallogenesis of the belt are Yakovlev (1977), Gerel and others (1984), Dolgov and others (1984), Sotnikov and others (1984, 1985a,b), Koval and Gerel (1986), Gerel (1990), and Lamb and Cox (1998).

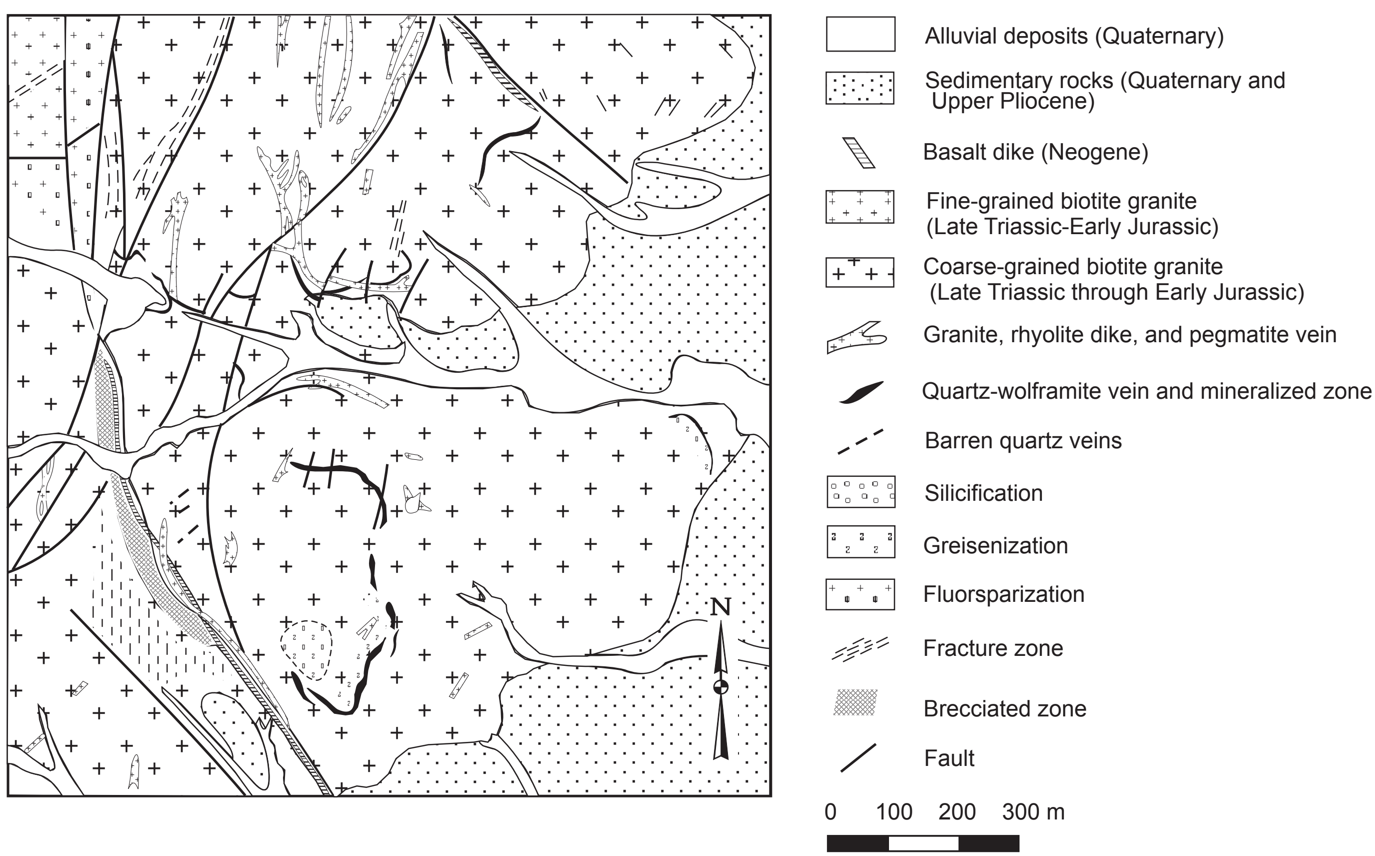


Figure 9. Geologic sketch map of Late Triassic through Early Jurassic Tsagaan dabaa W-Mo-Be greisen, stockwork, and quartz-vein deposit, Central Hentii metallogenic belt. Adapted from Marinov and others (1977).

Bayan Uul District

This district (Koval and others, 1989, G.A. Dolgov written commun., 1984; Ariunbileg and Khosbayar, 1998) occurs in the southeastern Delgerhaan area, and is related to tourmaline explosive breccia and subvolcanic granodiorite porphyry, granite porphyry, and syenite porphyry stocks and dikes that occur along a 2 by 2 km ring structure. The ring structure is in an intensely-developed caldera that exhibits advanced argillic and quartz-sericitic metasomatite with extensive pyrite. Cu deposits extend 150 m downdip in explosive breccia. Cu grade is not high on the surface. Average Cu grade is 0.2 percent for a width of 600 m and includes 8 to 10 linear zones with a total thickness of 100 to 120 m. The ratio of Cu:Mo is 16:1. Au and Ag deposits occur mostly in the margin of the district. Au grade ranges up to 2 g/t, with an average of 0.2 g/t, for a thickness of 47.5 m in a drill hole. Ag grade ranges from 4.3 g/t for a thickness 15.6 m, to 15 g/t for a thickness 1.0 m. Au grade is as much as 10 g/t in tourmaline-pyrite veins and breccia. Some tourmaline explosive breccia pipes in margin of the Delgerhaan district contains Cu high grade. The Unegt district occurs north-northwest of the Bayan Uul district and contains Au-bearing pyrite-quartz-tourmaline, pyrite-magnetite-hematite-quartz-tourmaline veins and breccia, and Cu-bearing tourmaline explosive breccia.

Bayan Uul 2 Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (G.A. Dolgov written commun., 1984; Koval and others, 1989, Ariunbileg and Khosbayar, 1998) consists of quartz-tourmaline-chalcopyrite veins in an area of pervasive sericite and argillic alteration. The deposit is hosted in an early Mesozoic volcanic-plutonic system that includes small porphyritic intrusions of diorite to granite. The alteration zone is nearly oval, is 3 km wide and extends northeast for 5 km. Major ore minerals are pyrite, chalcopyrite, bornite and peripheral sphalerite, galena, and Ag minerals. The deposit consists of stockwork veinlets and veins of quartz, pyrite, chalcopyrite, and molybdenite that occur in or near porphyritic intrusions. The veins contain mainly quartz and carbonate minerals. The high-level intrusive porphyry is contemporaneous with abundant dikes, faults, and breccia pipes, and hydrothermal alteration zonation is centered on the porphyry intrusion. The central part of alteration zone consists of K-feldspar and biotite alteration and is surrounded by phylitic, and peripheral propylitic alteration zones. The deposit at the surface contains greater than 0.1 percent Cu, greater than 0.002 percent Mo, and greater than 0.1 ppm Au across an area of 0.6k by 2.3 km. A zone 300 by 900 m contains >0.3 percent Cu, and 0.005 percent Mo. The deposit occurs in the center of a biotite and potassic alteration. Grades correlate positively with quartz-veinlet intensity. In the south-eastern area, a 40-m-thick leached cap occurs with As, Sb, Bi, Pb minerals and minor secondary Cu. The dominance of sericite and advanced argillic and silica alterations at the surface suggests a relatively shallow porphyry Cu system. The deposit contains-contact zone reserves of 300,000 tonnes of Cu.

Origin and Tectonic Controls for Delgerhaan Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during the final closure of the Mongol-Okhotsk Ocean and formation of the Mongol-Transbaikal arc. The age and origin of the Bayan Uul ore-field is similar to that of the Erdenetiin Ovoo ore-field in the Orhon-Selenge metallogenic belt. The Delgerhaan metallogenic belt may be a direct continuation of the Orhon-Selenge metallogenic belt. The Oyuthonhor porphyry Cu-Mo (±Au, Ag) occurrence and the Out Ovoo Cu tourmaline breccia occurrences are hosted in the Avzaga Basin that contains Middle and Late Triassic rock, and Late Triassic through Early Jurassic trachyandesite.

Govi-Ugtaal-Baruun-Urt Metallogenic Belt of Fe-Zn Skarn, Cu-Zn-Pb (±Ag, Cu) Skarn, Zn-Pb (±Ag, Cu) Skarn, Sn-Skarn, Fe-Skarn, and Porphyry Mo Deposits (Belt GB) (Central and Eastern Mongolia)

This Late Triassic through Early Jurassic metallogenic belt is related to replacements in the Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlies Idermeg terane and Gobi-Khankaisk-Daxinganling volcanic-plutonic belt. The major deposits are the Tomortiin Ovoo Fe-Zn skarn deposit and the Oortsog Sn-skarn deposit.

The two major Govi-Ugtaal-Bayanjargalan and Salhit districts are at the southwestern and northeastern ends of the belt, respectively. A few Fe-skarn deposits and occurrences are between these two major districts in Borondor area. Major three types of skarn occur (1) Fe-skarn at Mandalyn Hiid, Sainshand hudag,; (2) Fe-Zn skarn at Tomortei; and (3) Fe-Sn skarn at Oortsog in the Goviugtaal-Bayanjargalan district. These skarns are closely related to Late Triassic and Early Jurassic alkaline alaskite and granite stocks (Dorjgotov, 1996). Fe-skarn consists mostly of pyroxene, phlogopite, garnet, magnetite, and hematite, and Fe-Zn skarn consists mostly of andradite, pyroxene, epidote, quartz, magnetite, sphalerite, galena, and pyrite. Fe-Sn skarn consists mostly of pyroxene, andradite, vesuvianite, actinolite, epidote, magnetite, molybdenite, and cassiterite. Hematite, sphalerite, molybdenite, and pyrite occur in all three types, but in varying amounts. Fe-skarn and Fe-Zn skarn occur mostly in the Salhit district near Baruunurt city. Salhit and Tomortein Ovoo deposits are Fe-Zn skarn deposits, however, sphalerite is dominate. The deposits are hosted in Devonian carbonate and sedimentary rock along the contact of subalkaline biotitic granite (Podlessky and others, 1988). Ore assemblages are: magnetitic-hematite, sphalerite-magnetite, and sphalerite. Sphalerite is major ore mineral in magnetite-sphalerite and sphalerite skarn, and ranges from 45 to 90 percent. Other sulfides are minor molybdenite, chalcopyrite, and pyritec and galena, and compriseless than 5 to

10 percent ore. Above mentioned three skarns are overprinted on clinopyroxene, clinopyroxene-garnet, and garnet skarn (Podlessky and others, 1998).

The main references on the geology and metallogenesis of the belt are Fillippova and Vydrin (1977), Batjargal and others (1997), Yakovlev (1977), Podlessky and others (1988), and Tomurtogoo and others (1999).

Tumurtiin-Ovoo Fe-Zn Skarn Deposit

This deposit (Yakovlev, 1977; Podlessky and others, 1998; D. Dorjgotov, written commun., 1990) consists of a calcic skarn that occurs along the contact between Devonian limestone and a Mesozoic subalkaline granite. The skarn is elongated to the northwest and dips concordantly with host rock to the southwest. The skarn extends for about 800 m along strike, 480 m downdip in the central part, and 200 to 230 m downdip on the eastern and western flanks. Average thickness is 14 m. The major minerals are andradite, hedenbergite, grossular, epidote, quartz, and wollastonite. The deposit is zoned, and the major ore minerals are sphalerite and magnetite. The deposit is large with resources of 750,000 tonnes Zn and 1,770 tonnes Cd. The average grades are 17 percent Fe, 9.9 to 13.1 percent Zn.

Oortsog ovoo Sn-Skarn Deposit

This deposit (Podlessky and others, 1998, Jargalsaihan and others, 1996) consists of a steeply dipping skarn that forms sheets like along the contact between a late Paleozoic granite pluton and marble with beds of calc-silicate schist. The skarn sheets range from 200 to 1500 m long, 5 to 80 m wide, comprise as much as 25 lenticular bodies composed of garnet, pyroxene, and magnetite, and Sn and base metal minerals. Three stages are: (1) an early stage of pyroxene-garnet and magnetite; (2) cassiterite, stannite, lollingite, Zn sulfide, Pb sulfide, Cu sulfide, and Fe sulfide, and (3) less common fahlore, enargite, bismuthite, and scheelite. Also occurring are hypergene cerussite, smithsonite, anglesite, greenockite, martite, montmorillonite, kaolinite, and gypsum. Grades are 0.02-1.28 percent Sn, 0.001 to 0.06 percent W, 0.02 to 1.28 percent Zn, and 0.01 to 0.9 percent Cu. Reserves are 39,200 tonnes Sn, 11,500 tonnes Zn, and 1.500 tonnes Cu.

Origin and Tectonic Controls for Govi-Ugtaal-Baruun-Urt Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc. The belt is hosted in Late Triassic through Early Jurassic age alaskite, granite, and alkaline granite of the Mongol-Transbaikalia volcanic-plutonic belt. The deposits ae hosted in an alaskite granite and alkaline granite plutons (Dorjgotov, 1996).

Harmorit-Hanbogd-Lugiingol Metallogenic Belt of Sn-W Greisen, Stockwork, and Quartz Vein, REE (±Ta, Nb, Fe) Carbonatite, Peralkaline Granitoid-related Nb-Zr-REE, and REE-Li Pegmatite Deposits (Belt HL) (Mongolia)

This Middle Triassic through Early Jurassic metallogenic belt is related to replacements and granitoids in the South Mongolian volcanic-plutonic belt that intrudes and overlaps the Hutaguul-Xilinhot and Gurvansayhan terranes and Lugyngol overlap volcanic and sedimentary basin. The carbonatite related REE deposit at Lugiin gol, the REE – Nb-Zr alkaline granite and pegmatite deposit at Khanbogd, and Sn-occurrences at Kharmorit are related to high alkaline potassic granitoid and Li-F facies leucogranite. The deposits are related to the Khalzan uul Complex with a Rb-Sr isotoic age of 194±9.06. The major deposits are at Khar morit, Lugiin gol, and Khanbogd. Also occurring are associated Sn placer deposits.

The main references on the geology and metallogenesis of the belt are Kovalenko and others (1974), Koval and others (1982), Luchitsky (1983), Ruzhentsev and others (1992), Amory and others (1994), Batbold (1998), and Munkhtsengel and Iizumi (1999).

Lugiin Gol REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (Jargalsaihan and others, 1996; Batbold, 1998) consists of bastneasite carbonatite dikes that occur mainly along the contact zone of the Lugingol alkaline nepheline syenite pluton that intrudes Permian sedimentary rock of the Lugin gol Formation (Batbold, 1998). For the Lugiin gol nepheline syenite pluton a Rb-Sr whole rock isochron age is 244±22.4 Ma and a Rb-Sr whole rock-mineral isochron ages are 222±3.2 and 199 to 180 Ma (Kovalenko and others, 1974; Munkhtsengel and Iizumi, 1999). K-Ar isotopic ages range from 242 to 228 Ma. A linear to oval eruptive breccia, cemented by carbonatite, crops out in the western part of the pluton. Carbonatite veins occur in the pluton, host rock, and along the contact. Pluton is altered fluorite, feldspar, sericite, hematite, and Fe sulfides. The veins trend north or east, are as much as 430 m long, and are 0.1 to 0.8 m thick. Synchysite is predominant ore mineral and gangue minerals are fluorite and calcite. The deposit is small and has reserves of 14,000 tonnes grading 0.5-3.5 percent TR_2O_3, 50.7 percent Ce, 33.0 percent La, 5.0 percent Nd, 2.85 percent Sr, 1 to 5 percent Ba, 0.03 to 0.3 Y, and 5 to 20 percent CaF_2.

Khan Bogd Ta-Nb-REE Alkaline Metasomatite Deposit

This deposit (Vladykin and others, 1981; Jargalsaihan and others, 1996) is hosted in an alkaline granite pluton composed of medium-grained arfvedsonite-aegirine granites with dikes of eckerites, pantellerites, grorudits, and alkaline pegmatite with REE. Pegmatite is composed of microcline, quartz, arfvedsonite, and elpidite, and local aegirine. The metasomatic zone contain aegirine and elpidite. The uppermost part of the pluton contains elpidite and Ti-silicate, and accessory polilitionite, synchisite, monazite, sphene, and other REE minerals. Grades are as much as 2 to 3 percent, REE, 1 percent Nb, 0.07 percent Th, and 7 to 8 percent Zr. REE are concentrated in synchizite, monazite, and sphene. Zr is concentrated in elpidite and armstrongite. The average grades are 620 g/t Nb_2O_3, 0.8 percent TR_2O_3, and 0.04 percent Hf.

Khar morit Sn-W Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Amory and others, 1994; Armory, 1996, Batbold, 1998) consists of zones of greisen and veins in the apical part of a Li-F granite porphyry stock and in adjacent host rocks. The granite has a Rb-Sr isochron age of 194± 9.06 Ma. The zones extend from 100 to 500 m long and as much as 3 m wide. The deposit has two parts: cassiterite-wolframite-quartz vein, and cassiterite-wolframite-zinwaldite-quartz greisen; and (2) cassiterite-sulfide with Sn, Cu, Pb, and Zn. The ore minerals are cassiterite, pyrite, arsenopyrite, galena, sphalerite, and chalcopyrite, and rare scheelite and wolframite. Gangue minerals are quartz, muscovite, zinnwaldite, beryl, tourmaline, sericite, and chlorite. The most common minerals are topaz and fluorite. A well developed oxidized zone contains relics of sulfides and secondary minerals. Sn is very irrregular and sometimes very high. The deposit exhibits a complex mineralization and includes Sn-sulfide, Zn-Pb and Be, Sn-W greisen, and Sn-W vein stages. The various stages are zoned and occur in the altered cupola of the stock with wolframite and cassiterite, in the contact hornfels with cassiterite and sulfides, and with cassiterite in host sandstone and shale. Associated Sn placer deposits also occur. The deposit is small and has resources of 780 tonnes of Sn and 65 tonnes of WO_3.

Origin and Tectonic Controls for Harmorit-Hanbogd-Lugiingol Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc.

Kalgutinsk Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz Vein, Ta-Nb-REE Alkaline Metasomatite Deposits (Belt KG) (West Siberia, Gorny Altai Mountains, Russia)

This Early Jurassic metallogenic belt is related to granitoids and replacements related to the Belokurikha plutonic belt (too small to show at 10 M scale) that intrudes the Altai and West Sayan terranes. The belt occurs in the southern part of Gorny Altai region in southern Eastern Siberia and Mongolia, extends along a sublatitudinal trend for 300 km, and ranges from 80 to 100 km wide. The belt belt is hosted in early Mesozoic REE plumasite granite plutons that are composed of porphyritic biotite granite, leucogranite, and muscovite-tourmaline pegmatite. Also occurring are local Li-Cs ongonite and spodumene granite porphyry (Dergachev, 1989; Vladimirov and others, 1996, 1997; Dovgal and others, 1997). REE deposits occur in granite plutons and along exocontact zones in contact metamorphosed host rock that is mainly Cambrian and Ordovician flysch. Local associated scheelite deposits also occur (Urzarsaiskoye deposit). The major deposit is the large Kalgutinskoye W-Mo-Be greisen, stockwork, and quartz-vein deposit that is being mined. Another prospective, medium-size deposit is the Akalakhinskoye Li-Ta-Nb-REE deposit that is hosted in an alkali metasomatite.

The main references on the geology and metallogenesis of the belt are Sotnikov and Nikitina (1977), Dergachev (1989), Il'in and others (1994), Shokalskiy and others (1996), Vladimirov and others (1996, 1997), and Dovgal and others (1997).

Kalgutinskoye 1 W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Sotnikov and Nikitina, 1977; Sharov and others, 1998) consists of quartz veins that occur in Kalguta granite pluton and in adjacent country Devonian extrusive rock. The deposit consists of more than 300 veins that occur in a northeastern-striking band that is about 2 km long and as much as 500 m wide. Single veins range from a few meters to 330 m long. The quartz veins are divided into W, W-Mo, and Mo types. Major minerals are wolframite, molybdenite, chalcopyrite, pyrite, beril, muscovite, fluospar, scheelite, feldspar, and topaz. Veins are associated with greisen that contains dissiminations and nests of ore minerals. A pipe of muscovite and quartz greisen occurs in porphyry granite and consists of breccia with granite fragments and matrix intensely altered to greisen. The ore minerals occur in the altered matrix and are disseminated molybdenite, chalcopyrite, pyrite, and rare wolframite. The deposit is large and has reserves of 12,000 tonnes of WO_3, 5,500 tonnes of Mo; 235 tonnes of Bi_2O_3; and 48 tonnes of BeO. The average grades are 1.9 percent WO_3; 0.36 percent Mo; 0.11 percent Bi_2O_3; 0.35 percent Be.

Urzarsaiskoye W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Obolenskiy, 1960; Sotnikov and Nikitina, 1977; Kuznetsov and others, 1978) consists of a stockwork of scheelite-bearing veinlets hosted in contact metamorphosed and locally in weakly metasomatized Cambrian and Early Ordovician sandy shale. The stockwork is 600 m long, 400 m wide, and extends as much as 500 m at depth. The stockwork consists of a dense network of quartz, quartz-feldspar, and quartz-feldspar-carbonate veinlets with scheelite, fluorite, beryl, chalcopyrite, and pyrite. Increased W occurs in quartz-feldspar veinlets. Mo increases downward. Wall rocks are silicified and altered to greisen and sericite. The thickness of the veinlets varies from 0.2 to 15 cm and averages 0.5 to 4 cm. Veinlets comprise from 10 to 30 percent of the host rocks. The deposit is large and has reserves of 100,000 tonnes. The average grade is 0.11 percent WO_3, with as much as 0.3 percent WO_3.

Akalakhinskoye (Alakha) Ta-Nb-REE alkaline MetasomatiteDeposit

The deposit (Vladimirov and others, 1997) consists of a stock (with dimensions of 1 by 1.5 km) of spodumene-granite porphyry and biotite porphyry granite in the main phase of the Chindagatui pluton. The spodumene granite porphyry is white with a fine-grained groundmass of albite, quartz, and muscovite. Phenocrysts range as much as 1 cm and are composed of quartz and spodumene (10 to 30 percent) and local microcline and muscovite. Accessory minerals are columbite, tantalite, magnetite, and garnet. Grades range from 50 to 150 ppm Ta, 120 to 264 ppm Nb, 3700 to 5100 ppm Li, 1200 ppm Rb, and 260 ppm Cs. Spodumene aplite and muscovite aplite dikes also occur. Muscovite aplite and spodumene granite porphyries are interpreted as having formed in the late stage of crystallization of the pluton, significantly after intrusion of the early stage granite that comprises the major part of the pluton.The Ta-bearing spodumene granite porphyry and aplite are the analogues of spodumene and REE pegmatite and contain high Ta, Nb, Li, Rb, Cs, Sn, and Be. The deposit is medium size and has reserves of 128 million tonnes. The average grades are 0.8 percent Li_2O, 0.01 percent Ta_2O_5, 0.01 percent Cs, and 0.08 percent Rb.

Baliktigkhem W-Sn-W Greisen, Stockwork, and Quartz Vein Deposit

The deposit (Matrosov and Shaposhnikov, 1988) consists of cassiterite-quartz veins and greisen zones in the apical part of a Devonian granite pluton. The greisen contains tourmaline, topaz, cassiterite, pyrite, arsenopyrite, and beryl. The ore minerals are more abundant in veins and lenses of quartz, muscovite-quartz, and siderophyllite-quartz. Cassiterite is irregularly disseminated and also occurs in nests in veins. The deposit is small.

Origin and Tectonic Controls for Kalgutinsk Metallogenic Belt

The belt is interpreted as having formed during generation of REE granitoids along transpression zones (Hovd regional fault zone and companion faults) that formed during final closure of the Mongol-Okhotsk Ocean. The REE deposits are genetically related to early Mesozoic REE plumasite granite in the Belokurikha plutonic belt. The age of hosting granite is Late Triassic and Early Jurassic. Rb-Sr isotopic ages are 201.0±1.5 Ma for the Chindagatui pluton, and 204.0±1.6 Ma for the Kalguta pluton-(Vladimirov and others, 1997). The initial $^{87}Sr/^{86}Sr$ ratio is 0.7069 to 0.7103 indicating an incorporation of significant crustal rock. The U-Pb ages of Ta spodumene granite in the Alakha stock are 188 and 183 Ma, whereas the Rb-Sr age is 195±3 Ma (Il'in and others, 1994). The Rb-Sr age of Li-F granite porphyry in the Dzulaly stock is 188.0±6.4 Ma (Dovgal and others, 1997). The belt of REE granite intrudes a middle Paleozoic continental-margin arcs consisting of a calc-alkalic volcanic-plutonic belts (Shokalskiy and others, 1996).

Mino-Tamba-Chugoku Metallogenic Belt of Volcanogenic-sedimentary Mn, Podiform Chromite, and Besshi Cu-Zn-Ag Massive Sulfide Deposits (Belt MTC) (Japan)

This Permian (or older) to Jurassic metallogenic belt is hosted in structural units in the Mino-Tamba-Chichibu and Akiyoshi-Maizuru subduction-zone terranes. The belt occurs in the western part of Honshu Island in the Inner Zone of southwestern Japan, trends east-northeast to west-southwest for more than 900 km, and is as much as 150 km wide. The eastern margin of the belt is the Tanakura tectonic line. Tsuboya and others (1956) named the belt the Chichibu geosyncline Fe-Mn metallogenic province. The North Kitakami metallogenic belt is interpreted as an eastern extension of this belt. The Mino-Tamba belt contains a large number of various types of deposits. Mn deposits are hosted in the Mino-Tamba-Chichibu terrane, and podiform chromite and Besshi Cu-Zn-Ag massive sulfide deposits are hosted in in the Akiyoshi-Maizuru terrane. The Mino-Tamba-Chichibu terrane is a Jurassic accretionary complex, and Mn deposits are associated with Triassic and Jurassic chert. Podiform Cr deposits occur in ophiolite in the pre-Permian Sangun metamorphic complex. Massive sulfide deposits occur in the Permian forearc Maizuru group. The significant deposit is at Awano.

The main reference on the geology and metallogenesis of the belt is Tsuboya and others (1956).

Wakamatsu Podiform Chromite Mine

This deposit (H. Miyake and others, written commun., 1997) occurs in serpentinite derived from dunite of the Tari-Misaka ultramafic body in the Sangun belt. The ultramafic body is mostly composed of massive harzburgite and dunite. The ultramafic rocks are contact metamorphosed by a Cretaceous granite. The mine contains three main ore bodies. Main number 7 body is 190 m long, 60 m wide, and 30 m thick and yielded 1 million tonnes of ore. The ore mineral is refractory grade chromite. Serpentine and olivine occur in the ore. The deposit was discovered in 1899, and the mine closed in 1994. The deposit is medium size and it produced 780,000 tonnes of ore grading 32 percent Cr_2O_3.

Yanahara Besshi Cu-Zn-Ag Massive Sulfide Mine

This mine (Mining and Metallurgical Institute of Japan, 1965; Dowa Mining Corporation, 1981) consists of the main Yanahara ore body and nine smaller ore bodies. The ore bodies are stratiform and lenticular and occur in a 4.5 by 2 km area. The Yanahara deplsit consists of the upper, lower, and lowest ore bodies. The upper body is 350 m long along strike, extends 1,000 m down dip, and is as much as 100 m wide. The lower ore body is similar. The main ore mineral is pyrite; minor ore minerals are pyrrhotite, magnetite, chalcopyrite, and sphalerite. Gangue minerals are quartz, sericite, and chlorite. The deposit is hosted in rhyolite pyroclastic rock and mudstone of the Paleozoic Maizuru Group. The deposit occurs immediately above the basalt of the Yakuno Group. The mine started in 1916 and closed in 1991. The mine is medium size and has reserves of 3.7 million tonnes grading 44 percent Fe, 47 percent S, 0.2 percent Cu, and 0.3 percent Zn.

Hamayokokawa Volcanogenic-Sedimentary Mn Mine

This mine (Mining and Metallurgical Institute of Japan, 1968; Uemura and Yamada, 1988) is located in the Yokokawa (Shiojiri) Mn deposit district that contains 17 deposits. The Hamayokokawa deposit contains six main ore bodies. The main ore body is 50 m long, 8 m thick, and extends 120 m down dip. The ore bodies occur in Paleozoic and Mesozoic chert and slate of the Mino belt. The ore minerals are rhodochrosite, hausmannite, manganosite, rhodonite, tephroite, and braunite. The mine closed in 1984. The mine is medium size, and produced 260,000 of tonnes ore grading 33 to 42 percent Mn.

Origin and Tectonic Controls for Mino-Tamba-Chugoku Metallogenic Belt

The belt is hosted in a subduction-zone complex composed of marine sedimentary and volcanic rock and fragments of oceanic crust with ultramafic rock. The Besshi deposits are interpreted as having formed along a spreading ridge. In the oceanic crustal fragments are podiform chromite deposits hosted in ultramafic rocks and chert-hosted Mn deposits. The deposits and host rocks were subsequently incorporated into an accretionary wedge of the Mino-Tamba-Chichibu subduction-zone terrane.

Mongol Altai Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposits (Belt MA) (Western Mongolia)

This Late Triassic(?) to Early Jurassic(?) metallogenic belt is related to small bodies of leucogranite that intrude the Altai and Hovd Hovd terranes. The belt extends northeast to east (Kovalenko and others, 1988) and subsequently defined the late Paleozoic east-west-trending North Hangai-Selenge metallogenic belt of REE deposits (Kovalenko and others, 1990). Three major mineral districts occur along the northwest-striking Hovd regional fault zone (Borisenko and others, 1992). Herein, we interpret the northwest-striking, early Jurassic Mongol Altai metallogenic belt that occurs along the major Hovd fault zone. The major deposits are at Ulaan Uul and Tsunkheg.

The main references on the geology and metallogenesis of the belt are Luchitsky (1983), Kovalenko and others (1988, 1990), Borisenko and others (1992), and Dandar and others (1999).

Ulaan uul W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Amitan, 1993; A.N. Demin and others, written commun., 1990; S. Dandar and others, written commun., 1999) consists of about 40 northeast-trending quartz-wolframite veins that occur in the western part of the Jurassic Ulaanuul leucocratic granite pluton. The veins are as much as 1000 m long and from 0.1 to 1.5 m wide and contain beryl, molybdenite, Y-bearing fluorite and sulfides. The Ulaanuul pluton is 10 by 2.5 km in size and is elongated northwest along the major Khovd fault. K-Ar isotopic ages range from 200 to 180 Ma, and Rb-Sr isochron ages are 180 to 170 and 196 ± 20 Ma. Granite pluton consists of porphyritic coarse-grained biotite granite, medium-grained microcline granite, and microcline-albite leucogranite. The deposit is small and has reserves of 2,280 tonnes WO_3 and resources of 5,870 tonnes of WO_3, 8.4 tonnes of Nb, and 500 kg of Y.

Tsunkheg W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Jargalsaihan and others, 1996) consists of complex vein and W stockwork that are hosted in a northeast-trending zone of Ordovician-Silurian sandstone, siltstones, tuffstone, and tuffaceous siltstone. Host rock is altered to sulfides, contact metamorphosed, and intruded by minor bodies of gabbro and diabase. Three steeply-dipping quartz-wolframite veins extend for 200 to 300 m along strike, more than 100 m downdip, and range from 0.3 to 0.45 m thick. The northeast-trending zone extends for 950 m and is as much as 270 m wide, and extends to a depth of 300 m. The ore mineral assemblages are scheelite-quartz-feldspar-molybdenite, wolframite-quartz-pyrite-pyrrhotite-scheelte-chalcopyrite, and sporadic quartz-carbonate. The deposit is large with resources of 8,000 tonnes of WO_3 grading 0.1 to 40 percent WO_3 and average grade of 2.39 percent WO_3; 50,000 tonnes of WO_3 grading 0.12 to 0.2 percent WO_3, 100 g/t Ag, 0.5 to 1.0 percent Cu, 1 percent Sb, 0.5 to 1.0 percent Zn, and 2 percent As.

Origin and Tectonic Controls for Mongol Altai Metallogenic Belt

The belt is interpreted as having formed during Mesozoic intraplate rifting related to magmatism along transextension zones. The belt is hosted in granitoids that intrude along the major Early Jurassic Hovd fault zone. In this region various REE deposits are related to Middle Devonian collisional, Carboniferous postcollisional, and Permian and Early Jurassic late-stage and post-orogenic granitoids (Dandar and others, 1999). For the Mongol Altai metallogenic belt, the W-Mo-Be deposits and occurrences in the Ulaan Uul ore-field are related to Early Jurassic granite. The major deposits are the Ulaan Uul and Tsunheg W-Mo-Be deposits; the Tsunheg II, Buraat and Mo stockwork; and W-Mo occurrences in the Ulaan Uul district. The Maraagiin (W, Sn, Mo) and Bodonchiin (W-Sn) districts are similar to the Ulaan Uul district. This belt is interpreted as having formed during Mesozoic continental interplate rifting associated with a mantle plume.

North Hentii Metallogenic Belt of Granitoid-Related Au Vein and Au in Shear Zone and Quartz Vein Deposits (Belt NH) (North Mongolia)

This Middle Triassic through Middle Jurassic metallogenic belt is related to granitoids in the Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlaps Zag-Haraa turbidite basin. The granitoids that host granitoid-related Au deposits consist of small intrusive stocks and dikes and are part of the Yoroogol gabbro and granite sequence (Koval and Tsypukov, 1977; Koval and others, 1982) that consists of small hypabyssal stocks and dikes in the margin of a calc-alkaline granitoid baholith in northeast-striking zone bounded by the Bayangol fault to the northwest and the Yoroogol fault to the southeast. These early Mesozoic intrusive stocks consist of simple gabbro, and (or) multiphase plutons composed of gabbro, diorite, and granite, and single granite plutons with abundant gabbro schlieren. The Au deposits occur throughout and the Sn deposits occur in simple granite stocks (Tsypukov, 1977). The Yorogol sequence contains abundant variable composition dikes and hydrothermal-metasomatitic alterations. The K-Ar isotopic age of the Yoroogol sequence ranges from 235 to 166 Ma (Koval and others, 1982). REE granite in the Yorogol sequence is mostly Jurassic.

The north and northwestern marginal part of the Central Hentei REE belt of Sn and Sn-W greisen, stockwork, and quartz-vein deposits, described below, is overprinted on the eastern and southeastern margin of the North Hentii 2 metallogenic belt. This North Hentii metallogenic belt was previously defined as a multiple age Au metallogenic belt containing early Paleozoic and early Mesozoic age hard rock Au, Late Cretaceous Au-bearing conglomerate, and placer Au deposits and occurrences (Blagonaravov and Shabalovskii, 1977; Blagonravov and Tsypukov, 1978; Poznyak and Dejidmaa, 1977; Blagonravov and others, 1984; Tcherbakov and Dejidmaa, 1984).

From northeast to southwest, the granitoid-related Au vein deposits and occurrences are at Yorogol, Boroo-Zuunmod, and Zaamar-Ugtaaltsaidam (Dejidmaa, 1996). Only early Mesozoic granitoid-related Au deposits occur in the Boroo-Zuunmod district, Yorogol district, in the Ugtaaltsaidam-Argalynnuruu group in the Zaamar-Ugtaaltsaidam district, and in the Zaamar group of the Zaamar-Ugtaaltsaidam district. Also occurring are a few early Mesozoic Au quartz deposits or disseminated Au-sulfide and quartz-vein deposits that are hosted in a metasomatitic zone (Dejidmaa, 1985). The Narantolgoi, Boroo 7, Tsagaanchuluut, Ereen, Urt and Baabgait deposits in the Boroo-Zuunmod district are typical Au-quartz-vein deposits. The Boroo and Sujigt deposits contain both large disseminated Au-sulfide deposits and high-grade Au-quartz veins. These deposits are hosted in early Paleozoic clastic rock, Devonian granite, Late Devonian through early Carboniferous subvolcanic rhyolite, and early Mesozoic granodiorite. The Au deposits in the North Khenti belt are interpreted as having formed during multistage hydrothermal activity related to multistage dikes. For example, gabbro and diabase dikes formed before the deposits, while diorite dikes intruded between the early disseminated Au-pyrite-arsenopyrite and the middle disseminated Au-pyrite-beresite stages of mineralization in the large Boroo deposit (Dejidmaa, 1985).

The main references on the geology and metallogenesis of the belt are Gottesman (1978), Blagonravov and others (1984), Tcherbakov and Dejidmaa (1984), and Dejidmaa (1985).

Boroo Granitoid-Related Au Vein Deposit

This deposit (fig. 10) (R. Barsbold and others, written commun.,1960; R. Khenel and others, written commun., 1968, 1970; G. Choren and others, written commun., 1986, 1988; Cluer and others, 2005) occurs along a major sublatitudinal fault zone that dips gently north and cuts sedimentary rock in the early Paleozoic Khara Group of the early Paleozoic Borogol granitoid complex. These rocks are intruded by early Mesozoic gabbro, diabase, and diorite dikes that are altered and host the deposit. The deposit extends approximately 2.0 km along strike and ranges from 3 to 34 m thick. The ore mineral assemblages, from older to younger, are preore epidote-chlorite; quartz-sericite-albite-chlorite; gold-pyrite-arsenopyrite-K-feldspar-quartz; gold-beresite; quartz; gold-sulphide-quartz vein; and postore calcite. Gold is fine-grained and occurs in pyrite and arsenopyrite and as free gold in quartz veins. Fineness of gold varies from 700 to 940. Main ore minerals are pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, tetrahedrite, and gold. Main gangue minerals are quartz, sericite, iron-carbonates, calcite, albite and muscovite. Sulphides comprise 5 to 25 percent in replacements and 1 to 2 percent in quartz veins. The average grade is 3.0 g/t Au in the replacement zone and 10 to 20 g/t Au in quartz veins in the replacement zone. The deposit was mined through openpit and underground workings from 1948 to 1955. The deposit contains reserves of 40.0 tonnes grading 3.0 g/t Au.

Sujigt Granitoid-Related Au Vein Deposit

This deposit (R. Kruse and others, written commun., 1970; Jargalsaihan and others, 1996) consists of quartz veins and stockwork that occurs along a northeast-striking minor fault-altered zone that cuts early Paleozoic granite and granodiorite of the Boroogol Complex. The fault zone is a part of the Sujigtgol regional fault and occurs between a middle Paleozoic rhyolite subvolcanic body and early Paleozoic granodiorite-granite massif. The deposit includes five main quartz veins that range from 110 to 250 m long, 0.27 to 0.48 m wide, and dip southeast to northeast. Grades range from 10 to 25 g/t Au. A lower grade stockwork occurs between the veins. Primary ore minerals are pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, tetrahedrite, burnonite, altite, and gold. Ore minerals in the oxidized zone are limonite, covellite, chalcocite, malachite, azurite, and cerussite. Sulphides comprise from 2 to 10 percent veins. The deposit extends to 275 m below the surface with downward decrease in Au grade and thickness of the Main vein. The deposit deposit was discovered by Mongolor joint venture in 1913 and mined from 1914 to 1916. The deposit is medium size with resources of 2,918.2 kg Au, and 975.1 kg Ag.

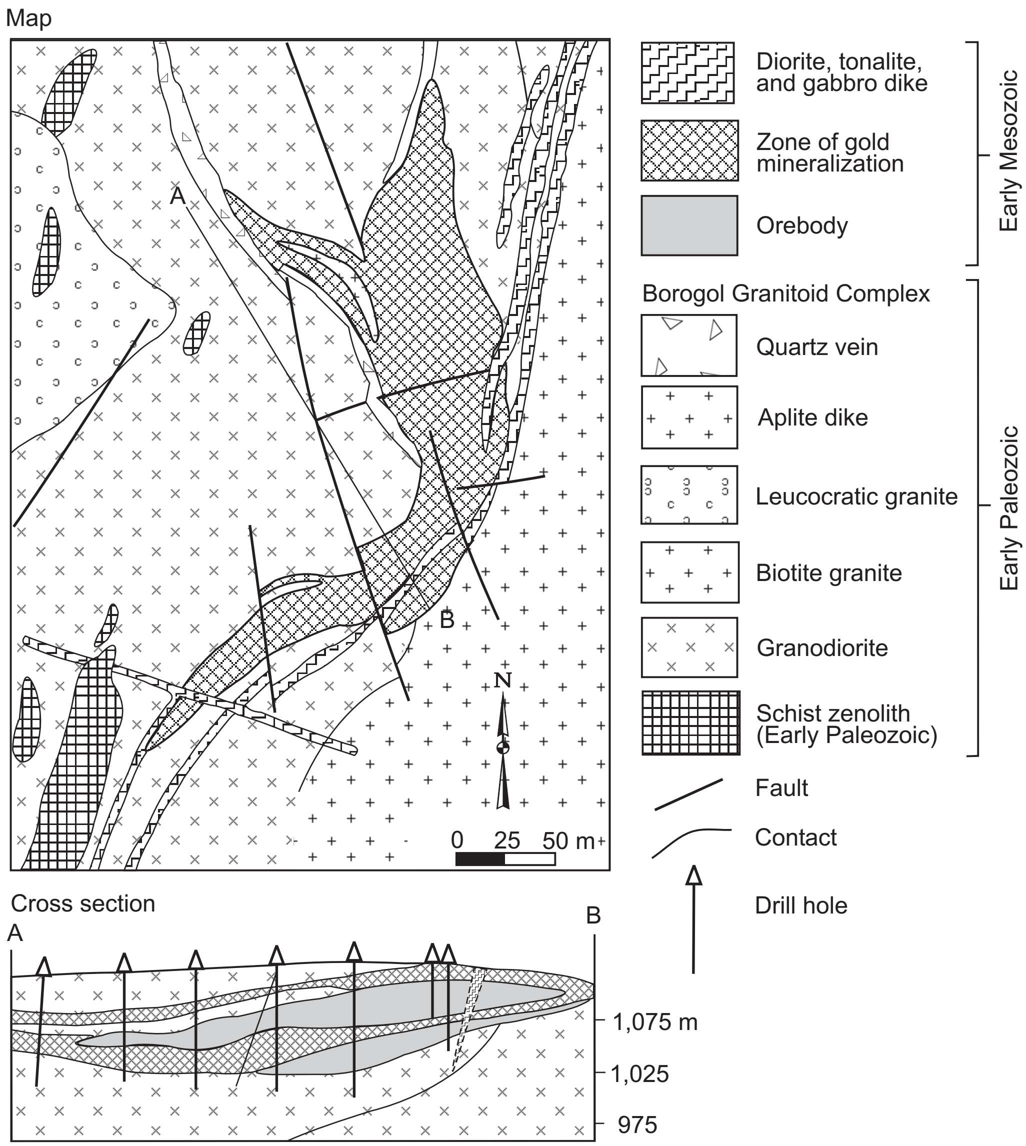


Figure 10. Geologic sketch map of Boroo granitoid-related Au vein deposit, North Hentii metallogenic belt. Adapted from Jargalsaihan and others (1996) and Cluer and others (2005).

Origin and Tectonic Controls for North Hentii Metallogenic Belt

The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc. The metallogenic belt is overprinted on the Orodovician Zaamar-Bugant Au quartz vein belt. The granitoid-related Au-vein deposits of the North Hentii belt are clearly distinguished by intrusives, mineralogy, and deposit morphology.

North Kitakami Metallogenic Belt of Volcanogenic-Sedimentary Mn and Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposits (Belt NK) (Japan)

This Triassic through Early Cretaceous metallogenic belt is related to stratiform units in the Mino Tamba Chichibu subduction-zone terrane. The belt occurs in the northern Kitakami Mountains, trends approximately north-south for more than 150 km, ranges up to 75 km wide, and occurs north of the Hayachine tectonic line. The metallogenic belt may extend further northwest onto southwestern Hokkaido Island. In the northern Kitakami mountains, two tectonic units are defined, the Kuzumaki-Kamaishi and Akka-Tanohata belts (Okami and Ehiro, 1988) that are separated by the Iwaizumi tectonic line. The Kuzumaki-Kamaishi belt consists of chert, limestone, and clastic rock. The chert and limestone form olistoliths in the clastic rocks. The olistolith ages range from Permian through Early Jurassic, and the age of clastic rock is Middle Jurassic through Late Cretaceous. The units form a typical Jurassic accretionary complex. The Akka-Tanohata belt consists of Middle Jurassic through Early Cretaceous shale, sandstone, mafic pyroclastic rock, limestone, and abundant Triassic through Jurassic chert. Early Cretaceous siliceous tuff, black shale, and andesitie occur in the eastern Akka-Tanohata belt and host the Kuroko Taro deposit. Manganese deposits occur in or adjacent to the chert. The belt contains a large number of stratiform Mn deposits, and one Kuroko massive sulfide deposit occurs in the belt. Tsuboya and others (1956) defined the Chichibu geosyncline Fe-Mn metallogenic province that contains the Mn deposits of the North Kitakami metallogenic belt. The significant deposits are at Nodatamagawa and Taro.

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956) and Okami and Ehiro (1988).

Nodatamagawa Volcanogenic-Sedimentary Mn Mine

This mine (fig. 11) (Mining and Metallurgical Institute of Japan, 1968) consists of three major stratiform ore bodies hosted in Jurassic chert. The ore bodies are stratiform or lenticular and are controlled by folding in the host chert. Cretaceous granite occurs near, and have contact metamorphosed the deposit with formation of biotite and cordierite in the slate around the deposit. The ore bodies are 600 m long and 1m thick. The ore minerals are rhodonite, tephroite, pyrochroite, hausmannite, rhodochrosite, and brounite. The gangue mineral is quartz. The ores are typically zoned with a central pyrochroite-haumannite, medial tephroite, and the outermost rhodonite that is adjacent to wall rock chert. The deposit is medium size and has produced 311,600 tonnes of Mn grading 30 to 35 percent Mn.

Taro Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type) MIne

This mine (Mining and Metallurgical Institute of Japan, 1965) consists of seven main bodies that strike in a northwest direction and dip southwest at 60 to 70 degrees. The main body extends 500 m along strike and ranges as much as 12 m thick. The main ore minerals are chalcopyrite, pyrite, galena, sphalerite, pyrrhotite, magnetite, and chalcocite. Gangue minerals are chlorite, calcite, and quartz. Host rocks are Mesozoic shale and sandstone. Mining started in 1854. The deposit is smalland has produced 36,857 tonnes of Cu, 18,942 tonnes of Zn, 5,825 tonnes of Pb grading 0.8 percent Cu.

Origin and Tectonic Controls for North Kitakami Metallogenic Belt

The Mn deposits are interpreted as having formed in a syngenetic setting on the ocean floor. The Kuroko deposits are interpreted as having formed in an island arc. The deposits and host rocks were subsequently incorporated into an accretionary wedge.

North Taimyr Metallogenic Belt of Granitoid-Related W-Mo-Be Greisen, Stockwork, and Quartz Vein, W±Mo±Be Skarn, and Porphyry Cu-Mo (±Au, Ag) Deposits (Belt NT) (Taimyr Peninsula, Russia)

This Middle and Late Triassic metallogenic belt is related to replacements and granitoids (too small to show on 5 million-scale map) intruding the Permian and Triassic volcanic and sedimentary rock of the Lenivaya-Chelyuskin sedimentary assemblage, Central Taimyr superterrane, and Kara terrane. The belt occurs in the Gorny Taimyr region, extends east-northeast for more than 600 km, and contains small early Mesozoic granitoid intrusions and numerous small W-Mo occurrences (Ravich, 1959; Ravich and Markov, 1959). The small intrusions occur in tectonic blocks bounded by postorogenic faults and consist of stocks and tabular bodies of granosyenite, syenite, granodiorite, and rare quartz monzonite with dimensions of 1 to 2 to 70 to 75 km^2. Granite porphyry dikes are common. Granitoids intrude Permian and Triassic volcanic and sedimentary rock, a Precambrian metamorphic sequence, and older granitoid plutons. The deposits occur mainly along the exocontacts. The metallogenic belt is still poorly studied and is prospective for undiscovered porphyry Cu-Mo (±Au, Ag) deposits. The significant deposits are at Kolomeitseva River, Morzhovoye, and Mamont River.

The main references on the geology and metallogenesis of the belt are Ravich (1959), Ravich and Markov (1959), and Vernikovsky (1996).

Kolomeitseva River W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Ravich, 1959; Ravich and Markov, 1959) consists of quartz veins with disseminated molybdenite. The veins cut Precambrian granitoid and Paleozoic clastic rock and exocontacts of small Permian and Triassic syenite intrusions. Molybdenite occurs also in the exocontact of an augite syenite intrusion in an older granitoid pluton. Scheelite occurs in heavy concentrates. The deposit is small and poorly studied.

Morzhovoye W±Mo±Be Skarn Deposit

This deposit (Ravich, 1959) consists of a grossular-diopside-calcite skarn with disseminated molybdenite in a roof pendant in a Triassic(?) syenite intrusive. The ore minerals are fine-grained molybdenite and disseminated pyrrhotite, pyrite, pentlandite, and marcasite. A stockwork of thin garnet-epidote-calcite veins with coarse molybdenite occurs in the northern part of the roof pendant. Altered rock along vein walls contains disseminated pyrite, chalcopyrite, and magnetite. Scheelite occurs in heavy concentrate. The deposit is small.

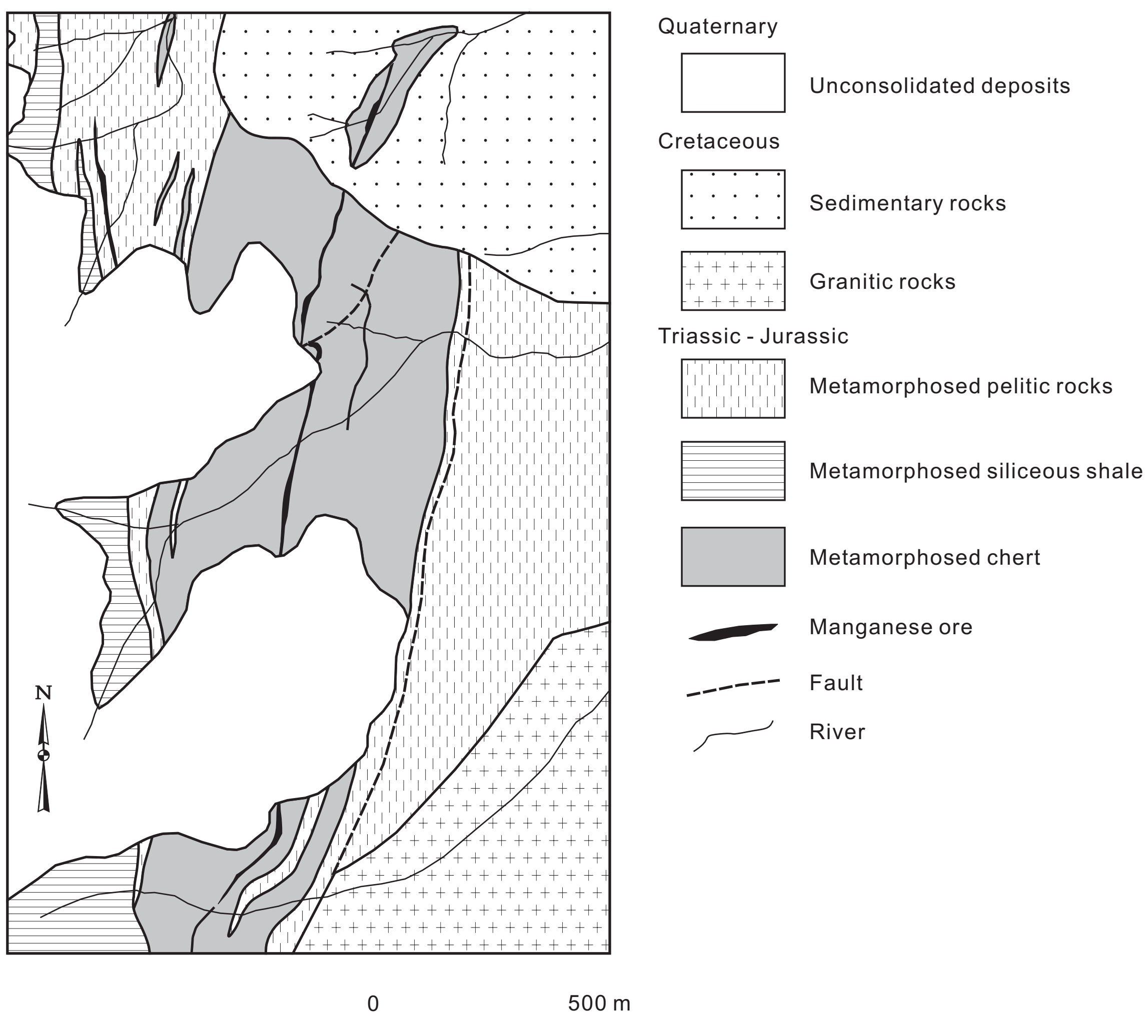


Figure 11. Geologic sketch map of Triassic through Early Cretaceous Nodatamagawa volcanogenic-sedimentary Mn deposit, North Kitakami metallogenic belt. Adapted from Sato and others (1957).

Mamont River 2 Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (Ravich, 1959; Ravich and Markov, 1959) consists of quartz veins with disseminations and nests of molybdenite. The veins occur in small Permian and Triassic syenite intrusions that cut large Precambrian granitoid plutons. Quartz veins are accompanied by silica and sericite alteration. Along with molybdenite, the quartz veins contain pyrite, scheelite, sericite, and feldspar. The deposit is small and poorly studied.

Origin and Tectonic Controls for North Taimyr Metallogenic Belt

The belt is interpreted as having formed during generation of granitoids during and after collision between the North Asian craton and Kara superterrane. The belt is hosted in intrusions in tectonic blocks bounded by post-orogenic faults. The host granitoids intrude Permian and Triassic tuff and lava sequence of the age. Granitoid pebbles occur in Early Cretaceous conglomerate (Ravich, 1959). The isotopic age of granitoid is about 233 to 223 Ma (Vernikovsky, 1996).

Sambagawa-Chichibu-Shimanto Metallogenic Belt of Besshi Cu-Zn-Ag Massive Sulfide (Cu, Zn, Ag), Volcanogenic-sedimentary Mn, and Cyprus Cu-Zn Massive Sulfide Deposits (Belt SCS) (Japan)

This Early Jurassic through Albian metallogenic belt is related to stratiform units in the Shimanto and Mino Tamba Chichibu accretionary-wedge terranes and the Sambagawa metamorphic terrane. The belt occurs in the outer zone of Southwestern Japan, trends approximately northeast-southwest for about 800 km, ranges as much as 70 km wide, and occurs in the Chubu district and Kii Peninsula on Honshu, Shikoku, and Kyushu Islands. The belt contains a large number of Besshi and Cyprus Cu-Zn massive sulfide deposits, and stratabound Mn deposits. Most of the Besshi deposits occur in the Sambagawa terrane in the northern part of the belt. The Besshi deposit occurs on Shikoku Island. The Besshi deposits and host rocks in the Sambagawa terrane are generally metamorphosed to epidote-amphibolite facies, high-pressure greenschist facies, or pumpellyite-actinolite facies metamorphism (Watanabe and others, 1998). The age of peak metamorphism is interpreted at about 110 Ma, and the age of submarine basalt volcanism and formation of related Besshi deposits is interpreted as being between 200 and 140 Ma (Watanabe and others, 1998). Geochemical characteristics of basalt associated with the deposits suggest submarine volcanism occurred in an oceanic intraplate setting or in a constructive plate margin (Watanabe and others, 1998). Several Besshi deposits occur in the Chichibu terrane south of the Sambagawa terrane, but most of them are small and not of economic value. The Shimanto terrane, south of the Chichibu terrane, hosts several Besshi deposits, including the Makimine deposit that occurs in the Mikabu greenstone zone of the Chichibu terrane. Manganese deposits in the metallogenic belt occur mainly in the Chichibu terrane, with fewer occurring in the Sambagawa and Shimanto terranes. The deposits are stratiform volcanic and sedimentary deposits and occur in or adjacent to chert. Three metallogenic provinces, a Besshi metallogenic province, the Chichibu Fe-Mn metallogenic province, and the outer zone of Southwest Japan pyrite and Fe-Mn metallogenic province, were defined by Tsuboya and others (1956) for the area of the Sambagawa-Chichibu-Shimanto metallogenic belt in this study. The significant deposits in the belt are at Besshi, Ananai, and Okuki.

The main references on the geology and metallogenesis of the belt are Tsuboya and others (1956) and Watanabe and others (1998).

Besshi Cu-Zn-Ag Massive Sulfide (Cu, Zn, Ag) Mine

This Mine (Mining and Metallurgical Institute of Japan, 1965; Suyari and others, 1991; Watanabe and others, 1998) consists of four srtratiform ore bodies. The Main Motoyama body extends 1,600 m along strike, 2,000 m down dip, and has dimensions of 3,000 by 11,000 m. Average thickness is 2.4 m with a maximum thickness of 15 m. The main ore minerals are pyrite, chalcopyrite, bornite, and magnetite. Gangue minerals are chlorite, hornblende, glaucophane, and quartz. The deposit is hosted in pelitic schist of Cretaceous Sambagawa Metamorphic Rocks. Mafic schist and piedmontite schist occur in the ore zone. Geochemistry indicates mafic schist derived from basalt that formed in an oceanic intraplate or constructive plate margins. Age of peak of metamorphism is 110 Ma according to Rb-Sr and K-Ar isotopic studies. Possible age for submarine basaltic volcanism and deposit formation is 200 (Late Triassic) to 140 Ma (Jurassic). The deposit was discovered in 1690. The deposit is large with production of 706,000 tonnes of Cu, reserves of 8 million tonnes of Cu, and average grades of 1.0 to 1.8 percent Cu, 0.1 to 1.4 percent Zn, 11.9 to 40 percent S, 0.3 to 0.7 g/t Au, and 7 to 20 g/t Ag.

Ananai Volcanogenic-Sedimentary Mn District

This district (Yoshimura, 1969; Suyari and others, 1991) contains more than eleven small ore bodies and is also named the Amatubo district. The ore bodies are hosted in Paleozoic and Mesozoic greenstone and sandstone of the Chichibu belt. The main Ananai deposit produced about 300,000 tonnes ore and consists of seven ore bodies that trend east-west for 4 km. Thickness of the deposit is typically 2 to 12 m. Ore minerals are rhodochrosite, braunnite, and bementite. The deposit is medium size with production of 300,000 tonnes of Mn ore.

Okuki Cyprus Cu-Zn Massive Sulfide Mine

This mine (Mining and Metallurgical Institute of Japan, 1965; Watanabe and others, 1970; Suyari and others, 1991) consists of Cu sulfide and pyrite massive sulfide that occurs conformably in metamorphosed mafic volcanic and pyroclastic rock associated with a gabbro body and thin chert beds in the Mikabu ophiolite. The deposit consists of the Honko and Otoko ore zones. Each ore zone contains several small ore bodies, which typically occur at hinges of anticlines. The hanging wall of the deposits is mafic volcanic rock and red chert, and the foot wall is phyllite. The red chert marks the ore horizon. The Honko ore zone is 1,500 by 400 m. The main ore minerals are pyrite, chalcopyrite, sphalerite, and native gold, and minor bornite, tetrahedrite, and cobaltite. Gangue minerals are chlorite, quartz, and calcite. The deposit is medium size with production of 50,000 tonnes of Cu, 2 tonnes of Au, and 7 tonnes of Ag grading 2.14 percent Cu, 4 g/t Au, and 60 g/t Ag.

Origin and Tectonic Controls for Sambagawa-Chichibu-Shimanto Metallogenic Belt

The Mn deposits in the belt are interpreted as having formed in a syngenetic, ocean floor setting. The Besshi and Cyprus deposits are interpreted as having formed during submarine volcanism along a spreading ridge. The deposits were subsequently incorporated into an accretionary wedge.

Wulashan-Zhangbei Metallogenic Belt of Alkaline Complex Hosted Au, Au Potassium Metasomatite, and Granitoid-Related Au Vein Deposits (Belt WZh) (North-Central China)

This Middle Jurassic metallogenic belt is related to granitoids in the Alashan-Yinshan Triassic plutonic belt (too small to show at 10 million scale) that intrudes the Sino-Korean craton, the Erduosi and Solon terranes, and adjacent units. The belt extends from the Wulashan Mountain of the western Inner Mongolia to the Zhangbei area in the Northwest Hebei Province. The belt is related to a Late Triassic through Early Jurassic alkaline complex and alkaline to subalkaline granite. The belt trends east-west, is about 600 km long, and ranges from 20 to 50 km wide. The discontinuous plutons related to Au deposits form a belt that is 40 to 50 km long and as much as 5 to 8 km wide. The significant deposits are at Dongping and Hadamen.

The main references on the geology and metallogenesis of the belt are Nie and others (1989), Zhou (1995), Song and Zhao (1996), and Shi and Xie (1998).

Dongping Alkaline Complex Hosted Au Deposit

This deposit (Song and Zhao, 1996), that was discovered in 1985 and was explored as a large Au deposit in 1992, consists of several tens of clusters of veins that trend northeast to north to northwest. Each vein cluster contains numerous parallel and oblique veins. The main deposit varies from a Au-pyrite-quartz vein to Au-sulphide-quartz vein to Au sulphides in veinlets-stockworks altered rock. Most of the numerous parts of the deposit are 1 to 4 m thick, 200 to 500 m long, and 200 to 500 m downdip. Sulphides comprise mostly less than 3 percent and consist mainly of pyrite and lesser chalcopyrite, galena, and sphalerite. Gold occurs mainly as native Au, and to a lesser amount in calaverite. Gangue minerals are mainly quartz and K-feldspar. Alteration consists of K-feldspar, silica, sericite, and carbonate. The deposit and alteration is strongly controlled by faults and related fissures. The host rock is the Shuiquan alkaline complex that is 5 to 8 km wide, 55 km long, trends east-west, and intrudes Archean granulite facies metamorphic rock. The intrusion exhibits strong petrologic zoning. The main rock types are alkali feldspar syenite, quartz-alkali feldspar syenite, pyroxene-amphibole-alkali feldspar syenite, pyroxene syenite, and amphibole monozite. The $^{40}Ar/^{39}Ar$ isotopic ages are 327.4±9 Ma and 177 to 157 Ma for the intrusion and K-feldspar in the deposit, respectively. The deposit is controlled by the east-west striking major Chicheng-Chengde fault at the northern margin of the Sino-Korean craton. Numerous similar deposits in the area are also related to alkaline intrusions. The deposit is large, and has reserves of 16.06 tonnes of Au grading 5 to 20 g/t Au.

Hadamen Au Potassium Metasomatite Deposit

This deposit (Zhou, 1995) occurs in veins in the middle and upper Archean Wulashan Group, mainly in garnet gneiss, granulite, magnetite quartzite, cordierite-, sillimanite-, garnet and graphite-biotite schist, quartzite, and marble. The Dahuabei potassic granite intrusion is 3 km to the west. The veins occur in clusters and swarms in large vein groups or plates. Three types of veins occur (1) Au quartz vein with gold, quartz, pyrite, chalcopyrite, galena, and sphalerite; (2) Au-K-feldspar and quartz-K-feldspar veins with Au, K-feldspar, quartz, pyrite, sericite, chlorite, and speculaite; and (3) Au potassic and silica-altered rock with gold, quartz, K-feldspar, albite, sericite, chlorite, calcite, and pyrite, and minor biotite, magnetite, muscovite, and garnet. Alterations include K-feldspar, silica, sericite, and carbonate alteration. Temperature of the formation of the deposit varied from an early high temperature of about 400 to 450°C to a later, low temperature of about 172°C. Pressure is estimated at 425 to 461±105 Pa. The deposit is interpreted as having formed during magmatic-related hydrothermal alteration related to the Dahuabei granite. The deposit is large, and has reserves of 20.86 tonnes grading Au 5.21 g/t Au.

Origin and Tectonic Controls for Wulashan-Zhangbei Metallogenic Belt

The belt is interpreted as having formed during intrusion of granitoids generated above a mantle plume in an extensional tectonic setting. The host intrusions are alkaline syenite, alkaline monzonite, subalkaline granite, and lesser calc-alkaline granite. The Au deposits are assocated with potassium metasomatism. The intrusions in the belt are controlled by major east-west-trending faults. These intrusions may have formed from the remelting deep crust (Zhou Kun, 1995), or from mantle-derived magma (Song and Zhao, 1996). Shi and Xie (1998) interpret the magmatism and deposits as being related to a mantle plume that formed in a tensile tectonic setting. There are many ages in the mineralization. Reliable isotopic data suggest a Late Triassic and Early Jurassic age (Shi and Xie, 1998; Nie and others, 1989).

Late Carboniferous (Pennsylvanian) to Early Triassic Tectonic and Metallogenic Model

Major Metallogenic and Tectonic Events

For the Late Carboniferous (Pennsylvanian) to Early Triassic (320 to 240 Ma), the major metallogenic-tectonic events were (fig. 12; tables 1, 2) (1) in the northern North Asian craton, formation of the Tungus Plateau igneous province and associated metallogenic belts with widespread intrusive traps consisting of extensive belts of sills and rare dikes that intruded major fault zones; (2) accretion of the Argun-Idermeg superterrane(Amur microcontinent composed of Agun and Idermeg passive continental margin terranes); (3) formation of the Gobi-Khankaisk-Daxing’anling continental-margin arc and associated metallogenic belts along the outboard edge of the accreted South Mongolia-Khingan collage and Argun-Idermeg superterrane (Amur microcontinent composed of Agun and Idermeg passive continental margin terranes); (4) formation of the North Margin continental-margin arc and associated metallogenic belts along the edge of the Sino-Korean craton; (5) formation of the transform-continental-margin Hangay arc and associated metallogenic belts along the southern margin of the North Asian craton and accreted terranes; (6) beginning of closure of the Mongol-Okhotsk Ocean and inception of an extensive, mainly right-lateral series of transform faults; (7) formation of the Jihei continental-margin arc and associated metallogenic belts along the margin of the Bureya-Jiamusi superterrane; and (8) inception of the Alazeya island arc.

The major Late Carboniferous through Early Triassic metallogenic belts in Northeast Asia are summarized in appendix C and portrayed on figure 3. The tectonic setting of each metallogenic belt is portrayed on figure 12.

Metallogenic Belts and Tectonic Origins

Metallogenic Belts Related to Selenga Arc

Four major metallogenic belts are hosted in the Selenga transform continental-margin arc along the margin of the Mongol-Okhotsk Ocean (figs. 3, 12). This arc is preserved manily in the Selenga sedimentary-volcanic plutonic belt (fig. 2).

The Battsengel-Uyanga-Erdenedalai belt (BUE, figs. 3, 12; appendix C) contains granitoid-related Au vein deposits that are hosted in small Late Carboniferous through Permian stitching plutons that formed during an early stage of intrusion of the Hangay plutonic belt that intrudes Hangay-Dauria and Onon subduction-zone terranes, part of the Mongol-Okhotsk collage. The plutonic rocks are part of Selenga sedimentary-volcanic plutonic belt.

The Buteeliin nuruu belt (BU, figs. 3, 12; appendix C) contains peralkaline granitoid-related, Nb-Zr-REE, REE-Li pegmatite, and W-Mo-Be greisen, stockwork, and quartz-vein deposits that are hosted in Permian granitoids related to the Selenga sedimentary-volcanic plutonic belt that intrudes the West Stanovoy terrane. The belt is part of a Permian core complex that contains granitoids that intrude granite-gneiss and mylonite.

The Central Mongolia belt (CM, figs. 3, 12; appendix C) contains Fe-Zn skarn, Sn-skarn, Zn-Pb (±Ag, Cu) skarn, W±Mo±Be skarn, Cu (±Fe, Au, Ag, Mo) skarn, porphyry Cu-Mo (±Au, Ag), porphyry Mo (±W, Bi); Au-skarn, granitoid related Au vein, and W-Mo-Be greisen, stockwork, and quartz-vein deposits that are hosted in Early to Late Permian that are part of the Selenga sedimentary-volcanic plutonic belt.

The Orhon-Selenge belt (OS, figs. 3, 12; appendix C) contains porphyry Cu-Mo (±Au, Ag) deposits that are hosted in Triassic granitoids in the Selenga sedimentary-volcanic plutonic belt.

Metallogenic Belts Related to South-Mongolia Continental-Margin Arc

The Harmagtai-Hongoot-Oyut belt (HH, figs. 3, 12; appendix C) contains porphyry Cu-Mo (±Au, Ag), porphyry Au, granitoid-related Au vein, and Au-Ag epithermal-vein deposits that are hosted in Middle Carboniferous through Early Permian granitoids that are part of the South-Mongolian volcanic-plutonic belt that formed the South Mongolian continental-margin arc.

Metallogenic Belts Related to South-Mongolia-Khingan Island Arc

The Duobaoshan belt (DB, figs. 3, 12; appendix C) contains porphyry Cu-Mo (±Au, Ag) deposits that are hosted in Pennsylvanian granitoids related to the Nora-Sukhotin-Duobaoshan island-arc terrane that is part of South Mongolia-Khingan collage. The belt is interpreted as having formed in the late stage of the South-Mongolia-Khingan subduction-related island arc.

The Kalatongke belt (KL, figs. 3, 12; appendix C) contains mafic-ultramafic related Cu-Ni-PGE and granitoid-related Au-vein deposits that are hosted in the Pennsylvanian Waizunger-Baaran island-arc terrane, part of Atasbogd collage. The belt is interpreted as having formed in the South Mongolia-Khingan subduction-related island arc.

Metallogenic Belts Related to Tungus Plateau Igneous Province

Four major metallogenic belts are hosted in the Tungus Plateau Igneous Province (figs. 3, 11; appendix C). The belts are interpreted as being related to Late Permian and Early Triassic mantle superplume magmatism that resulted in widespread development of trapp magmatism on the North Asian craton.

The Angara-Ilim belt (AI, figs. 3, 12; appendix C) contains Fe-skarn, REE (±Ta, Nb, Fe) carbonatite, and weathering crust carbonatite REE-Zr-Nb-Li deposits and is hosted in replacements related to Tungus plateau basalt, sills, dikes, and intrusions that intrude North Asian craton. The REE-Ta-Nb carbonatite deposits are associated with alkali-ultramafic intrusions.

The Kureisko-Tungsk belt (KT, figs. 3, 12; appendix C) contains Fe-skarn, mafic-ultramafic related Cu-Ni-PGE, and metamorphic graphite deposits that are hosted in Permian through Triassic replacements and plutons. The belt ocurs along the long-lived West-Siberian rift system and Yenisei sublongitudinal major fault.

The Maimecha-Kotuisk belt (MK, figs. 3, 12; appendix C) contains Fe-Ti (±Ta, Nb, Fe, Cu, apatite), carbonatite, REE (±Ta, Nb, Fe), carbonatite, and phlogopite-carbonatite deposits that are hosted in Late Permian through Early Triassic alkali-ultramafic-carbonatite intrusions. The magmatic rocks include tholeiite, diabase, trachybasalt, melanonephelinite volcanic rocks and intrusive rocks, and ijolite-carbonatite and kimberlite complexes.

The Norilsk belt (NR, figs. 3, 12; appendix C) contains mafic-ultramafic related Cu-Ni-PGE, basaltic native Cu (Lake Superior type) and porphyry Cu-Mo (±Au, Ag) deposits that are hosted in Early Triassic intrusions.

Miscellaneous Metallogenic Belts

The Altay belt (AT, figs. 3, 12; appendix C) contains REE-Li pegmatite and muscovite pegmatite depsoits that are hosted in veins, dikes, and replacements related to Late Carboniferrous granitoids in Altai volcanic-plutonic belt that intrudes Altai continental margin turbidite terrane. The belt formed during intrusion of collisional granite that formed during collision of the Kazakhstan and North Asian cratons. The belt formed during high-grade metamorphism associated with with crustal melting and generation of anatectic granite.

The Hitachi belt (HT, figs. 3, 12; appendix C) contains Permian volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) deposits that are hosted in the South Kitakami island-arc terrane that probably formed on the margin of the Sino-Korean craton.

The Shanxi belt (SX, figs. 3, 12; appendix C) contains Pennsylvanian sedimentary bauxite deposits that occur in stratiform units in the upper part of Sino-Korean platform units overlapping the Sino-Korean craton. The belt is interpreted as having formed during weathering of metamorphic rocks of the Northern China Platform.

Middle Triassic through Early Jurassic Tectonic and Metallogenic Model

Major Metallogenic and Tectonic Events

For the Middle Triassic through Early Jurassic (240 to 175 Ma), the major metallogenic-tectonic events were (fig. 13; tables 1, 2): (1) accretion of the Argun-Idermeg superterrane (Amur microcontinent composed of Agun and Idermeg passive continental-margin terranes), Bureya-Jiamusi supterterrane, and Sino-Korean craton, and formation of associated metallogenic belts; (2) continuation of closure of the Mongol-Okhotsk Ocean and continuation of an extensive, mainly right-lateral series of transform faults along the western, closed part of the ocean and formation of associated metallogenic belts; (3) inception of the Uda-Murgal continental-margin and island-arc system and associated metallogenic belts; (4) continuation of the Alazeya island arc; and (5) collision between the North Asian craton and Kara superterrane with formation of postcollisional granitoid intrusions (with isotopic ages of about 233 to 223 Ma) and associated metallogenic belts.

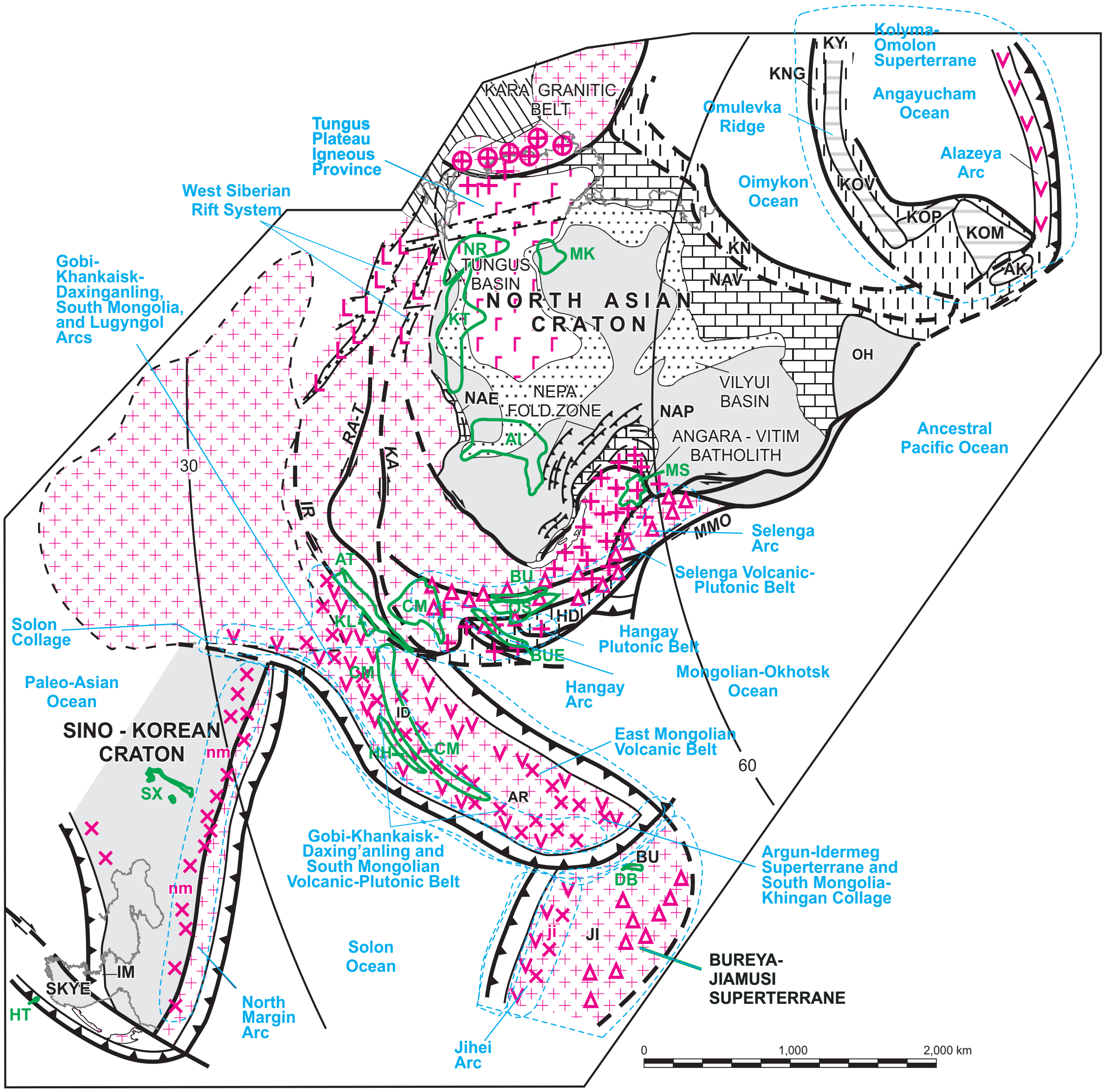
The major Middle Triassic through Early Jurassic metallogenic belts in Northeast Asia are summarized in appendix C and portrayed on figure 4. The tectonic setting of each metallogenic belt is portrayed on figure 13.

Metallogenic Belts and Tectonic Origins

Metallogenic Belts Related to Mongol-Transbaikalia Volcanic-Plutonic Belt

Several metallogenic belts are hosted in the Mongol-Transbaikalia volcanic-plutonic belt that is interpreted as having formed during generation of collisional granitoids and associated volcanic units during final closure of the Mongol-Okhotsk Ocean. This igneous belt is named the Mongol-Transbaikal arc (fig. 13).

The Central Hentii belt (CH, figs. 4, 13; appendix C) contains Sn-W greisen, stockwork and quartz vein, REE-Li pegmatite, Ta-Nb-REE alkaline metasomatite, W±Mo±Be skarn, and peralkaline peralkaline granitoid-related Nb-Zr-REE deposits that are hosted in Late Triassic through Early Jurassic replacements and granitoids related to the Late



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Terranes and Superterranes

AK - Avekov terrane
AR - Argunsky terrane
BU - Bureya terrane (Metamorphic)
ID - Idermeg terrane
IM - Imjingang terrane (Accretionary wedge, type B) (Devonian)
JI - Jiamusi terrane
KN - Kular-Nera terrane (Continental-margin turbidite) (Permian through Early Jurassic)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
ND - Nora-Sukhotin-Duobaoshan terrane (Island arc) (Neoproterozoic through Early Carboniferous)
OH - Okhotsk terrane
SKYE - Yeongnam terrane (Granulite-paragneiss) (Late Archean to Paleoproterozoic)

Overlap Continental-Margin Arcs and Granite Belts

ji -Jihei plutonic belt (Permian)
nm - North marginal plutonic belt Carboniferous and Permian)

Strike-Slip Fault and Shear Zone

IR - Irtysh shear zone
KA - Kuznetsk-Altai
MMO - Main Mongol-Okhotsk
RA-T - Rudny Altai - Taimyr

METALLOGENIC BELTS

AI - Angara-Ilim
AT - Altay
BU - Buteeliin nuruu
BUE - Battsengel-Uyanga-Erdenedalai
CM - Central Mongolia
DB - Duobaoshan
HH - Harmagtai-Hongoot-Oyut
HT - Hitachi
KL - Kalatongke
KT - Kureisko-Tungsk
MK - Maimecha-Kotuisk
MS - Muiskiy
NR - Norilsk
OS - Orhon-Selenge (185-240, 250)
SX - Shanxi

Figure 12. Early Permian (275 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).

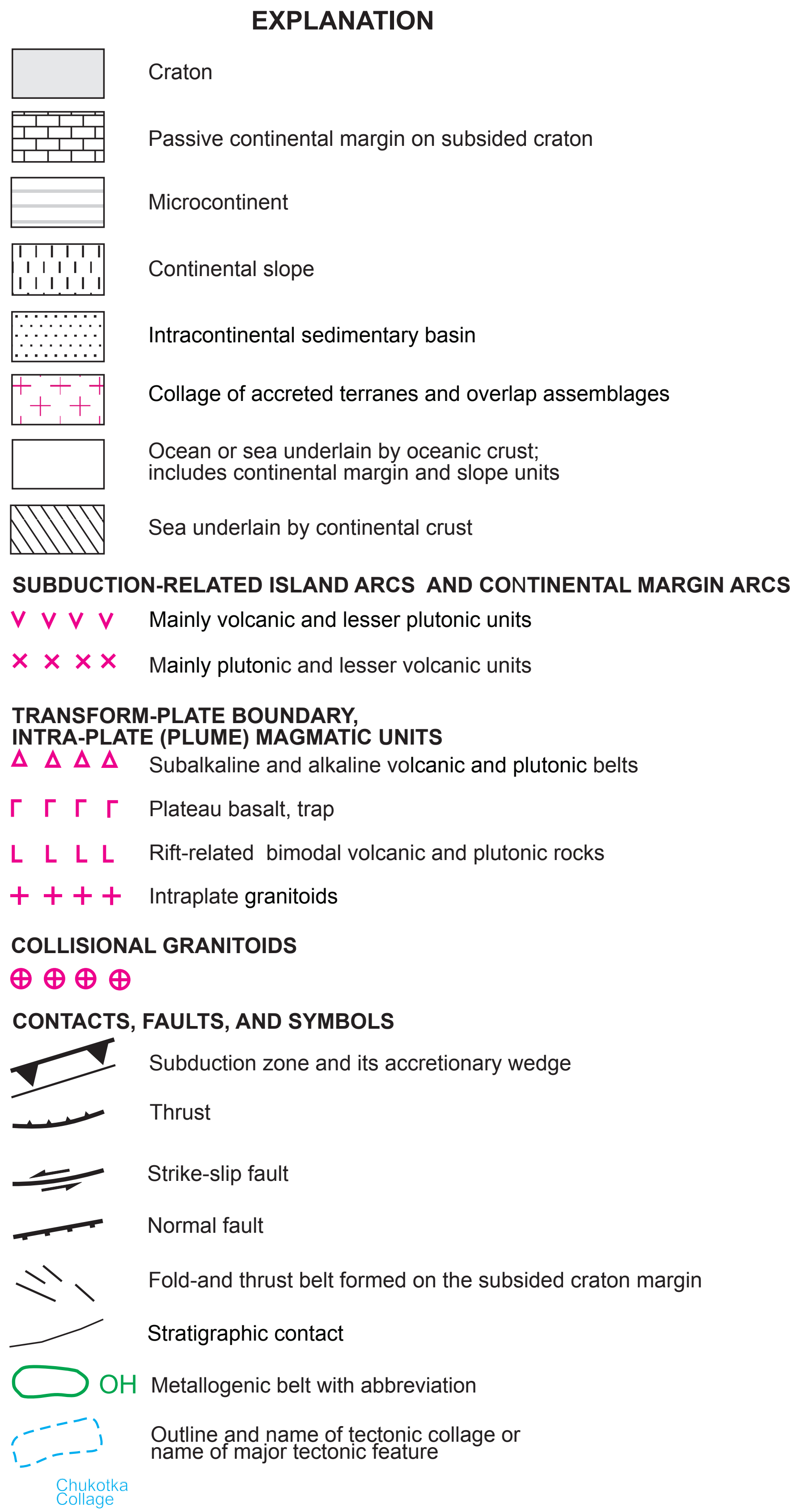
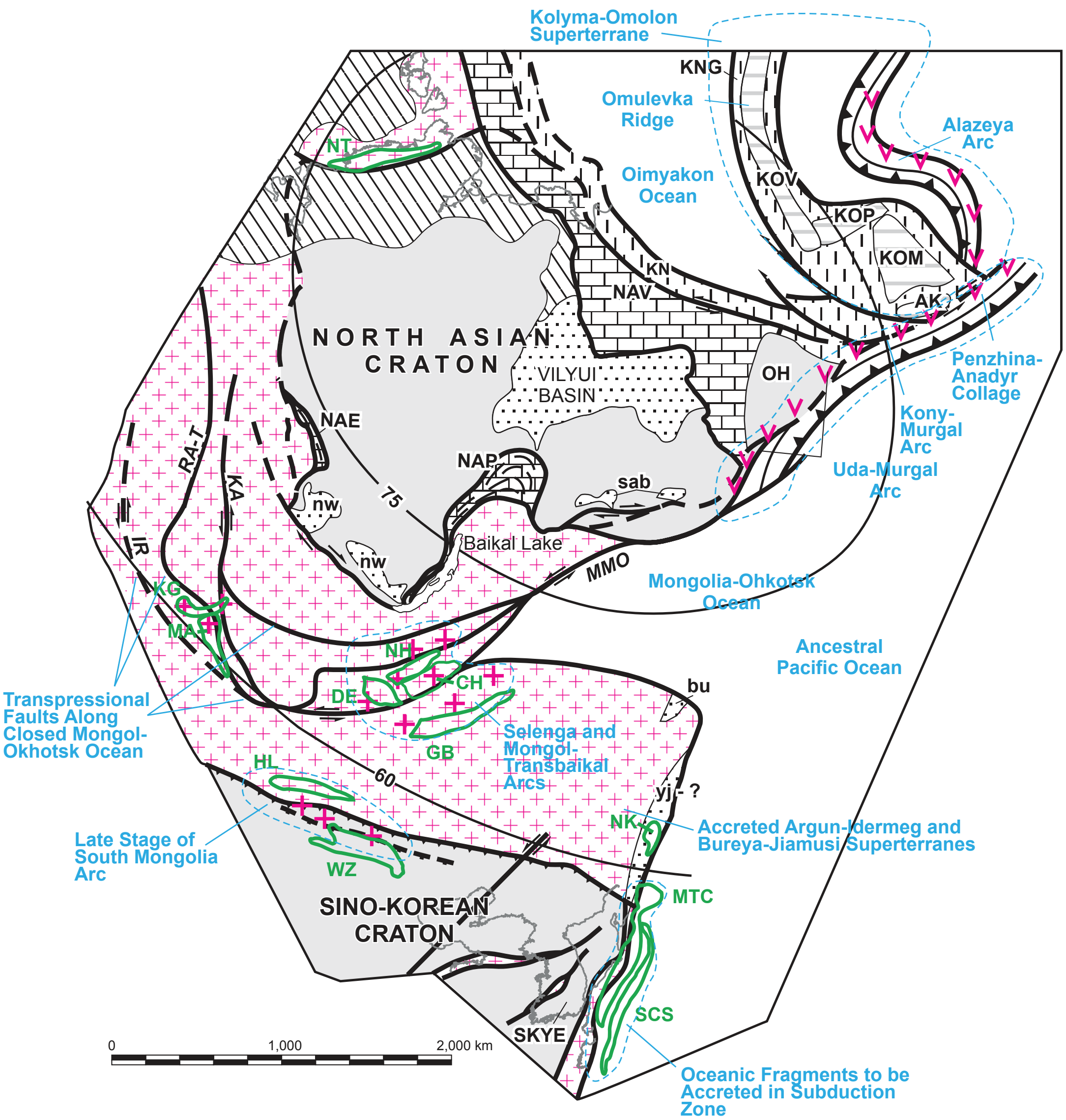


Figure 12.—Continued



GEOLOGIC UNITS

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAV - Verkhoyansk

Intracontinental Sedimentary Basin

bu - Bureya sedimentary basin (Early Jurassic to Early Cretaceous)
nw - Western Siberia sedimentary basins (Mesozoic and Cenozoic)
sab - South Aldan sedimentary basin (Jurassic)
yj - Yanji-Jixi-Raohe overlap sedimentary assemblage (Mesozoic and Cenozoic)

Terranes and Superterranes

AK - Avekov terrane
KN - Kular-Nera terrane (Continental-margin turbidite) (Permian through Early Jurassic)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
OH - Okhotsk terrane
SKYE - Yeongnam terrane (Granulite-paragneiss) (Late Archean to Paleoproterozoic)

Strike-slip Fault and Shear Zone

IR - Irtysh shear zone
KA - Kuznetsk-Altai
MMO - Main Mongol-Okhotsk
RA-T - Rudny Altai - Taimyr

METALLOGENIC BELTS

CH - Central Hentii
DE - Delgerhaan
GB - Govi-Ugtaal-Baruun-Urt
HL - Harmorit-Hanbogd-Lugiingol
KG - Kalgutinsk
MTC - Mino-Tamba-Chugoku
MA - Mongol Altai
NH - North Hentii
NK - North Kitakami
NT - North Taimyr
SCS - Sambagawa-Chichibu-Shimanto
WZ - Wulashan-Zhangbei

Figure 13. Late Triassic (210 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume).

Triassic through Early Jurassic Mongol-Transbaikalia volcanic-plutonic belt that intrudes and overlaps Hangay-Dauria terrane, part of Mongol-Okhotsk collage, and adjacent units. The small plutons hosting REE deposits intruded in a continental post-collisional event.

The Delgerhaan belt (DE, figs. figs. 4, 13; appendix C) contains Late Triassic porphyry Cu (±Au) and granitoid-related Au vein deposits that are part of the Mongol-Transbaikalia volcanic-plutonic belt.

The Govi-Ugtaal-Baruun-Urt belt (GB, figs. figs.4, 13; appendix C) contains Fe-Zn skarn, Cu (±Fe, Au, Ag, Mo) skarn; Zn-Pb (±Ag, Cu) skarn, Sn-skarn, Fe-skarn, and Porphyry Mo deposits that occur as Late Triassic through Early Jurassic replacements related to the Mongol-Transbaikalia volcanic-plutonic belt.

The North Hentii belt (NH, figs. 4, 13; appendix C) contains granitoid-related Au vein and Au in shear-zone and quartz-vein deposits that are hosted in Middle Triassic through Middle Jurassic granitoids that are part of the Mongol-Transbaikalia volcanic-plutonic belt.

Metallogenic Belts Related to Closure of Mongol-Okhotsk Ocean

The Kalgutinsk belt (KG, figs. 4, 13; appendix C) contains W-Mo-Be greisen, stockwork, and quartz vein, Ta-Nb-REE alkaline metasomatite, and Sn-W greisen, stockwork, and quartz-vein deposits that are hosted in Early Jurassic granitoids and replacements in the Belokurikha plutonic belt that intrudes the Altai and West Sayan terranes, both part of Altai collage. The belt is interpreted as having formed during generation of REE granitoids along transpression zones (Hovd regional fault zone and companion faults) that formed during final closure of the Mongol-Okhotsk Ocean.

The Mongol Altai belt (MA, figs. 4, 13; appendix C) contains W-Mo-Be greisen, stockwork, and quartz-vein deposits that are hosted in small bodies of Late Triassic through Early Jurassic leucogranite that intrude Altai and Hovd Hovd terranes, both part of Altai collage. The belt is interpreted as having formed during generation of collisional granitoids during final closure of the Mongol-Okhotsk Ocean and formation of Mongol-Transbaikal arc.

Metallogenic Belt Related to South Mongolian Continental-Margin Arc

The Harmorit-Hanbogd-Lugiingol belt (HL, figs. 4, 13; appendix C) contains Sn-W greisen, stockwork, and quartz-vein, Ta-Nb-REE alkaline metasomatite, REE (±Ta, Nb, Fe) carbonatite, peralkaline granitoid-related Nb-Zr-REE, and REE-Li pegmatite deposits that occur as Middle Triassic through Early Jurassic replacements and granitoids related to South Mongolian volcanic-plutonic belt.

Metallogenic Belts Hosted in Tectonic Fragments in Subduction Zones

The Mino-Tamba-Chugoku belt (MTC, figs. 4, 13; appendix C) contains volcanogenic-sedimentary Mn Podiform chromite and Besshi Cu-Zn-Ag massive sulfide deposits that are hosted in tectonic fragments in the Mino Tamba Chichibu subduction-zone terrane, part of Honshu-Sikhote-Alin collage. The host rocks were incorporated into a subduction zone that formed along the margin of the Sino-Korean craton. The subduction zone contains various marine sedimentary and volcanic rocks, and fragments of oceanic crust with ultramafic rock. Besshi deposits are interpreted as having formed along a spreading ridge.

The North Kitakami belt (NK, figs. 4, 13; appendix C) contains Triassic through Early Cretaceous volcanogenic-sedimentary Mn and volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) deposits that are hosted in the Mino Tamba Chichibu subduction-zone terrane, part of Honshu-Sikhote-Alin collage. The Mn deposits formed in syngenetic setting on the ocean floor, and the Kuroko deposits formed in an island arc. The deposits were subsequently incorporated into a subduction zone.

The Sambagawa-Chichibu-Shimanto belt (SCS, figs. 4, 13; appendix C) contains Besshi Cu-Zn-Ag massive sulfide (Besshi), volcanogenic-sedimentary Mn, and Cyprus Cu-Zn massive sulfide deposits that are hosted in Early Jurassic and to Campanian fragments in the Shimanto subduction-zone terrane (part of Sakhalin-Hokkaido collage), the Mino Tamba Chichibu subduction-zone terrane (part of Honshu-Sikhote-Alin collage), and the Sambagawa metamorphic terrane (part of Honshu-Sikhote-Alin collage). The Mn deposits formed in a syngenetic setting on the ocean floor. The Besshi and Cyprus deposits formed during submarine volcanism related to a spreading ridge. All the deposits were subsequently incorporated into a subduction zone.

Miscellaneous Metallogenic Belts

The North Taimyr belt (NT, figs. 4, 13; appendix C) contains W-Mo-Be greisen, stockwork, and quartz vein, W±Mo±Be skarn, and porphyry Cu-Mo (±Au, Ag) deposits that are associated with Middle and Late Triassic replacements and granitoids intruding Permian-Triassic volcanic and sedimentary rocks of Lenivaya-Chelyuskin sedimentary assemblage, Central Taimyr superterrane, Kara superterrane. The belt is interpreted as having formed during generation of granitoids during and after collision between the North Asian craton and Kara superterrane. The belt hosted in intrusions in tectonic blocks bounded by postorogenic faults.

The Wulashan-Zhangbei belt (WZ, figs. 4, 13; appendix C) contains alkaline complex-hosted Au, Au potassium metasomatite, and granitoid-related Au vein deposits that are hosted in the Middle Jurassic granitoids related to the Alashan-Yinshan Triassic plutonic belt that intrudes the Sino-Korean craton - Erduosi terrane. The belt is interpreted as having formed in Late Triassic through Early Jurassic alkaline to subalkaline granitoids above a mantle plume in an extensional tectonic setting.

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