Metallogenesis and Tectonics of Northeast Asia
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# Chapter 6

# Devonian through Early Carboniferous (Mississippian) Metallogenesis and Tectonics of Northeast Asia

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## Introduction

This article presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia for the Devonian through Early Carboniferous (Mississippian) (410 to 320 Ma). The major purposes are to provide a detailed summary of these features for readers who are unfamiliar with Northeast Asia. Several parts of this book on Northeast Asia provide background information. An overview of the geology, metallogenesis, and tectonics of the region, and other materials, such as a geologic time scale and standard geologic definitions, are provided in Chapter 1. The methodology for the metallogenic and tectonic analysis of this region is provided in Chapter 2. Descriptions of mineral deposit models are provided in Chapter 3. Additional information on project publications, descriptions of major geologic units, and summaries of metallogenic belts are provided in appendixes A-C.

### Compilations Employed for Synthesis, Project Area, and Previous Study

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

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

The Northeast Asia project extends and is built on data and interpretations from a previous project on the “Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera” (fig. 1) that was conducted by the USGS, the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada. A summary of

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the major products of this project is available online at: http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.pdf and in appendix A.

# Major Geologic Units

The major Devonian through Early Carboniferous (Mississippian) geologic and tectonic units of Northeast Asia are cratonal margin units, sedimentary basins formed on craton and cratonal margins, and accreted terranes and superterranes (fig. 2, table 1). Short descriptions of map units are given in appendix B. Summary descriptions of the major units are provided in descriptions of metallogenic belts (below), and detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004), and Parfenov and others (2004b).

## Major Cratonal margins and Craton-Margin Terranes

For an analysis of Devonian through Early Carboniferous (Mississippian) metallogenesis and tectonics, the cratonal units that contain major metallogenic belts are the North Asian Craton (NAC) and overlying Phanerozoic units, the North Asian (Verkhoyansk) Cratonal margin (VR) (fig. 2, table 1) that consists chiefly of a thick wedge of Mesoproterozoic, Neoproterozoic through Jurassic miogeoclinal deposits.


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

During the Devonian through Early Carboniferous, in the northern and eastern margins of the North Asian Craton, the Verkhoyansk and South Taimyr passive continental margins related to subsidence and deposition of carbonate and clastic sediments derived from the craton continued to form. Widespread intracontinental rifting appears to have initiated along these passive continental margins, which led to the formation of the Vilyui, Sette-Daban, and probably the Tungus and other basins. Carbonate rocks and clastic sediments that were accompanied by alkaline volcanic rocks fill these basins. These basins are interpreted as being failed arm or aulacogens of the rift-rift triple junction or three-armed graben (Gaiduk, 1988; Levashov, 1974). The development of extensive intracontinental rifting was related to the domal uplifts and mantle plume activity during the stable period of plate motion. The intracontinental rifting along the northern and eastern margins of the North Asian craton was responsible for the continued development of the Omulevka (KOV), Kotel'nyi (KY), and Nagondzha (KNG) terranes. The Omulevka and Kotel'nyi terranes are interpreted as a distal part of the passive continental margin of the North Asian craton. The Nagondzha terrane is interpreted as being a continental margin that formed during the opening of Oimyakon ocean basin.

The paleomagnetic data available suggest that the Omulevka terrane and the Okhotsk terrane formed part of the North Asia craton in the Early-Middle Paleozoic and were detached from it as a result of rifting by way of clockwise rotation (Parfenov, 1991; Neustroev and others, 1993; Prokopiev and others, 1999). The break up of the terranes from the Siberian continent and the opening of a minor ocean basin between them, the Oimyakon basin, occurred in the early Carboniferous.

Along the western and southern margin (in present-day coordinates) of the North Asian craton occur a wide collage of terranes that were accreted to the cratonal margins, principally during the Late Cambrian through Ordovician. The growth of the western and southern continental margin of the North Asian craton by terrane accretion is a significant feature of the tectonic history of the region. Most of the accreted terranes are herein interpreted as having been derived from various parts of cratons, cratonal margins, or from fringing island arcs and companion subduction-zone complexes. To the south, adjacent to the margin was a continental slope now preserved in the Hangay-Daurian subduction-zone terrane.

During the Devonian through Early Carboniferous, the western and southern margins of the North Asian craton were characterized by a transform margin environment and were accompanied by strike-slip faulting, formation of subalkaline and alkaline volcanic and plutonic belts, and associated sedimentary basins superimposed on the accreted terranes (Berzin and others, 1994; Obolenskiy and others; 1999). This transform fault system consists of several left-lateral strike-slip faults near the southern margin of the craton that oroclinally bend to the west. The right-lateral strike-slip fault that occurs along the northern boundary of this fault system splays out to the east into series of subparallel faults and is accompanied by the Nepsky overthrust- fault zone in Transbaikal area. The main basins are the Agul (ag), Khmelev (kh); Kolyvan-Tom (kt); Kuznetsk (kz), Minusa (mn), South Altai (sal) and Tuva (tv) that are composed mainly of shallow-marine sedimentary rocks with minor volcaniclastics. The volcanic-plutonic belts include the Altai (alv, alp), Deluun (dl), Sinegorsk (sg), South Siberian (ss, ssp), and Tes (te, tep) that chiefly contain diorite, granodiorite, subalkaline and alkaline granite, leucogranite, granosyenite, quartz syenite, and coeval basalt, andesite, dacite, rhyolite, tuff, and volcaniclastic rocks.

## Superterranes

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

The Bureya-Jiamusi superterrane consists of fragments of Archean through Cambrian metamorphic complexes, and it occurs in Northeastern China and the southern part of the Russian Far East. The superterrane contains the Bureya, Jiamusi, Matveevka, and Nakhimovka metamorphic terranes. The Bureya- Jiamusi superterrane also includes overlapping units of pre-Neoproterozoic volcanic and sedimentary rocks (Turans suite), Neoproterozoic limestone (Melgiysk suite), Cambrian archaeocyathes limestone (Allingsk and Chergelensk suites), and Paleozoic marine sediments (Kozlovsky, 1988, Natal'in, 1991; Khanchuk, 2000). The Bureya-Jiamusi superterrane is interpreted as being a separate block within a paleoocean plate southwest of the South Mongolia-Khingan island arc.

## Tectonic Collages Between North Asian and Sino-Korean Cratons

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

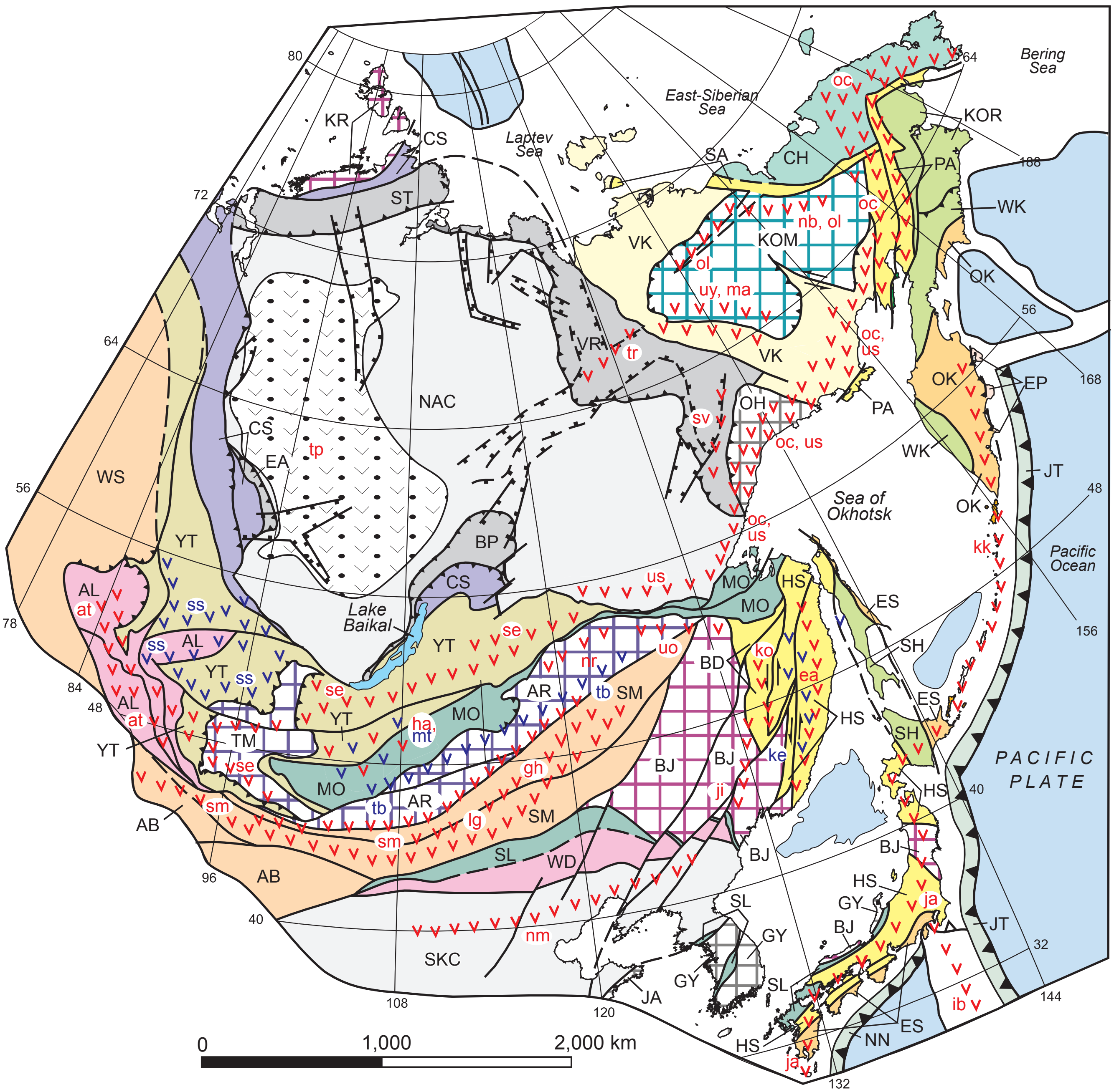


**Figure 2.** Northeast Asia summary geodynamics map. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a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

## EXPLANATION

**Cratons and Cratonal Margins**

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

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

**Tectonic Collages Between the North Asian and Sino-Korean Cratons**

CS - Circum-Siberia (Proterozoic)

YT - Yenisey-Transbaikal (Vendian through Early Ordovician)

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

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

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

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

CH - Chukotka (Paleozoic and Triassic)

VK - Verkhoyansk-Kolyma Paleozoic through Early Jurassic)

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

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

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

EP - East Kamchatka Peninsular (Mainly Paleocene)

**Active Subduction Zones**

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

**Cratonal Terranes and Superterranes**

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

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

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

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

**Pelagic and Oceanic Rocks**

Surficial deposits

Oceanic crust

**Overlap Continental-Margin Arcs and Igneous Belts**

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

**Plume-Related Igneous Province**

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

**Active Arcs**

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

**Transpressional Arcs**

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

**Symbols, Faults, and Contacts**

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

**Figure 2.**—Continued.

**Table 1.** Summary of major Devonian and Early Carboniferous (Mississippian) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan).

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

| Name of unit. Map Symbol | Type of unit (craton, terrane, overlap assemblage) | Age range | Tectonic environment | Tectonic linkage |
|---|---|---|---|---|
| **NORTH ASIAN AND SINO-KOREAN CRATONS AND OVERLYING PROTEROZOIC AND PHANEROZOIC UNITS** | | | | |
| North Asian. NAC<br>Sino Korean. SKC | Craton | Archean through Mesozoic | Cratonal and passive continental margin | |
| **NORTH ASIAN CRATONAL MARGIN UNITS** | | | | |
| Baikal-Patom. BP<br>Verkhoyansk. VR | Overlap assemblages | Neoproterozoic through Mesozoic | Passive continental margin | Original overlap assemblages on North Asian craton that were subsequently transformed into fold and thrust belts and terranes. |
| **SUPERTERRANES** | | | | |
| Argun-Idermeg. AR | Superterrane | Paleoproterozoic through late Paleozoic | Passive continental-margin | May be either exotic with respect to the North Asian craton or may be a rifted fragment of the craton. Accreted in Ordovician through Silurian. |
| Bureya-Jiamusi. BJ | Superterrane | Proterozoic through Permian | Composite | Consists of early Paleozoic metamorphic, continental-margin arc, subduction zone, passive continental-margin and island-arc terranes. Interpreted as being a fragment of Gondwanaland. Accreted to the Sino-Korean craton in the Late Permian and accreted to the North Asian craton in the Late Jurassic. |
| **TECTONIC COLLAGES** | | | | |
| Atasbogd. AB | Collage | Ordovician through Permian | Composite | Consists of the Ordovician through Permian Waizunger-Baaran terrane, Devonian through Carboniferous Beitianshan-Atasbogd terrane, and Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. Collage is interpreted as being a southwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terrane. Accreted in Late Carboniferous or Early Permian. |
| South Mongolia-Khingan. SM | Collage | Ordovician through Carboniferou | Island arc and subduction zone | Consists of the South Mongolia-Khingan arc and tectonically-linked subduction-zone terranes. The collage is interpreted as being a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian craton and cratonal margin and previously accreted terranes. Collage was separated from the North Asian craton by a large back-arc basin. Accreted in Late Carboniferous or Early Permian. |

**Table 1.** Summary of major Devonian and Early Carboniferous (Mississippian) geologic units and characteristics for Northeast Asia (Russian Far East, Yakutia, Siberia, Transbaikalia, Northeastern China, Mongolia, South Korea, and Japan). —Continued

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

| Name of unit. Map Symbol | Type of unit (craton, terrane, overlap assemblage) | Age range | Tectonic environment | Tectonic linkage |
|---|---|---|---|---|
| | | | **TECTONIC COLLAGES** | |
| West Siberian. WS | Collage | Ordovician through Carboniferous | Island arc and subduction zone | Consists of the Late Silurian through Early Carboniferous Rudny Altai island arc and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. Collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage. Accreted in Late Carboniferous or Early Permian. |
| | | | **Devonian and Carboniferous Continental-Margin Arcs Occurring on North Asian and Sino-Korean Cratons** | |
| North Okhotsk | Overlap assemblage | Devonian through Early Carboniferous | Continental-margin arc | Occurs in the northeastern flank of the North Asian craton and preserved in various fragments of the Kolyma-Omolon superterane. Interpreted as having formed during subduction of the Ancestral Pacific ocean plate. |
| | | | **Devonian through Early Carboniferous Island Arcs** | |
| Norovlin arc nr | Overlap assemblage | Devonian through Early Carboniferous | Island arc formed on Argun-Idermeg superterrane | Interpreted as having formed during subduction of the northern part of Mongol-Okhotsk Ocean plate under the Argun-Idermeg superterrane. |
| South Mongolian (Khingan) sm | Overlap assemblage | Devonian through Early Carboniferous | Island arc formed on South Mongolian and Atasbogd collages. | Interpreted as having formed during subduction of the Paleoasian Ocean plate. |
| | | | **Devonian Transpressional Arc** | |
| Altai arc at | Overlap assemblage | Devonian and Early Carboniferous | Transpressional-margin arc | Occurs on the previously accreted Altai and Yenisey-Transbaikal collages. The arc is interpreted as having formed along an active continental margin in an oblique subduction zone environment. |
| South Siberian arc ss | Overlap assemblage | Early Devonian | Transpressional-margin arc | Interpreted as having formed along the southern margin of the North Asian craton and cratonal margin during Early Devonian rifting that successively evolved into a continental-margin transform margin and, subsequently, into a convergent margin. |

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

1. The Atasbogd collage (AB) (Ordovician through Permian age and accreted in Late Carboniferous or Early Permian) consists of the Ordovician through Permian Waizunger-Baaran island-arc terrane, Devonian through Carboniferous Beitianshan-Atasbogd forearc and back-arc terrane, and Paleoproterozoic through Permian Tsagaan Uul-Guoershan continental-margin arc terrane. The collage is interpreted as being a northwest continuation (present-day coordinates) of the South Mongolia-Khingan island arc that formed southwest and west (present-day coordinates) of the deformed margin of the North Asian craton.
2. The South Mongolia-Khingan collage (SM) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the South Mongolia-Khingan arc (now a series of early and middle Paleozoic arc terranes), subduction-zone terranes, and back-arc basins. Tectonically linked to the South Mongolia-Khingan island arc was a subduction zone now preserved in the discontinuous collage of the Kalba-Narim and Zoolen subduction-zone terranes that occur outward (oceanward) of, and parallel to the South Mongolia-Khingan island arc. Also tectonically linked to the South Mongolia-Khingan island arc was an elongate back-arc basin now preserved in a discontinuous and disrupted collage of terranes in Southern Mongolia. These terranes are the Bayanleg (BL) and Mandah (MN) subduction-zone terranes. The South Mongolia-Khingan arc is interpreted as having formed during the Devonian through Early Carboniferous subduction of the Paleoasian ocean basin. The collage formed southwest and west (present-day coordinates) of the North Asian craton and previously accreted terranes.
3. The West Siberian collage (WS) (Ordovician through Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the Late Silurian through Early Carboniferous Rudny Altay island arc and the tectonically-linked Ordovician through Early Carboniferous Kalba-Narim subduction-zone terrane. The collage is a northwest continuation (present-day coordinates) of the South Mongolia-Khingan collage.
4. The Yenisey-Transbaikal collage (YT) (Vendian through Devonian age and accreted in Vendian through Early Ordovician) consists of the Vendian through Middle Cambrian Kuznetsk-Tannuola, Dzhida-Lake island-arc terranes, tectonically-linked back-arc basins, and now tectonically eroded subduction-zone terranes. The collage is interpreted as being a linear array of island-arc systems that formed south (present-day coordinates) of the deformed margin of the North Asian craton. The eastern part of the collage also includes the West Stanovoy metamorphosed terrane that may be a displaced fragment of the North Asian craton or of another craton.

## Devonian and Carboniferous Continental-Margin Arc Occurring on the North Asia Craton

The North Okhotsk continental-margin arc occurs in the northeastern flange of the North Asian craton and overlaps the Okhotsk cratonal (OH), Omolon cratonal (KOM) and Avekova cratonal (AK) terranes. The North Okhotsk continental-margin arc and associated subduction zone northward extended out from the continental margin and along the boundary of the ancestral Pacific Ocean and Angayucham Ocean. This part of the arc is interpreted as being an intraoceanic island arc formed above the subduction of the Ancestral Pacific ocean plate. In that case unknown back arc basin is expected behind of the oceanic island arc. Tectonically paired to the North Okhotsk arc was a subduction zone now preserved in a discontinuous collage of the Galam subduction-zone terrane in the northern part of the Russian Far East. The North Okhotsk arc is interpreted as having formed during the Devonian through Early Carboniferous subduction of the ancestral Pacific Ocean plate (Nokleberg and others, 2000). Remnants of this oceanic plate are now preserved in the discontinuous fragments of the Galam terrane, and remnants of the arc – on the Okhotsk, Omolon and Avekova terranes (Parfenov and Kuzmin, 2001; Parfenov and others, 2003). The Anagyucham ocean and/or back-arc basin was formed as a result of back-arc rifting and spreading behind the North Okhotsk arc. The Sette-Daban Basin also may have resulted from back-arc rifting.

## Devonian through Early Carboniferous Island Arcs

### South Mongoia-Khingan Arc

The South Mongolia-Khingan island arc (sm) (Middle Carboniferous through Triassic) overlies and intrudes the South Mongolian-Khingan and Atasbogd collages. The arc consists of a series of related Early and Middle Paleozoic arc terranes, including the Rudny Altai, Beitianshan-Atasbogd, Edren, Waizunger-Baaran, Gurvansayhan, Dongujimqin-Nuhetdavaa, Mandalovoo-Onor terranes. The Rudny Altai and Kalba-Narim terranes are underlain by fragments of accreted terranes that were rifted from the margin of the North Asian craton. The other terranes are built on oceanic crust or Ordovician through Silurian sedimentary wedges. The arc is interpreted as having formed during subduction of the Paleoasian Ocean plate under the South Mongolia-Khingan and Atasbogd collages.

### Norovlin Island Arc

The Norovlin island arc (nr) (Devonian through Early Carboniferous) overlaps the Argun-Idermeg superterrane (Argunsky and Idermeg passive continental-margin terranes, part of the Atasbogd and South Mongolia-Khingan collages) (fig. 2). The arc consists of (1) Lower to Middle Devonian calc-alkaline andesite, dacite, rhyolite, tuff, conglomerate, sandstone, and siltstone intruded by gabbro and diabase bodies; and (2) Middle to Upper Devonian volcanoclastic rocks, chert, mudstone and minor reef limestone. The arc is interpreted as having formed during subduction of the Mongol-Okhotsk Ocean plate beneath northern margin (present-day coordinates) of the Argun-Idemeg superterrane (Atasbogd and South Mongolia-Khingan collages). This plate is preserved in discontinuous fragments in the older parts of the Ononsky terrane.

### Transpressional Arc (Devonian through Cretaceous)

Two major transpressional continental-margin arcs occur on the south margin of the North Asian craton and collages and terranes accreted to the southern margin.

1. The Altai transpressional continental-margin arc (at) (Devonian and Early Carboniferous) occurs on the Altai and Yenisey-Transbaikal collages. The arc consists of the Devonian and Early Carboniferous Altai volcanic-plutonic belt (appendix B) that overlays the Altai collage. The arc is is interpreted as having formed along a transpressional continental margin where the convergence was oblique with respect to an outboard blocks. The tectonic environment consisted of lithospheric blocks (terranes) migrating along the margin of a continental plate.
2. The major South Siberian transpressional continental-margin arc (Early Devonian) (ss; fig. 2) occurs in Southern Siberia along the margins of the North Asian craton and various accreted collages and terranes to the south. The arc formation was associated with strike-slip faulting and local compression and extension. The arc consists of the Early Devonian South Siberian volcanic-plutonic belt (appendix B) that overlies the North Asian craton and adjacent accreted Yenisey-Transbaikal and Altaiy collages to the southwest.

## Summary of Devonian through Early Mississippian (410 to 320 Ma) Metallogenesis

### Major Devonian through Early Carboniferous Metallogenic Belts

The major Devonian through Early Carboniferous metallogenic belts are the Botuobiya-Markha, Bayangovi, Daldyn-Olenyok, Edrengiin, Edren-Zoolon, Hongqiling, Kizhi-Khem, Mamsko-Chuiskiy, Rudny Altai, Salair, Sette-Daban, Sorsk, Tsagaan-suvarga, Udzha, Ulziit, and Yaroslavka belts (fig. 3, appendix C).

#### Metallogenic Belts Related to Island Arcs

Four metallogenic belts possess geologic units favorable for a wide variety of island-arc magmatism-related deposits, including the Edrengiin, Rudny Altai, Salair, and Tsagaan-suvarga belts. The deposits types are volcanogenic Cu-Zn massive sulfide (Urals type), volcanogenic Zn-Pb-Cu massive sulfide, volcanogenic-sedimentary Mn, volcanogenic-sedimentary Fe, barite vein, volcanic-hosted metasomatite, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, porphyry Cu-Mo (±Au, Ag), porphyry Cu (±Au), porphyry Cu-Au, and granitoid-related Au vein. The fossil or isotopic ages of the deposits or hosting units range from Early Devonian through Early Carboniferous. The favorable geologic units are Edren island-arc terrane, part of the South Mongolia-Khingan collage; Rudny Altai island-arc terrane, part of West Siberian collage; the Altai volcanic-plutonic belt, part of the South Mongolia-Khingan island arc; and the Gurvansayhan island-arc terrane, part of South Mongolia-Khingan collage.

#### Metallogenic Belts Related to Terrane Accretion

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

#### Metallogenic Belts Related to Transpressive Continental-Margin Arcs

Five metallogenic belts (Deluun-Sagsai, Kizhi-Khem, and Korgon-Kholzun, Sorsk, and Teisk) possess geologic units favorable for a wide variety of major granite-hosted deposits. The major deposit types are polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite; polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite; polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork; volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type); sediment-hosted Cu, volcanogenic-sedimentary Fe; porphyry Cu-Mo (±Au, Ag);

Ag-Pb epithermal vein; granitoid-related Au vein; W-Mo-Be greisen, stockwork, and quartz vein; granitoid-related Au vein; mafic-ultramafic related Ti-Fe (+V); porphyry Mo (±W, Bi); polymetallic (Pb, Zn, Ag); carbonate-hosted metasomatite; Fe-skarn; Zn-Pb (±Ag, Cu) skarn; and Ta-Nb-REE alkaline metasomatite. The host geologic units are the Deluun sedimentary-volcanic-plutonic belt (part of the South Siberian and Altai transpressional- margin arcs), and replacements and granitoids related to the South-Siberian volcanic-plutonic belt, and the Altai volcanic-plutonic belt. The isotopic ages of the deposits or hosting units range from Devonian through Early Carboniferous. The favorable geologic units and deposits are the South Siberian and Altai transpressive continental-margin arcs.

### Metallogenic Belts Related to Transpressional Faulting

Two metallogenic belts (Hongqiling and Mamsko-Chuisky) possess geologic units favorable for major vein deposits or plutonic-hosted deposits. The major deposit types are mafic-ultramafic related Cu-Ni-PGE, polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, and muscovite pegmatite deposits. The fossil ages of the deposits or hosting units are Devonian and Early Carboniferous, and the isotopic ages range from 416 to 330 Ma. The favorable geologic units that host the tracts and deposits are (1) mafic and ultramafic plutons intruding and overlapping the Zhangguangcailing superterrane and Laoling terrane, part of Bureya-Jiamusi supterterrane; and (2) veins and dikes in the Mamsky and Konkudero-Mamakansky complexes intruding the Chuja paragneiss terrane that is included in the Baikal-Patom cratonal margin. These units and deposits are interpreted as having formed during transpressional faulting and associated interplate rifting.

### Metallogenic Belts Related to Rifting

Two metallogenic belts (Sette-Daban and Udzha) possess geologic units favorable for a wide variety of rift-related deposits. The major deposit types are sediment-hosted Cu, Basaltic native Cu (Lake Superior type), REE carbonatite, and carbonate-hosted Pb-Zn (Mississippi valley type deposits). The fossil ages of the deposits or host units are Devonian and Early Carboniferous. The favorable geologic units and deposits are interpreted as having formed during rifting of the North Asian craton or cratonal margin.

### Unique Metallogenic Belts

Two unique metallogenic belts (Botuobiya-Markh and Daldyn-Olenyok) are hosted in Devonian diamond-bearing kimberlite intruding the North Asian craton. The origin of the diamond-bearing kimberlite deposits is not well known.

The unique Edrengiin belt (with volcanogenic Cu-Zn massive sulfide, volcanogenic-sedimentary Mn and Fe deposits) is hosted in the Edren island-arc terrane, part of the South Mongolia-Khingan collage, and is interpreted as being having formed during island arc marine volcanism.

# Major Devonian and Early Mississippian (410 to 320 Ma) Metallogenic Belts and Host Units

## Bayangovi Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt BG) (Southern Mongolia)

This Devonian metallogenic belt (Zabotkin and others, 1988) is related to replacements in the Govi-Altai continental-margin turbidite terrane. The deposits are mainly Au-quartz carbonate vein occurrences. The Govi-Altai turbidite terrane consists of mainly Ordovician through Silurian turbidite that is overlain by Devonian shallow marine sedimentary rock (Tomurtogoo and others, 1999). The metallogenic belt was defined by Dejidmaa and others (1996) and contains the Bayangovi Au district (Dejidmaa, 1996). Au quartz-carbonate-vein occurrences consist of concordant pyrite alteration zones with thin, ladder quartz veins that are spatially related with Early Devonian granitoid in the Nudenhudag gabbro, tonalite, and plagiogranite complex. The host Silurian and Early Devonian sedimentary rock is metamorphosed to greenschist facies. The major deposits are at Bayangovi, Oortsog, and other occurrences.

The main references on the geology and metallogenesis of the belt are Dejidmaa (1996), Dejidmaa and others (1996), Zabotkin and others (1998), and Tomurtogoo and others (1999).

### Bayangovi Au in Shear-Zone and Quartz-Vein District

This deposit (D. Togtokh and others, written commun., 1991; A.A. Rauzer and others, written commun., 1987) consists of quartz veins in the Early Devonian Ulaan Khan uul, Gichigenet, and Khondolon Formations that are composed of sedimentary and volcanic rocks. The formations are intruded by concordant bodies of foliated quartz diorite, plagiogranite, and gabbro of the Nuden khudag Complex and by extensive subvolcanic bodies and dikes of andesite, basalt, gabbro, and diabase. Main faults strike to the northwest direction and they are cut by more late faults striking to the north and northeast. Intensive development of quartz veins and silicification are characteristic for the target area. There are few Au occurrences. Veins consist of milk-white, coarse- and medium-grained quartz in long extended zones. Chip samples contain 0.1 to 0.5 g/t Au. Also occurring are quartz stockworks and polymictic sandstone with chlorite cement. Pyrite occurs in

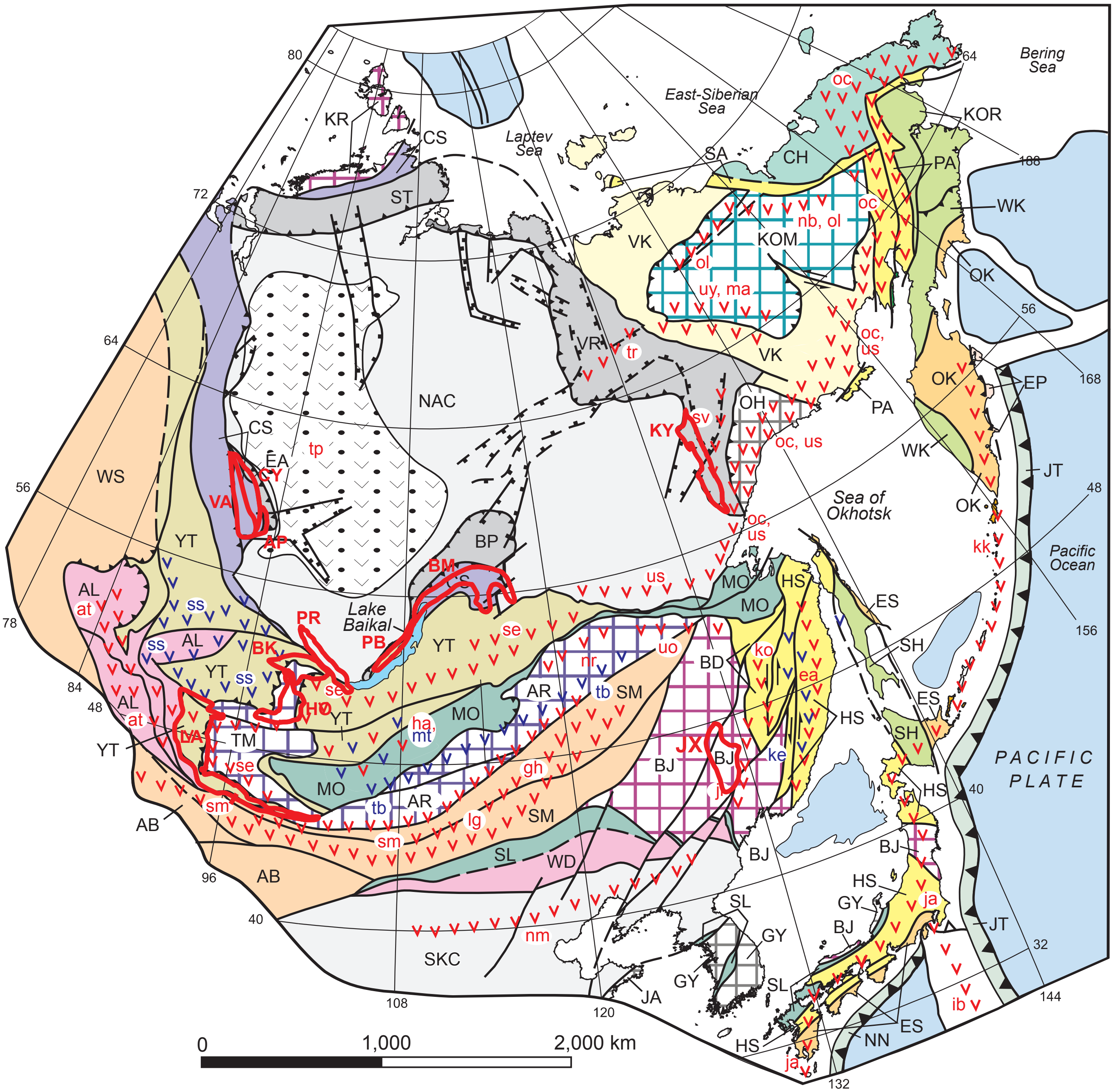



**Figure 3.** Generalized map of major Devonian and Early Carboniferous metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy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

margins of quartz stringers and in host sandstone, and it ranges up to 3 to 5 percent. Gold is fine-grained, and ranges from 0.1 to 0.2 mm and rarely up to 0.5-0.8 mm. Most gold forms plates, and some is intergrown with quartz and pyrite. Other ore minerals are galena and chalcopyrite. Also occurring is the similar Bayangovi II gold occurrence with a stockwork that grades 0.05 to 3.0 g/t Au. Also in the district is the Bituugiin khar occurrence with a quartz stockwork that is 2 m thick and 600 m long with channel samples grading 0.3 to 1.5 g/t Au.

## Origin and Tectonic Controls for Bayangovi Metallogenic Belt

The belt is interpreted as having formed during regional metamorphism of the Govi-Altai terrane that occurred during accretion of the South Mongolia-Khingan collage with the accreting margin of the North Asian craton and cratonal margin.

## Botuobiya-Markha Metallogenic Belt of Diamond-Bearing Kimberlite Deposits (Belt BM) (Russia, Central part of the Siberian platform)

This Devonian metallogenic belt is hosted in kimberlite intruding mainly early Paleozoic carbonate sedimentary rock in the North Asian craton. The belt extends 300 km in a southwest-northeast trend and contains several diamond-bearing kimberlite pipes of Devonian age. The major deposits are the Mir and Internatsional'naya pipes that intrude Cambrian and Ordovician carbonate and clastic rocks. The Mir pipe was mined from the 1950's until recently.

The main references on the geology and metallogenesis of the belt are Khar'kiv and others (1997), Brakhfogel' and others (1997), and Parfenov and others (1999, 2001).

## Internatsional'naya Diamond-Bearing Kimberlite Deposit

This deposit (Khar'kiv and others, 1997) consists of a well-defined, funnel-shaped pipe in the upper part which changes at depth into an almost cylindrical diatreme with subvertical contacts. The size of the pipe is constant to a depth of 1000 m. The pipe intrudes horizontal Cambrian and Early Ordovician clastic and carbonate rocks and is overlain by Early Jurassic deposits that range from 2,200 to 9,200 m thick. A characteristic feature of the pipe rocks is sparse Ti minerals (picroilmenite, orange pyrope) and abundant Cr minerals (chrome spinel, chrome diopside, chrome pyrope). The deposit is large.

## Mir Diamond-Bearing Kimberlite Deposit

This deposit (fig. 4) (Khar'kiv and others, 1997) consists of a pipe intruding Ordovician and Cambrian carbonate, terrigenous, and halogen-bearing rocks. The pipe is associated with two Late Devonian sills and a diabase dike. From the surface to a depth of 200 m, the pipe is funnel-shaped and at greater depth, down to 900 m, and it is cylindrically-shaped. At greater depths, the pipe grades into a feeding dike. Diamond forms are octahedra (61.2 percent), rhombododecahedra (9.7 percent), combined habit crystals (28.8 percent), and cubes (0.6 percent). The most common colors are colourless (75.4 percent), brown (7.2 percent), bluish-green (0.6 percent), lilac (2 percent) and smoky-grey (13.9 percent). Serpentine, carbonate, and chlorite are secondary minerals and comprise most of the kimberlite throughout the pipe. The deposit is large.

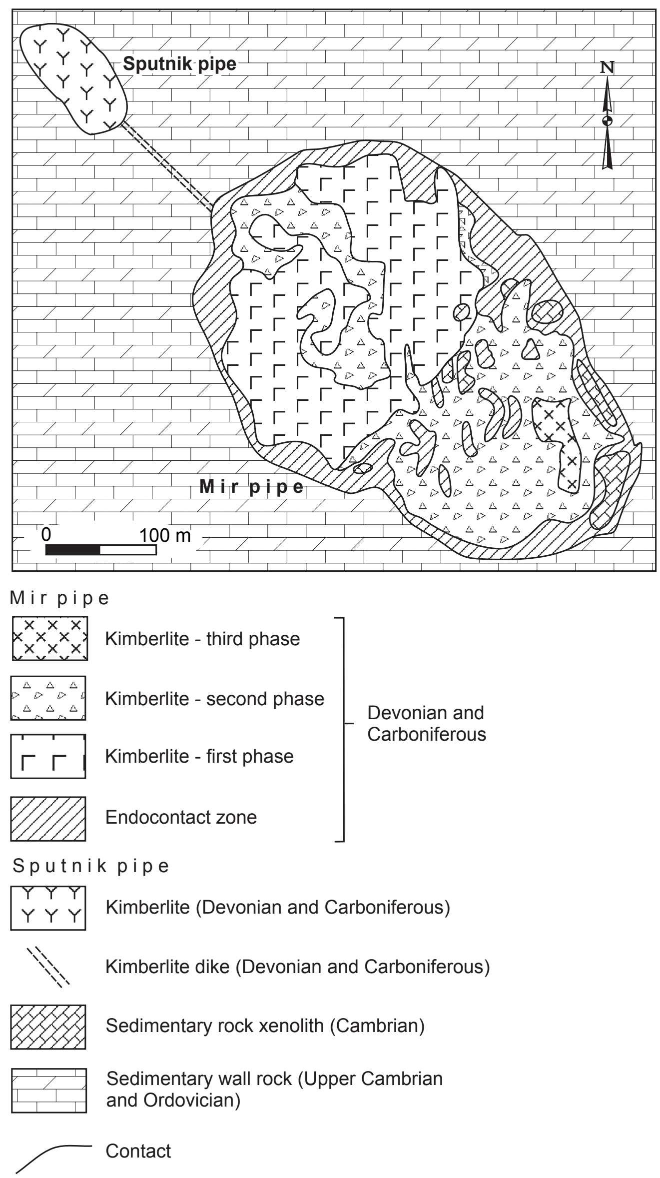



**Figure 4.** Geologic sketch map of the Mir diamond kimberlite pipe, Botuobiya–Markha metallogenic belt. Adapted from Khar'kiv and others (1997).

## Origin and Tectonic Controls for Botuobiya-Markha Metallogenic Belt

The tectonic environment for the origin of the belt is unknown. Devonian kimberlite pipes intrude mostly Cambrian through Silurian carbonate sedimentary rocks of the North Asian craton.

## Daldyn-Olenyok Metallogenic Belt of Diamond-Bearing Kimberlite Deposits (Belt DO) (Russia, Northeastern Siberian Craton)

This Devonian metallogenic belt is hosted in kimberlite intruding Phanerozoic sedimentary rock in the North Asian craton. The belt extends 800 km southwest-northeast and occurs north of the Botuobiya-Markha belt. The belt contains several diamond-bearing kimberlite pipes (Aikhal, Udachnaya, Ubileinaya, Sytykanskaya, and others) that intrude Cambrian through Silurian carbonate sedimentary rock of the North Asian craton. The major deposits are at the Aikhal, Udachnaya, Yubileinaya, and Sytykanskaya pipes.

The main references on the geology and metallogensis of the belt are Khar'kiv and others (1997), Brakhfogel' and others (1997), and Parfenov and others (1999, 2001).

## Aikhal Diamond-Bearing Kimberlite Deposit

This deposit (fig. 5) (Brakhfogel' and others, 1997) consists of a kimberlite pipe hosted in Lower annd Middle Ordovician and Lower Silurian argillaceous carbonate sedimentary rock. The pipe is elongated to the northeast and has irregular outlines in plan view at different levels and in cross-section. The pipe narrows at depth and grades into a dike that is 2 to 3 m thick with swells. Also occurring are numerous kimberlite dikes that crop out at the surface (four dikes) and at various depths. The amount of deep-level, associated minerals is minor. The minerals are rare picroilmente and more abundant chrome-spinel, pyrope, and olivine. In breccia in the southwestern ore shoot and in tuff, the concentration of chrome-spinel is higher than pyrope, whereas in the central part of the pipe, the two minerals occur in equal amounts. Olivine only occurs in a third-phase breccia, up to 5 to 9 percent. The deposit is large.

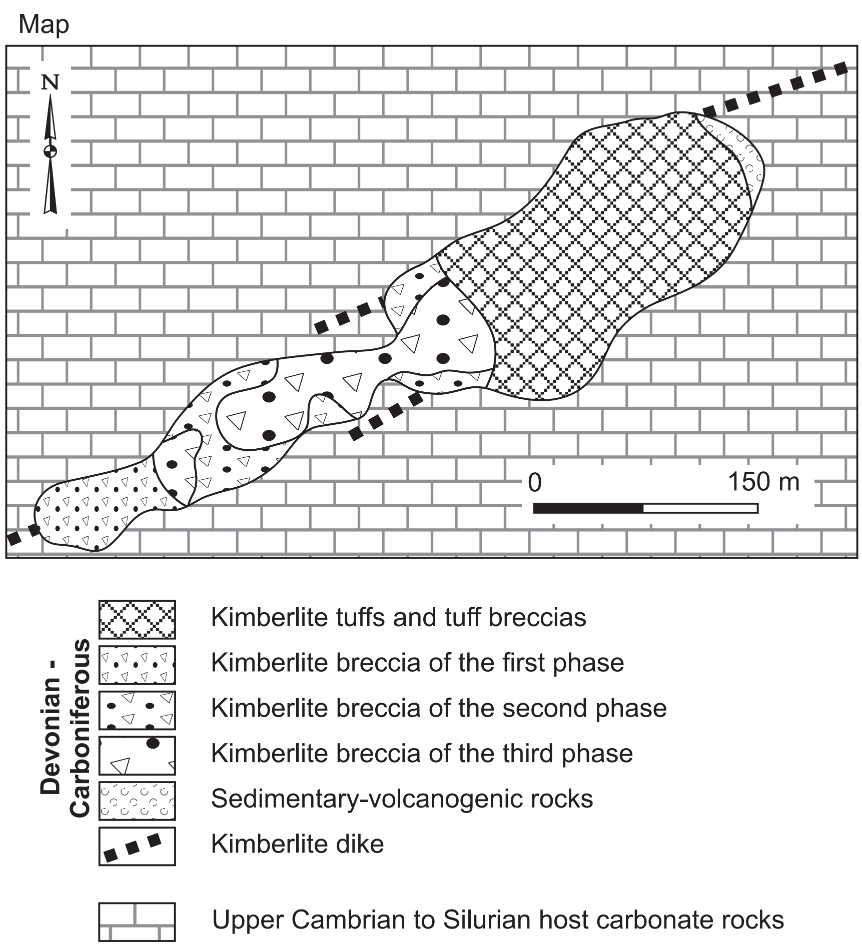



**Figure 5.** Geologic sketch map of the Aikhal diamond kimberlite pipe, Daldyn-Olenyok metallogenic belt. Adapted from Khar'kiv and others (1997) and Parfenov and others (2001).

## Udachnaya Diamond-Bearing Kimberlite Deposit

This pipe (fig. 6) (Brakhfogel' and others, 1997) consists of two conjugate western and eastern bodies that are shaped like a distorted figure eight in plan view. The pipe extends downward to 1,400 m. In the upper levels, to a depth of about 250 to 270 m, the western and eastern bodies merge, but they separate again at deeper levels. At a depth of 280 m, both bodies are isometric and almost round in plan view. The pipe is Devonian. The host rocks are Early Ordovician and Late and Middle Cambrian massive dolomite, dolomitized limestone, marl, mudstone, silstone, sandstone, and calcareous conglomerate.

The kimberlites consist mainly of serpentine pseudomorphs after olivine and local fresh olivine. Pyrope and picroilmenite are relatively rare. The amount of sedimentary rock xenoliths is smaller in the eastern body than in the western body where deep rock xenoliths are more abundant. The content of autoliths ranges from 10-15 to 35-40 percent.

Xenoliths of sedimentary rocks consist of limestone, dolomite limestone, and dolomite with admixture of clay and sand, and marl and siltstone. The size of xenoliths ranges from fractions of a millimeter to 100 m. Most reseachers believe that the western body predated the eastern one. The bodies differ in the composition of their constituent kimberlite rocks.

Several independent phases of a kimberlite magma were emplaced in the western body. Kimberlite breccia in varous phases differ in the picroilmenite/pyrope ratio, morphological characteristics of diamonds, and chemical composition of the rocks. Late kimberlite phases occur at deeper pipe levels. Kimberlite breccias at deep levels are characterized by higher concentrations of pseudomorphs after olivine (15 to 30 percent), autoliths (up to 25 percent), and xenoliths of sedimentary rock (10 to 25 percent). The western body is strongly serpentinized throughout (to a depth of 1,400 m). Concentration of fresh olivine relics is somewhat higher at levels deeper than 400 m. The amount of hydrothermal formations of geodes and veinlets of calcite, celestite, barite, and other minerals decreases with depth.

The pipe contains a large amount of xenoliths of the basement metamorphic rock. Their maximum concentration occurs in the central part of the body. Both bodies of the Udachnaya pipe contain a high content of deep rock xenoliths. The most common are undulose garnet serpentinite (apolherzolite) that range up to 57.1 percent. Less frequent are equigranular garnet serpentinite xenoliths (31.1 percent), including apodunite, apoharzburgite, and apolherzolite.

The eastern body is unique and contains relatively abundant deep rock xenoliths (0.3 to 0.6 percent) and nodules. The xenoliths are irregularly distributed and tend to occur in central areas of the body; they include both small clasts and giant blocks weighing more than 100 kg. Morphology of diamond crystals does not regularly change with depth. The deposit is large.

## Origin and Tectonic Controls for Daldyn-Olenyok Metallogenic Belt

The tectonic environment for the origin of the belt is unknown. Devonian kimberlite pipes intrude mainly Cambrian through Silurian carbonate sedimentary rocks of the North Asian craton.

# Deluun-Sagsai Metallogenic Belt of Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite, Polymetallic Pb-Zn±Cu (±Ag, Au) Vein and Stockwork, Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai type), Sediment-Hosted Cu, Ag-Pb Epithermal Vein, and Granitoid-Related Au Vein Deposits (Belt DS) (Western Mongolia)

This Early Devonian(?) to Early Carboniferous(?) metallogenic belt is related to granitoids and replacements in the Deluun sedimentary-volcanic-plutonic belt. The metallogenic belt occurs in the Mongol Altai area and is interpreted as being one of two belts that occur in a large metallogenic aureole related to Devonian calc-alkaline igneous rocks that constituted an Andean type active continental margin in north and northwestern Mongolia ((Berzin and others, 1994; Kovalenko and others, 1995). The metallogenic aureole contains two large metallogenic belts. The metallogenic belts and host Deluun overlap assemblage (Tomurtogoo and others, 1999) are intruded by Middle and Late Devonian calc-alkaline granitoids. This overlap assemblage (Byamba and Dejidmaa, 1999) stitches the Mongol Altai and Hovd terranes. An alternative interpretation is that the Deluun-Sagsai metallogenic belt formed during accretion (Dandar and others, 2001). The major deposits are the Dulaan khar uul Ag-Pb-Zn deposit, the Burged Cu-Pb-Zn occurrence, the Khatuugiin gol Cu occurrence, and the Nominy Am occurrences.

The main references on the geology and metallogenesis of the belt are Kovalenko and others (1995), Berzin, and others (1994), Byamba and Dejidmaa (1999), and Dandar and others (2001).

## Dulaan khar uul Ag-Pb Epithermal Vein Deposit

This deposit (Shubin, 1984; V. Filonenko and others, written commun., 1991) occurs in the margin of a volcano tectonic caldera containing the Early to Middle Devonian Dulaankhar Formation that consists of rhyolite tuff, flows, tuffaceous sandstone, rhyolite and dacite porphyry subvolcanic bodies and dikes, and diabase dikes. The deposit occurs in layers and sheets of siliceous tuff breccia. Four bodies occur and vary from 200 to 700 m long and 10 to 40 m wide.

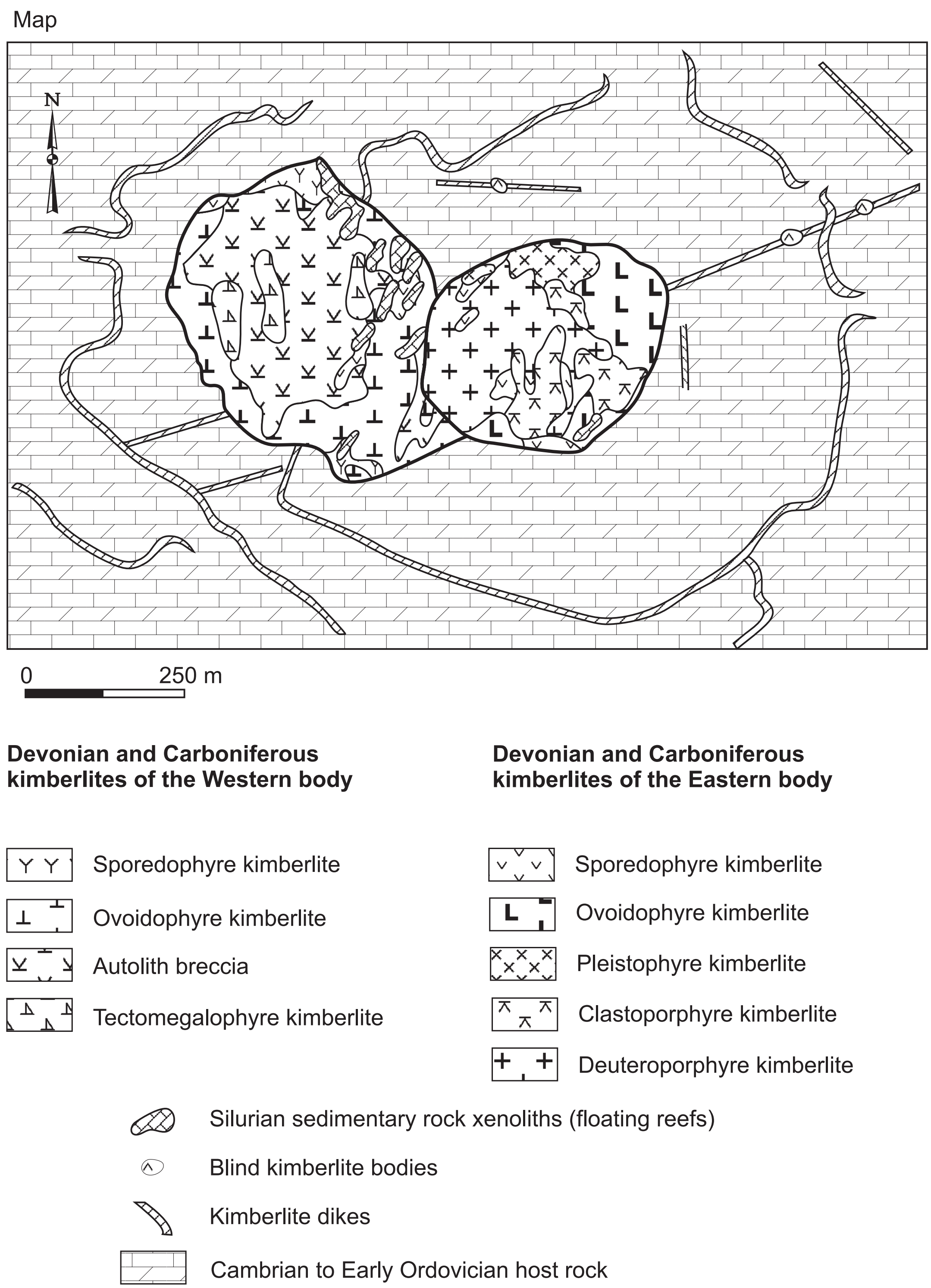



**Figure 6.** Geologic sketch map of the Udachnaya diamond kimberlite deposit, Daldyn-Olenyok metallogenic belt. Adapted from Khar'kiv and others (1997).

Primary ore minerals are sphalerite, galena, chalcopyrite, and gold. Sulfides occur in altered chlorite-sericite-quartz tuff and at the intersection of the Dulaankhar fault with a dike swarm that is 600 m wide. The sulfide bodies vary from 0.7 to 20 m thick, occur in layers, lenses, and veins; extend more than 100 m on surface, and downdip to a depth of 400 to 500 m. A large SP anomaly in the northeast part of the deposit has potential for new sulfide bodies. Oxidized parts of the deposit contain cerussite, calamine, galena, wulfenite, barite, fluorite, calcite, and malachite. Grades are 1.0 percent Pb, 1.0 to 10.0 percent Zn, 0.5 to 1.0 percent Cu, up to 2000.0 g/t Ag, and up to 0.2 percent Ba, from 0.2 to 4.0 g/t Au. A silica cap 700 m by 10 to 20 m occurs in the southwest part of the deposit and contains Cu oxides and hematite. The eastern and central parts of the deposit are hosted in tuff breccia. These areas contain anomalous Pb, Zn, Cu, Mo, and Co. Anomaly aureoles also occur in the western part. The deposit is large with resources of 665,000 tonnes Zn, 430,000 tonnes Pb, and 16.0 tonnes Au. Average grade is 2.05 percent Zn, 0.1to 1.76 percent Pb, 1.1 g/t Au, 1.0 to 45.0 g/t Ag, and 0.1 to 0.3 percent Cu.

### Burgedtas Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (D. Dorjgotov, written commun., 1990) consists of zones in Devonian felsic volcanic and sedimentary rock (altered sandstone and siltstone). Wall rocks are hydrothermally altered to silica, sericite, and limonite. Sulfide zones are up to 3.2 km long and several hundreds meters wide. Ore minerals are pyrite, sphalerite, chalcopyrite, galena, arsenopyrite and oxide. Major gangue minerals are quartz, sericite, kaolinite, and chlorite. Average grade is 0.1 to 1.0 percent Cu, 0.2 percent Zn, and 0.2 to 1 percent Pb.

### Khatuugiin gol Sediment-Hosted Cu Deposit

This deposit (B.N. Podkolzin and others, written commun., 1990) consists of sulfides in lenses and horizons in a zone that extends for several km in black shale of the Middle to Late Devonian Khatuu gol Formation along the eastern tributary of the Khatuugiin gol River. Sulfides are pyrite, pyrrhotite, and chalcopyrite in disseminations, small nests, and stringers. A unit of carbonaceous siltstone and sandstone with disseminated chalcopyrite extends 12 km from the Tsagaan gol River to the Asysan gol River. The unit varies from 1 to 7 m thick and contains up to 1.0 percent Cu, 0.1 percent As, 0.3 percent Sb, and 0.1 percent Ba. Quartz-biotite-chlorite veins, with chalcopyrite and pyrrotite occur in carbonaceous shale and contain up to 2.88 percent Cu, 0.07 percent Zn, up to 30.0 g/t Ag, and 0.01 g/t Au. The deposit has an average grade of 1.0 percent Cu.

### Nominy Am Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork Deposit

This deposit (B.N. Podkolzin and others, written commun., 1990) consists of sulfides in quartz and quartz-barite veinlets in a breccia zone hosted in the Early to Middle Devonian Otogiin Formation that consists of dacite and andesite, tuff, tuff breccia, and quartz-calcite sandstone. The breccia zone strikes northwest and occurs at the intersection of northwest- and northeast-striking faults at the contact between volcanic and terrigenous rock. The breccia zone is 60 to 100 m wide and the 300 to 350 m long. Cataclastic host rock is intensely altered to silica and limonite. The quartz and quartz-barite veins vary from 0.1 m to 1.5 m thick extend for 60 to 70 m along strike. Ore minerals are chalcopyrite, pyrite, galena, arsenopyrite, malachite, and azurite. The largest vein is 1 to 1.5 m by 70 m and grades from 0.3 percent to 1.0 percent Cu, 0.0015 to 0.7 percent Pb, 0.007 to 0.5 percent Zn, up to 1 percent As, up to 1 percent Ba, 0.003 to 0.015 g/t Au, and 1.5 g/t to 500 g/t Ag. The average grade is 1.0 percent Cu.

### Origin and Tectonic Controls for Deluun-Sagsai Metallogenic Belt

The belt is interpreted as having formed during granitoid magmatism that formed during transpressional faulting along the accreting southern margin of the North Asian craton. The polymetallic volcanic-hosted metasomatite deposits, as at Dulaanhar and Burgedtas, are related to Early to Middle Devonian basalt, andesite, and rhyolite. The sediment-hosted Cu deposits are in Middle to Late Devonian black shale, siltstone, and sandstone of the Sagsai Formation. Granitoid-related vein, stockwork, and replacement occurrences are at Sagsai and Dert tolgoi; others are hosted in volcanic and sedimentary rocks that are probably spatially and genetically related to small Late Devonian calc-alkaline granodiorite and granite stocks that occur along fault zones that control this collisional stitching complex.

## Edrengiin Metallogenic Belt of Volcanogenic Cu-Zn Massive Sulfide (Urals type) and Volcanogenic-Sedimentary Mn and Fe Deposits (Belt ED) (Southwestern Mongolia)

This Early Devonian metallogenic belt is related to volcanic and sedimentary rock in the Edren island-arc terrane (Tomurtogoo and others, 1999). Massive Cu sulfides and volcanogenic-sedimentary Mn deposits occur in the Early Devonian Olgiibulag Formation that is composed of pillow basalt, chlorite shale, and siliceous sedimentary rock with quartzite layers. Cu and Mn occurrences are located in the northwestern part of the belt, trend northwest-southeast, and were discovered by Rauzer and others (1987). The major deposits are the Olgii nuruu Cu and Olgii bulag Mn occurrences.

The main references on the geology and metallogenesis of the belt are Rauzer and others (1987) and Tomurtogoo and others (1999).

### Olgii nuruu Massive Sulfide Cu Occurrence

This occurrence (Rauzer and others, 1987) is hosted in a brecciated pillow basalt horizon that ranges up to 25 m thick and extends up to 2 km. Massive sulfide lenses range up to 2 m thick and consist of chalcopyrite and chalcocite in the central part of a pillow basalt horizon and disseminated sulfides in the marginal part. Fe-quartzite lenses and horizons occur parallel to pillow basalt and consist of massive magnetite lenses that range up to 1.5 m thick. Massive pyrite sheet-like bodies have dimensions to 0.25 to 0.5 by 100 m and occur adjacent to massive and disseminated Cu sulfides. Sulfides are strongly oxidized with widespread Fe oxides, malachite, and azurite.

### Olgiibulag Volcanogenic-Sedimentary Mn Deposit

This deposit (A. Rauzer and others, written commun., 1987) consists of Mn minerals in quartzite lenses in a Early Devonian chert and quartzite bed that ranges up to 4 m thick in the Early Devonian Olgii Formation. Lenses range up to 1 m thick and 100 m long. The main ore minerals are pyrolusite and hematite. Grab samples contain 2 to 30 percent Mn, up to 0.4 percent Co, and up to 2.0 g/t Ag. The deposit is small and it has an average grade of 2.0 to 30 percent Mn+Fe and resources of 100,000 tonnes Mn.

### Origin and Tectonic Controls for Edrengiin Metallogenic Belt

The belt is interpreted as having formed in island arc and ophiolite complexes that were part of the South Mongolia-Khingan collage and island arc. The deposits are hosted in pillow basalt and siliceous rock.

## Edren-Zoolon Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt EZ) (Southern Mongolia)

This Late Devonian and Early Carboniferous metallogenic belt (Tcherbakov and Dejidmaa, 1984) occurs in veins and replacements in the Edren island-arc and the Zoolon subduction-zone terranes (Tomurtogoo and others, 1999). The belt consists of Au in shear-zone and quartz-vein deposits that are hosted in regionally metamorphosed rock. Numerous occurrences are in the Edren and Nemegt districts. The Edren island-arc terrane consists of Middle Devonian andesite, tuff, chert, siliceous tuff, limestone, Middle and Late Devonian basalt and andesite, and overlying Early to Middle Carboniferous molasse (Ruzhentsev and others, 1990). Early Devonian age pillow basalt and siliceous sedimentary rock of Olgiibulag Formation occur in the northwestern part of the terrane (Rauzer and others, 1987). The Zoolon terrane consists of tectonic sheets, slivers, and melanges of Silurian and Devonian volcanic rock, volcaniclastic rock, chert, and ultramafic rock that are metamorphosed to greenschist facies (Tomurtogoo and others, 1999). The major deposit is at Khadat Gunii khudag.

These Au quartz-carbonate vein and stockwork occurrences are mostly hosted in greenstone, greenschist, and local altered ultramafic rock (Dejidmaa, 1996; Dejidmaa and others, 1996, 2002). The quartz-carbonate veins are concordant with host shale. Vein size is variable and ranges from a few millimeters to several meters thick. Thin veins occur in linear zones that are about a hundred meters long and up to several tens of meters wide. Host rocks are mostly intensely altered to pyrite. Veins are low sulfide type. The major ore mineral is pyrite, and minor minerals are chalcopyrite and native Au. The deposits are mainly in the Edergenii nuruu and Nemegt Au districts (Dejidmaa, 1996). Related placer Au deposits occur in the Edren, Ongon Uul, and Nemegt districts where placer Au and placer Au-PGE deposits were mined in ancient times.

The main references on the geology and metallogenesis of the belt are Tcherbakov and Dejidmaa (1984), Rauzer and others (1987), Ruzhentsev and others (1990), Dejidmaa (1996), Dejidmaa and others (1996), Sharhuuhen (1999), and Tomurtogoo and others (1999).

### Khadat Gunii khudag Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Podlessky and others, 1988) consists of a northeast-trending steeply dipping, quartz vein that ranges from 0.3 to 0.5 m thick and extends 100 m in chert and basalt in the Early Devonian Olgii Formation. Host rocks are weak altered to silica, carbonate, limonite, and epidote. Ore minerals are pyrite, chalcopyrite, galena, and rare gold. Heavy concentrate samples contain galena, arsenopyrite, sphalerite, pyrite, cerussite, anglesite, and gold that ranges from 0.1 to 0.9 mm in diameter. Rock-chip samples contain 0.1-30.0 g/t Au. A northeast-trending quartz-veinlet zone occurs 500 m to the southeast and consists of sericite-chlorite schist cut by quartz veinlets and stringers with pyrite, chalcopyrite, galena, and gold that range up to 3 mm. A rock-chip sample contains 10 g/t Au. Local placer Au deposits were exhausted in ancient times.

### Origin and Tectonic Controls for Edren-Zoolon Metallogenic Belt

The belt is interpreted as having formed during regional metamorphism and vein emplacement associated with accretion of the Beitianshan-Atasbogd and Zhongtianshan terranes.

## Hongqiling Metallogenic Belt of Mafic-Ultramafic Related Cu-Ni-PGE, Polymetallic (Pb, Zn±Cu, Ba, Ag, Au), and Volcanic-Hosted Metasomatite Deposits (Belt HQ) (Northeastern China)

The belt is interpreted as having formed during extension that occurred after accretion of the Zhangguangcailing superterrane to the basement of the Sino-Korean craton (Jilin-Liaoning-East Shandong terrane). In the Hongqiling, Changren, Piaohechuan, and other areas, the mafic and ultramafic plutonic intrusions, which occur in swarms, and consist of gabbro, pyroxenite, peridotite, orthopyroxenite, and cortlandtite. The mafic-ultramafic intrusions have isotopic ages of 331 to 350 Ma, and are controlled mainly by northwest-trending major faults that occur along the northern margin of the Sino-Korea Platform. The plutons intrude metamorphosed volcanic rock, terrigeneous, clastic, and carbonate rock of the early Paleozoic Hulan Group. However, new data indicate a possible Triassic age for the mafic-ultramafic plutons and related Cu-Ni deposits (new $^{40}$Ar-$^{39}$Ar isotopic age is 250 Ma).The mafic-ultramafic plutonism and associated Cu-Ni deposits are herein interpreted as having formed during extension after accretion. The Early Carboniferous volcanic and sedimentary strata hosting the Guama deposit occur in an extensional basin that is interpreted as having formed after the accretion of the Zhangguangcailing superterrane. The Hongqiling Cu-Ni deposit may be related to major regional faults that controlled a back-arc basin (Fu, 1988).

The main reference on the geology and metallogenesis of the belt is Fu (1988).

### Hongqiling Mafic-Ultramafic Related Cu-Ni-PGE Deposit

This deposit (Ge and others, 1994) consists of stratiform, tabular, and pod-like deposits in a mafic-ultramatic intrusion that intrudes the early Paleozoic Hulan group. The mafic-ultramafic intrusions consist of norite, pyroxenite, enstatotitite, and peridotite. The deposit is hosted in olivine pyroxenite. Ore minerals are pentlandite, pyrrhotite, chalcopyrite, pyrite, violarite, millerite, niccolite, maucherite, molybdenite, magnetite, and rutile. Pentlandite, pyrrhotite, and chalcopyrite are dominant. The mafic-ultramafic pluton is controlled by a major fault zone and has K-Ar isotopic ages of 331 to 350 Ma. The deposit is part of a district in the east-west-trending Tianshan-Xingan orogenic belt that occurs adjacent to the northern margin of the Sino-Korean Plate. The deposit is large and has reserves of 188,230 tonnes grading 2.3 percent Ni, <0.1ppm RGE, and 5 to 50 percent sulfides

### Guanma Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposit

This deposit (Wang, 1989) occurs in thin-bedded horizons of intermediate and siliceous tuff and marble in the lower part of the Early Carboniferous Lujuantun Formation. Most deposits occur in tuff, in stratiform layers and lenses and are concordant and codeformed with host rocks. Five separate deposits occur. The No. 1 deposit is 300 m long, extends 200 m downdip, and ranges from several meters to more than ten meters thick. The main deposit occurs in gray siliceous rock that contains minor arsenopyrite and pyrite and is sulphide-poor. Some Au deposits also occur in the intercalated siliceous tuff in marble and in siliceous tuff intercalated with marble. Silica alteration occurs in siliceous rocks along the contact of marble and tuff. Local diopside skarn and wollastonite-bearing marble occur in Au-bearing siliceous rock. From siliceous rock outwards into tuff, 20 to 50 m wide, sericite, chlorite and carbonate alterations are widespread, along with local talc and dolomite. The deposit is interpreted as having formed during sedimentary exhalation or hydrothermal alteration. The deposit is medium size.

### Origin and Tectonic Controls for Hongqiling Metallogenic Belt

The belt is interpreted as having formed during extension that occurred after accretion of the Jilin-Liaoning-East Shandong terrane. The belt is hosted in Mississipian mafic-ultramafic plutons intruding the Shandong terrane. In the Hongqiling, Changren, Piaohechuan, and other areas, the mafic and ultramafic plutonic intrusions that occur in swarms, are composed of gabbro, pyroxenite, peridotite, orthopyroxenite, and cortlandtite. The mafic-ultramafic intrusions have isotopic ages of 331 to 350 Ma, and are controlled mainly by northwest-trending major faults along the northern margin of the Sino-Korea Platform. The plutons intrude metamorphosed volcanic rock, terrigenous, clastic, and carbonate rock of the early Paleozoic Hulan Group. However, new data indicate a possible Triassic age for the mafic-ultramafic plutons and related Cu-Ni deposits (a new $^{40}$Ar-$^{39}$Ar age is 250 Ma).The mafic-ultramafic plutonism and associated Cu-Ni deposits are herein interpreted as having formed in magmatic events during extension after accretion. The Early Carboniferous volcanic and sedimentary strata hosting the Guama deposit occur in an extensional basin that is interpreted as having formed after the accretion of the Zhangguangcailing superterrane. The Hongqiling Cu-Ni deposit may be related to major regional faults that controlled a back-arc basin.

## Kizhi-Khem Metallogenic Belt of W-Mo-Be Greisen, Stockwork, and Quartz Vein, Porphyry Cu-Mo (±Au, Ag), Porphyry Mo (±W, Bi) (±W, Bi), Ta-Nb-REE Alkaline Metasomatite, and Granitoid-Related Au Vein Deposits (Belt KZ) (Northeast Tuva, Southern Siberia, Russia)

This Devonian through Pennsylvanian metallogenic belt is related to replacements and granitoids in the South-Siberian volcanic-plutonic belt that overlies and intrudes the Khamsara island-arc terrane. The belt occurs in northeast Tuva, and extends from east-west for about 300 km, and ranges from 40 to 60 km wide. The metallogenic belt occurs in the Ordovician through Carboniferou Kandat granitoid belt that extends latitudinally along the major Kandat fault for more than 500 km. The granitoids intrude mainly Vendian and Early Cambrian basalt, andesite, and dacite and Devonian volcanic and sedimentary rock. The porphyry Cu-Mo (±Au, Ag) and porphyry Mo (±W, Bi) deposits occur in the eastern part of the metallogenic belt, often along margins of Devonian basins. The host porphyry complexes consist of stocks of diorite, tonalite, and plagiogranite, and dikes of diorite and tonalite porphyry and granodiorite porphyry (Popov and others, 1988; Dobryanskiy and others, 1992). The deposits consist of streaks and disseminations in both Early Devonian porphyry stocks and granitoids. W-Mo-Be greisen, stockwork, and quartz vein deposits are related to small subalkalic leucogranite stocks and dikes (Danilin, 1968) and occur mainly in exocontact zones. The Okunevskoye deposit with the rare leucophane mineral is part of this group. More significant is the Aksug porphyry Cu-Mo (±Au, Ag) deposit. The Aryskanskoye Ta-Nb-REE alkaline metasomatite deposit also occurs in the metallogenic belt, but is older and has a recently-determined Late Ordovician isotopic age (454.6±1.4 Ma) (Kosticyn and others, 1998).

The main references on the geology and metallogenesis of the belt are Danilin (1968), Popov and others (1988), Dobryanskiy and others (1992), Berzin and Kungurtsev (1996), Kosticyn and others (1998).

## Aksug Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit (fig. 7) (Popov and others, 1988; Dobrjanskiy and others, 1992; Sotnikov and Berzina, 1993, 2000) consists of a stockwork with streaks and disseminations of Cu-Mo minerals in intensely-sheeted and hydrothermally-altered Early Cambrian volcanic rock that is intruded by the Aksug stock. The stock varies from gabbro and diorite in the periphyry to granodiorite and granite porphyry in the core. The dominant rocks are tonalite and Na-rich plagiogranite. The deposits occur in the outer zone of the porphyry intrusive around the quartz core. Two circular deposits occur. Host rocks are altered to K-feldspar, silica, and propylite. Cu deposits occur in hydrothermal quartz and sericite. Locally, Mo occurs in quartz-K-feldspar metasomatite. The ore minerals are chalcopyrite, pyrite, bornite, molybdenite, fahl, enargite, and magnetite. The deposit is medium size and has an average grade of 0.5 to 1.0 percent Cu and 0.02 percent Mo.

## Dashkhemskoye Porphyry Mo (±W, Bi) (±W, Bi) Deposit

This deposit (V.I. Sotnikov, this study) consists of a Mo stockwork hosted in early Paleozoic silicified biotite granodiorite. Porphyry dikes occur in the district. The deposit occurs in seven areas that range from 1 to 10 m wide and up to 30 m long. The total area of Mo deposits is 400 m$^2$. Deposits consist of quartz-sulfide veins, veinlets (up to 1 cm thick), and fine molybdenite disseminations. Pyrite also occurs. Grade ranges up to 0.3 to 0.4 percent Mo. The deposit is small.

## Okunevskoye W-Mo-Be Greisen, Stockwork, and Quartz Vein Deposit

This Be and fluorite deposit (Kachalo and others, 1976; Serdyuk and others, 1998) consists of masses and lenses of fluorite-altered rock with beryl in the exocontact zone of the

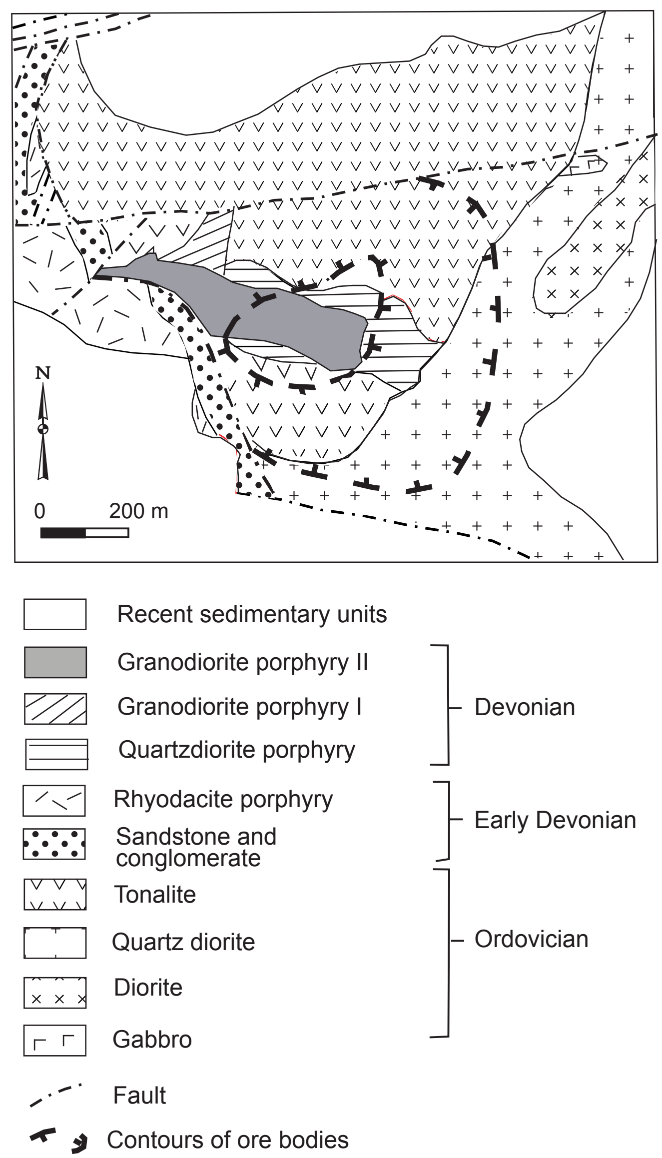



**Figure 7.** Geologic sketch map of the Aksug porphyry Cu-Mo deposit, Kizhi-Khem metallogenic belt. Adapted from Sotnikov and Berzina (2000)

alkalic Seibinsk granitoid pluton. The steeply dipping intrusive extends northeast for 2.5 km and is altered to albite and fluorite. Host rocks are marble, chert, and metamorphosed extrusive rock that locally are altered to skarn. Both host rocks and granite are altered to fluorite in the exocontact zone. Beryl deposits are closely associated with fluorite that contain leucophane and danalite. Deposits range from 1 to 3 m thick and extend along strike up to tens of meters. The deposit is small, has fluorite resources of 800,000 tonnes, and has an average grade of 30 percent fluorite.

### Aryskanskoye 1 Ta-Nb-REE Alkaline Metasomatite Deposit

This deposit (Kudrin and Kudrina, 1959) contains albite metasomatite with zircon (malacon) and Ti-Ta-Nb minerals and occurs along a northwest-striking fault zone in the apical part of a middle Paleozoic granitoid massif. The deposit is 375 m long, varies from 15 to 70 m thick, and increases to 110 m thick at a depth of 250 m. Albite formed during intrusion of aegirine-riebeckite granite and granosyenite and has an isotopic age of 390 to 400 Ma. Three stages of formation of albite metasomatite are recognized. The first stage is albite-zircon (malacon) metasomatic veins with riebeckite. The second stage is priorite and fergusonite that are closely associated with albitite metasomatite. The largest vein is 170 m long and 0.45 m thick. The third stage is quartz veinlets with ilmenite, sulfides, native As, Ta-Nb minerals, and thorite. Ore minerals are priorite, fergusonite, pyrochlore, zircon (malacon), thorite, gadolinite, astrophyllite, xenotime, apatite, gagarinite, fluorite, bastnaesite, and native As. The deposit is small and has an average grade of 0.2 to 0.5 percent REE.

### Origin and Tectonic Controls for Kizhi-Khem Metallogenic Belt

This belt is interpreted as having formed during granitoid magmatism associated with the South Siberian volcanic-plutonic belt that formed during transpressional faulting along the accreting southern margin of the North Asian craton. Deposit-related plutons intrude Early Cambrian volcanic rock of the Khamsara island-arc terrane and early Paleozoic granite of the Tannuola plutonic belt. The belt contains a broad variety of deposits that formed over a long period of time. The belt occurs along the major Kandatsk fault mainly in a large, early Paleozoic granitoid pluton that intrudes Vendian and Early Cambrian basalt of the Tuva ensimatic island arc, and is overlapped by Early Devonian extrusive rock that forms part of the South-Siberian volcanic-plutonic belt (Berzin and Kungurtsev, 1996). The formation of deposit-hosting granitoid complexes is followed by rift magmatism that formed trachybasalt and trachyrhyolite volcanic rock and subalkalic-leucogranite intrusions. The deposit-hosting porphyry intrusions structurally occur along edges of grabens that contain Early to Middle Devonian red-bed molasse. The $^{40}Ar/^{39}Ar$ isotopic age for the Aksug porphyry Cu-Mo (±Au, Ag) deposit is 380 to 400 Ma. Alaskite and alkalic granite hosting W-Mo-Be deposits cut the Silurian and Devonian granite and have a K-Ar isotopic age of 280 to 305 Ma (Danilin, 1968).

## Korgon-Kholzun Metallogenic Belt of Volcanogenic-Sedimentary Fe, Fe-Skarn, Mafic-Ultramafic Related Ti-Fe (+V), and Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposits (Belt KKh) (Gorny Altai, Russia, Eastern Siberia)

This Devonian through Carboniferous metallogenic belt is related to the Altai volcanic-plutonic belt that overlaps and intrudes the Altai and Charysh continental margin turbidite terranes. The belt occurs in the northwest part of Gorny Altai and is related to a Hercynian volcanic-plutonic belt that formed along an active continental margin. The host Devonian volcanic and sedimentary rock and intrusions overlap the Altai and Charysh terranes. The belt extends northwest for 275 km and ranges from 60 to 70 km wide. The major Charysh-Terekta fault zone forms the northeast boundary of the belt. The southwest boundary of the belt is the Northeastern shear zone that contains a group of Permian through Jurassic granite intrusions (Vladimirov and others, 1977; Gaskov and others, 1991). Volcanogenic-sedimentary Fe deposits, as at Beloretskoye, Inskoye, and Kholzunskoye, and associated Mn and polymetallic-vein deposits are dominant in the belt. Small metasomatic Ag and polymetallic sulfide occurrences are hosted in Silurian carbonate and clastic rock (Charyshskoye). Low-sulfide Au quartz occurrences are hosted in skarn, and the large Kharlovskoye Fe-Ti deposit is hosted in a stratified gabbroid pluton in the northern part of the belt (Charysh-Inskaya).

The main references on the geology and metallogenesis of the belt are Kalugin (1976, 1985), Shokalskiy (1990), Vladimirov and others (1997), and Gaskov and others (1999).

### Beloretskoye Volcanogenic-Sedimentary Fe Deposit

This deposit is hosted in a volcanic and sedimentary sequence of Eifelian age. The deposit consists of a layered volcanic and sedimentary magnetite body that is 1,400 long and 140 m thick. The ore horizon steeply extends for more than 1,150 m to depth (fig. 8). The Middle Devonian host rocks are volcanic and sedimentary silica-carbonate shale and sandstone, which are partly metamophosed by the Permian Tigirek granite pluton at depth. The ore minerals are layered, disseminated, massive, and brecciated. The main ore minerals are magnetite and muscovite with lesser actinolite, calcite, alite, ferro-salite, epidote, biotite, quartz, feldspar, chlorite, scapolite, turmaline, rare pyrhotite, pyrite, chalcopyrite, arsenopyrite, and sphalerite. The deposit is large and has reserves

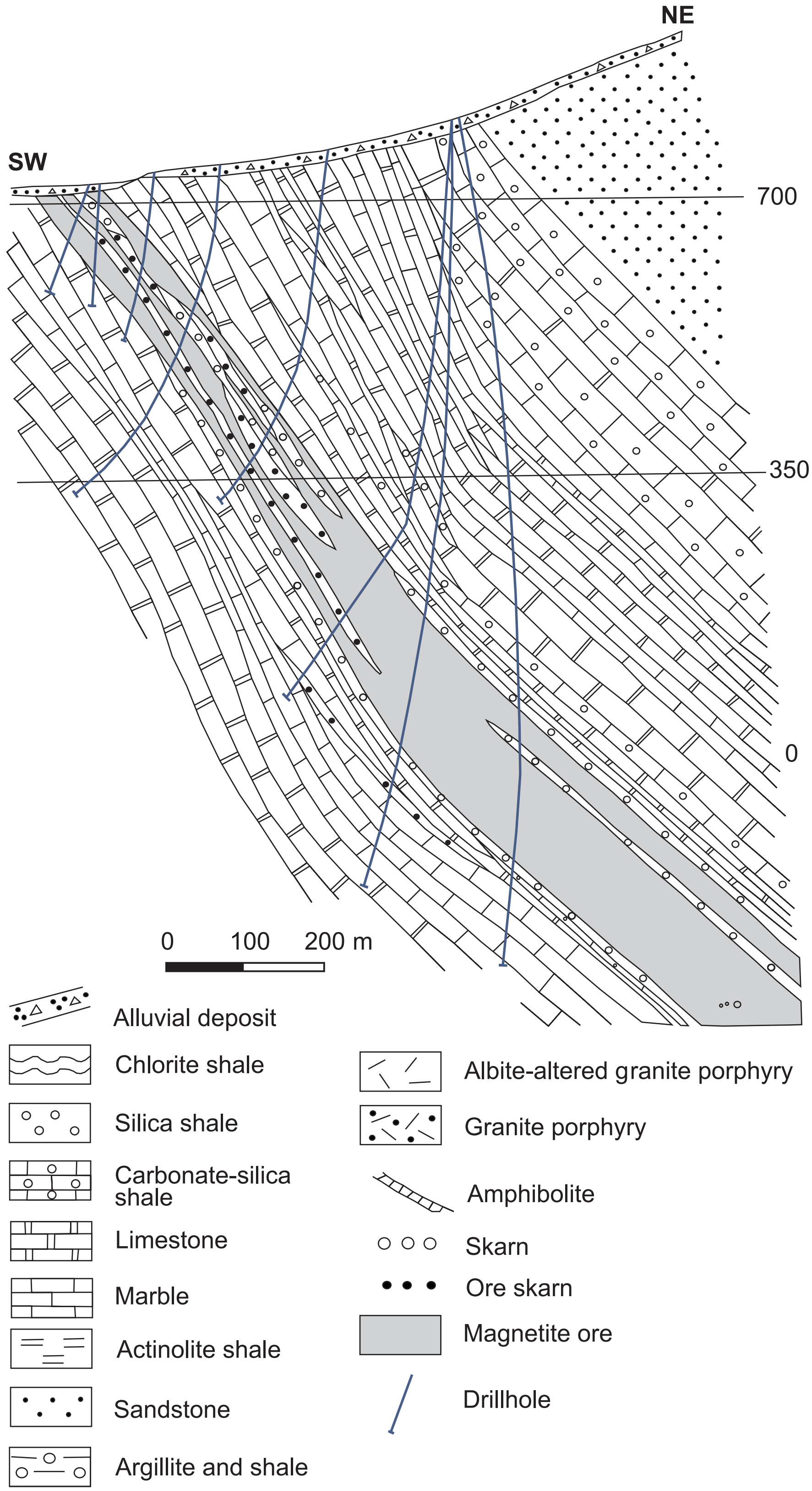



**Figure 8.** Schematic geologic cross section of the Beloretskoe volcanogenic sedimentary Fe deposit Rudny Altai metallogenic belt. Adapted from Kalugin and others (1981).

of 500,000,000 tonnes grading 33.5 percent Fe, 0.2 percent S, and 0.014 percent $P_2O_5$ (Kalugin and others, 1981).

## Kholzunskoye Volcanogenic-Sedimentary Fe Deposit

This deposit is the largest in the metallogenic belt (Kalugin, 1976, 1985; Orlov, 1988) and consists of layered volcanogenic-sedimentary magnetite hosted in intensely deformed Middle Devonian rock. Host rocks are limestone, tuff, dacite, and interbedded trachydacite porphyry and quartz albitophyre. The deposit ranges from 300 to 600 m thick and extends for 25 km. Devonian host rocks are intruded by a Permian biotite granite pluton in the southwest part of the deposit. Host rocks contact metamorphosed to quartz-muscovite-feldspar hornfels adjacent to the intrusive. Individual masses occur from 0.5 to 1 km from the granite pluton. Pegmatoid granite dikes cut the magnetite ore. The ore horizon consists of closely-spaced layers and lenses. Individual masses extend more than 700 m along strike and depth and range up to 70 to 100 m thick. The ore minerals alternate with schistose and recrystallized sedimentary and volcanic rock. Ore minerals occur in plications, layers, lenses, and in rare streaks and nests. Ore minerals are hydrosilicate-magnetite with high grade apatite (prevale), actinolite, biotite, carbonate, and sulfides. Secondary minerals are epidote, quartz, dolomite, zeolite, anhydrite, barite, pyrite, and chalcopyrite. The deposit is high in silica and low in Mg. Extensive superimposed metasomatism modified stratiform Fe layers and host rocks. The deposit is large and has reserves of 600 million tonnes grading 29.7 percent Fe. Average grades are 0.10 percent $V_2O_5$, 1.77 to 3.49 percent S, and 0.25 to 0.34 percent $P_2O_5$.

## Inskoye Fe-Skarn Deposit

This deposit (fig. 9) (Chekalin and Polovnikova, 1997; Orlov, 1998) consists of magntite layers hosted in an Eifelian volcanic and sedimentary sequence. The host rocks are intruded by the Permian Tigerek granitoid pluton. Along the contact with the granitoid, host rocks are recrystallized to hornfels and skarn. The deposit occurs in an economic deposit that extends 4.7 km and ranges from 100 to 400 m wide. The district contains four main deposits that each range from 180 to 1,000 m long, extend from 150 to 640 m deep, and have an average thickness of 8 to 40 m. Ore minerals occur in masses and bands and, rarely, in disseminations, spots, breccias, and streaks. The main ore assemblage is amphibole, pyroxene, and magnetite ore. Locally occurring are garnet, chlorite, epidote, carbonate, quartz, and scapolite. Associated ore minerals are pyrite, pyrrhotite, minor chalcopyrite, and sphalerite. One interpretation is formation during volcanism and sedimentation with subsequent regional and contact metamorphism (Kalugin, 1985). Another interpretation is formation during contact-metasomatism. The deposit is large and has reserves of 250 million tonnes and an average grade of 45.2 percent Fe and 0.06 percent $P_2O_5$.

## Kharlovskoye Mafic-Ultramafic Related Ti-Fe (+V) Deposit

This deposit (Shabalin, 1976, 1982; Kalugin and others, 1981; Kuznetsov, 1982) consists of layers of titanomagnetite in a gabbroic lopolith pluton that covers about 10 km$^2$ (Shokalskiy, 1990). The pluton contains alternating melanocratic olivine gabbro, and nonmineralized leucocratic gabbro, norite, and anorthosite. Thickness of igneous layers ranges up to several tens of meters. Ten ore layers occur, range from 425 to 3700 m long, extend to a depth of 225 to 2,250 m, and are 16 to 140 m thick. Ore minerals are rarely disseminated. The main ore minerals are titanomagnetite (23 to 31 percent), ilmenite (1.5 to 5.2 percent), olivine (1.6 to 31.5 percent), pyroxene (18 to 25 percent), plagioclase (14 to 28 percent), and calcite (up to 0.9 percent). Lesser minerals are serpentine, garnet, biotite, chlorite, apatite, hornblende, and epidote. Ores exhibit high V (0.08 percent). The deposit is large and has reserves of 1.7 billion tonnes and resources of 4 billion tonnes. Average grades are 15.3 percent Fe and 5.9 percent $TiO_2$.

## Origin and Tectonic Controls for Korgon-Kholzum Metallogenic Belt

The belt is interpreted as having formed interpreted during transpressional faulting along the accreting southern

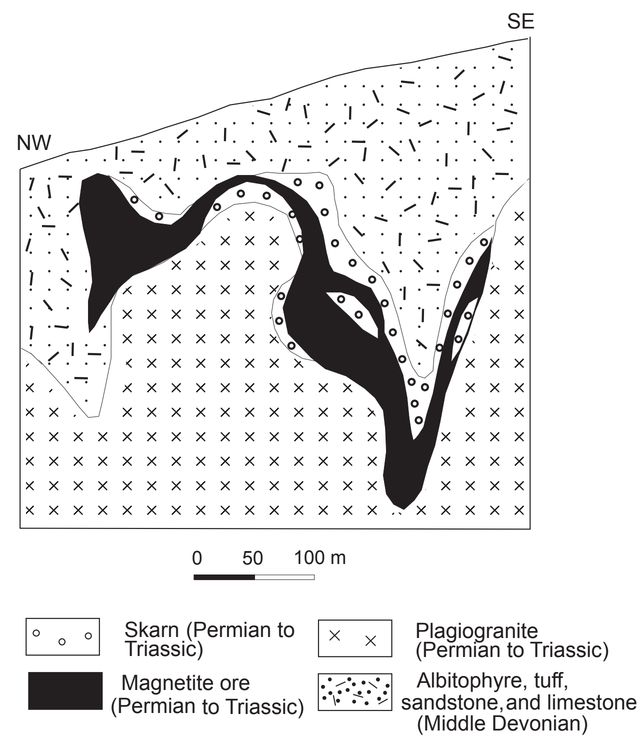



**Figure 9.** Schematic geologic cross section of the Inskoye Fe-skarn deposit, Korgon-Kholzun metallogenic belt. Adapted from Kuznetsov (1982).

margin of the North Asian craton, part of the South Siberian (Altai?) transform continental-margin arc during the Devonian and Carboniferous. The volcanic-plutonic belt had features similar to a cordillera type active continental margin (Kovalev, 1978). The belt contains widespread subalkalic basalt, andesite, and rhyolite sequences with siliceous volcanic rock being the most abundant. Subaeral and shallow water volcanic and sedimentary rock is typical. Metallogeny is related to volcanism and formation of Fe deposits (Kalugin, 1985; Gaskov and others, 1991). The main Fe deposits formed along tectonic sutures, as at Kholzunskoye and Timofeevskoye. Some large deposits (Inskoye, Beloretskoye) were later metasomatized during intrusion of collisional granitoids. The belt contains numerous small volcanogenic-sedimentary deposits (Korgonskoye, Kedrovskoye), magmatic-related deposits, and hydrothermal occurrences. Many deposits are Mn rich. Geodynamically, the Charysh terrane is interpreted as being a fragment of an Ordovician and Silurian passive continental margin that was weakly reactivated during the Devonian with formation of interfault basins and minor volcanism. The Eifelian and Jivetian volcanic rock consist of andesite, basalt, rhyolite, and dacite as in the Kur'ya and Novo-Firsovo Basins. Cutting the Ordovician and Silurian clastic and carbonate rocks are numerous Middle Devonian(?) subvolcanic andesite porphyry dikes and sills, small rhyolite and dacite stocks, granodiorite poprhyries, and layered intrusions of gabbro and anortosite (Shokalskiy, 1990).

## Mamsko-Chuiskiy Metallogenic Belt of Muscovite Pegmatite Deposits (Belt MC) (Russia, Northern Transbaikalia)

This Devonian through Early Carboniferous metallogenic belt is related to veins and dikes in the Mamsky and Konkudero-Mamakansky complexes (too small to show at 10 M scale) that intrude the Chuja paragneiss terrane that is overlapped by the Patom fold and thrust belt of the North Asian cratonal margin. The belt occurs in the North Baikalian Highland near the north end of Lake Baikal, extends northeast for 375 km, and is 85 km wide. The Chuja paragneiss terrane forms part of the Baikal-Patom fold and thrust belt that occurs along a passive continental margin. The Chuja terrane consists of hypersthene-diopside-plagioclase-amphibole schist, gneiss, and amphibolite (Braminsky Complex), plagiogneiss with horizons of quartzite, limestone, biotite-amphibole gneiss and amphibolite (Chuja Series), biotite and biotite-amphibole gneiss, cordierite, and sillimanite and andalusite schist. The units are dated as Archean (Neelov and Podkovyrov, 1983).

Occurring in this metallogenic belt are a large number of muscovite pegmatite deposits that are related to the final stages of intrusion of the alkaline granitoids of the middle Paleozoic Mamsky and middle Paleozoic through late Paleozoic Konkudero-Mamakan Complexes. The largest deposits (mica-bearing fields) are at Vitimsky, Lugovka, Bolshoe Severnoye, Komsomolskoye, Sogdiondon, and Chuysky. Part of the metallogenic belt is controlled by the northeastern zone of regional metamorphism and granitization. The commercial mica pegmatite bodies occur in local domes that contain widespread features of migmatization, granitization and pegmatite formation (Vasilieva, 1983). Both synkinematic and late synkinematic pegmatites are recognized (Velikoslavsky and others, 1963). The former formed in place during folding and progressive metamorphism jointly with formation of metasomatic zones and mica. The latter pegmatite veins are related to retrogressive metamorphism and plastic deformations and are the most economic. The mica-bearing pegmatite contains plagioclase-microcline and plagioclase types that occur primarily in mica gneiss and clinopyroxene schist. The shape of the bodies is diverse and consists of veins, lenses, stocks, and pipes. Mica occurs in quartz-muscovite nests and is associated with beryl. In addition to muscovite, the belt is promising for granitoid-related Au-vein deposits as at the Mukodek occurrence. The major deposits are at Vitimskoye, Lugovka, Kolotovka, Bolshoye Severnoye, Komsomolsko-Molodezhnoye, Sogdiondonskoye, and Chuyskoye.

The main references on the geology and metallogenesis of the belt are Velikoslavsky and others (1963), Sryvtsev and others (1980), Neelov and Podkovyrov (1983), Vasilieva (1983), Gusev and Khain (1995), Ivanov and others (1995), Gusev and Peskov (1996), and Makrygina and others (1993).

### Lugovka Muscovite Pegmatite Deposit

This deposit (Verkhozin and Kochnev, 1979; Kochnev, 1966, 1968, 1971; Rudenko and others, 1980) consists of two pegmatite fields and a series of veins that occur along a sublatitudinal tectonic zone and associated shear folds. Vein dimensions vary from small (920 to 950 by 1 to 5 m) to very large (200 to 500 by 10 to 30 m), at a depth of 115 m. The vein forms are concordant, plate-like, crosscutting, and pipe. Locally, the veins occur in clusters of extensive veins. Petrologic types are plagioclase-microcline pegmatite, quartz-muscovite and pegmatite, plagioclase pegmatite, and fractured biotite-muscovite (pegmatite). Host rocks are Mesoproterozoic two-mica gneiss and schist. Veins are associated with Mesoproterozoic through early Paleozoic granites. The deposit occurs in the central part of the Mamsky muscovite province. Twenty-two veins have been mined. Reserves are 150 kg/m$^3$ of large-scale muscovite with a raw muscovite content of 100 to 300 kg/m$^3$. The deposit is large and contains up 14 percent total mica in the Mamsky mica-bearing province.

### Sogdiondonskoye Muscovite Pegmatite Deposit

This deposit (fig. 10) (Chesnokov, 1966; Tyurin, 1966, 1967; Galkin, 1969) consists of a series of veins (20 to 300 by 1 to 25 by 150 m) of various shapes with predominant crosscutting veins and dikes controlled by sublatitudinal fractures zones and flexures. The deposit consists of plagioclase-microcline pegmatite and quartz-muscovite pegmatite. The host rocks are Mesoproterozoic mica schist and gneiss and Mesoproterozoic-early Paleozoic pegmatite-bearing granitoids. The deposit is controlled by the Chuya-Sludianka structural zone and occurs along the intersection of the fault with a granite and migmatite dome in the northwest and central parts of the Mamsky muscovite province. The deposit contains rare large veins.

## Origin and Tectonic Controls for Mamsko-Chuiskiy Metallogenic Belt

This belt is interpreted as having formed during intrusion of alkaline granitoid of the Mamsky and Konkudero-Mamakansky Complexes into the Chuja paragneiss terrane that formed part of a passive margin. The host granitoids are interpreted as having formed during post-accretionary magmatism in transpression zones related to transform microplate boundaries and within plate (plume) environment.

## Muiskiy Metallogenic Belt of Granitoid-Related Au Vein, Au in Shear-Zone and Quartz-Vein, Carbonate-Hosted Hg-Sb-Sb, and Porphyry Sn Deposits (Belt MS) (Russia, Northwestern Transbaikalia)

This Devonian through Early Carboniferous metallogenic belt occurs in the granitoid complexes of the Barguzin-Vitim granitoid belt that forms a major suture complex. The belt occurs in the central part of the Vitim Highland and extends northwest along the Muysky Range, which is a watershed for Lake Baikal and the Vitim River. The belt is about 250 km long and 75 km wide. The granitoid belt intrudes the Baikal-Muya island arc, Olokit-Delunurian subduction-zone terranes, the Aldan cratonal, and Muysky terranes. The metallogenic belt contains various large metalliferous and nonmetalliferous deposits and small occurrences of various deposit types. The

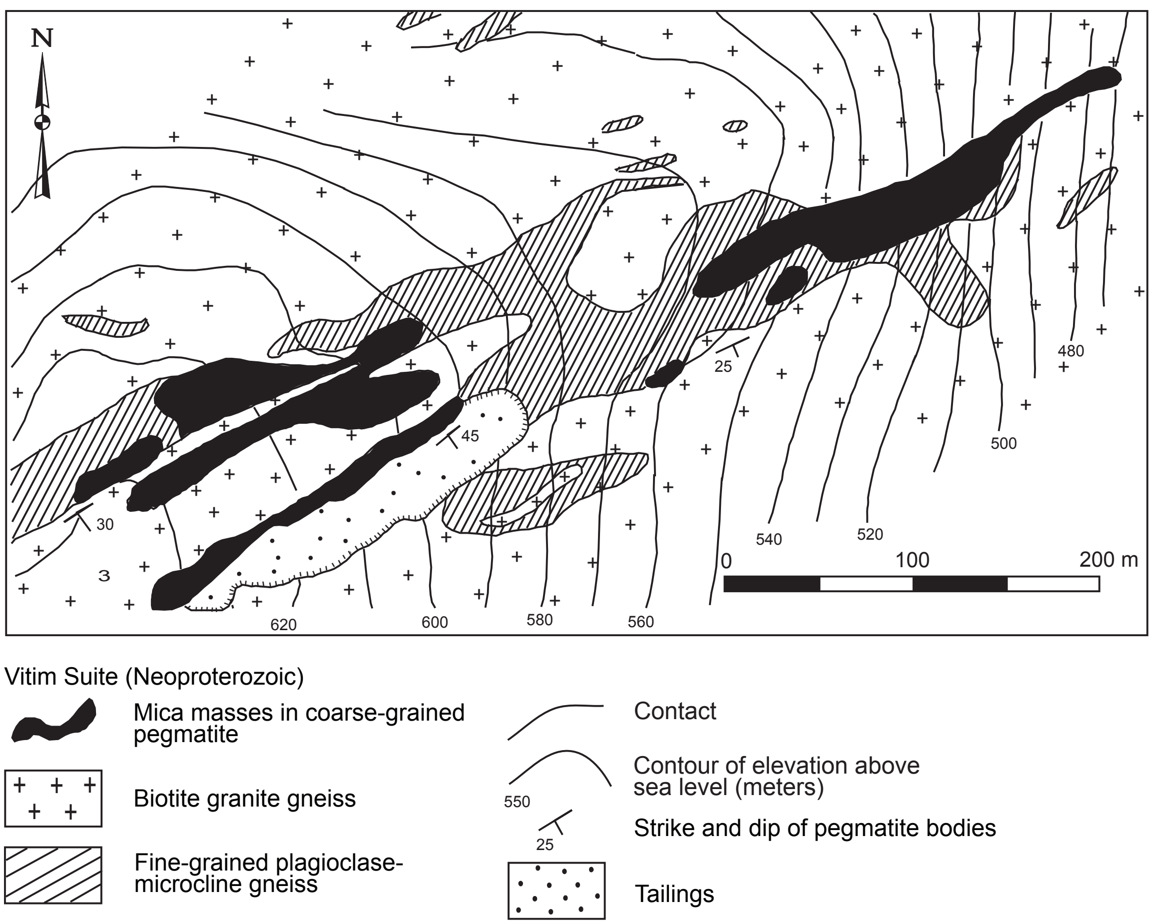



**Figure 10.** Geologic sketch map of the Sogdiondonskoye muscovite pegmatite deposit, Mamsko-Chuiskiy metallogenic belt. Adapted from Markov (1937).

belt occurs in two large districts, the North Muysky and South Muysky districts, both of which occur in the Muya terrane. The major deposits are at Irokindinskoye, Verkhne-Sakukanskoye, Mokhovoye, and Kelyanskoye. The belt is promising for undiscovered Au, Sn, and Hg deposits. The main references on the geology and metallogenesis of the belt are Berger and Murina (1972), Rubanov and others (1970), Bulgatov (1983), Dzasokhov (1985), Dobretsov and others (1989), Znamirovsky and Malykh (1974), Mitrofanova (1979), Mitrofanov and others (1983), Obolenskiy (1985).

The granitoid-related Au-vein deposits are hosted in Archean and Proterozoic basement as at Irokindinskoye and Kedrovskoye. The characteristics of the deposits are (1) occurrence of deposits in garnet-pyroxene, amphibole-pyroxene, and amphibole gneiss along the major Kelyano-Irokinda fault zone (Rubanov and others, 1970); (2) quartz-rich and sulfide-poor composition, with major sulfide minerals being pyrite, galena, sphalerite, pyrrhotite, and arsenopyrite; (3) sulfides comprising about 0.5 to 1.5 percent; (4) abundant quartz-vein generations (Dzasokhov, 1985); (5) occurrence of deposits along gently-dipping thrusts; (6) close age of deposits; (7) vein shape of deposits; and (8) interblock position of veins.

The major Au in shear-zone and quartz-vein deposits are at Verkhne-Sakukansky and Yubileynoye (Zhilyaeva and Naumov, 2000), Irbinskoye and Vitimkonskoye and occur in Precambrian sulfide-bearing schist and amphibolite in the Olokit-Delunuran subduction-zone terrane. The deposits occur in thick, hydrothermal zones of diaphtorites that occur along oblique-thrust-strike-slip faults. Common features are elevated Ag content and the occurrence of galena, pyrite, chalcopyrite, and sphalerite.

The carbonate-hosted Sb-Hg deposits are hosted in Vendian and Cambrian clastic and carbonate rocks and in Middle Carboniferous jasperoid dolomite in the Yangudsky Suite (Berger and Murina, 1972; Znamerovsky and Malykh, 1974). The deposits consist of layered zones (to 300 m thick) of intense silica alteration and brecciation that occur along thrusts (Obolensky, 1985). The deposits contain Au, Sb, pyrite, fluorite, and potassic hydromica. Major deposits are at Kelyanskoye, Sosnovskoye, and Anomalnoye.

The porphyry Sn deposits occur in Paleoproterozoic through Mesoproterozoic granitoid that is hosted in tectonically reworked blocks containing hematite-magnetite-feldspar metasomatite (Mitrofanova, 1979) and cassiterite-sulfide deposits. Examples are the Mokhovoye deposit and occurrences at Korotkoye and Goltsovoye. REE deposits with beryl and molybdenite occur in addition to chalcopyrite, bornite, pyrite, and arsenopyrite.

## Kelyanskoye Carbonate-Hosted Hg-Sb Deposit

This deposit (Demidova, 1976) consists of a series of steeply-dipping zones that occur along a major thrust fault that cuts Early Cambrian dolomite. The zones consist of layers and lenses with dimensions of 160 to 450 by 2.8 to 4.0 m. They extend for a few tens of kilometers and consist of quartz dolomite breccia that is cemented by veins containing cinnabar. The vein minerals are quartz, calcite, and dolomite, and rare fluorite and barite. The ore minerals are cinnabar, antimonite, pyrite, galena, sphalerite, and chalcopyrite. Cinnabar is also disseminated in dolomite, and it also occurs in veins occurs irregularly. Cinnabar nests occur in areas of disseminations, crossing zones, and fractures. The deposit is large and has an average grade of 0.01 to 25.1 percent Hg, and 0.1to 0.78 percent Sb.

## Irokindinskoye Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Namolov, 1980; Rubanov, 1980; Dzasokhov, 1985; Dzasokhov, 1987; Shelkovnikov, written commun., 1986) consists of 36 varibly oriented and gently lying quartz veins that occur to a depth of 480 m. The average length is 150 to 180 m, and the average thickness is 0.5 is 0.9 m. Veins contain about 0.2 to 0.5 percent sulfides that consist of pyrite (up to 78 percent), galena (up to 15 percent), sphalerite, chalcopyrite, pyrrhotite, arsenopyrite, hessite, argentite, and scheelite. Gangue minerals are quartz and carbonate (to 2 to 4 percent veins). Gold has high fineness and locally occur in nests that range to 1 to 5 mm thick. In veins gold locally occurs in pillars with dimensions of 50 to 400 by 10 to 60 m. The most productive veins cut garnet-pyroxene gneiss that is altered to quartz, pyrite, sericite, and chorite in a band that varies from 3 to 4 to 30- to 40 m wide. The deposit occurs within a tectonic block with an area of 75 $km^2$ that consists of Paleoproterozoic gneiss, limestone, and amphibolites. The deposit occurs in the central part of the Archean-Proterozoic Southern Muya terrane where cut by the submeridional, major Kilyaro-Irokindinsky fault. The deposit is medium size, and has an average grade of 0.7 to 133.8 ppm Au.

## Mokhovoye Porphyry Sn Deposit

This deposit (Mitrofanova, 1979, 1981; Khrenov and others, 1983; Ignatovich and Martos, 1986; Skursky, 1996) consists of 23 lenses that range from 3 to 15 m thick and extend to 110 m depth. The deposit assemblages are: (1) cassiterite-hematite; (2) magnetite-feldspar metasomatite with chalcopyrite and rare bornite, pyrite, and scheelite; (3) micaceous-hematite-quartz in low-grade metasomatite (about 0.004 percent Sn); (4) arsenopyrite-carbonate-sericite in greisen; and (5) molybdenum with rare beryl in quartz vein. The first assemblage is more economically important and the second and third assemblages are secondary and occur along the edges of the deposit. The deposit occurs in a paleocaldera, with surface dimensions of 30 by 50 km, that consists of Riphean metavolcanic rocks, including basalt and rhyolite, which are intercalated with Vendian terrigenous calcareous sedimentary rock. The caldera is hosted in intensely deformed Mesoproterozoic granitoids that are alterted to K-feldspar and hematite. Metasomatism is most intense along northwest fracture zones and less intense along northeast-trending zones. The deposit contains traces of Cu, Co, Zn, and Mn. The deposit is medium size and has average grades of 1.0-2.0 percent Sn, rarely to 8 percent Sn, and up to 0.4 percent Cu.

## Origin and Tectonic Controls for Muiskiy Metallogenic Belt

The belt is interpreted as having formed in granitoids and veins in the Barguzin-Vitim granitoid belt that was generated during collision of the Baikal-Muya terrane with the Muysky terrane in a transpression zone related to a transform microplate boundary.

# Rudny Altai Metallogenic Belt of Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) and Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite Deposits (Belt RA) (South-Russia, Eastern Siberia).

This Middle to Late Devonian metallogenic belt occurs in volcanic and sedimentary rocks of the Rudny Altai island-arc terrane that is interpreted as having formed on the sialic basement of the Ordovician and Silurian passive continental margin of the Siberian paleocontinent (Rotarash and others, 1982; Berzin and Kungurtsev, 1996; Distanov and Gaskov, 1999). The belt extends southeast-northwest for about 500 km and ranges up to 100 km wide. The belt contains about 50 economic deposits, 20 of which occur in the northwestern belt in Russia. Most of the base-metal deposits are hosted in Devonian volcanic and sedimentary rock, including basalt and rhyolite, and siliceous and clastic rock. Siliceous volcanic rock prevails. Subvolcanic porphyry intrusions, diabase porphyry (Devonian and Early Carboniferous), gabbro and diabase, and granitoid intrusions of various ages (Middle Devonian, Carboniferous, Permian, and Early Triassic) are widespread. The two principal mineral types of base-metal deposits are (1) pyrite and polymetallic sulfide (Korbalichinskoye, Stepnoye, Talovskoye, Rubtsovskoye, Zakharovskoye, Yubileinoe, and others); and (2) Au, Ag, barite, and polymetallic sulfide (Zarechenskoye, Zmeinogorskoye). The deposits occur in the Zmeinogorsk, Korbalihinskoye, Zolotushinsk, and Rubtsovsk districts.

The main references on the geology and metallogenesis of the belt are Rotarash and others (1982), Shcherba and others (1984), Gaskov and others (1991), Berzin and Kungurtsev (1996), and Distanov and Gaskov (1999).

## Korbalihinskoye Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposit

This deposit (fig. 11) (Chekalin, 1985; Gaskov and others, 1991; Sharov and others, 1998) consists of lenses of pyrite and polymetallic sulfides that are hosted in Middle to Late Devonian volcanic and sedimentary rock. Host rocks are mainly basalt, rhyolite, siltstone, and sandstone. Numerous subvolcanic quartz porphyry, amygdaloidal diabase porphyry, gabbro, and diabase dikes occur. The deposit occurs in conformable lenses and ribbons, extends for 1,000 m along strike, and reaches a depth of 750 m. Six zones contain 90 percent of the total reserves. Mineral zonation occurs with (1) small barite and polymetallic sufides occurring in the hanging wall; (2) massive pyrite and polymetallic sulfides in a central part; and (3) Cu-sulfide pyrite in the footwall. The host rock exhibits chlorite, carbonate, talc, and sericite alteration. Main ore minerals are pyrite, sphalerite, galena, and chalcopyrite with lesser marcasite, fahl, and hematite. Gangue minerals are quartz, calcite, barite, and chlorite. Ore minerals occur in masses, breccias, disseminations, and layers. The Pb:Cu:Zn ratio is 1:0.6:3.6. Admixture elements are Au, Ag, Cd, Se, Te, Bi, Ga, In, Ta, and Ge. The deposit is large and has reserves of 497,800 tonnes Pb, 2,403,200 tonnes Zn, 360,100 tonnes Cu, and 1,360 tonnes Ag. Average grades are 2.01 percent Pb, 9.8 percent Zn, 1.46 percent Cu, and 54.2 g/t Ag.

## Yubileinoe Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altay type) Deposit

This deposit (fig. 12) occurs in the Zolotushinsky ore district of the northwestern part of the Rudny Altai metallogenic belt. A monoclinal structure characterizes the area, which is underlain by volcanic and sedimentary rocks. The sedimentary rocks are siltstone, sandstones, and limestones. The deposit is related to Devonian multistage basalt-rhyolitic volcanism. The volcanic rocks are felsic lavas, tuffs, subvolcanic rhyolites, and rhyolite-dacite porphyries. The tuffs and lavas occur mainly at the top part of the deposit and are intercalated with layers of Middle Devonian limestones. The rhyolite porphyries are genetically and spatially associated with pyrite-polymetallic mineralization. Pre-ore lava flows, syn-ore subvolcanic rhyolite porphyries, and post-ore subvolcanic rhyolite-dacite porphyries occur. The pre-ore rhyolite Middle Devonian lava flows occur in lower horizons. The syn-ore Frasnian rhyolite porphyry bodies are spatially associated with polymetallic ores. The post-ore subvolcanic rhyolite-dacite and dacite porphyries occur in younger Famennian sediments that overlap the sulfide mineralization (Gaskov and others, 1991).

The sulphides of the Yubileinoe deposit form stratified, lenticular, and tabular shapes. In the lower part of the deposit, the sulfides occur mainly in veinlets and disseminations, and in the central and top parts of the deposit sulfides are massive to brecciated. Pyrite-polymetallic sulfides are predominante, and pyrite and polymetallic types are minor. Copper-pyrite and barite-polymetallic sulfides are rare. The total amount of ore at the Yubileinoe deposit is about 6 million tonnes.

## Zarechenskoye Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) Deposit

This deposit (Kuznetsov, 1982; Gaskov and others, 1991; Sharov and others, 1998) consists of lenses and stockwork with masses, streaks, and disseminations of barite and sulfides that are hosted in Eifelian volcanic and sedimentary rock. The deposit occurs in a narrow basin with steeply-dipping bedding. The bordering sublatitudinal fault zones control subvolcanic quartz albitophyre and gabbro and diabase dikes that range from 0.5 to 5 m thick. The host rock for the deposit is an argillite horizon that ranges from 50 to 80 m thick and is underlain by felsic tuff. The main deposit occurs along the contact between shale and limestone. The deposit extends more than 1 km along strike and ranges from 30 to 100 m wide. Individual lenses in the deposit are 40 to 180 m long, 1 to 1.5 m thick, and extend to a depth of 30 to 200 m. The ore-mineral assemblages are barite, Au-Ag minerals and barite, and barite and polymemetallic sulfides. Barite occurs in the hanging wall of the large lenses of barite and polymetallic sulfides. Commonly, massive sulfides occur in the hanging wall. Streaks and dissemination occur in breccia in fissures in the footwall. Wall-rock exhibits silica, chlorite, hematite, and pyrite hydrothermal alteration. Altered

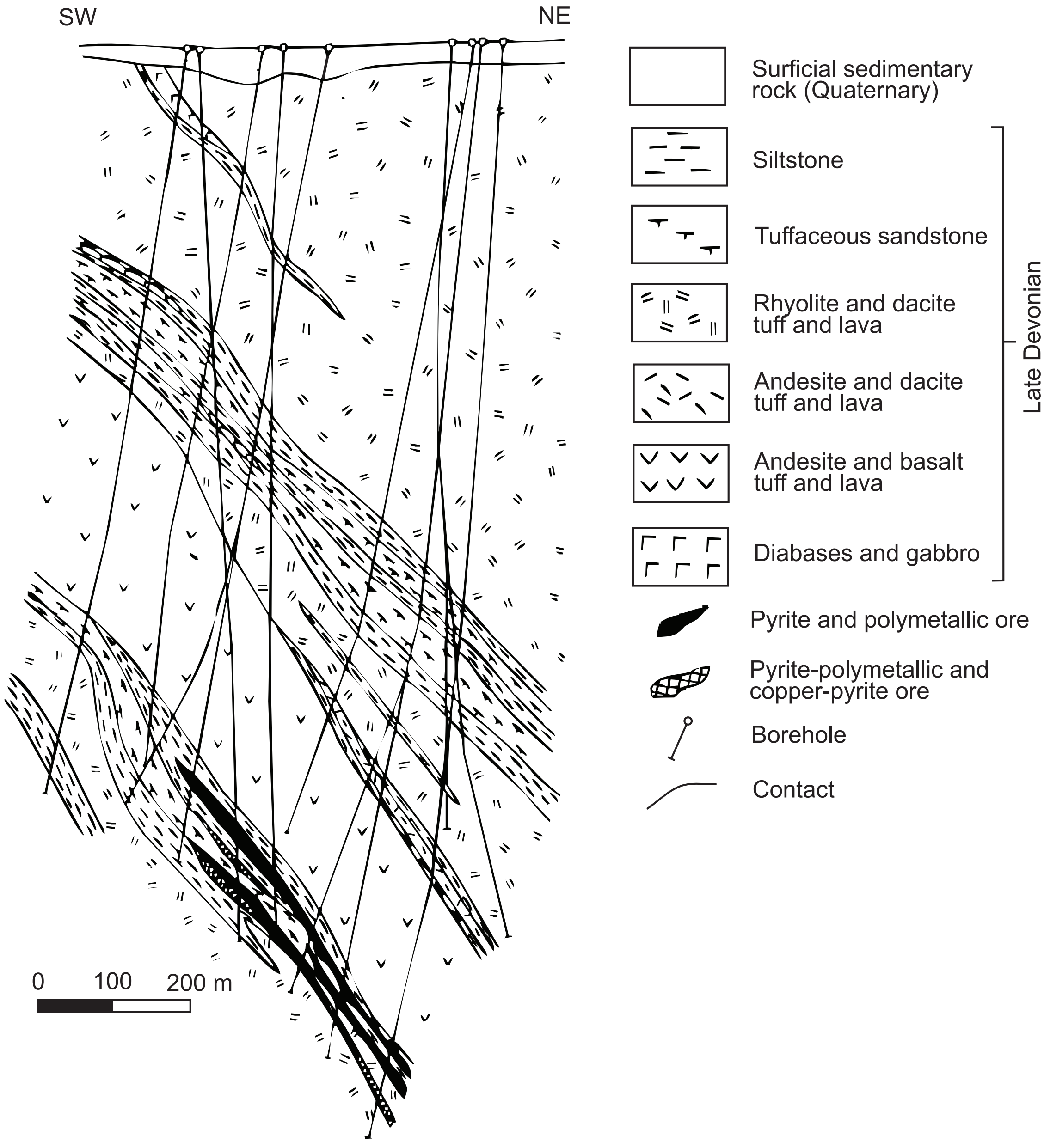



**Figure 11.** Schematic geologic cross section of the Korbalihinskoye volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type) deposit, Rudny Altai metallogenic belt. Adapted from Gaskov and others (1991).

rocks generally occur in the footwall. Main ore minerals are sphalerite, galena, fahl, chalcopyrite, bornite, chalcocite, native Au and Ag, electrum, argentite, silvanite, stromeyerite, jalpaite, pyrite, marcasite, and hematite. Gangue minerals are barite, quartz, calcite, dolomite, chlorite, and sericite. Ore minerals occur in masses, nests, breccia, streaks, and disseminations. The Cu:Pb:Zn ratio is 1:3.3:4.6. The deposit has been mined, is medium size, and has reserves of 11,2900 tonnes Pb, 44200 tonnes Zn, 10,000 tonnes Cu, 650,000 tonnes $BaSO_4$, and 432 tonnes Ag. Average grades are 2.89 percent Pb, 3.91 percent Zn, 0.89 percent Cu, 46.4 percent BaSO4, and 343 g/t Ag.

## Origin and Tectonic Controls for Rudny Altai Metallogenic Belt

The belt is interpreted as having formed in the Rudny Altai island arc that was part of the greater South Mongolia-Khingan island arc in shallow marine volcanic rock on a shelf. Regularities in distribution of deposits and districts reveal a genetic relation between pyrite and polymetallic sulfide deposits and Devonian volcanism and formation in volcanic centers wit bimodal basalt and rhyolite (Shcherba and others, 1984; Gaskov and others, 1991; Distanov and Gaskov, 1999). The position of major volcanic centers is

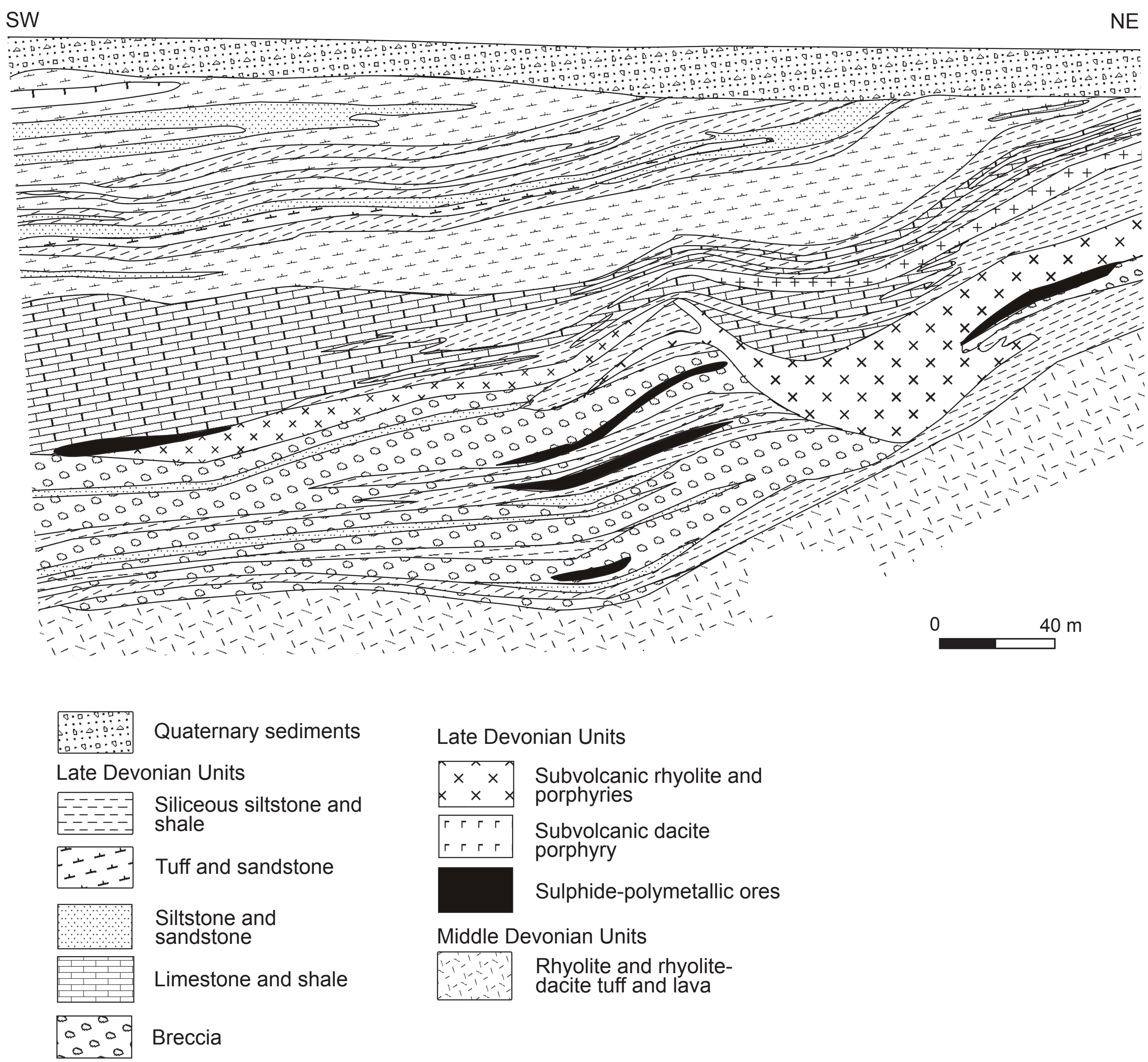



**Figure 12.** Schematic geologic cross section of the Yubileinoe volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai type) deposit, Rudny Altai metallogenic belt. Adapted from Gaskov and others (1991).

controlled by sublatitudinal-striking transform faults as at the Orlovsk-Karaguzhikha, Alei-Tigirek, and Varshavskiy deposits. The main ore districts, as at Zmeinogorskiy, Zolotushinskiy, and Rubtsovskiy, are associated with the largest volcanic structures. In each district, the deposits occur at two or three startigraphic levels and are related to the final stage of volcanic activity. Metasomatic ore deposition and filling of cavities of weakly lithified sedimentary rock occurred. The deposits with Au, Ag, barite, and polymetallic sulfides formed during early, essentially siliceous volcanism in the Eifelian and Jivetian. The widespread pyrite and polymetallic sulfides are hosted mainly in Jivetian and Frasnian rhyolite, dacite, basalt, and andesite volcanism.

## Salair Metallogenic Belt of Polymetallic (Pb, Zn, Cu) Metasomatic Volcanic-Hosted and Porphyry Cu-Mo (±Au, Ag) Deposits (Belt SL) (Russia, Eastern Siberia)

This Middle Devonian(?) to Early Carboniferous(?) metallogenic belt is hosted in porphyry intrusions and associated replacements that are related to the Altai volcanic-plutonic belt that overlies and intrudes the early Paleozoic Salair island-arc terrane. The belt occurs on the northeastern side of the Salair Range along the tectonic boundary between the Salair terrane and the Kuznetsk Basin. The belt extends northwest, is about 75 km long, and is 2.5 km wide. The age of a deposit-related quartz-porphyry intrusion is interpreted as being Middle Devonian through Early Carboniferous. The polymetallic deposits are hosted in volcanogenic and volcanic and sedimentary rock of the Early to Middle Cambrian Pechorkinskaya Suite. Host rocks are underlain by Early Cambrian limestone, are overlain by Middle Cambrian volcaniclastic rock, and are intruded by Cambrian subvolcanic diabase and dacite porphyries, and by small middle Paleozoic, Permian, and Triassic siliceous and mafic intrusions. Middle Devonian through Early Carboniferous rhyolite and dacite porphyry, Early Carboniferous gabbro and diabase and diabase porphyry, and Permian and Triassic diabase and diabase porphyry dike swarms are widespread in the metallogenic belt (Distanov, 1977; Lapukhov, 1966). The Cambrian sedimentary rock are deformed into isoclinal northwest-overturned folds and are cut by lengthwise faults that contain fissure and schistose zones that host diabase porphyry dike swarms that controlled hydrothermal activity. Large deposits in the Salair district have been explored and mined. The large deposits of the Urskoye district are explored in detail. The major varities of deposits are (1) barite-polymetallic (Salair district); (2) pyrite-polymetallic (Urskoye district, Uskandinskoye deposit); and (3) porphyry Cu (Kamenushinskoye deposit). Numerous small Au placer deposits also occur.

### Salairskoye Polymetallic (Pb, Zn, Cu) Metasomatic Volcanic-Hosted Deposit

This deposit (Distanov, 1977, 1983; Lapukhov, 1966; Sharov and others, 1998) occurs in the southeastern part of the metallogenic belt and consists of massive, streaky, and disseminated barite-polymetallic metasomatite that is hosted in intensely schistose Early to Middle Cambrian volcanic rock. The deposit occurs in the Salair district in a large lens (4 by 1.5 km) of volcanogenic and subvolcanic porphyry that intrude Early Cambrian limestone. Deposits are hosted in rhyolite and dacite lava and tuff, porphyry, and argillaceous and carbonaceous shale. Stratified rocks are intruded by Devonian and Early Carboniferous rhyolite, and dacite quartz porphyries occur in the central and western parts of the district. Numerous diabase porphyry dikes occur in the district. The deposits occur in steeply-dipping, sublongitudinal shear zones. The deposits consist of complex lenses with masses, streaks, and disseminations. The major deposits occur in quartz porphyry intrusions in ore bodies that extend to depths of 400 to 450 m. The ore minerals are barite and polymetallic sulfide with low Fe-sulfides. The main ore minerals are pyrite, sphalerite, galena, chalcopyrite, and fahl. Minerals are argentite, magnetite, and hematite. Gangue minerals are barite, quartz, carbonate, albite, sericite, chlorite, and rare fluorite. The deposits are mainly massive banded quartz, barite, and sulfide that grade into spots, bands, and disseminations. Zone of oxidation is 25 to 170 m deep. An age of Middle Devonian through Early Carboniferous is interpreted for the quartz porphyry intrusion. The deposit has been mined, is large, and has reserves of 72,400 tonnes Pb, 545,700 tonnes Zn, 219 tonnes Ag, and 2,812,000 tonnes $BaSO_4$. The average grade is 0.13 percent Pb, 2.42 percent Zn, 8.5 g/t Ag, and 11.22 percent $BaSO_4$.

### Kamenushinskoye Porphyry Cu-Mo (±Au, Ag) Deposit

This deposit consists of bodies of disseminated and streaky-disseminated copper sulfides in shear zones in a dacite quartz-porphyry that intrudes tuff and tuff breccia. Host rocks are altered to silica, sericite, argillite, and propylite. Host and altered rock are cut by diabase and gabbro dikes that range from 0.5 to 45 m thick. The deposit dimensions are 100 by 300 by 500 m. The deposit contains some parallel and echelon-like lenses and ore layers that are concordant with host rocks and dip steeply. Individual deposit bodies extend from 40 to 420 m along strike. Ore minerals are pyrite and chalcopyrite and lesser tennantite, sphalerite, galena, pyrrhotite, and molybdenite. Gangue minerals are quartz and lesser chlorite, sericite, dolomite, calcite, ankerite, barite, and fluorite. A gossan occurs to 70 to 80 m depth. A weak zone of secondary enrichment occurs, is 1 to 3 m thick, and consists of bornite, chalcocite, and covellite. The deposit is small and has reserves of 110,000 tonnes Cu grading 1.71 percent Cu.

### Origin and Tectonic Controls for Salair Metallogenic Belt

This belt is interpreted as having formed along the South Mongolia-Khingan island arc in which mafic dike swarms and small siliceous porphyries intruded. The belt occurs in a complicated nappe area that was deformed in several stages. The early Paleozoic Salair island arc was deformed and intruded in the middle Paleozoic during Hercynian development of an active continental margin that resulted in intrusion of mafic dike swarms and small and siliceous porphyry and formation of deposits. These deposits include Au-barite-polymetallic deposits of the Salair district, pyrite-polymetallic deposits of the Urskoye district, and associated Au quartz deposits (Distanov, 1977; 1983). Strike-slip zones and transverse faults controlled distribution of deposits.

Two interpretations exist about the origin of the Salair metallogenic belt. The first interpretation is that a relation exists between ore deposition and Cambrian volcanism, and a direct relation exists between ores and volcanic vents and subvolcanic quartz keratophyre intrusions (Distanov 1983). The second interpretation, which is from this study, suggests that the majority of the deposits younger and are related to Middle Devonian through Early Carboniferous rhyolite and dacite quartz porphyry and small gabbro and diabase and diabase intrusions that are controlled by the post-orogenic fissures and schistose zones (G.S. Labasin, G.L. Pospelov, E.G. Distanov, A.S. Lapukhov, written commun., 2000). The age of the Salair metallogenic belt is interpreted as being coeval with the Rudny Altai island arc and associated polymetallic metallogenic belt that occurs to the southwest (Distanov, 1983; Obolenskiy and others, 1999).

**REFERENCES**: Distanov; 1983; Lapukhov, 1966; Gladkov and others, 1969; Obolenskiy and others, 1999.

## Sette-Daban Metallogenic Belt of Sediment-Hosted Cu, Basaltic Native Cu, REE (±Ta, Nb, Fe) Carbonatite, and Carbonate-Hosted Pb-Zn (Mississippi Valley type) Deposits (Belt SD) (Russia, Southern Verkhoyansk Fold and Thrust Belt)

This Middle Devonian through Early Carboniferous metallogenic belt is hosted in Middle and Late Devonian through Early Carboniferous clastic and carbonate sedimentary rock, alkalic basalt lava and tuff, and coarse clastic rock of the Verkhoyansk fold and thrust belt of the North Asian cratonal margin. The belt occurs in the central part of the Southern Verkhoyansk fold and thrust belt in a thick (up to 10,000 m) Vendian through middle Paleozoic sequence. The metallogenic belt contains two districts, the Dzhalkan-Menkyule district to the north, and the Sakhara district to the south. The Dzhalkan-Menkyule district contains several deposits and occurrences of stratiform Cu deposits at Kurpandzha, Dzhalkan, Kemyus-Yuryakh, Segenyakh, and Allakh-Yun'. Cu deposits in sandstone and shale tend to occur at the top of the section of the carbonate and clastic rock unit along with Middle Devonian and Early Carboniferous trachybasalt sheets. The basalt lava flows contain native copper occurrences. In the Sakhara ore district Ta, Nb, REE, and apatite deposits occurs in alkalic ultramafic and carbonatite plutons that are interpreted as having formed during Devonian rifting. A discontinuous chain (about 100 km long) of small plutons and dikes of alkalic ultramafic rock, carbonatite, and alkalic syenite intrudes early Paleozoic carbonate rock. Rb-Sr isotopic ages for the plutonic rocks range from 146 to 480 Ma. Most of the age determinations of carbonatite and alkalic syenite are Middle to Late Devonian and are supported by geological data. The major deposits are at Kurpandzha (sediment-hosted Cu), Dzhalkan and Rossomakha (basalt native copper), Gornoye Ozero, and Povorotnoye (REE (±Ta, Nb, Fe) carbonatite).

The main references on the geology and metallogenesis of the belt are Elyanov and Moralov (1973), Arkhipov (1979), Ioganson (1988), Kutyrev and others (1988), Entin and others (1991), and Parfenov and others (1999, 2001).

### Dzhalkan Sediment-Hosted Cu Deposit

This deposit (Kutyrev and others, 1988) consists of disseminated Cu in Famennian basalt flows that are 180 m thick. The flows were erupted into a shallow-marine to subaerial environment. The deposit occurs in horizons from 0.5 to 2.0 m thick in breccia and amygdaloidal basalt at the top of flows. Ore minerals are native copper and cuprite with lesser bornite, chalcocite, and chalcopyrite. Epidote and quartz wallrock alteration occurs locally. Deposits range from 0.3 to 1.0 m thick and up to 100 m long. Areas of Cu deposits are separated by unmineralized areas that range up to several kilometers wide. Host basalt is folded, and fold limbs generally dip 40 to 60°. The average grade is 0.3 to 4.5 percent Cu.

### Gornoye Ozero REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (fig. 13) (Samoilov, 1991; Entin and others, 1991; Tolstov and others, 1995) occurs in two carbonatite stages, early and late. The early stage occurs in steep veins up to 25 m thick and up to 150 m long. The veins are composed of augite, diopside, calcite, forsterite, calcite, and pyrochlore-betafite. The late stage consists of a small stock with an area of 1 km$^2$ that is composed of aegirine, dolomite, and ankerite along with bastnaesite, parisite, monazite, pyrochlore, and columbite. K-Ar isotopic ages range from 280 to 350 Ma. The stock is concentrically zoned and composed of 90 percent carbonatite along with pyroxenite, ijolite, and nepheline and alkalic syenite. The complex covers an area of 10.3 km$^2$. The age of deposits is interpreted as being probably 290 Ma. The ore body has no visible boundary and is defined by concentrations of $Nb_2O_5$ and $Ta_2O_5$. The deposit is large and has resources to a depth of 200 m of 5,423,000 tonnes of $Nb_2O_5$ (grading 0.10 to 0.12 percent), 246,500 tonnes $Ta_2O_5$ (grading 0.01 to 0.011 percent) and 223,446,491 tonnes REE. A range of 2.04 to 5.38 percent $P_2O_5$ occurs in carbonatite with average of 4 percent. Resources to a depth of 200 m are 24 million tonnes $P_2O_5$.

Average grades are 0.35 percent REE oxides, 0.09 to 0.36 percent $Nb_2O_5$, and 0.011 percent $Ta_2O_5$.

## Segenyakh Carbonate-Hosted Pb-Zn (Mississippi Valley type) Deposit

This deposit (Kutyrev, 1984) consists of concordant horizons of disseminations, stringers, and bedded breccia of sphalerite and fluorite that are hosted in Late Silurian (Ludlovian) dolomite and limestone that is overlain by Pridolian marl. Deposit horizons consist of dolomite, calcite, fluorite, sphalerite, lesser galena, and common metasomatic quartz, microcline, hyalophane, and pyrite. Bedded breccia contains up to 20 percent sphalerite and 15 percent fluorite. Also occurring are cross-cutting breccia veins that contain up to 70 percent fluorite and up to 8 percent sphalerite. The two known deposit horizons trend north-south for 10 km and dip eastward from 40 to 60°. The distribution and concentration of sulfides is irregular.

## Origin and Tectonic Controls for Sette-Daban Metallogenic Belt

The stratiform Cu deposits in the belt are interpreted as having formed during Devonian rifting. The REE and apatite deposits hosted in alkalic ultramafic and carbonatite plutons are also interpreted as having formed during Devonian rifting.

## Sorsk Metallogenic Belt of Porphyry Mo (±W, Bi), Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite, and Zn-Pb (±Ag, Cu) Skarn Deposits (Belt SO) (Kuznetsk Alatau Mountains, Eastern Siberia, Russia)

This Early and Middle Devonian metallogenic belt is hosted in granitoids and associated replacements that are related to the South Siberian volcanic-plutonic belt, and it occurs on the eastern slope of the Kuznetsk Alatau Ridge. The belt extends sublongitudinally for about 200 km and ranges from 30 to 60 km wide. The belt is controlled by the north-northwest-striking major Kuznetsk-Altaisk fault and by northeast fractures. Porphyry Mo (±W, Bi) deposits are dominant. The largest deposit is the Sorskoye porphyry Mo (±W, Bi) deposit (Amshinskiy and Sotnikov, 1976; Pokalov, 1992) that has been discovered in 1937. The Agaskyrskoye and Ipchulskoye porphyry Mo (±W, Bi) deposits are also explored. These deposits are closely related to Devonian subalkalic porphyry stocks and dikes. The porphyry intrusions and related metasomatic rocks are hosted in older, early Paleozoic granitoid plutons and wall rocks. Skarn and polymetallic metasomatic deposits are hosted in Vendian and Cambrian carbonate shelf rocks along intrusive contacts of granitoid plutons. Other types of deposits are (1) large porphyry Mo deposits at Sorskoye,

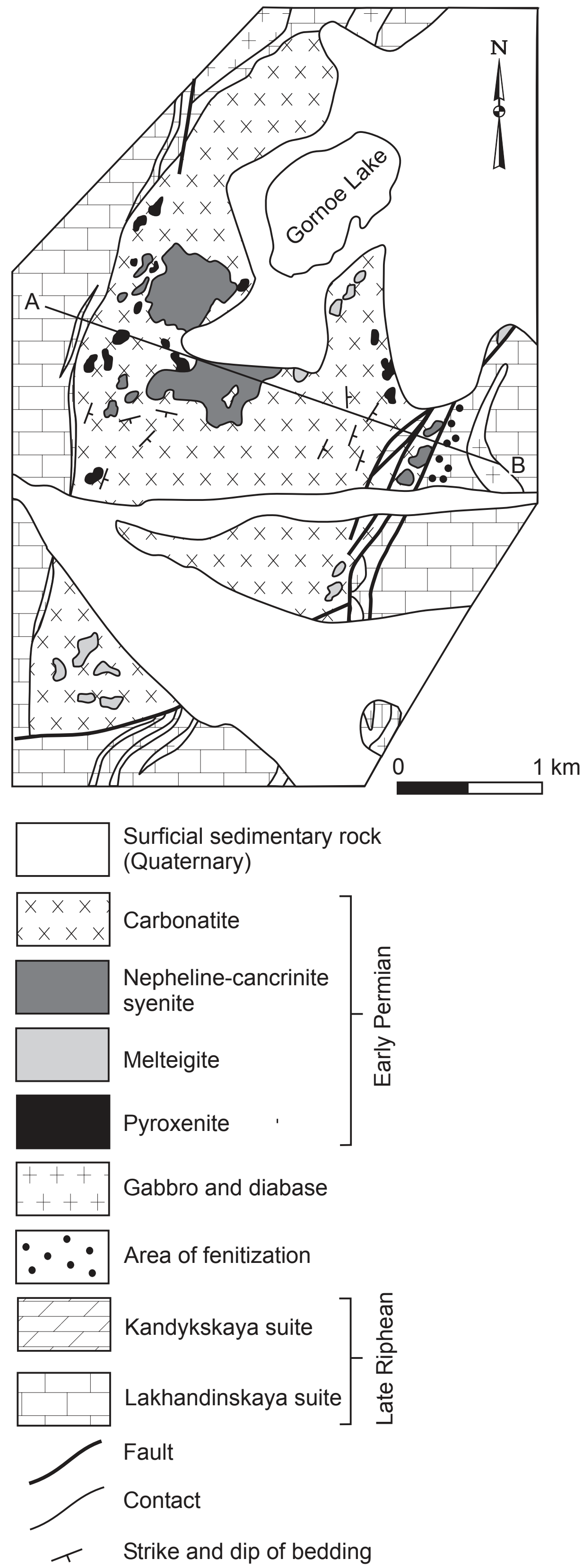



**Figure 13.** Geologic sketch map of the Gornoye Ozero REE (±Ta, Nb, Fe) carbonatite deposit, Sette-Daban metallogenic belt. Adapted from Korostylyov (1982)

Agaskyrskoye, and Ipchulskoye; (2) small Pb-Zn skarn deposit at Yulia Svintsovaya; (3) small polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposits at Karasuk and others; and (4) a small Ag-Sb vein deposit at Tibik.

The main references on the geology and metallogenesis of the belt are Amshinskiy and Sotnikov (1976), Rikhvanov and others (1987), Pokalov (1992), and Sotnikov and others (1984, 1985, 1995, 1999, 2004).

## Sorskoye Porphyry Mo (±W, Bi) Deposit

This deposit (fig. 14) (Amshinskiy and Sotnikov, 1976; Pokalov, 1992; Sotnikov and others, 1995) consists of disseminations, streaks, and breccia that occur in intensely hydrothermally-altered gabbro and granitoid in the Cambrian and Ordovician Uibat pluton. The ore minerals are associated with numerous stocks and dikes of subalkalic granite porphyry. The host rocks are extensively hydrothermally altered to K-feldspar, quartz-biotite-K-feldspar, albite, sericite, and silica. Mafic rock is altered to chlorite. Dissemination and streaks are the most economic and consist of quartz-molybdenite veins and veinlets that range from less than 1 cm to 0.5 to 1.0 m thick. The associated stockwork in the central part of deposit extends to a depth of about 1 km, and decreases along the flanks to 300 to 500 m. Stockwork ores consists of molybdenite, pyrite, chalcopyrite, bornite, quartz, feldspar, and sericite. Average grade is 0.04 to 0.7 percent Mo and 0.2 to 0.3 percent Cu. The rich Cu contents are typical for the central part of deposit. Cu decreases along the flanks, and Mo is relatively constant. At depth, the Cu/Mo ratio decreases. Breccia ores also contains fluorite, galena, sphalerite, and fahl, and grade locally ranges from 0.5 to 1 percent Mo. The $^{40}Ar/^{39}Ar$ isotopic age is 385 to 400 Ma. The deposit is large and has an average grade of 0.04 to 0.07 percent Mo and 0.2 to 0.3 percent Cu.

## Julia Svintsovaya Zn-Pb (±Ag, Cu) Skarn Deposit

This deposit (Bulynnikov, 1960; Levchenko, 1975) consists of Pb-Zn metasomatic layers and nests in the Cambrian limestone. Host limestone grades upward into intercalating limestone, shale, and tuff. Limestone is intruded by Devonian syenite, granosyenite, and granite. Garnet-diopside skarn occur along the intrusive contact and consists of layers, veins, and pipes that are concordant to host limestone. The major ore

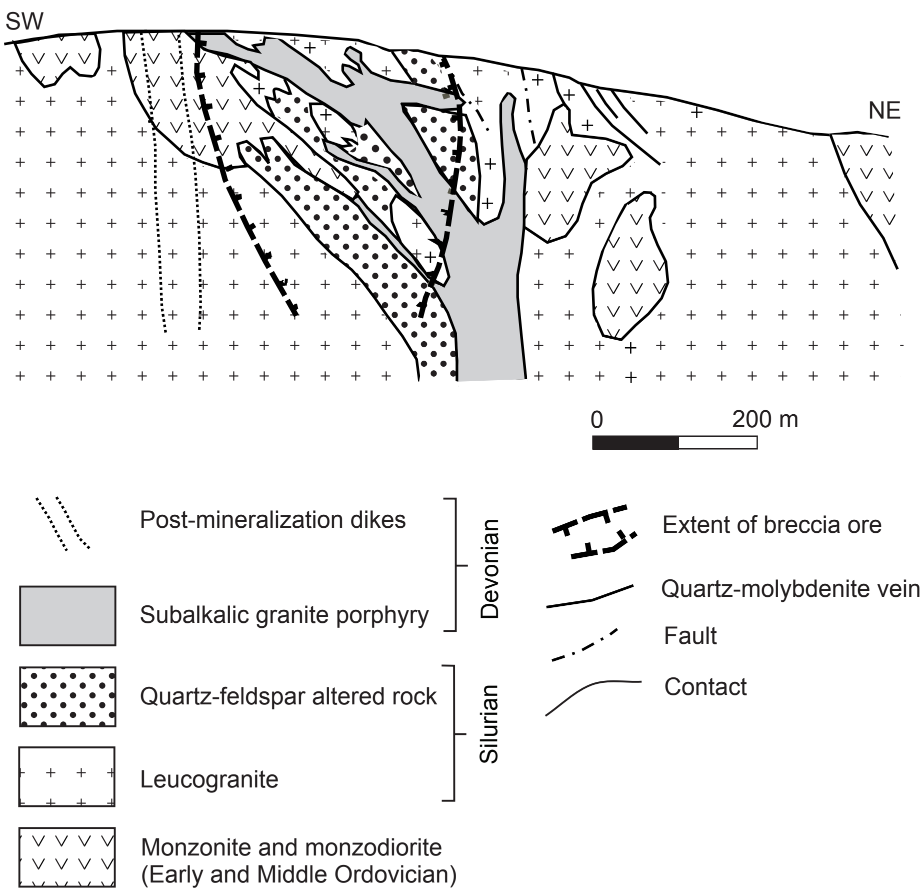



**Figure 14.** Schematic geologic cross section of the Sorskoye porphyry Mo (±W, Sn, Bi) deposit, Sorsk metallogenic belt. Adapted from Sotnikov and Berzina (2000).

minerals are galena, sphalerite, and pyrite, along with lesser chalcopyrite, pyrrhotite, tennantite, burnonite and molybdenite. Gangue minerals are siderite, quartz, ankerite, sericite, calcite, and rare fluorite and barite. A well-defined oxidation zone occurs. Ores contain up to 1 percent Bi and up to 0.6 ppm Au. The deposit is small.

### Karasuk Polymetallic (Pb, Zn, Ag) Carbonate-Hosted Metasomatite Deposit

This deposit (Bulynnikov, 1960; Levchenko, 1975) consists of Pb-Zn lenses and pipes in Cambrian limestone. The deposit occurs in a syncline formed in crystalline, microlaminated limestone interbedded with bituminous limestone and siltstone. Limestone is intruded by small granosyenite bodies surrounded by a wide zone of intrusive breccia. Quartz porphyry dikes cut the granosyenite. All intrusive rocks are interpreted as Devonian. The deposit occurs along the dike contact and ranges from 0.4 to 0.8 m thick. The major ore minerals are galena, sphalerite, and pyrite, and minor minerals are arsenopyrite, chalcopyrite, tetrahedrite, and marcasite, and native Au. Gangue minerals are calcite, quartz, ankerite, siderite, chlorite, sericite, and adularia. Ore minerals occur in masses, layers, and disseminations. Wall rocks display sideritie, silica, and pyrite alteration. A weak oxidation zone occurs. The deposit has been mined and is small.

### Tibik Ag-Sb Vein Deposit

This deposit (Amshinskiy and Sotnikov, 1976) consists of quartz veins and quartz zones that occur in propyliticallyaltered Cambrian extrusive rock. Separate zones range from 50 to 800 m long and from 1.5 to 12 m thick. Zones are irregularly saturated with quartz veins and veinlets. The veins do not persist along strike or at depth. Deposits in veins and zones consist of disseminations and nests of ore minerals. Ore minerals are stibinite, allemontite, pyrite, marcasite, chalcopyrite, berthierite, and realgar. The deposit is small.

### Origin and Tectonic Controls for Sorsk Metallogenic Belt

The belt is interpreted as having formed during Devonian subalkalic porphyry magmatism related to transpressional faulting along the the accreting southern margin of the North Asian craton. The belt is hosted in granitoids and associated replacements related to the South Siberian volcanic-plutonic belt (South Siberian arc). Devonian subalkalic porphyry magmatism is related to interplate rifting. The deposit-related porphyry intrusions intrude older, early Paleozoic granitoid plutons. Skarn and metasomatic polymetallic deposits are hosted in Vendian and Cambrian shallow-water marine carbonate rocks. The Devonian sedimentary and extrusive rock occurs in superimposed sedimentary basins and grabens. The volcanic rock consist of basalt, andesite, and trachyandesite porphyry and tuff, along with rare dacite, rhyolite, and trachyte porphyry. The K-Ar isotopic age is 396 Ma, a Rb-Sr isotopic age is 416±13 Ma, and the initial $^{87}Sr/^{86}Sr$ ratio is 0.7043 (Rikhvanov and others, 1987). Also occurring are Early to Middle Devonian granite and syenite intrusions along with widespread dikes. The K-Ar isotopic age for porphyry at the Sorskoye deposit and associated K-feldspar and albite metasomatite is 380 to 400 Ma. Based on the initial $^{87}Sr/^{86}S$ ratio of 0.70460 (Sotnikov and others, 1999), a mantle source is interpreted for the Sorsk ore-magmatic system.

## Teisk Metallogenic Belt of Fe-Skarn, Volcanogenic-Sedimentary Fe, and Mafic-Ultramafic Related Ti-Fe (±V) Deposits (Belt TE) (Kuznetsk Alatau Mountains, Eastern Siberia, Russia)

This Early Devonian metallogenic belt is related to plutonic rocks in the South Siberian volcanic-plutonic belt and occurs in the eastern part of Kuznetsk Alatau. The sickle-shaped belt is about 120 km long, ranges up to 50 km wide, and occurs at the intersection of geological structures of Kuznetsk Alatau and the Devonian Minusa Basin. The structure of the metallogenic belt is complex and heterogeneous. The belt is hosted in Neoproterozoic limestone and quartzite; Early to Middle Cambrian tuffaceous shale and clastic and carbonate rocks; and Devonian trachyandesite, rhyolite, basalt, andesite extrusive rock, and sedimentary rock. Intrusive rocks are widespread in the Fe districts and consist of early Paleozoic gabbro and granitoids and Devonian gabbro and syenite and granosyenite (Polyakov, 1971). Fe-skarn deposits occur along contact zones of gabbro and albitite and granosyenite intrusions (Dolgushin and others, 1979; Mazurov, 1985; Orlov, 1998). Mafic-ultramafic related Ti-Fe deposits occur in layered syenite, gabbro, and pyroxenite plutons (Kuznetsov, 1982) and often are concentrically zoned. Main ore minerals are titanomagnetite and ilmenite; they occur in mafic layers, and comprise up to 5.5 to 15 weight percent of the rock. The major deposits are Fe-skarns at Teiskoye and Khaileolovskoye and zoned mafic-ultramafic Fe-Ti deposits at Patynskoye and Kul-Taiga.

The main references on the geology and metallogenesis of the belt are Polyakov (1971), Dolgushin and others (1979), Rikhvanov and others (1987), Mazurov (1985), and Orlov (1998).

### Teiskoye Fe-Skarn Deposit

This deposit (Kalugin and others, 1981; Mazurov, 1985; Orlov, 1998) consists of magnesium-silicate skarn and occurs in pipes of explosive breccia in Early Cambrian dolomite and limestone. The deposits types are magnesium-silicate skarn, calc-silicate skarn, and aposkarn metasomatite. Magnesium-silicate skarn consists of forsterite and spinel. Calc-silicate skarn is younger, replaces magnetite skarn, and contains a complex mineral assemblage. The deposit forms a lens in plan view, extends more than 1,500 m along the strike, is 1,400 m deep, and is about 300 m thick. Mineral assemblages are serpentine and magnetite (60 percent), carbonate and magnetite (25 percent), magnetite (5 percent), gematite and magnetite (8 percent), and carbonate, serpentine, phlogopite, and magnetite (2 percent). Ore minerals occur in masses, disseminations, breccia, rhythmic layers, and colloform masses. The principal ore mineral is magnetite, with lesser hematite. From 1966 to 1977 total production was 39.2 million tonnes of ore, and has an average grade of 28.8 percent Fe. The deposit is large and has reserves of 136,400,000 tonnes grading 29.9 percent Fe.

### Patynskoye Mafic-Ultramafic Related Ti-Fe (+V) Deposit

This deposit (Kuznetsov, 1982; Orlov, 1998) consists of titanomagnetite layers in the differentiated Patynsk gabbro pluton that intrudes and metamorphoses Proterozoic and Cambrian carbonaceous and volcanic rock. The pluton forms a lopolith that extends more than 100 km$^2$. The pluton contains layers that are rich in pyroxene, amphibole, titanomagnetite, olivine, and titanaugite. In the upper part of the pluton are twelve layers of titanomagnetite-gabbro. The layers vary from 1 to 100 m wide, extend for 100 m to 10 km along strike, and extend to a depth of 600 m. Titanomagnetite content ranges from 5 to 20 percent. Ore minerals are mostly disseminated. Small lenses (100 by 10 cm) of massive ore also occur. Associated minerals are olivine, sphene, apatite, actinolite, biotite, hornblende, epidote, and chlorite. Gabbro contains of 2.5 to 12.8 percent Fe, 0.5 to 7.8 percent $TiO_2$, and 0.01 to 0.12 percent $V_2O_5$. The deposit is large and has average grades of 2.5 to 12.8 percent Fe, and 0.5 to 7.8 percent $TiO_2$.

### Chilanskoye Volcanogenic-Sedimentary Fe Deposit

This deposit (Belous and Klyarovskiy, 1969; Levchenko, 1975) consists of hematite layers hosted in Eifelian and Givetian sedimentary and volcanic rock and tuff. Low-grade layers contains about 27 percent Fe in a horizon up to 43 m thick. The horizon contains layers from 130 to 420 m long, and 4 to 10 m thick. The ore minerals are hematite, lepidocrocite, hydrogoethite, and limonite that forms a breccia cement. Hematite is concentrated in breccia zone that cuts Devonian host rock. Veinlets and nests of recrystallized, colloform hematite occur in fracture zones. A dense network of hematite veinlets occurs in overlapping sandstone and locally forms a stockwork. The deposit is large and has resources of 5,000,000 tonnes. The average grade is 27 to 48 percent Fe.

### Origin and Tectonic Controls for Teisk Metallogenic Belt

This belt is interpreted as having formed during transpressional faulting along the the accreting southern margin of the North Asian craton in the South Minusa volcanic basin that is part of the South Siberian volcanic-plutonic belt. The deposit-related Early Devonian granosyenite plutons occur along marginal faults of Devonian basins. Two interpretations exist for the age of mafic-ultramafic intrusions hosting Fe-Ti deposits in the belt, either Ordovician and Silurian, or Early Devonian. K-Ar isotopic ages for syenite and diorite of the Malaya Kul-Taiga pluton are 411 to 438 Ma (Polyakov, 1971). Fe-skarn deposits of the belt are polygenetic and polychronous. In the Teisk district that occurs along the sublongitudinal major Teisk fault, Fe-skarn deposits are related to Late Cambrian gabbro and granitoid and Early Devonian granosyenite. Small plutons of Early Devonian granosyenite occur along the faults bounding Devonian basins and are associated with Devonian volcanic rock bordering the basins. Subvolcanic granite and syenite intrusions are interpreted as being comagmatic with trachyandesite and rhyolite volcanic rock (Polyakov, 1971). Explosive breccia is widespread in Fe-skarn districts. The final stage in formation of these deposits is related to the development of the South-Minusa rift volcanic basin. A K-Ar isotopic age for volcanic rock is 396 Ma; a Rb-Sr isotopic age is 416±3 Ma; and the initial $^{87}Sr/^{86}Sr$ ratio is 0.7043 (Rikhvanov and others, 1987).

## Tsagaansuvarga Metallogenic Belt of Porphyry Cu (±Au) and Porphyry Cu-Mo (±Au, Ag) and Granitoid-Related Au-Vein Deposits (Belt TsS) (Southeastern Mongolia)

This Late Devonian through Early Carboniferous metallogenic belt is related to granitoids in the Gurvansayhan island-arc terrane. The major deposits are the Oyu Tolgoi porphyry Cu deposit, the Tsagaansuvarga Cu-Mo deposit, and the Oyut, Bor Ovoo, and other porphyry Cu-Mo occurrences, including the Alagtolgoi Au occurrence. Yakovlev (1977) first defined the Cu Tsagaansuvarga district, and Shabalovskii and Garamjav (1984) and Sotnikov and others (1984, 1985) assigned the district to the South Mongolian metallogenic belt that contains Early Carboniferous porphyry Cu (±Au) deposits, including the Tsagaan suvarga deposit. Various porphyry Cu-Mo (±Au, Ag) occurrences at Oyut, Bor Ovoo, Kharmagtai, and Khatavchiin tolgod occur in Ordovician volcanic and sedimentary rock, or in Early Devonian volcanic rock, and are closely related to intrusive porphyry dikes or small intrusive bodies. Various granitoid-related Cu vein-stockwork occurrences, as at Alagbayan, Zargyn Ovoo, Yamaat uul, and others, occur in Early Carboniferous basalt and andesite of the Sainshand khudag Formation.

The main references on the geology and metallogenesis of the belt are Berman and Vogdin (1968), Chebanenko and others (1968), Yakovlev (1977), Goldenberg and others (1978), Sotnikov and others (1980), Shabalovskii and Garamjav (1984), Sotnikov and others (1984, 1985), Byamba (1996), Lamb and Cox (1998), Perello and others (2001), and Kerwin and others (2005a,b).

## Oyu Tolgoi Group of Porphyry Cu (±Au) Deposits

The Oyu Tolgoi (figs. 15*A, B, C, D*) group of deposits (Perello and others, 2001; Kirwin and others, 2005a; Bat-Erdene and others, 2006, Ivanhoe Mines Ltd, at http://www.ivanhoe-mines.com/s/OyuTolgoi.asp, written commun., 2009) is hosted in the middle to late Paleozoic Gurvansaihan island-arc terrane (Lamb and Bardach, 1997) that forms an arcuate belt across southern Mongolia and is about 200 km wide and more than 750 km long. The deposits are related to Late Devonian quartz monzodiorite intrusions that occur along a north-northeast trending zone that extends for 20 km (Khashgerel and others, 2006) and that is interpreted as being a deep crustal structure. The Oyu Tolgoi group of deposits are the Southwest Oyu, South Oyu, Central Oyu, and Hugo Dummett (North and South) deposits, and the newly discovered Heruga porphyry Cu-Au deposit. Kirwin and others (2005a) summarize the early exploration history for the Oyu Tolgoi project, that was done by BHP-Billiton and Ivanhoe Mines Mongolia, Ltd., from the late 1990s to 2005. The major references on this major new deposit in East-Central Asia are Perello and others (2001), Kavalieris and Wainwright (2005), Kirwin and others (2005a), Wainwright and others (2005), Khashgerel and others (2006), Oyungerel and others (2007), Bat-Erdene and others (2008), and Oyunchimeg (2008).

The Oyu Tolgoi group of deposits occurs in three main mineralized zones that are interpreted as three zones and two centers (figs. 15*A, B*). The central part of deposit consists of a multiphase hydrothermal breccia that crosscuts an altered, fine-grained feldspar porphyry. Advanced argillic alteration occurs with several assemblages of quartz, alunite, dickite, pyrophyllite, sericite, and other minerals that overprint older K-silicate and quartz-sericite-illite assemblages. The Cu deposit consists of a large supergene chalcocite blanket that replaces a pyrite-rich, hypogene chalcocite-covellite-tennantite suite that formed during advanced argillic alternation. Younger fine-grained granite dikes intrude the host volcanic rocks and are generally less-altered and mineralized than other rocks. Potassic alteration occurs mainly in intrusive rock in southern part of the deposit. At South Oyu, the deposit is magnetite-rich, pyrite-poor, and chalcopyrite dominant. At Central Oyu, advanced argillic alteration of quartz, alunite, dickite, pyrophyllite, sericite, zunyite, svanbergite, and fluorite occurs with high sulfidation pyrite and hypogene chalcocite, covellite, and tennantite.

Cu and Au grades exhibit a positive correlation with intensity of quartz stockwork. Disseminated Cu sulphides are also common. Magnetite, chalcopyrite and bornite are the principle hypogenal minerals along with with chalcocite. Oxidation extends to depths of 5 to 85 m and is underlain by weak supergene minerals. Cu sulfides are associated with the sericite and potassic alteration. Cu grade correlates positively with frequency of quartz veinlets. The group of deposits is large and has an estimated total measured and indicated resource of 1,397 million tones, grading 0.98 percent Cu and 0.24 g/t Au (Ivanhoe Mines Mongolia Ltd. 2006 Annual Information, p. 35-42, written commun., 2006)

The high-grade core of the Southwest Oyu deposit (Ivanhoe Mines Mongolia Ltd., at http://www.ivanhoe-mines.com/s/OyuTolgoi.asp, written commun., 2009) is a cylindrical shaped Cu-Au porphyry, 250 m in diameter, that extends vertically for more than 800 m. The deposit is centered on small 10-30 m wide quartz monzodiorite dikes and extends for more than 100 m into the adjacent host basaltic volcanics. Contorted, milky white quartz veins are developed in both the mineralized quartz monzodiorite and basaltic volcanics. The quartz veins appear to have formed largely as an early, relatively high-temperature event. Chalcopyrite and subordinate pyrite and bornite occur as disseminated and late fracture fillings within the quartz veins and host rocks. Gold to copper ratios increase from 2:1 to 3:1 at depth. Alteration within the quartz monzodiorite is predominantly quartz sericite with minor tourmaline and fluorite.

A K-Ar biotite age is 411±3 Ma from South Oyu suggests a Late Silurian age. Two K-Ar ages from supergene alunite veins from Central Oyu range from 93±1 to 177 Ma are as young as Cretaceous. The alunite veins are related to deep oxidation and formation of a secondary chalcocite-enrichment zone. Kirwin and others (2005a) report Re-Os age dates from molybdenite cutting quartz monzodiorite intrusions from Southwest and Central Oyu Tolgoi and from Hugo Dummett South that range from 370 to 373±1.2 Ma. Subsequent U-Pb age dates on zircon from similar intrusions (Wainwright and others, 2005; Khashgerel and others, 2006) also support a Late Devonian age.

Kavalieris and Wainwright (2005) described the stratigraphy and whole rock geochemistry of the main rock units. The porphyry-related intrusions are typically phenocryst-crowded, mainly quartz monzodiorite, and belong to a high K calc-alkaline suite. Augite basalt is the main host rock and is geochemically characterized by almost flat chrondrite-normalized REE patterns that are characteristic of a primitive calc-alkaline island arc. Oxygen-, H-, and S-isotope studies (Khashgerel and others, 2006) indicate that hydrothermal fluids involved in formation of muscovite (sericite), pyrophyllite and alunite are mainly of magmatic origin, and that alunite formed from a magmatic vapor condensate at temperatures of about 260º C. A study of the Hugo Dummett (figs. 15*C, D*) advanced argillic zone by Khashgerel and others (2006) shows that the alteration is hosted by dacitevolcanic rock, quartz monzodiorite, and augite basalt. The alteration occurs at the contact between dacite and basalt and is developed mainly in the augite basalt

The Hugo Dummett deposit (figs. 15*C, D*) is an exceptionally high-grade porphyry Cu-Au deposit with estimated reserves of 329 million tones, grading 3 percent Cu and 0.76 g/t Au (Oyungerel and others, 2007; Oyunchimeg, 2008). The deposit occurs at depths of 300 to 1,800 m and is related to a Late Devonian quartz monzodiorite intrusion that intrudes late Paleozoic basalt volcanic rocks that occur in a fold and thrust belt that formed during or soon after development of the porphyry system. The Hugo Dummett deposit is divided into two stages with overlapping stages of porphyry alteration and mineralization, and each sequence may contain multiple intrusions. Porphyry stage 1 consists of small dike-like intrusions with intense quartz veining, while porphyry stage 2 consists of larger dome-shaped intrusions that form the core of the northern part of the deposit. The intrusive complex is intensely overprinted by muscovite (sericite alteration) and advanced argillic alteration. Copper mineralization is bornite dominant, with subordinate chalcopyrite, and minor chalcocite, pyrite, enargite, and tennantite, and trace amounts of covellite, sphalerite, colusite, clausthalite, and hessite. The most common sulfide assemblage is bornite-chalcopyrite that comprises the

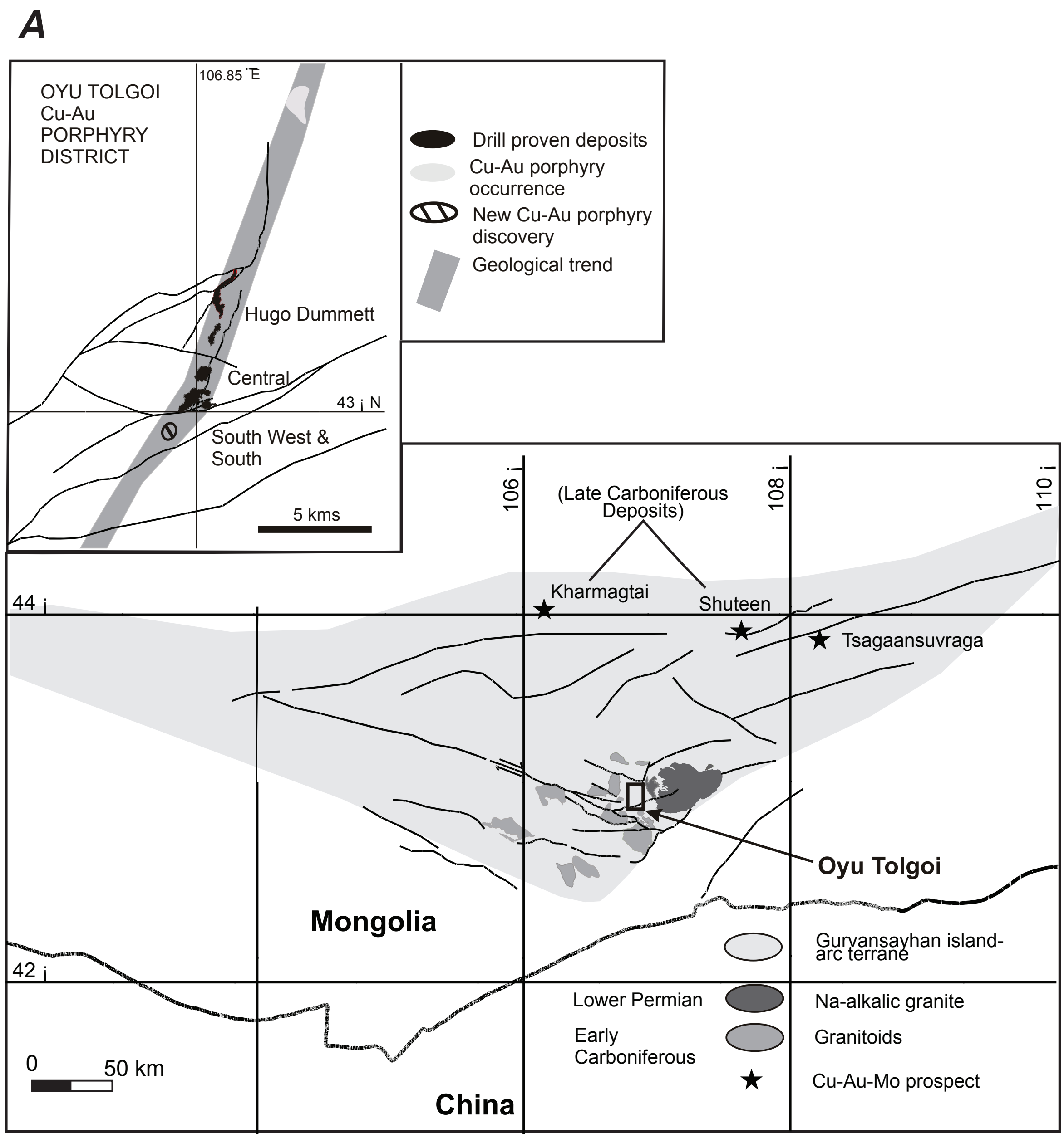



**Figure 15*A*.** Regional geologic sketch map of southern Mongolia showing location of Oyu Tolgoi group of deposits, Tsagaansuvarga metallogenic belt, and other major porphyry Cu-Mo-Au deposits in region. Adapted from published 1:20,000 geological map sheets, of Ivanhoe Mines Mongolia Ltd. exploration programs, 1990-2008.

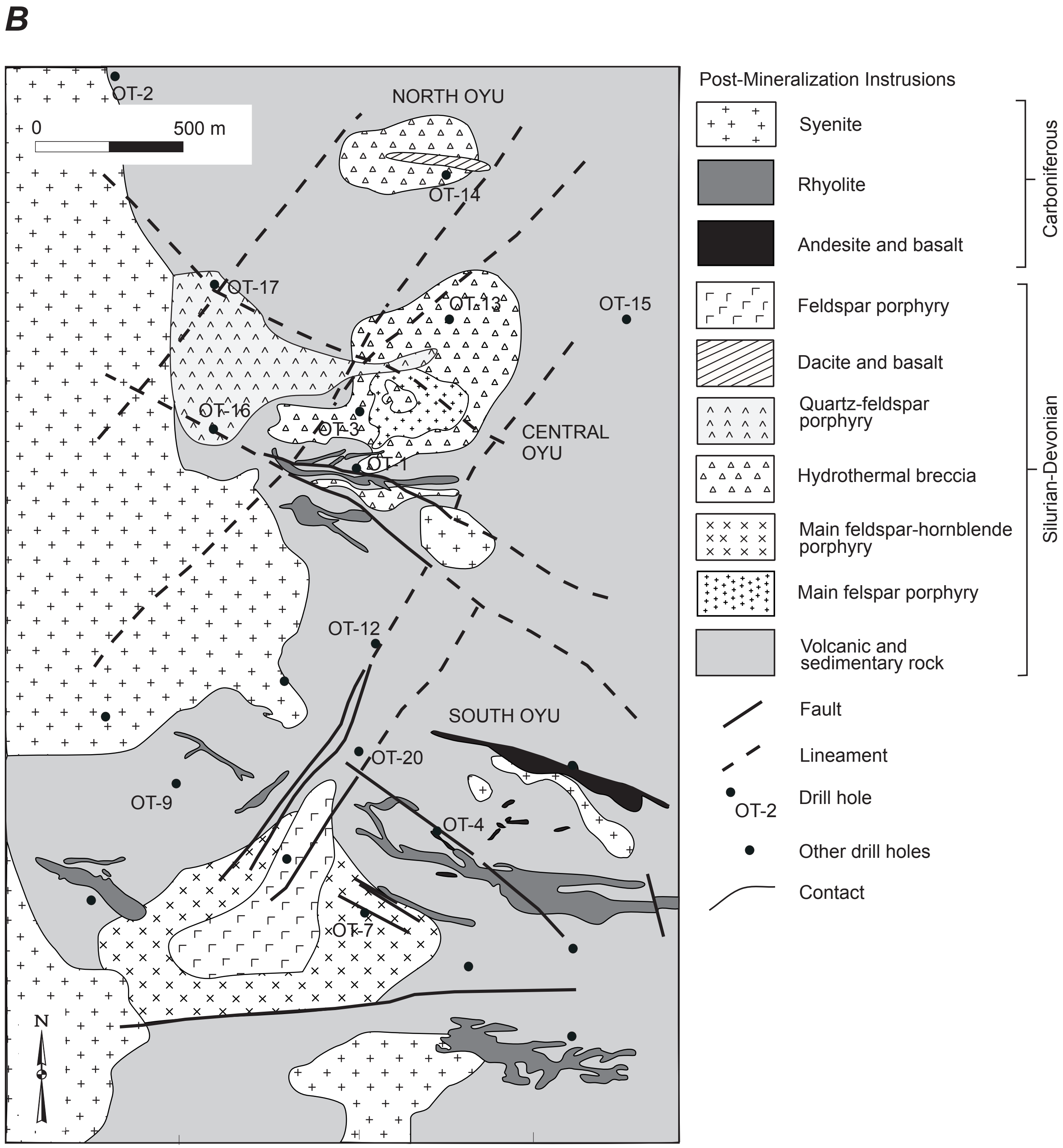



**Figure 15*B*.** Geologic sketch map of the Oyu Tolgoi group of porphyry Cu (±Au) deposits. Adapted from published 1:20,000 geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd. C. Simplified geologic map of Hugo Dummett deposit forming northern part of OyuTolgoi group. Map is drawn as a horizontal slice at 0 m elevation (surface is at 1170 m). The >2.5 percent Cu grade is projected from 700 m depth. Adapted from Kerwin and others (2005), Oyunchimeg (2008), and from unpublished 1:20,000-scale geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd.

main ore in both porphyry stages 1 and 2. Unusual assemblages include sooty bornite that consists of very fine bornite and chalcopyrite that are intimately intergrown with muscovite, and a minor assemblage that consists of pyrite and enargite that occurs on the margins of the ore body. The high-grade bornite mineralization (>2.5 percent Cu) is characterized by bornite in fractured quartz and zones of intense ductile deformation of bornite and chalcopyrite. Unusual features include alunite and molybdenite enclosed by high-grade bornite. The latest mineralization consists of gold-base metal Mn-carbonate quartz veins. Gold contains a high fineness (>800) and exhibits a close correlation to copper grade. Gold and minor electrum occur mainly with bornite and also with chalcopyrite in the deeper parts of porphyry stage 2. Gold typically occurs at contacts or grain boundaries of sulfides and varies in size from <1 to 170 microns, with most grains <20 microns.

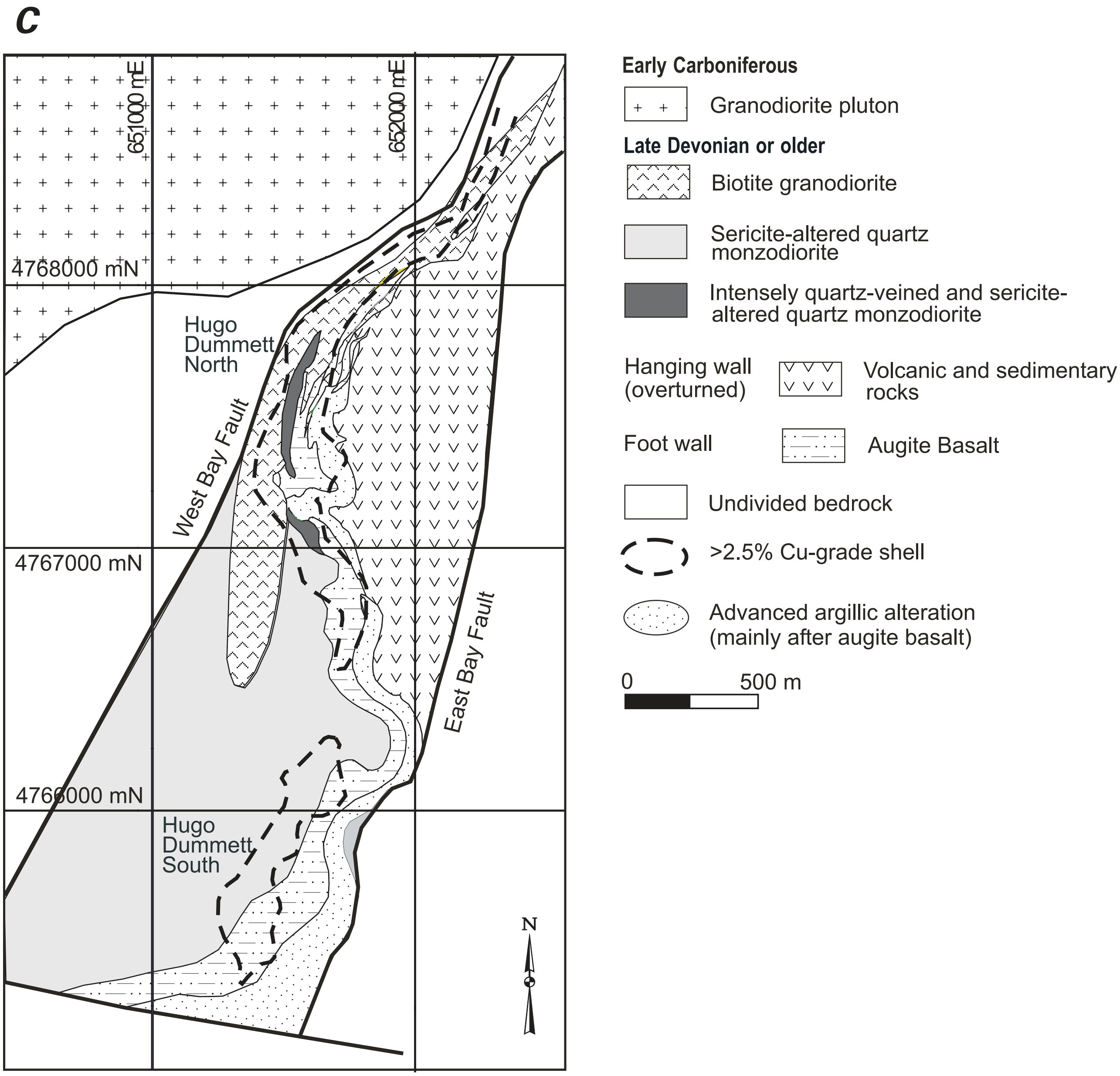



**Figure 15*C*.** Simplified geologic map of Hugo Dummett deposit forming northern part of OyuTolgoi group. Map is drawn as a horizontal slice at 0 m elevation (surface is at 1170 m). The >2.5 percent Cu grade is projected from 700 m depth. Adapted from Kerwin and others (2005), Oyunchimeg (2008), and from unpublished 1:20,000-scale geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd.

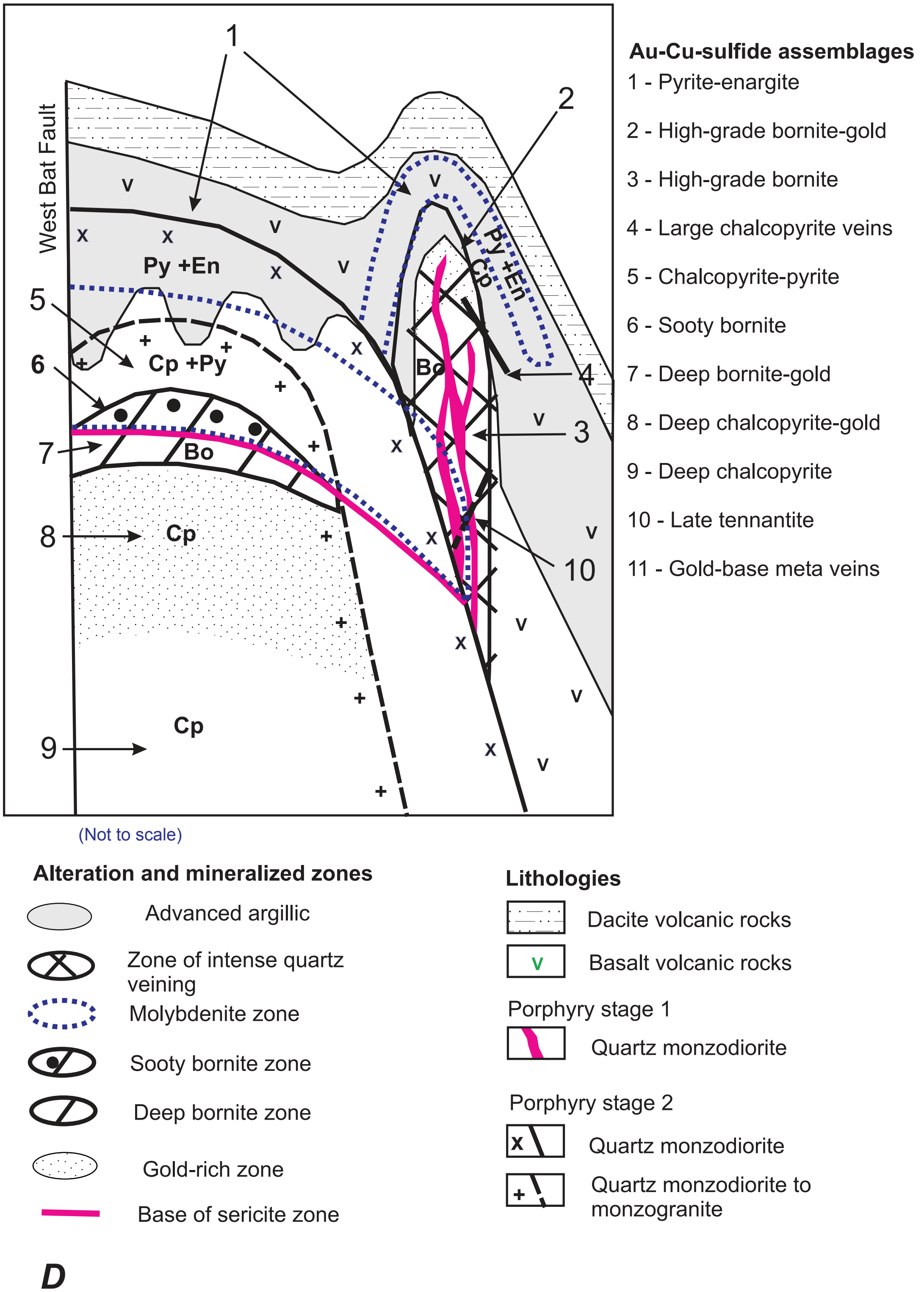



**Figure 15*D*.** Schematic cross section of Hugo Dummett deposit forming northern part of OyuTolgoi group. Adapted from Kerwin and others (2005), Oyunchimeg (2008), and from unpublished 1:20,000-scale geological map sheets and drill hole logging data of Ivanhoe Mines Mongolia Ltd.

## Tsagaansuvarga Porphyry Cu-Mo (±Au, Ag) Deposit

After the Oyu Tolgoi group of deposits is the Tsaagan Survarga deposit (fig. 16), where exploration drilling during the in the 1980s indicated a porphyry Cu-Mo with about 240 million tones, grading 0.53 percent Cu and 0.018 percent Mo (Yakovlev, 1977; Sotnikov and others, 1985; Gotovsuren 1991; Lamb and Cox, 1998; Watanabe and Stein, 2000; Perello and others, 2001). The deposit is hosted by Late Devonian intrusions with a Re/Os molybdenite age of 370.4±0.8Ma (Watanabe and Stein, 2000).

The deposit consists of stockwork veinlets and veins of quartz, chalcopyrite, and molybdenite that occur in or near porphyritic intrusions, and it is hosted in the Late Devonian Tsagaan-suvarga granosyenite and granodiorite porphyry stock that is overlain by Carboniferous volcanic and sedimentary rock. The deposit and host rocks are structurally controlled by an important northeast-striking fault. The pluton exhibits both potassic and sericite alteraton. Companion sulfide minerals are cut by felsic dikes and hydrothermal breccia. Cu and Mo minerals occur in centers of potassic alteration. Grade correlates positively with quartz veinlet intensity. Secondary Cu enrichment is minor. The alteration zone is 50 to 400 m wide and extends for 1 or 2 km. Major ore minerals are chalcopyrite, pyrite, barite, covillite, and local chalcocite and molybdenite. Gangue minerals are quartz, sericite, chlorite, azurite, malachite, and calcite. Alteration minerals are quartz, K-feldspar, sericite, and local biotite or chlorite. The highest-grade part of the deposit occurs in the potassic alteration zone that contains a well-developed quartz vein stockwork. Intensity of potassic alteration increases with depth. The deposit is developed over an area of 1,000 by 300 m and has been traced by drilling to a depth of 600 m. The deposit is large and has a newer estimated resource of 317.5 million tones, grading 0.53 percent Cu, 0.018 percent Mo, 119.68 tonnes Re, 26 tonnes Au, and 810 tonnes Ag.

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

This deposit (fig. 17) (Yakovlev, 1977; Sotnikov and others, 1985; Kirwin and others, 2005b; Ivanhoe Mines Mongolia Ltd., written commun., 2009) is hosted in Early Carboniferous diorite and granodiorite (with a U/Pb zircon isotopic age of 330.2 Ma) that intrudes Devonain tuff, andesite, and tuffaceous sandstone and siltstone. The ore minerals are chalcopyrite, covellite, bornite, and molybdenite. Oxidation minerals are malachite, azurite, and cuprite. Associated minerals are pyrite and magnetite and peripheral sphalerite, galena, and gold. The deposit is related to subvolcanic bodies of diorite and granodiorite porphyry in two stocks and bodies explosive breccia. Each bodies ranges from 200 to 400 m wide, 900 m long. Surface grades are 0.05-0.4 percent Cu and 0.003-0.03 percent Mo over an area of 400 by 900 m. A zone 100 by 300m contains >0.3 wt percent Cu. Deposit extends at least to a depth of 250 m and is defined by stockwork veinlets of quartz with chalcopyrite and molybdenite that occur across the breccia pipe. Hydrothermal alteration minerals are weakly developed silica, sericite, K feldspar, chorite, epidote, and tourmaline. Sericite, potassic, and silicic alterations occur in the center of alteration zone, and chlorite and epidote alteration occurs along the periphery. Potassic alteration occurs mainly in the deeper part of deposit. The deposit is being drilled and assessed by Ivanhoe Mines Mongolia Ltd.

## Origin and Tectonic Controls for Tsagaansuvarga Metallogenic Belt

The belt is interpreted as having formed in the South Mongolia-Khingan collage that was part of the South Mongolia-Khingan island arc. The Tsagaansuvarga pluton consists of gabbro, diorite, granodiorite, granosyenite, syenite and related dikes. An $^{40}Ar/^{39}Ar$ isotopic age of 364.9±3.5 Ma (Late Devonian) has been obtained for biotite alteration in the associated Tsagaansuvarga pluton and associated deposit (Lamb and Cox, 1998). The overlying volcanic and sedimentary strata are Early Carboniferous (Goldenberg and others, 1978). The host rock assemblage is interpreted as being part of a Late Devonian Andean magmatic belt (Lamb and Cox, 1998; Watanabe and Stein, 2000). The shape of the metallogenic belt is complicated by younger, late Paleozoic, Mesozoic and Cenozoic tectonic events. The belt occurs in two parts (1) a northeastern half that hosts the Tsagaan suvarga deposit and extends northeast-southwest; and (2) a western half that trends east-west and contains the Oyu Tolgoi, Bor-Ovoo Cu-Mo, and other Cu and Au occurrences.

# Udzha Metallogenic Belt of REE (±Ta, Nb, Fe) Carbonatite Deposits (Belt UD) (Russia, Northeastern North Asian Craton)

This Devonian(?) metallogenic belt is hosted in carbonatite intruding late Precambrian sedimentary rock in the northern part of the North Asian craton. The belt age is interpreted as being Devonian. Host rocks have Rb-Sr and K-Ar ages of 240 to 810 Ma. The belt occurs in the Udzha uplift that contains the Riphean Udzha aulacogen; it is 30 km wide and extends longitudinally for 200 km. Several plutons of alkalic ultramafic rock and carbonatite occur in the belt, and the largest Tomtor pluton contains a deposit with a uniquely large Nb and REE resource. The Tomtor pluton is about 20 km in diameter, is almost circular in plan view, and is concentrically zoned. The central part consists of carbonatite surrounded by ultramafites and foidolites. The outer part contains alkalic nepheline syenite. The alkali ultramafic rock and carbonatite are interpreted as related to Devonian rifting. The major deposit is at Tomtor.

The main references on the geology and metallogenesis of the belt are Entin and others (1991), Orlov (1994), Tolstov and others (1995), and Parfenov and others (1999, 2001).

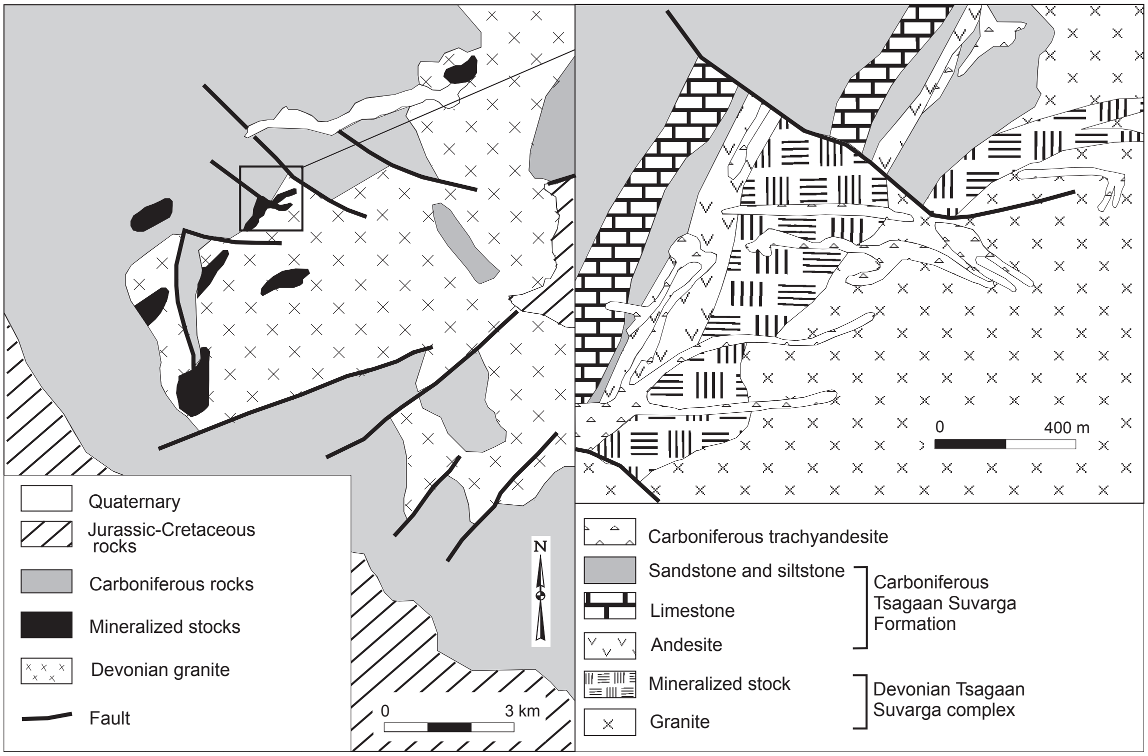



**Figure 16.** Regional and detailed geologic sketch maps of the Tsagaan Suvarga porphyry Cu-Mo (±Au, Ag) deposit, Tsagaansuvarga metallogenic belt. Adapted from Watanabe and Stein (2000).

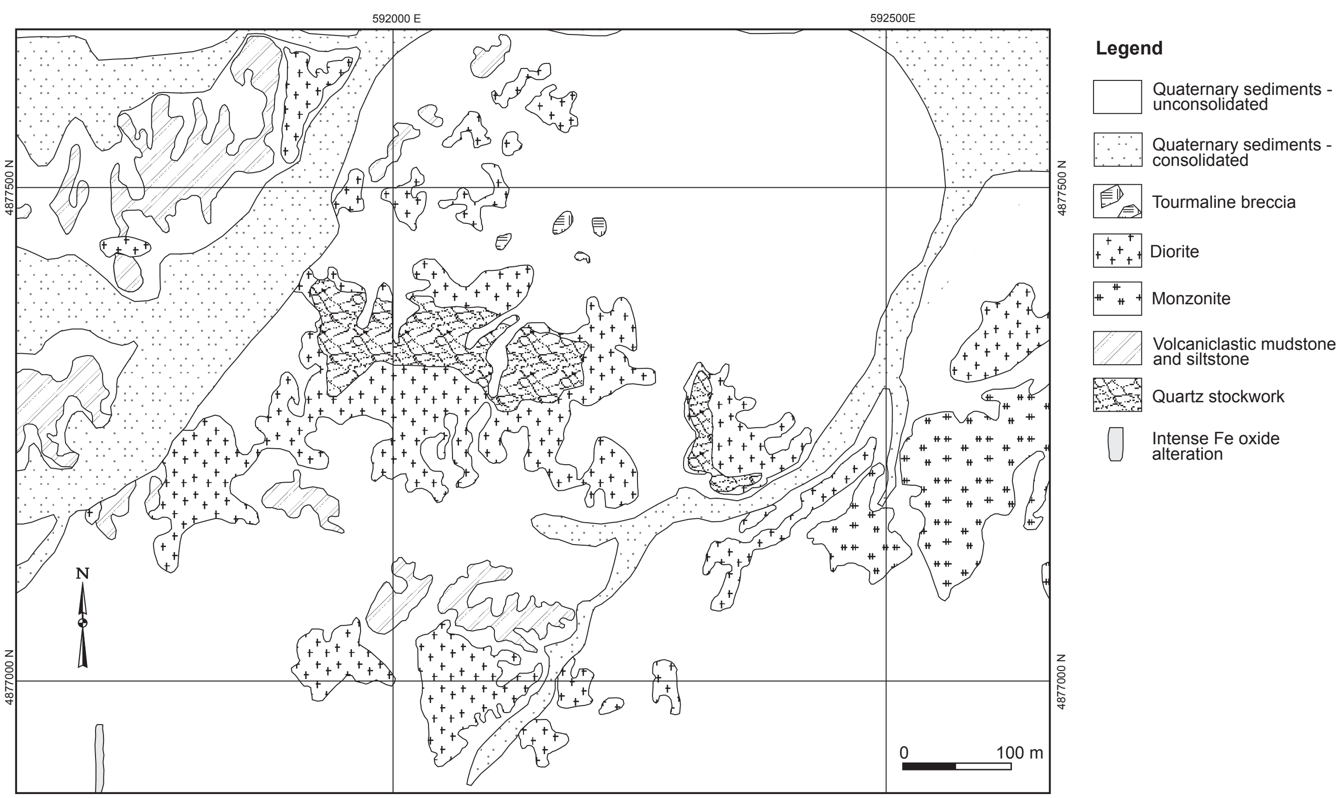



**Figure 17.** Geologic sketch map of Kharmagtai porphyry Cu-Mo deposit. Adapted from Ivanhoe Mines Mongolia Ltd. (written commun., 2009).

## Tomtor REE (±Ta, Nb, Fe) Carbonatite Deposit

This deposit (fig. 18) consists (Orlov, 1994; Tolstov and others, 1995) of a volcanic-plutonic assemblage comprised of three groups of rocks. (1) Carbonatite II comprise the bulk of the carbonatite core of the pluton with $P_2O_5$, $Nb_2O_5$, and $TR_2O_3$ values of 0.7 to 11.4, 0.1 to 0.78, and 0.45 percent, respectively. The carbonatite comprises the substratum for a weathering crust that constitutes a hypergene ore complex that forms a phosphorus-REE deposit. The weathering crust consists of alternating subhorizontal goethite-siderite, francolite, francolite-goethite-siderite, hematite, and groutite. (2) The francolite horizon consists of francolite (>60 percent), siderite, rhodochrosite, and goethite in varying proportions (up to 40 percent). $Nb_2O_5$ ranges from 0.2 to 2.4 percent, $TR_2O_3$ ranges from 0.8 to 4.5 percent, $P_2O_5$ ranges from 10 to 35 percent, $Sc_2O_3$ ranges up to 0.011 percent, $Y_2O_3$ ranges up to 0.09 percent, and $V_2O_3$ ranges up to 0.22 percent. (3) The goethite horizon contains goethite and hydrogoethite (70 to 80 percent), francolite (5 to 15 percent), siderite (up to 10 percent), and chlorite, francolite, siderite, hematite, and rhodochrosite. $Nb_2O_5$ varies from 0.1 to 3.0 percent, $Tr_2O_3$ varies from 1.3 to 5.4 percent, $P_2O_5$ varies from 0.2 to 8 percent, and $Sc_2O_3$ ranges up to 0.006 percent. The siderite horizon is made of siderite (50 to 80 percent), alumophosphates of the crandallite group (20 to 30 percent), goethite (up to 10 percent), and chlorite or kaolinite (up to 10 percent). $Nb_2O_5$ ranges from 0.3 to 0.8 percent, $TR_2O_3$ ranges from 0.8 to 1.3 percent, $Sc_2O_3$ ranges from 0.009 to 0.01 percent, $P_2O_5$ ranges up to 12 percent, and $Y_2O_3$ ranges up to 0.09 percent. The main upper ore horizon of the Tomtor deposit consists of thin-bedded alumophosphate pyrochlore monazite, alnoite, tinguaite, and carbonatite, and varies from a few meters to 12 to 15 m thick. Carbonate and ore breccia occur. The upper ore horizon is a weathering crust for the carbonanite III metasomatite substratum that is rich in REE and phosphates. Economic metals occur mainly in monazite and rhabdophanite (REE, Y, Sc), pyrochlore (Nb), and alumo- and ferro-alumophosphates ($P_2O_5$, $Al_2O_3$). The deposit is large and has estimated reserves of 500 million tonnes to a depth of 500 m. No commercial concentrations of $P_2O_5$ and $Nb_2O_5$ are known.

## Origin and Tectonic Controls for Udzha Metallogenic Belt

The alkalic ultramafic rock and carbonatite that host the deposits are interpreted as having formed in Devonian rifting.

## Ulziit Metallogenic Belt of Au in Shear-Zone and Quartz-Vein Deposits (Belt UZ) (Southern Mongolia)

This Devonian(?) metallogenic belt is related to replacements in the Govi-Altai continental-margin turbidite terrane that is part of the South Mongolia-Khingan collage. The metallogenic belt (Dejidmaa and others, 1996) contains Au quartz-carbonate vein occurrences (Goldenberg and others, 1978). The host Govi-Altai continental-margin turbidite terrane consists of mainly of Ordovician through Silurian turbidite that is overlain by Devonian shallow-marine sedimentary rock (Tomurtogoo and others, 1999). The major deposits are at Olon Ovoot, Khorimt hudag, Dayangar, An tsavyn, and Altagany uhaagchin hudag.

The main references on the geology and metallogenesis of the belt are Dejidmaa (1996), Dejidmaa and others (1996), Goldenberg and others (1978), and Tomurtogoo and others (1999).

## Olon Ovoot Au in Shear-Zone and Quartz-Vein Deposit

This deposit (Goldenberg and others, 1978; L. Dorligjav and others, written commun., 1993; Sillitoe and others, 1996; Jargalsaihan and others, 1996; Dejidmaa, 1996; Dejimaa and others, 1996) is hosted in the Silurian Mandal Ovoo Formation that contains siliceous sandstone and mudstone and is intruded by syn-orogenic gabbro-diorite and diorite sills. The deposit occurs in altered quartz diorite with sericite-quartz replacement and in quartz veins. Quartz diorite is altered to epidote, chlorite, sericite, and carbonate. Quartz veins consist of white, partly limonitized, massive and brecciated quartz with up to 10 percent carbonate and up to 2 percent ore minerals. More than 10 quartz veins occur in a 0.5 by 0.2 km area. Veins range up to 0.7 m thick and 80 m long. The main Tsagaantolgoi vein forms a saddle reef. The main ore mineral is pyrite with rare gold. The size of gold grains ranges from 0.0050 to 0.7 mm.

## Origin and Tectonic Controls for Ulziit Metallogenic Belt

The belt is interpreted as having formed during regional metamorphism of Govi-Altai terrane during collision with the Idermeg terrane.

## Yaroslavka Metallogenic Belt of Fluorite Greisen and Sn-W greisen, Stockwork, and Quartz Vein Deposits (Belt YA) (Russia, Far East)

This Late Cambrian through Devonian metallogenic belt is hosted in numerous Paleozoic granitoid plutons that intrude Cambrian clastic and limestone units of the Vosensenka continental-margin terrane of the Khanka superterrane. The Li-F alaskite granite that hosts the Voznesenka-II deposit has Rb-Sr isotopic ages of about 475 to 512 Ma. The formation of the deposits is interpreted as being related to intrusion of Late Cambrian leucogranite. The major fluorite greisen deposit is at Voznesenka-II, and the major Sn-W greisen, stockwork, and quartz vein deposit is at Yaroslavka.

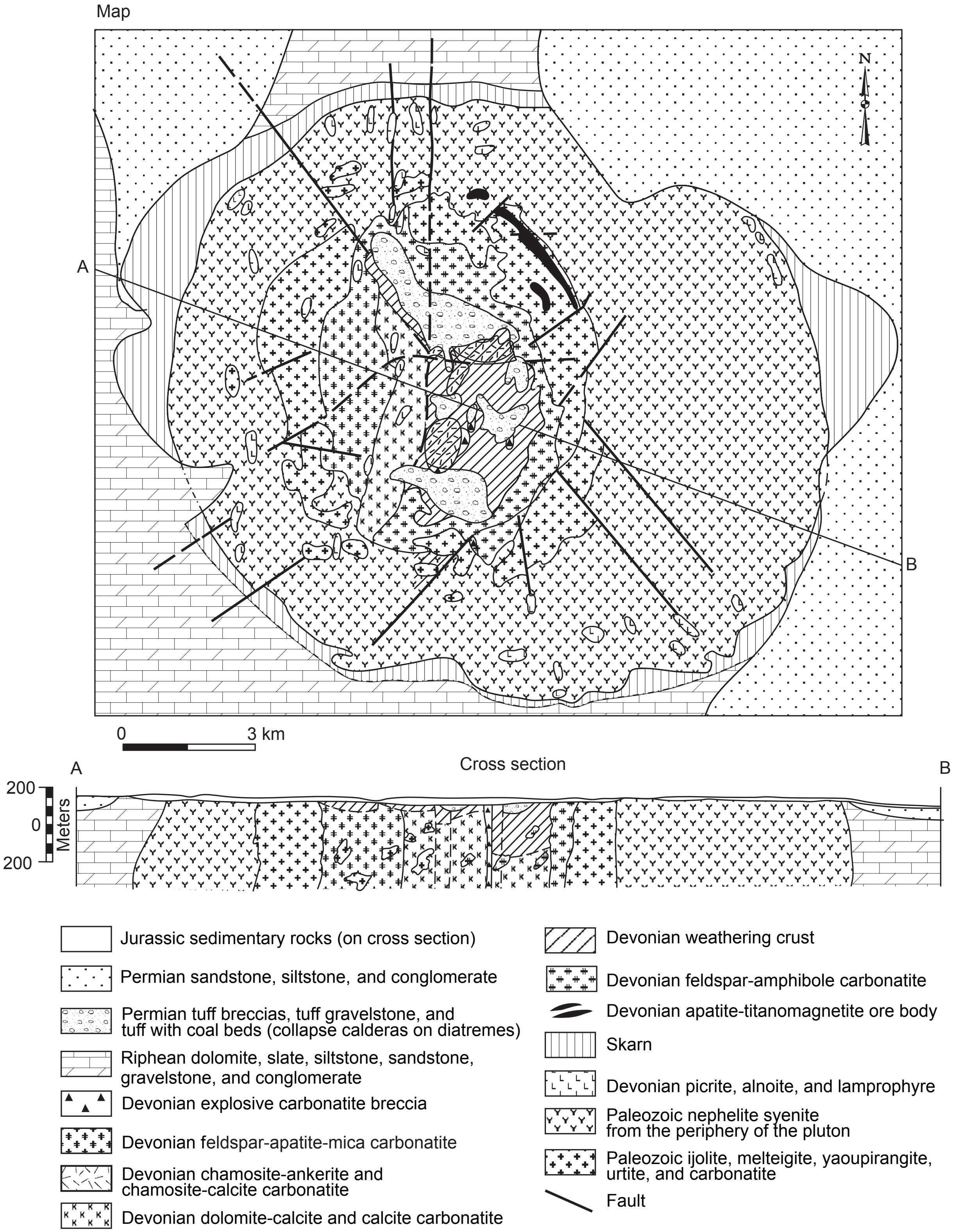



**Figure 18.** Geologic sketch map and cross section of the Tomtor weathering crust carbonatite REE-Zr-Nb-Li deposit, Udzha metallogenic belt. Adapted from Lapin and Tolstov (1995)

The main references on the geology and metallogenesis of the belt are Govorov (1977), Nokleberg and others (1997, 1998, 2003), Androsov and Ratkin (1990), Ryazantzeva and Shurko (1992), Ryazantzeva (1998), and Khanchuk and others (1996, 1998, 2000).

### Yaroslavskoe Sn-W Greisen, Stockwork, and Quartz Vein Deposit

This deposit (Govorov, 1977) occurs mainly in greisen that mainly replaces skarn, limestone, and shale and, to lesser extent granite and granite porphyry that has a Rb-Sr isotopic age of 408 Ma and an initial Sr ratio of 0.7136. Sn quartz and quartz-tourmaline veins also replace skarn along with greisen. The Sn bodies occur in three mineral assemblages (1) tourmaline and quartz; (2) tourmaline and fluorite; and (3) sulfide, tourmaline, and quartz with subordinate cassiterite, polymetallic sulfides, and chlorite. The sulfides are mainly pyrite, arsenopyrite, galena, and sphalerite. The deposit occurs along the contact of a early Paleozoic biotite granite (with an approximate isotopic age of 400 Ma) that intrudes Early Cambrian shale, siltstone, sandstone, and limestone. The relatively older pyroxene-scapolite, vesuvianite-garnet, and epidote-amphibole skarns replace limestone and shale along granite contacts and in rare limestone inclusions in the granite. More than forty Sn occurrences occur in the metallogenic belt. The deposit is medium size and has an average grade of 0.52 percent Sn. The deposit was mined from the 1950s to 1970s.

### Voznesenka-II Fluorite Greisen Deposit

This deposit (Androsov and Ratkin, 1990) consists of massive to disseminated fluorite that occurs above the apex of a 1.5 km wide intrusion of Late Cambrian Li-F alaskite granite and has an isotopic age of 475 to 512 Ma. The deposit consists of vein and greisen that occurs along a north-south-trending fault. The deposit consists of muscovite-fluorite aggregates that occur along the periphery, whereas vein greisen occurs in the middle. Greisen is often brecciated, indicating a two-stage origin. Fragments of breccia consist of mica, fluorite, fluorite limestone, greisen, and granite altered to greisen. Fragments are cemented by quartz-topaz-micaceous-fluorite aggregate that formed during a second stage. The deposit is interpreted as having formed during metasomatic replacement of Early Cambrian black organic limestone and alteration to greisen. The deposit is large and contains 450 million tonnes fluorite ore and has an average grade of 30 to 35 percent fluorite. The deposit has been mined since the 1960s, and, currently, is the largest producer of fluorite in Russia.

### Origin and Tectonic Controls for Yaroslavka Metallogenic Belt

The belt is interpreted as having formed in a collisional arc that formed along the margin of a fragment of Gondwanaland. The host leucogranite hosting the fluorite and Sn-W greisen, stockwork, and quartz-vein deposits is Li-F-REE enriched. The extensive deposits occur in the apical parts of plutons that are altered to quartz-mica-fluorite-REE greisen. The host leucogranite plutons are interpreted as having formed during anatectic melting of older granitic gneiss and Cambrian sedimentary rock. The anatectic melting is interpreted as having occurred during early Paleozoic collision of the Voznesenka and Kabarga terranes. The host leucogranite plutons intrude Early Cambrian limestone of the Voznesenka passive continental-margin terrane that is interpreted as being a fragment of a Neoproterozoic through early Paleozoic carbonate and rich sedimentary-rock sequence that formed on a passive continental margin.

# Devonian through Early Carboniferous (Mississippian) Tectonic and Metallogenic Model

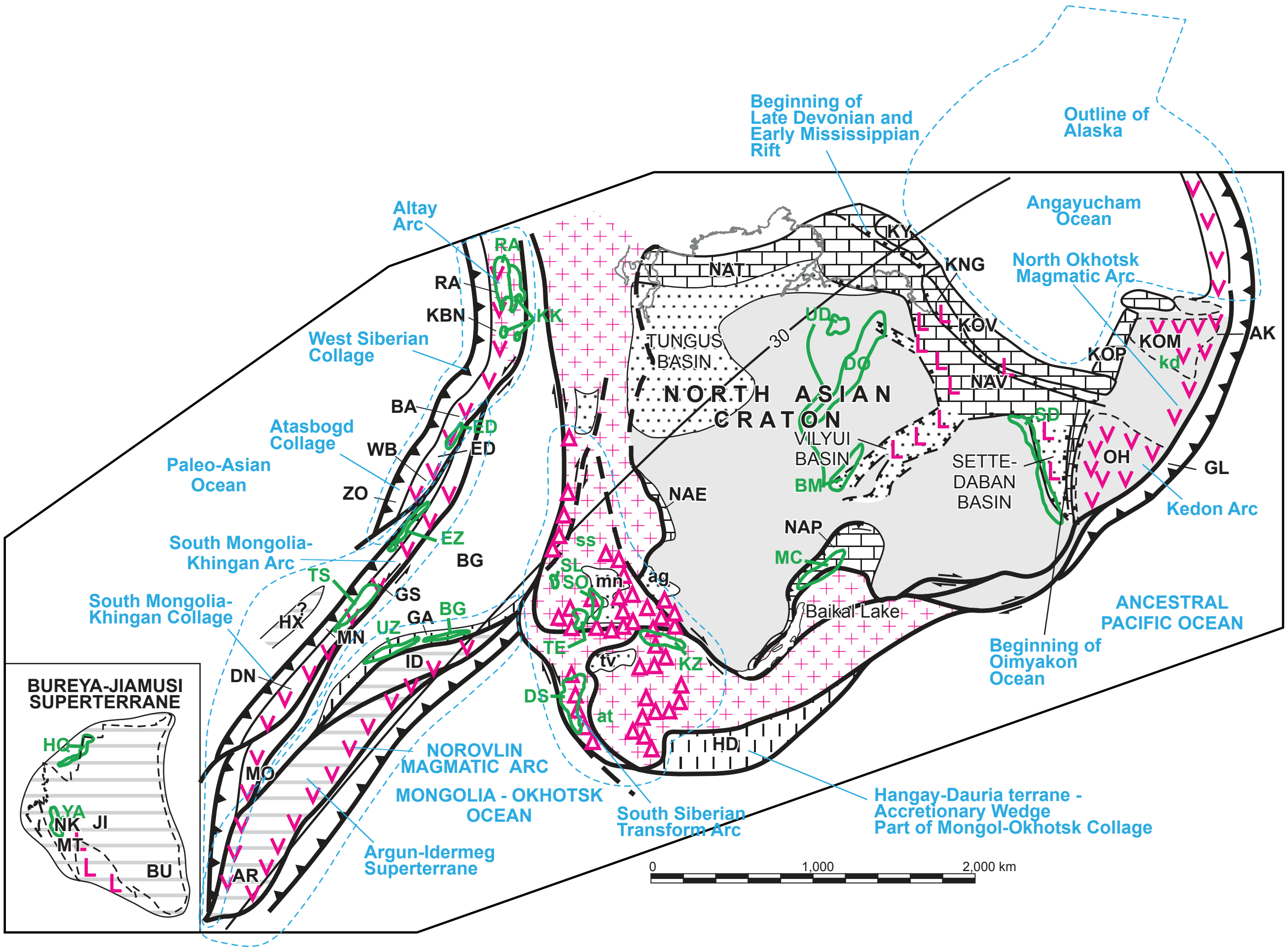
## Major Metallogenic and Tectonic Events

For the Devonian through Early Carboniferous (420 to 320 Ma), the major-metallogenic tectonic events were (fig. 19; table 1): (1) formation of the South Mongolia-Khingan arc and associated subduction zone and associated metallogenic belts; (2) back-arc spreading behind the South Mongolia-Khingan island arc resulting in formation of the Bayanleg back-arc basin and associated metallogenic belts; (3) beginning assembly of cratonal and passive continental-margin terranes in the Russian Far East and Northeastern China to form the Bureya-Jiamusi superterrane and formation of associated metallogenic belts; (4) inception of the North Okhotsk continental-margin arc and associated subduction zones that were associated with subduction of the Mongol-Okhotsk ocean plate; (5) oblique-convergence between the Mongol-Okhotsk ocean plate and the North Asian craton, resulting in transform displacement and oroclinal wrapping of the southern and western margins of the North Asian craton and formation of the South Siberian and Altai transpressional arc and associated metallogenic belts; (6) continued sea-floor spreading in the Paleoasian, Mongol-Okhotsk, and Ancestral Pacific Oceans and formation of associated metallogenic belts; and (7) rifting and associated sedimentation and formation of rift-related deposits long the northeast continental margin of the North Asian craton.

The major Devonian through Pennsylvanian metallogenic belts in the Far East, Yakutia, Northern Transbaikalia, Southern and Eastern Siberia of Russia, and Mongolia and Northeastern China are shown on figure 3. The tectonic origins of the metallogenic belts are described below in alphabetical order of the belt name. The tectonic setting of each metallogenic belt is shown on figure 19.

## Metallogenic Belts and Tectonic Origins

The Bayangovi belt (BG, figs. 3, 19) contains Au in shear-zone and quartz-vein deposits and is hosted in the




**GEOLOGIC UNITS**

North Asian Craton Margin

NAE - East Angara
NAP - Patom-Baikal
NAT - South-Taimyr
NAV - Verkhoyansk

**Intracontinental sedimentary basin**

ag - Agul (Rybinsk) molasse basin (Middle Devonian to Early Carboniferous)
mn - Minusa molasse basin (Middle Devonian through Early Permian)
tv - Tuva molasse basin (Middle Devonian through Late Carboniferous)

**Terranes**

AK - Avekov terrane
AR - Argunsky terrane
BU - Bureya terrane (Metamorphic)
DN - Dongwuzhumuqin-Nuhetdavaa terrane (Island arc) (Cambrian through Middle Devonian)
ED - Edren terrane (Island arc) (Devonian and Early Carboniferous)GA - Govi Altai terrane (Continental-margin turbidite) (Cambrian through Devonian)
GL - Galam terrane (Subduction zone) (Cambrian through Early Carboniferous)
GS - Gurvansayhan terrane (Island arc) (Silurian through Early Carboniferous)
HD - Hangay-Dauria terrane (Subduction zone) (Silurian through Late Carboniferous)
HX - Hutaguul-Xilinhot terrane
ID - Idermeg terrane
JI - Jiamusi terrane
KBN - Kalba-Narim terrane (Subduction zone) (Ordovician through Early Carboniferous)
KNG - Nagondzha terrane (Continental margin) (Carboniferous through Late Triassic)
KOM - Kolyma-Omolon superterrane
KOP - Prikolyma terrane
KOV - Omulevka terrane (Passive continental margin) (late Neoproterozoic through Triassic)
KY - Kotel'nyi terrane (Passive continental margin) (Late Neoproterozoic through Late Triassic)
MN - Mandah terrane (Subduction zone) (Devonian)
MO - Mandalovoo-Onor terrane (Island arc) (Middle Ordovician through Early Carboniferous)
MT - Matveevka terrane (Metamorphic)
NK - Nakhimovka terrane (Metamorphic)
OH - Okhotsk terrane
RA - Rudny Altai terrane (Island arc) (Late Silurian through Early Carboniferous)
WB - Waizunger-Baaran terrane (Island arc) (Ordovician through Permian)
ZO - Zoolen terrane (Subduction zone) (Ordovician(?) and Devonian)

**Overlap Continental-Margin Arcs and Granite Belts**

at - Altai volcanic-plutonic belt (Devonian and Early Carboniferous)
kd - Kedon volcanic-plutonic belt (Devonian and Early Carboniferous)
ss - South Siberian volcanic-plutonic belt (Early Devonian)

**METALLOGENIC BELTS**

BG - Bayangovi
BM - Botuobiya -Markha
DO - Daldyn-Olenyok
DS - Deluun-Sagsai
ED - Edrengiin
EZ - Edren-Zoolon
HQ - Hongqiling 331 to 350 Ma.
KK - Korgon-Kholzun
KZ - Kizhi-Khem
MC - Mamsko-Chuiskiy
RA - Rudny Altai
SL - Salair
SD - Sette-Daban
SO - Sorsk
TE - Teisk
TS - Tsagaan-suvarga
UD - Udzha
UZ - Ulziit
YA - Yaroslavka

**Figure 19.** Devonian and Early Carboniferous (370 Ma) metallogenic and tectonic model for Northeast Asia. Adapted from Parfenov and others (this volume)

## EXPLANATION

Craton

Passive continental margin on subsided craton

Microcontinent

Continental slope

Intracontinental sedimentary basin

Collage of accreted terranes and overlap assemblages

Ocean or sea underlain by oceanic crust;
includes continental margin and slope units

Sea underlain by continental crust

### SUBDUCTION-RELATED ISLAND ARCS AND CONTINENTAL MARGIN ARCS

V V V V Mainly volcanic and lesser plutonic units

× × × × Mainly plutonic and lesser volcanic units

### TRANSFORM-PLATE BOUNDARY, INTRA-PLATE (PLUME) MAGMATIC UNITS

Δ Δ Δ Δ Subalkaline and alkaline volcanic and plutonic belts

Γ Γ Γ Γ Plateau basalt, trap

L L L L Rift-related bimodal volcanic and plutonic rocks

+ + + + Intraplate granitoids

### COLLISIONAL GRANITOIDS

⊕ ⊕ ⊕ ⊕

### CONTACTS, FAULTS, AND SYMBOLS

Subduction zone and its accretionary wedge

Thrust

Strike-slip fault

Normal fault

Fold-and thrust belt formed on the subsided craton margin

Stratigraphic contact

OH Metallogenic belt with abbreviation

Outline and name of tectonic collage or
name of major tectonic feature

Chukotka
Collage

**Figure 19.**—Continued.

Govi-Altai continental-margin turbidite terrane, part of the South Mongolia-Khingan collage. The belt is interpreted as having formed regional metamorphism of the Govi-Altai terrane, part of the South Mongolia-Khingan collage, during collision with the Idermeg terrane.

The Botuobiya-Markha (BM, figs. 3, 19) and Daldyn-Olenyok (DO, figs. 3, 16; table 2) belts occur in northeast and in central Yakutia, respectively, and contain diamond-bearing Devonian kimberlite deposits. The tectonic origin of these metallogenic belts is unknown. The kimberlite pipes intrude mostly Cambrian through Silurian carbonate sedimentary rocks of the North Asian craton.

The Deluun-Sagsai belt (DS, figs. 3, 19) contains polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite, polymetallic Pb-Zn±Cu (±Ag, Au) vein and stockwork, volcanogenic Zn-Pb-Cu massive sulfide, sediment-hosted Cu, Ag-Pb epithermal vein and granitoid-related Au-vein deposits and occurrences. The deposits and occurrences are hosted in granitoids and replacements related to the Deluun sedimentary-volcanic-plutonic belt, part of Altai and South Siberian transpressional continental-margin arc. The belt is interpreted as having formed during granitoid magmatism that occurred during transpressional faulting along the accreting southern margin of the North Asian craton as part of the South Siberian arc. This arc contained the South Siberian and West and North Mongolian volcanic-plutonic belts.

The Edrengiin belt (ED, figs. 3, 19) contains volcanogenic Cu-Zn massive sulfide and volcanogenic-sedimentary Fe and Mn deposits and is hosted in the Edren island-arc terrane, part of South Mongolia-Khingan collage. The belt is interpreted as having formed during the South Mongolian-Khingan island arc. The deposits are hosted in pillow basalt and siliceous rocks.

The Edren-Zoolon belt (EZ, figs. 3, 19) contains Au quartz-vein deposits. The belt is related to the Zoolen subduction zone of the South Mongoial-Khingan island arc. The belt is interpreted as having formed during regional metamorphism related to collision of the Govi-Altai turbidite and Idermeg continental-margin terranes.

The Hongqiling belt (HQ, figs. 3, 19) contains mafic-ultramafic related Cu-Ni-PGE and polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposits. The belt is hosted in Mississipian or possibly Triassic mafic and ultramafic plutons that intrude and overlap the Bureya-Jiamusi supterterrane. The belt is interpreted as having formed during extension of the Bureya- Jiamusi superterrane.

The Kizhi-Khem belt (KZ, figs. 3, 19) contains W-Mo-Be greisen, stockwork, and quartz vein, porphyry Cu-Mo (±Au, Ag); Ta-Nb-REE alkaline metasomatite; and granitoid-related Au vein deposits. The belt is hosted in replacements related to Devonian subalkalic porphyry granitoids that are part of the South-Siberian volcanic-plutonic belt and the Tannuola plutonic belt. The host units are interpreted as having formed during transpressional faulting along the accreting southern margin of the North Asian craton.

The Korgon-Kholzun belt (KKh, figs. 3, 19) contains volcanogenic-sedimentary Fe, Fe-skarn, mafic-ultramafic related Ti-Fe (±V) and polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposits. The belt is hosted in the Altai volcanic-plutonic belt that overlaps and intrudes the Altai and Charysh continental-margin turbidite terranes that are part of the Altai collage. The belt is interpreted as having formed during transpressional faulting along the accreting southern margin of the North Asian craton.

The Mamsko-Chuiskiy belt (MC, figs. 3, 19) contains muscovite- pegmatite deposits and is hosted in Devonian through Early Carboniferous veins and dikes in the Mamsky and Konkudero-Mamakansky complexes that intrude the Chuja paragneiss terrane, part of the Baikal-Patom cratonal margin. The belt is interpreted as having formed during intrusion of alkaline granitoids that formed during post-accretionary magmatism in transpression zones related to a transform microplate boundary.

The Muiskiy belt (MS, figs. 3, 19) contains granitoid-related Au vein, Au in shear-zone and quartz-vein, carbonate-hosted Hg-Sb, and porphyry Sn deposits that are hosted in granitoids and veins related to the Barguzin-Vitim granitoid belt that intrudes terranes accreted along the southern margin of the North Asian craton. The host granitoids are interpreted as having formed during post-accretionary magmatism in transpression zones related to a transform microplate boundary.

The Rudny Altai belt (RA, figs. 3, 19) contains volcanogenic Zn-Pb-Cu massive sulfide, barite vein, and volcanic-hosted metasomatite deposits that are hosted in the (Rudny) Altai island-arc terrane that part of the West Siberian collage The belt is interpreted as having formed in the same name island arc. The host rocks are interpreted as having formed in the South Mongolia-Khingan island arc.

The Salair belt (SL, figs. 3, 19) contains polymetallic (Pb, Zn, ±Cu, Au, Ag) volcanic-hosted metasomatite, and porphyry Cu-Mo(±Au,Ag) deposits that are hosted in the (Rudny) Altai island-arc terrane that is part of the West Siberian collage The belt is interpreted as having formed in the same name island arc. The host rocks are interpreted as having formed in the South Mongolia-Khingan island arc.

The Sette-Daban belt (SD, figs. 3, 19) contains sediment-hosted Cu, basaltic native Cu, REE (± Ta, Nb, Fe) carbonatite, and carbonate-hosted Pb-Zn deposits that are hosted in the Verkhoyansk (North Asian) cratonal margin. The deposits are interpreted as having formed during Devonian rifting in the passive continental margin of the North Asian craton. The sediment-hosted Cu deposits are hosted in Middle Devonian through Early Carboniferous carbonate and terrigenous rocks that also contain basalt lava flows with native Cu deposits. The REE and apatite deposits are hosted in alkali-ultramafic and carbonatite plutons that are also interpreted as having formed during Devonian rifting

The Sorsk belt (SO, figs. 3, 19) contains porphyry Mo, polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite, and Zn-Pb (±Ag, Cu) skarn deposits. The hosting Early and

Middle Devonian porphyry intrusions are part of the South Siberian volcanic-plutonic belt (South Siberian arc) and intrude older early Paleozoic granitoid plutons. The skarn and metasomatic polymetallic deposits are hosted in Vendian and Cambrian shallow-water marine carbonate rock. The belt is interpreted as having formed during Devonian subalkalic porphyry magmatism related to interplate rifting and transpressional faulting along the accreting southern margin of the North Asian craton.

The Teisk belt (TE, figs. 3, 19) contains Fe-skarn, mafic-ultramafic related Ti-Fe (±V), and volcanogenic-sedimentary Fe deposits that are hosted in plutonic rocks of the South Siberian volcanic-plutonic belt (part of the South Siberian arc). The belt is interpreted as having formed during transpressional faulting along the the accreting southern margin of the North Asian craton in the South Minusa volcanic basin. The Fe-skarn deposits are related to early Devonian granosyenite plutons that occur along marginal faults of Devonian basins.

The Tsagaan-suvarga belt (TS, figs. 3, 19) contains porphyry Cu-Mo (±Au, Ag), porphyry Cu (±Au), porphyry Au-Cu and granitoid-related Cu-Au vein deposits and occurrences that are hosed in the Gurvansayhan island-arc terrane, part of the South Mongolia-Khingan collage. This belt is interpreted as having formed in the South Mongolia Khingan island arc.

The Udzha belt (UD, figs. 3, 19) contains REE (± Ta, Nb, Fe) carbonatite deposits that are hosted in the North Asian craton. The belt is is interpreted as having formed during intrusion of alkali-ultramafic rock and carbonatite associated with Devonian rifting.

The Ulziit (belt UZ, figs. 3, 19) contains Au in shear-zone and quartz-vein deposits that are hosted in the Govi-Altai continental-margin turbidite terrane, part of the South Mongolia-Khingan collage. The belt is interpreted as having formed during regional metamorphism of Govi-Altai terrane during collision with the Idermeg terrane.

The Yaroslavka belt (YA, figs. 3, 19) contains Sn-W greisen, stockwork and quartz- vein deposits, and fluorite greisen deposits and occurrences. The belt is interpreted as having formed in a collisional arc that formed in a fragment of Gondwanaland. The host leucogranite plutons are associated with early Paleozoic collision of the Voznesenka and Kabarga terranes along the margin of Gondwanaland. The deposit-related granitoids intrude Cambrian clastic rocks and limestone

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