Chapter 4

Archean through Mesoproterozoic Metallogenesis and Tectonics of Northeast Asia

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Introduction

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

Compilations Employed for Synthesis, Project Area, and Previous Study

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

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

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

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Major Geologic Units

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

Major Cratons and Craton Margins

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

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

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

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

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

Cratonal Terranes and Superterranes

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

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

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

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

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

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

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

Passive Continental-Margin Terranes of Unknown Affinity

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

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

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

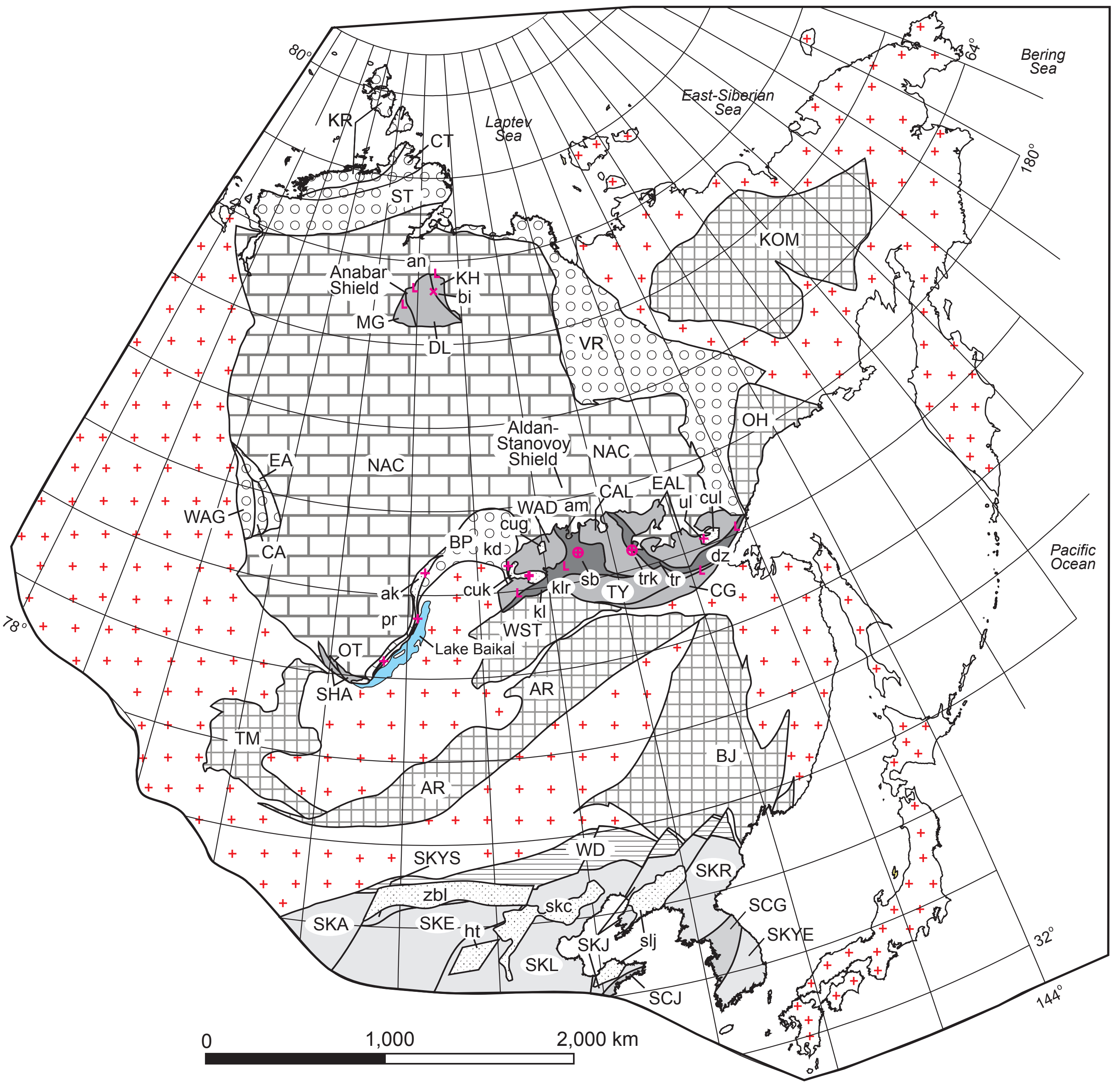

Figure 2. Generalized geodynamics map of Northeast Asia showing major Archean and Proterozoic cratons, cratonal margin, and passive continental-margin units. Map is derived from (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004a,b); and (2) a more detailed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

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

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

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

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

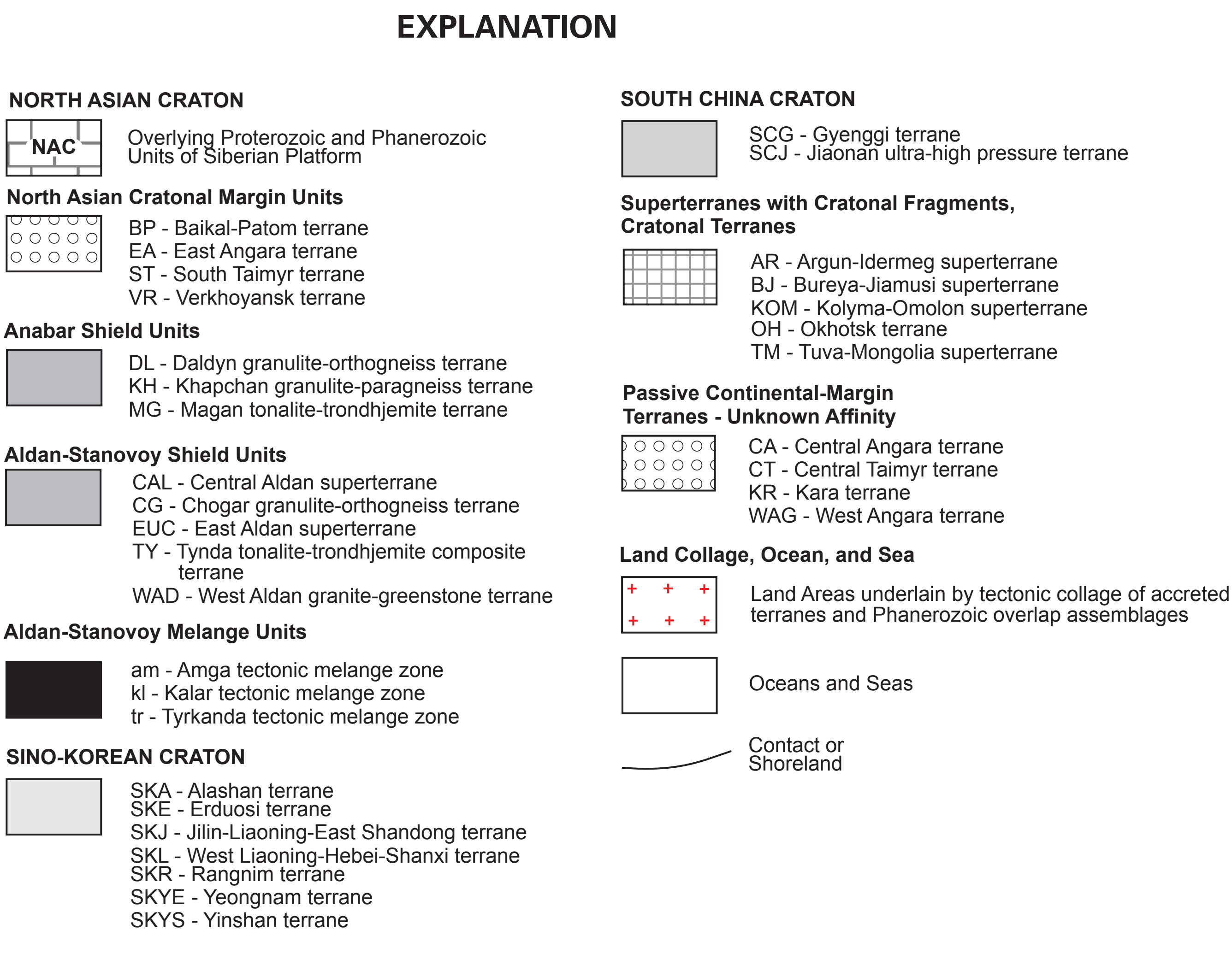

Figure 2.—Continued.

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

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

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

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

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

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

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

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

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

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

Shuichang Banded Iron Formation (BIF, Algoma Fe) Deposit

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

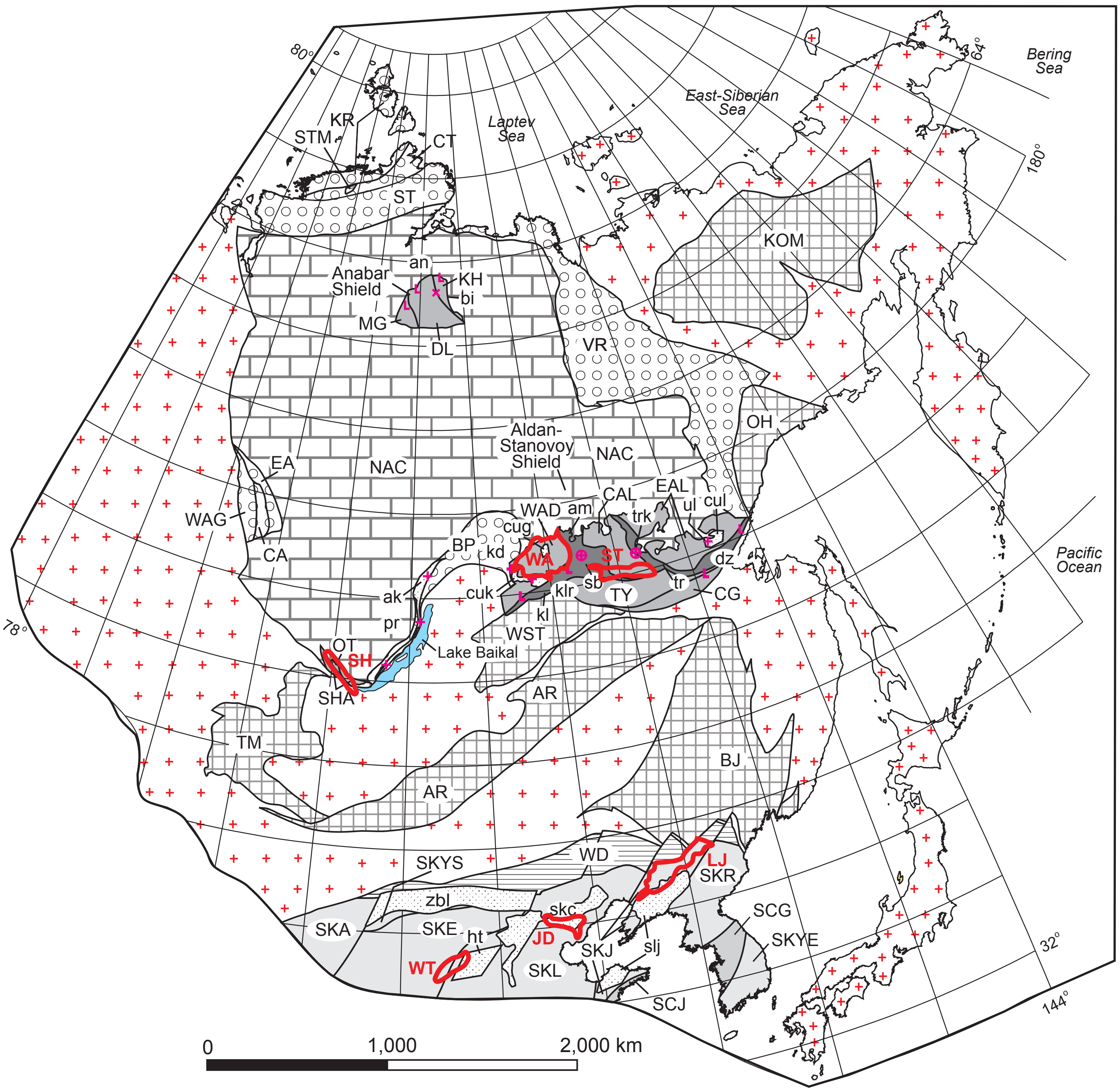


Figure 3. Generalized map of major Archean metallogenic belts and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 and table 1 for explanation of geologic units. Metallogenic belt outlines are adapted from Obolenskiy and others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

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

Sijiaying Banded Iron Formation (BIF, Algoma Fe) Deposit

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

Jinchangyu Au in Shear0Zone and Quartz-Vein Deposit

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

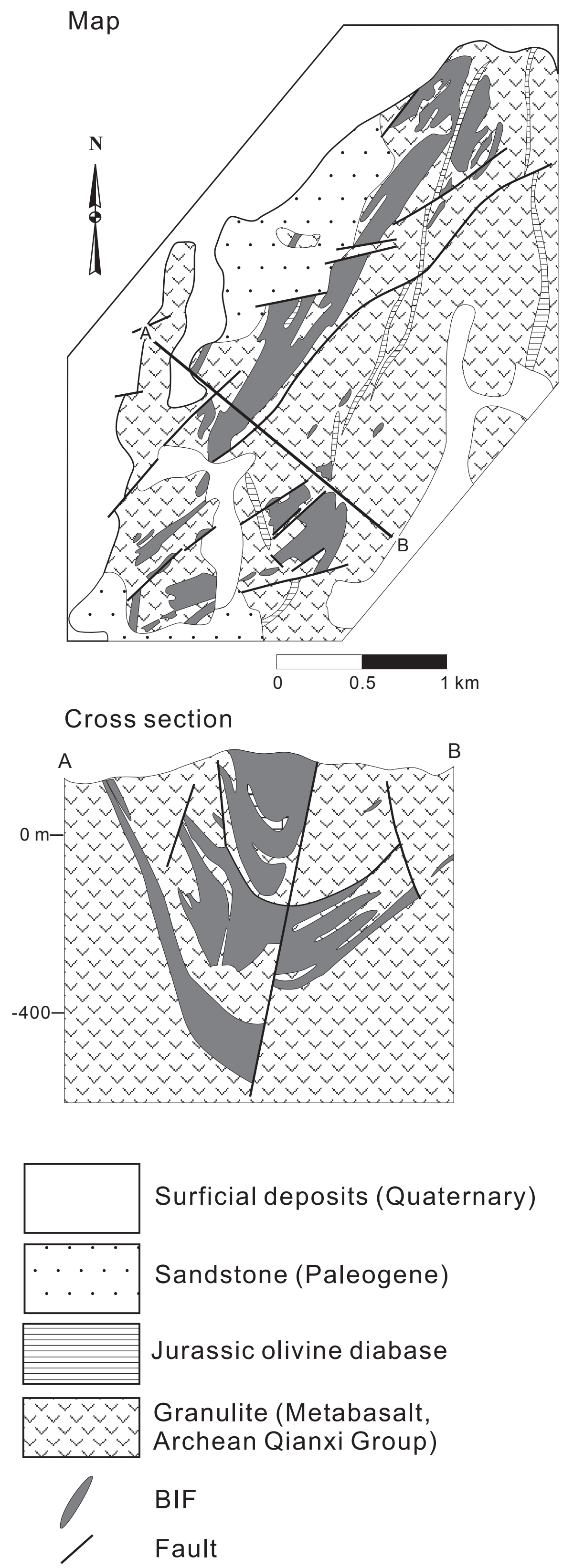


Figure 4. Shuichang iron deposit (BIF, Algoma type), Jidong metallogenic belt, west Hebei, North China. Schematic geological map and cross section. Adapted from Ma Guogun (1993).

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

Origin and Tectonic Controls for Jidong Metallogenic Belt

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

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

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

Gongchangling Banded Iron Formation Deposit (BIF, Algoma Fe)

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

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

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

Jiapigou Au in Shear-Zone and Quartz-Vein Deposit

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

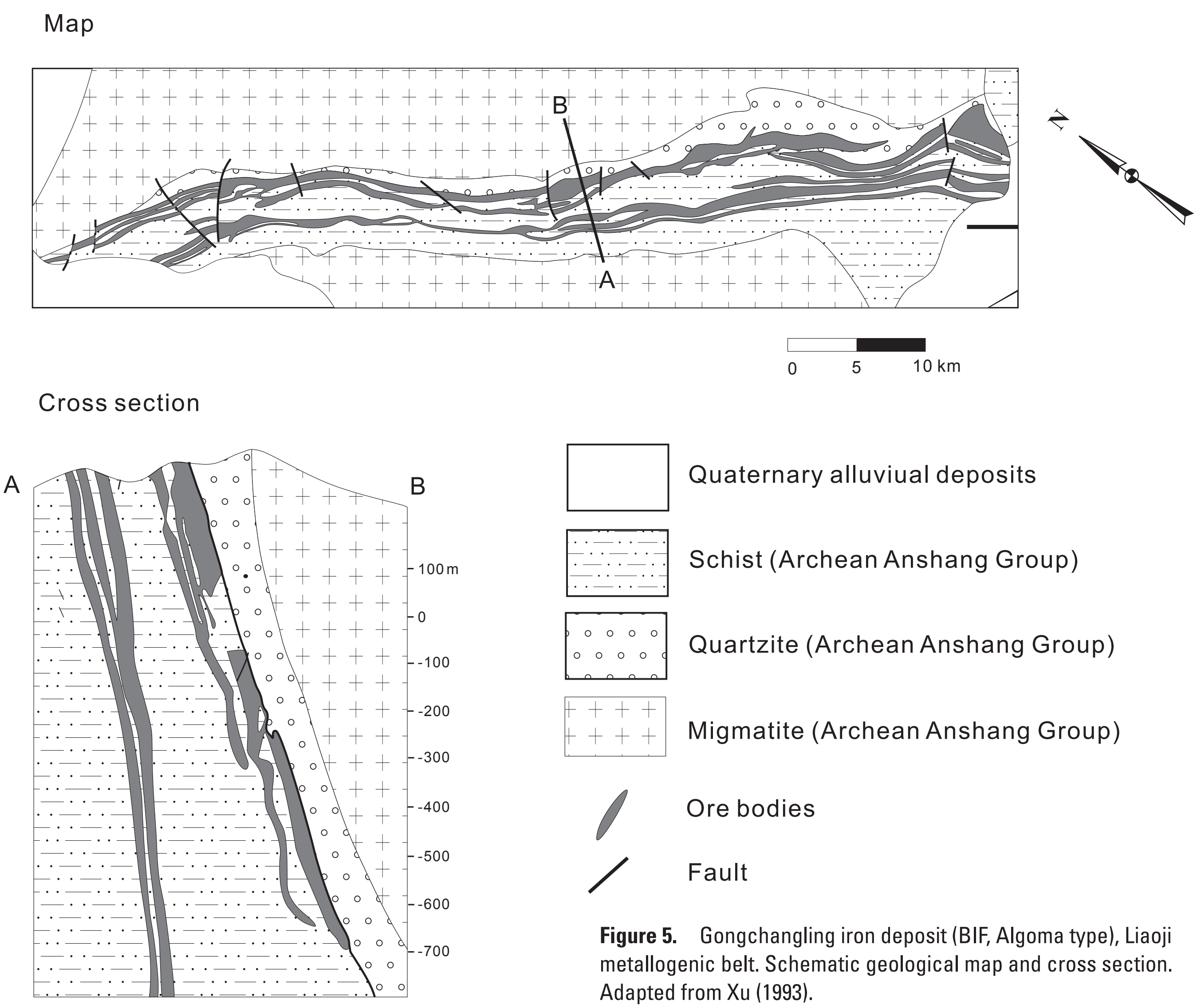


Figure 5. Gongchangling iron deposit (BIF, Algoma type), Liaoji metallogenic belt. Schematic geological map and cross section. Adapted from Xu (1993).

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

Origin and Tectonic Controls for Laioji Archean Metallogenic Belt

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

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

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

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

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

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

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

Savinskoe Talc (magnesite) Replacement Deposit

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

Origin and Tectonic Control for Sharizhalgaiskiy Metallogenic Belt

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

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

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

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

Olimpiyskoe Banded Iron Formation (BIF, Superior Fe) Deposit

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

Origin and Tectonic Controls for Sutam Metallogenic Belt

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

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

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

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

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

Tarynnakh Banded Iron Formation (BIF) Deposit

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

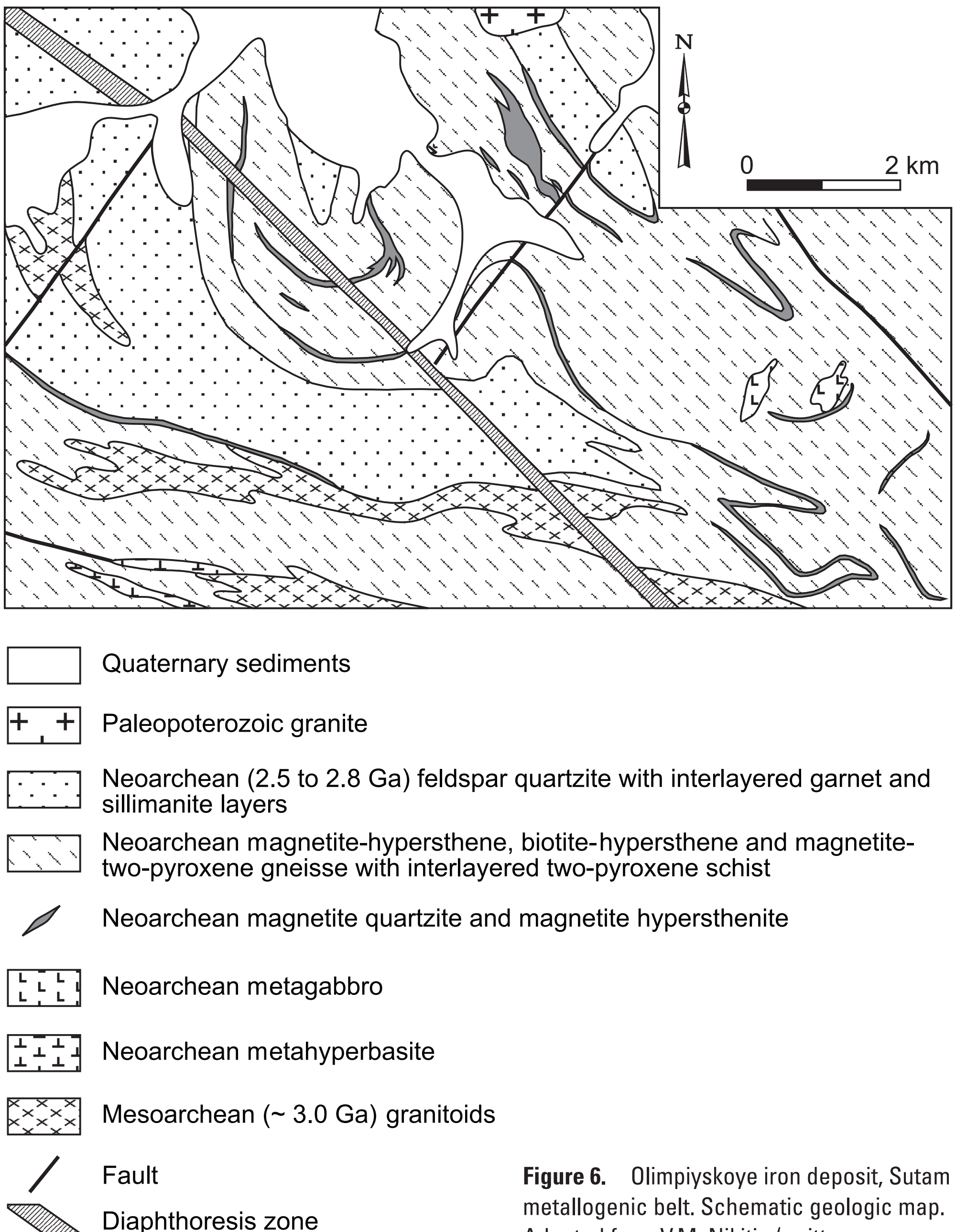


Figure 6. Olimpiyskoye iron deposit, Sutam metallogenic belt. Schematic geologic map. Adapted from V.M. Nikitin (written commun., 2003).

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

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

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

Olondo Au in Shear-Zone and Quartz-Vein Occurrence

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

Origin and Tectonic Controls for West Aldan Metallogenic Belt

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

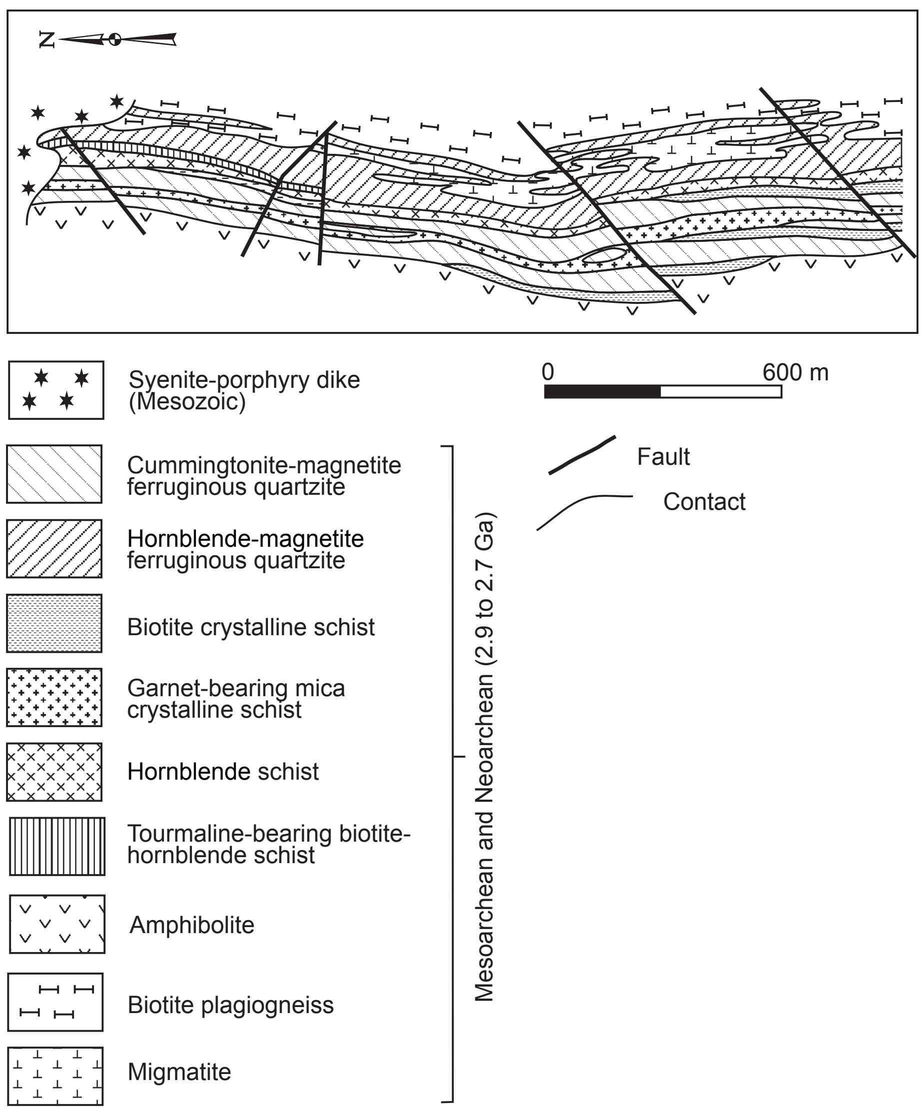


Figure 7. Tarynnakh banded iron formation deposit, West Aldan metallogenic belt. Schematic geologic map. Adapted from Gorelov and others (1984).

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

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

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

Baizhiyan Banded Iron Formation (BIF, Algoma Fe) Deposit

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

Origin and Tectonic Controls for Wutai Metallogenic Belt

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

Origin of Metallogenic Belts in North China

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

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

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

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

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

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

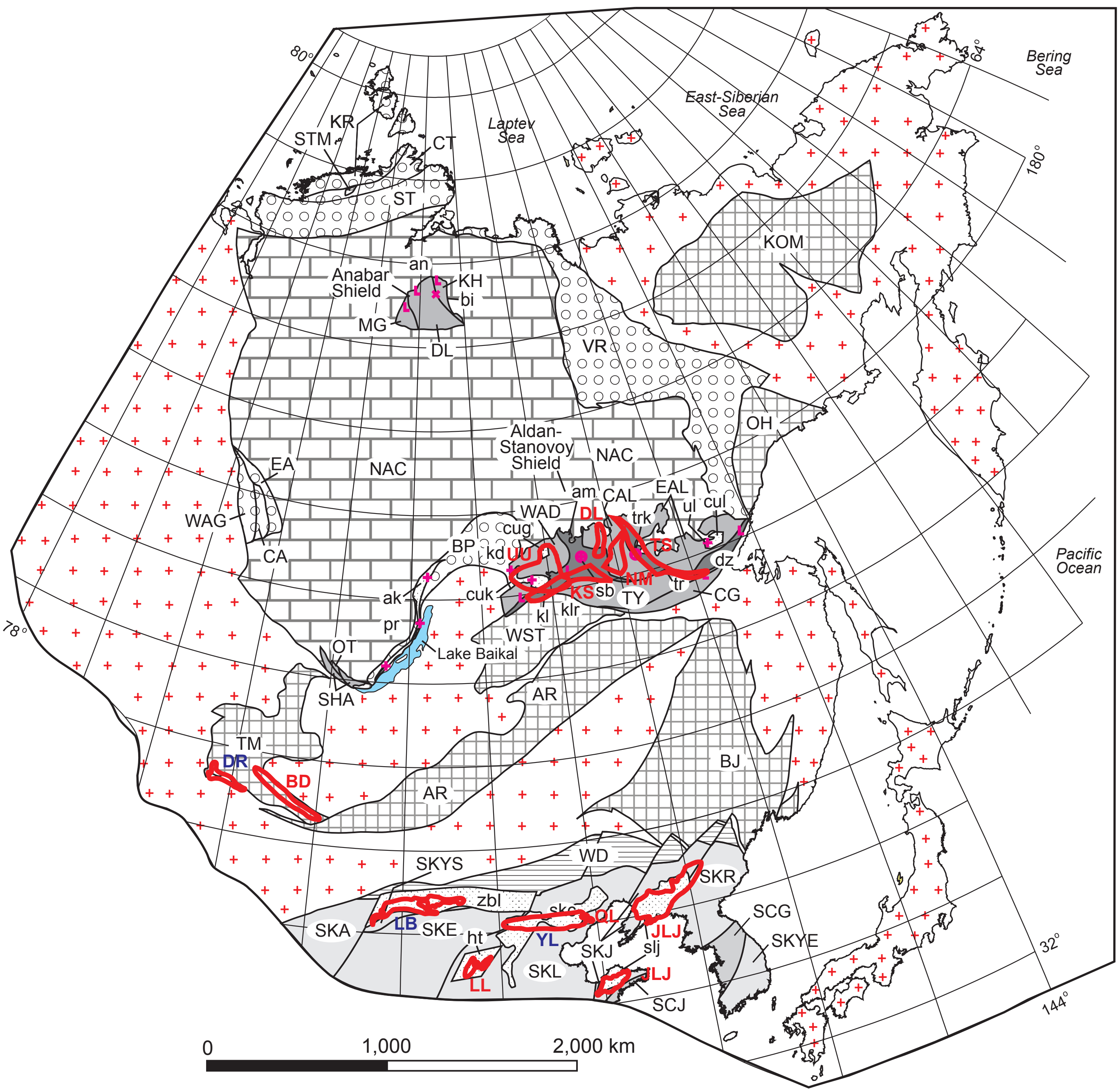


Figure 8. Generalized map of major Paleoproterozoic belts (in red), Mesoproterozoic metallogenic belts (in purple), and major geologic units for Northeast Asia. Refer to text and appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines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

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

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

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

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

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

Baydragiin Gol III BIF Occurrence

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

Origin and Tectonic Controls for Baydrag Metallogenic Belt

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

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

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

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

Dyosovskoe Fe Skarn Deposit

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

Tayozhnoe Fe Skarn Deposit

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

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

Origin and Tectonic Controls for Dyos-Leglier Metallogenic Belt

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

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

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

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

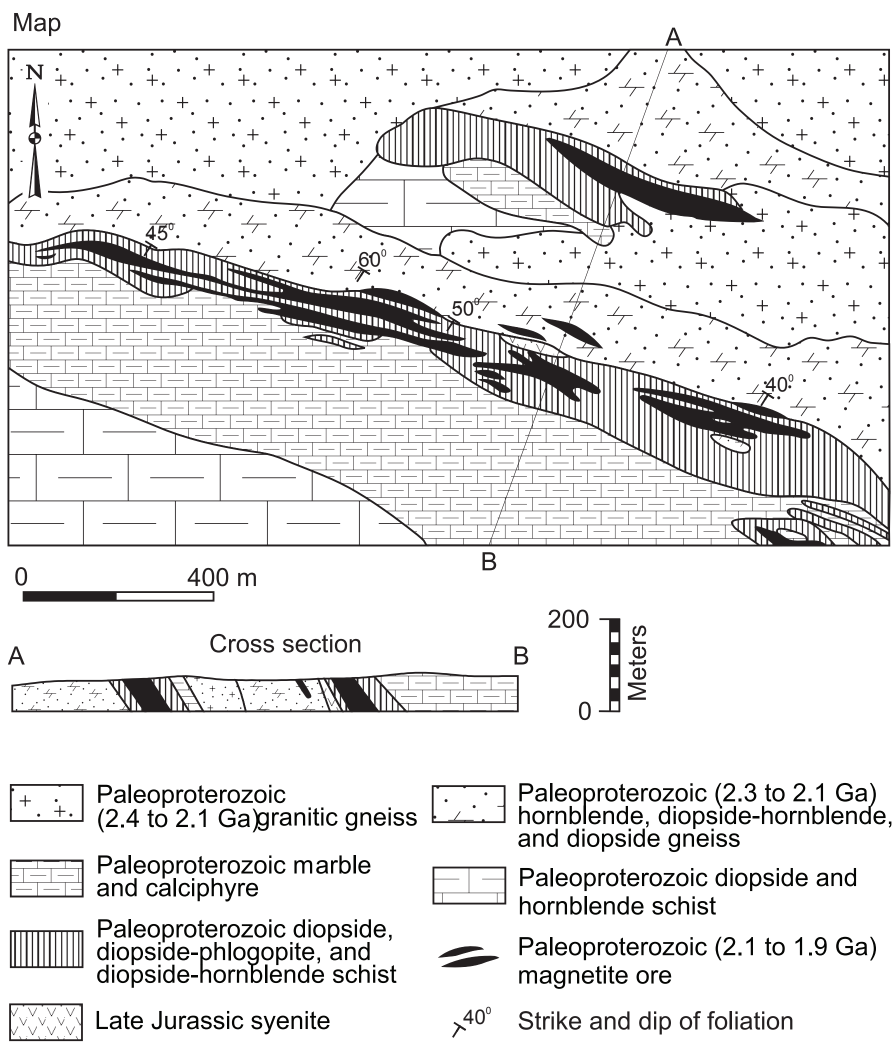
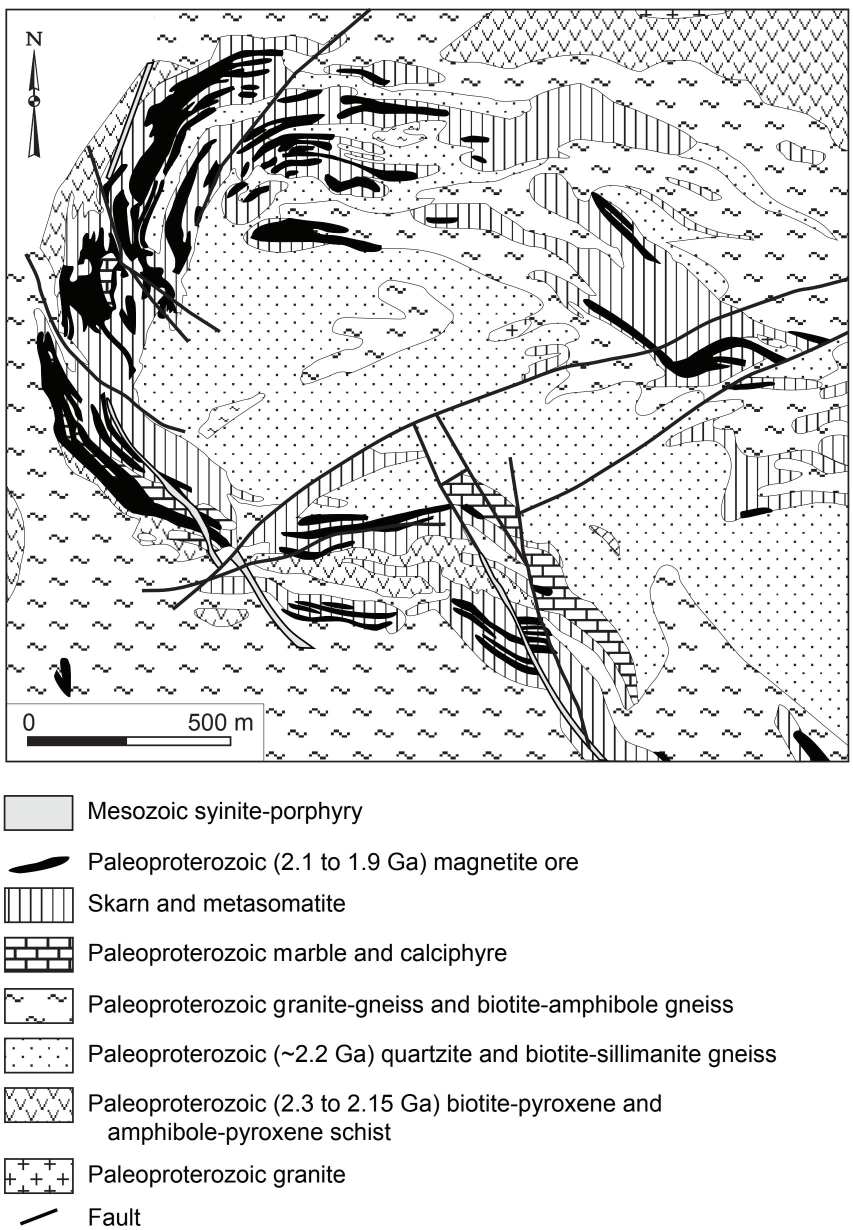


Figure 9. Dyosovskoe Fe-skarn deposit, Dyos-Leglier metallogenic belt. Schematic geologic map and cross section. Adapted from Serdyuchenko and others (1960).

Wengquangou Sedimentary Metamorphic Borate Deposit

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



Xiafangshen Sedimentary Metamorphic Magnesite Deposit

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

Fanjiapuzi Talc (Magnesite) Replacement Deposit

This deposit (Li and others, 1994) occurs in the eastern Liaoning Proterozoic rift zone and is closely associated with Mg host rocks in the upper part of the Paleoproterozoic Dashiqiao Formation. The deposit occurs on

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

the northern limb of a north-northeast-trending synclinorium in the huge Yingkou-Dashiqiao-Fanjiapuzi magnesite belt. Deposits are stratiform and lenticular and are comfortable with wallrocks. Coarse-grained magnesite often occurs in talc ores. Where talc content is more than 70 percent, hand sorting produces high quality, rose or white ores that contains 30 to 32 percent MgO, 59 to 62 percent SiO_2, <19 percent CaO, and <0.5 percent Fe_2O_3. Where ore whiteness is more than 85 and talc content is between 50 and 90 percent, flotation process produces a high quality talc powder. The deposit is superlarge and has reserves of 36 million tonnes.

Dalizi Banded Iron Formation (BIF, Superior Fe) Deposit

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

Qingchengzi Korean Pb-Zn massive Sulfide Deposit

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

Baiyunshan Au in Shear-Zone and Quartz-Vein Deposit

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

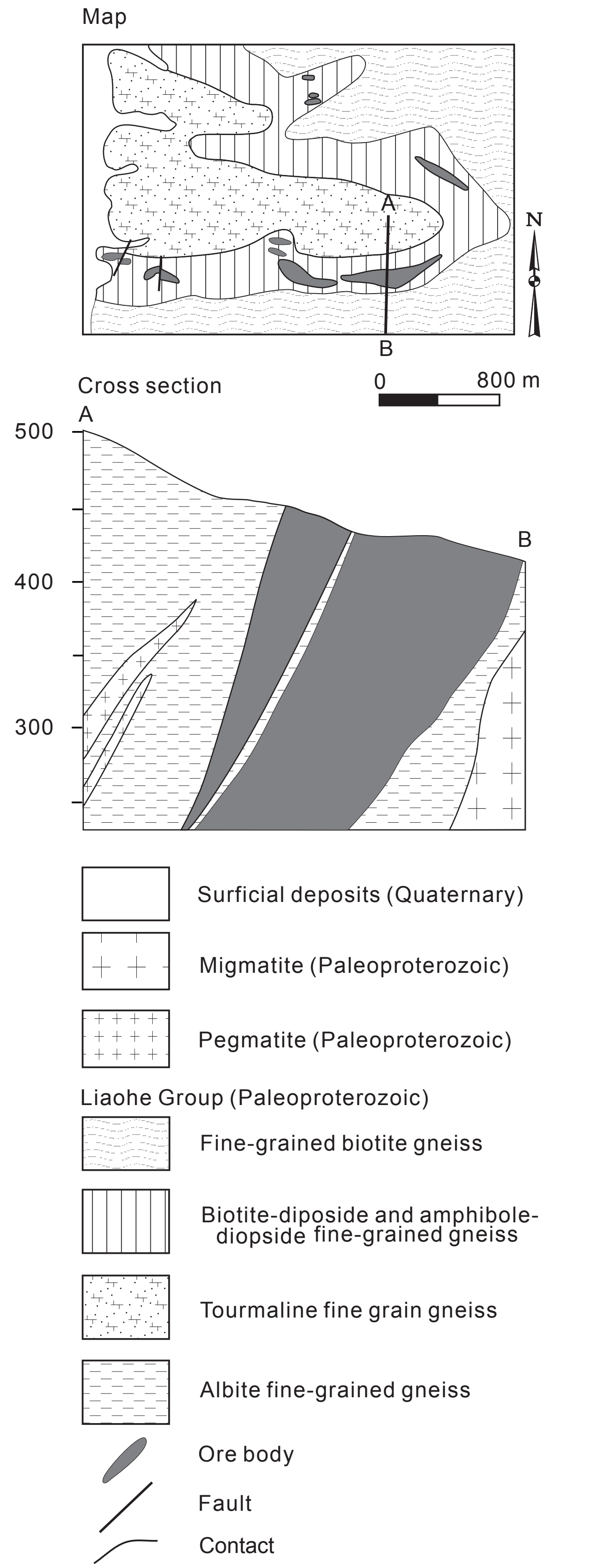


Figure 11. Wengquangou sedimentary-metamorphic borate deposit, Jiliaojiao metallogenic belt. Geologic sketch map and cross section. Adapted from Jiang and others (1994).

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

Nancha Au in Shear-Zone and Quartz-Vein Deposit

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

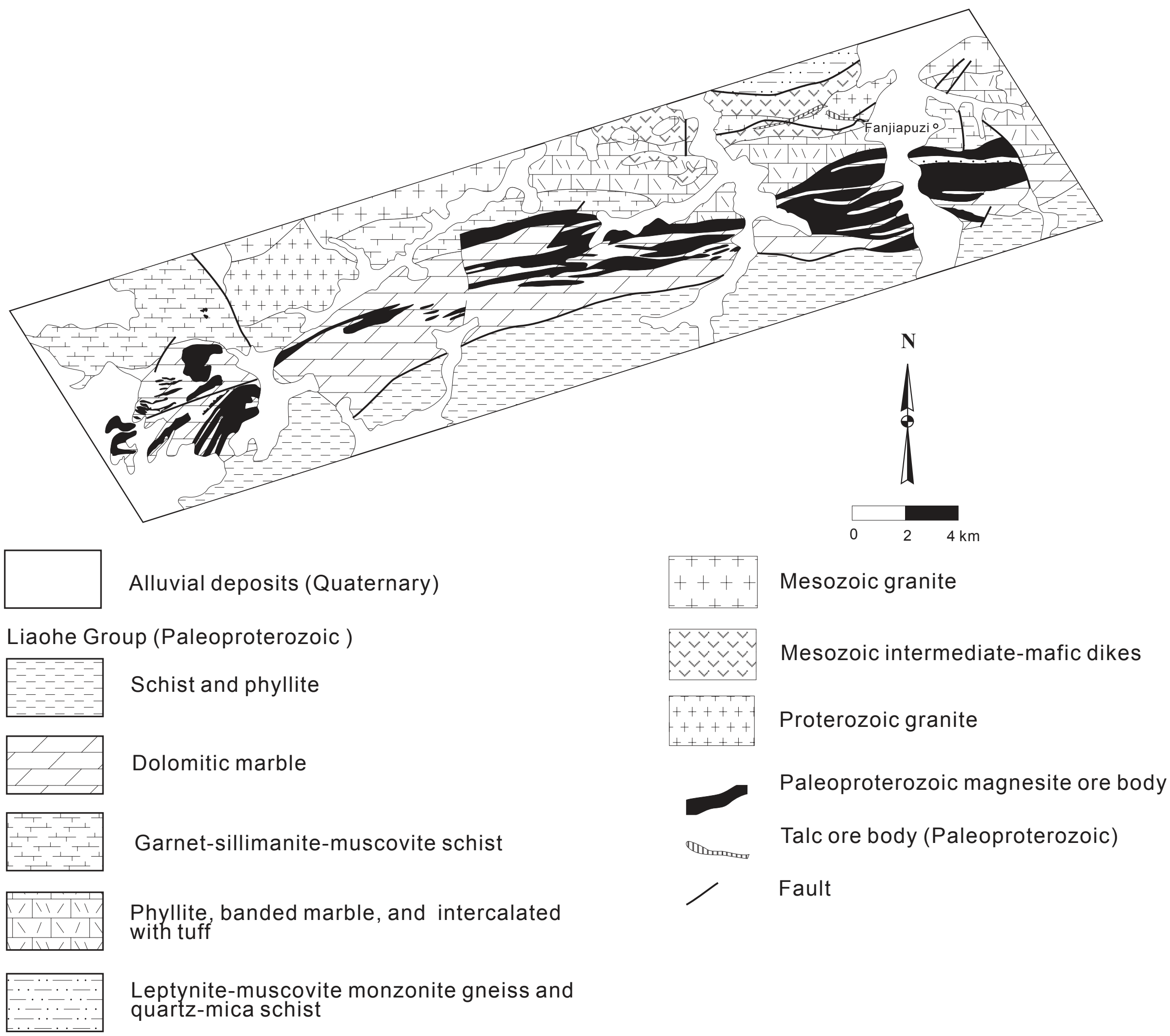


Figure 12. Xiafanshen metamorphic-sedimentary magnesite deposit and Fanjiapuzi talc replacement deposit, Jiliaojiao metallogenic belt. Regional schematic geological map. Adapted from Zhang (1984).

Nanshu Metamorphic Graphite Deposit

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

Origin and Tectonic Controls for Jiliaojiao Metallogenic Belt

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

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

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

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

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

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

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

Ledyanoe Au in Shear-Zone and Quartz-Vein Deposit

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

Origin and Tectonic Controls for Kalar-Stanovoy Metallogenic Belt

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

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

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

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

Yuanjiachun Banded Iron Formation (BIF, Superior Fe) Deposit

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

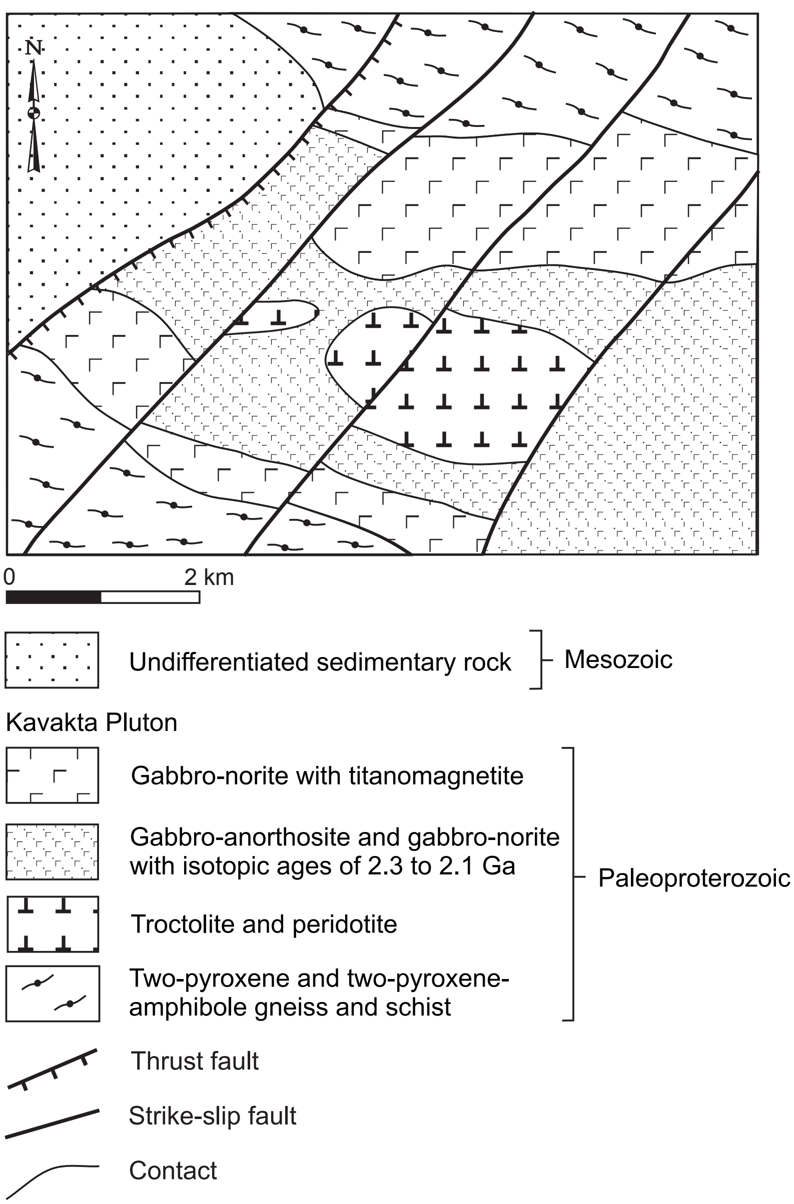


Figure 13. Kavakta mafic-ultramafic related Ti-Fe (V) deposit, Kavakta metallogenic belt. Adapted from Stogniy and others (1996).

Hulishan Au in Shear-Zone and Quartz-Vein Deposit

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

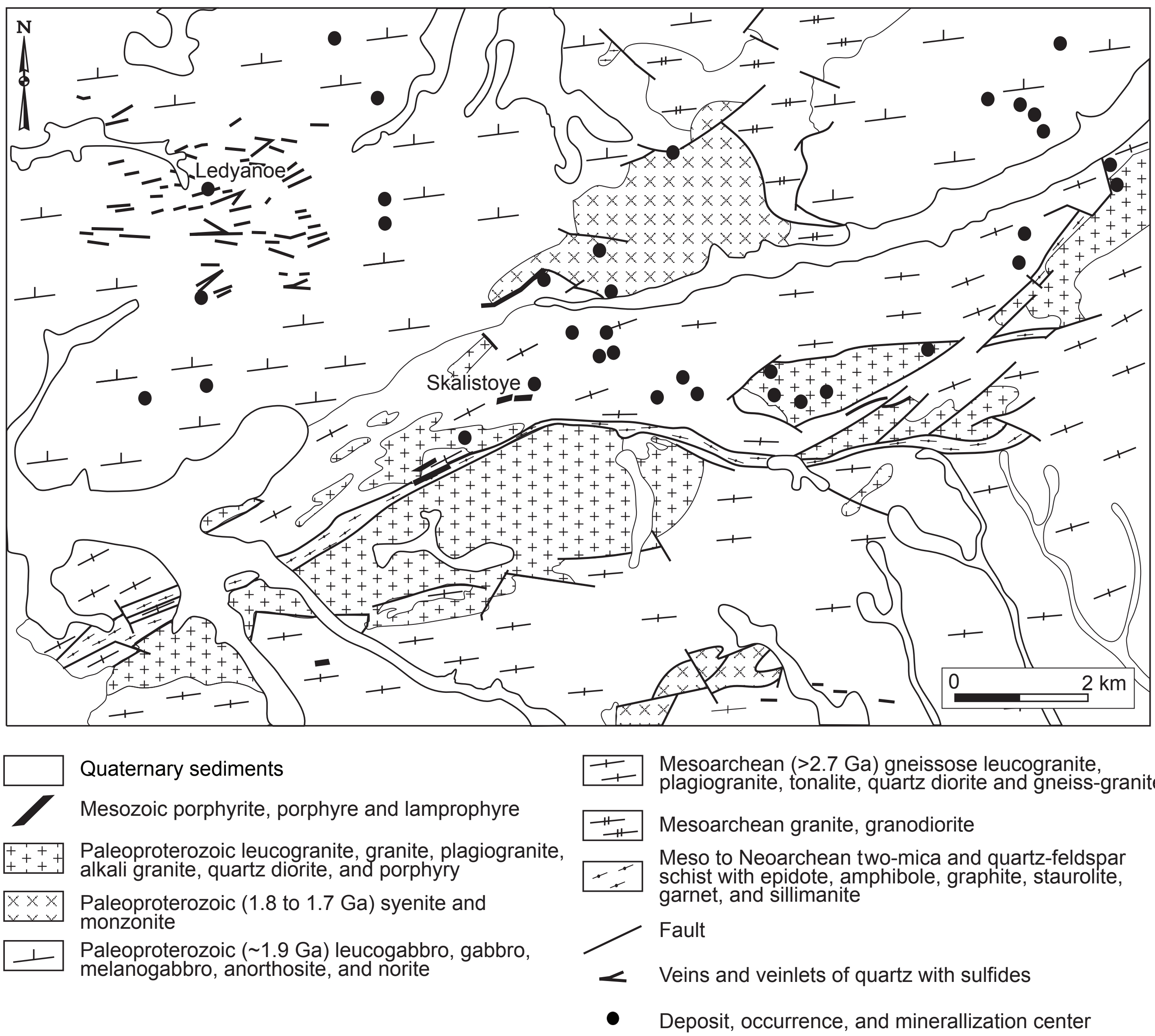


Figure 14. Ledyanoe Au in shear-zone and quartz-vein deposit, Kalar-Stanovoy metallogenic belt. Schematic geologic map. Adapted from Moiseenko and Eirish (1996) and Parfenov and others (2001).

Origin and Tectonic Controls for Luliangshan Metallogenic Belt

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

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

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

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

Seligdar Apatite Carbonatite Deposit

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

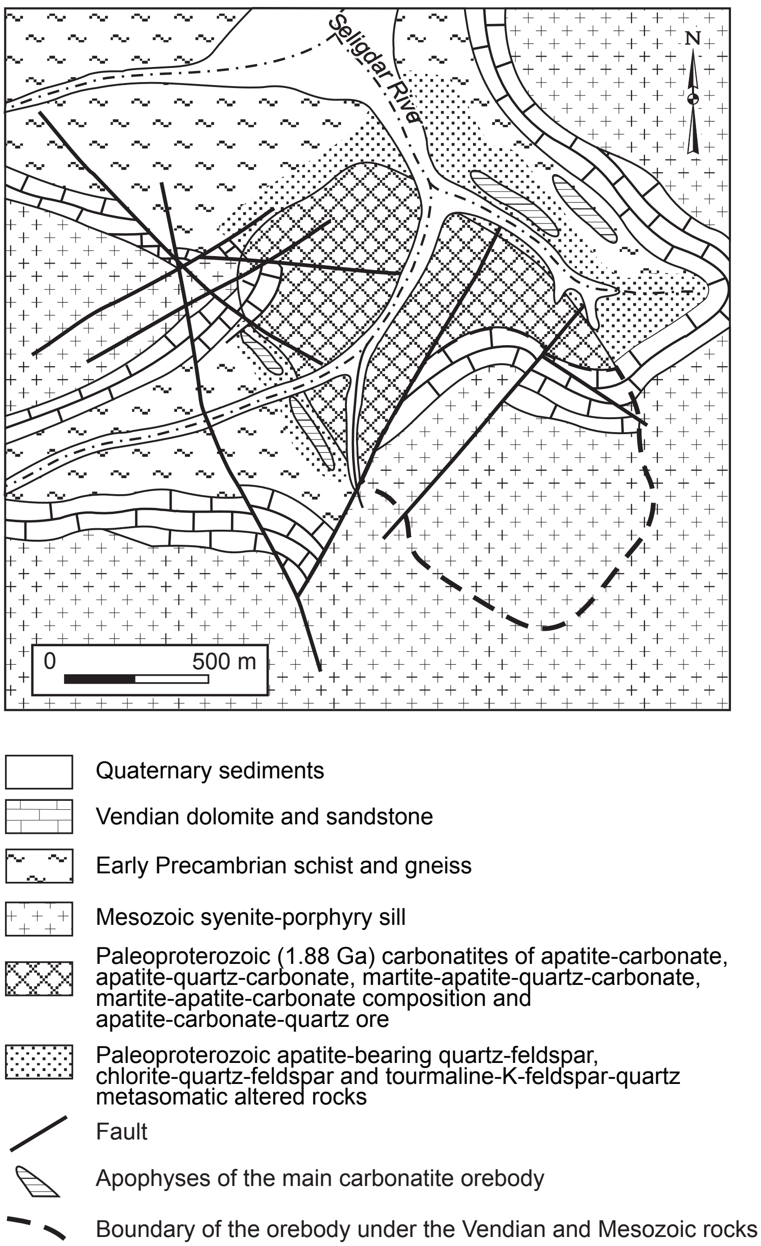


Figure 15. Seligdar apatite carbonatite deposit, Nimnyr metallogenic belt. Schematic geologic map. Adapted from Vasilenko and others (1982).

Origin and Tectonic Controls for Nimnyr Metallogenic Belt

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

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

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

Zhalanzhangzhi Iron (BIF, Algoma Fe) Deposit

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

Qinglonghe Clastic-Sediment-hosted Au-Sb Deposit

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

Origin and Tectonic Controls for Qinglong Metallogenic Belt

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

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

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

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

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

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

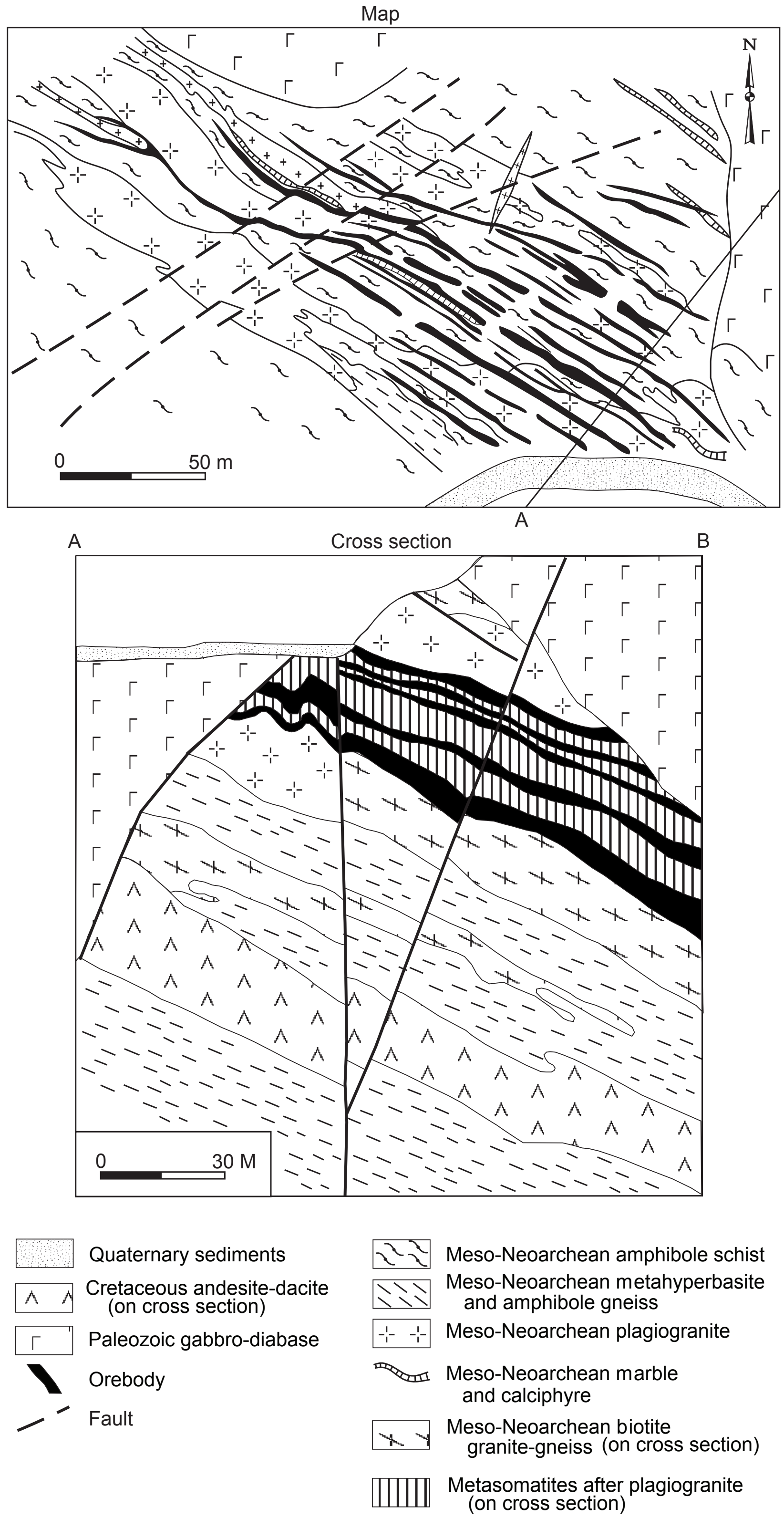


Figure 16. Kolchedannyi Utyos Au in shear-zone and quartz-vein deposit, Tyrkanda-Stanovoy metallogenic belt. Schematic geologic map and cross section. Adapted from Moisenko and Eirish (1996) and Parfenov and others (2001).

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

Origin and Tectonic Controls for Tyrkanda-Stanovoy Metallogenic Belt

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

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

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

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

Udokanskoye Sediment-Hosted Cu Deposit

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

Usuu Sediment-Hosted Cu Occurrence

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

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

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

Katuginskoye Ta-Nb-REE Alkaline Metasomatite Deposit

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

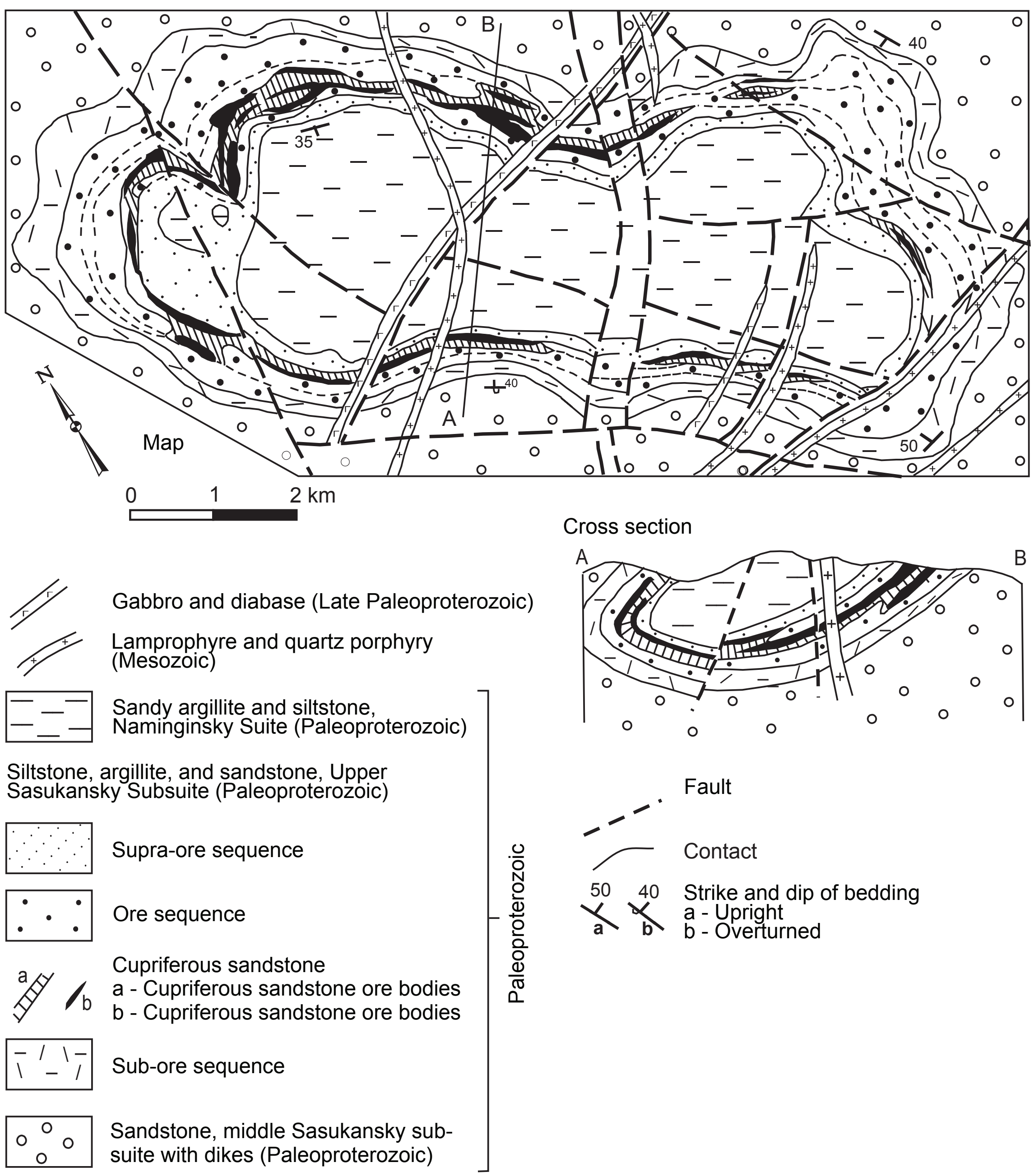


Figure 17. Udokanskoye sediment-hosted Cu deposit, Uguy-Udokanskiy metallogenic belt. Schematic geological map and cross section. Adapted from Chechetkin and others (1995).

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

Origin and Tectonic Controls for Uguy-Udokanskiy Metallogenic Belt

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

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

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

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

This Mesoproterozoic metallogenic belt (fig 8, appendix C) is related to sedimentary layers in the Baydrag cratonal terrane in the Govi-Altai region. The main sedimentary bauxite deposit is at Alag uul. The Alaguul diaspore deposit is hosted in Riphean sedimentary rocks in the Darvi fragment of the Baydrag terrane.

The main references on the geology and metallogenesis of the belt are Pinus and others (1984), Zaitsev and others (1984), and Tomurtogoo (1999).

Alag Uul Sedimentary Bauxite Deposit

This deposit (Pinus and others, 1984) is hosted in intercalated chloritite, amphibolite, graphite-bearing metaclastic rock and is closely spatially related to sedimentary Fe deposits (Zaitsev and others, 1984). The Riphean diaspore bauxite occurs in a zone up to 10 km long and 5 km wide. The belt is interpreted as having formed during bauxite sedimentation in a Riphean sedimentary basin that overlapped the Baydrag cratonal terrane and subsequent regional metamorphism of sedimentary bauxite. The average grades are 49 percent Al_2O_3, 36 percent of Fe_2O_3, 2 percent SiO_2, 4 percent TiO_2. Probable reserves are 100,000 tonnes bauxite.

Origin and Tectonic Controls for Darvi Metallogenic Belt

The belt is interpreted as having formed during bauxite sedimentation in Lower to Middle Riphean sedimentary basin along a passive continental margin.

Langshan-Bayan Obo Metallogenic Belt of Sedimentary Exhalative Pb-Zn (SEDEX) and Polygenetic REE-Fe-Nb Deposits (Belt LB) (Northwestern and North-Central China)

This metallogenic belt (fig. 8, appendix C) occurs in the central part of Inner Mongolia, along the Yinshan Mountains. The belt is 600 km long and 50 km wide, strikes northeast in the western part and changes to east-west strike in the eastern part. The belt is hosted in the Early Mesoproterozoic Zhangbei-Bayan Obo-Langshan rift-related metasedimentary and metavolcanic rocks deposit onthe Sino-Korean craton. The sedimentary exhalative Pb-Zn (SEDEX) and Pb-Zn-Cu deposits in the belt are large to superlarge, and the Bayan Obo Fe-Nb-REE deposit is world class. The stratigraphic horizons hosting SEDEX deposits are in the Mesoproterozoic Zhartaishan and Agulugou Formations though the horizon varies for different SEDEX deposits (Xu Guizhong and others, 1998). The Bayan Obo Fe-Nb-REE deposit is hosted in the 8th of 9 members in the Mesoproterozoic Bayan Obo Group. The significant deposits in are at Bayan Obo and Hugeqi.

The main references on the geology and metallogenesis of the belt are Chao and others (1992), Shi and others (1994), Tu (1998), and Xu and others (1998).

Bayan Obo Polygenic REE-Fe-Nb Deposit

This deposit (Lin and others, 1994; Xiufu and others 1997; Tu, 1998; Qiao and others, 1997) (fig. 18) occurs in am east-west trending Mesoproterozoic rift zone along the northern margin of Sino-Korean craton. The mining district containing the deposit contains several ore bodies that occur in a zone that is about 18 km long along an east-west trend and 5 km wide. Host strata are quartzite, slate, limestone, and dolomite that is main host rock. The bodies are stratiform and lenticular, with masses, bands, layers, and veins, and disseminations. Based on mineralogy, nine types of ores are identified that include sixty

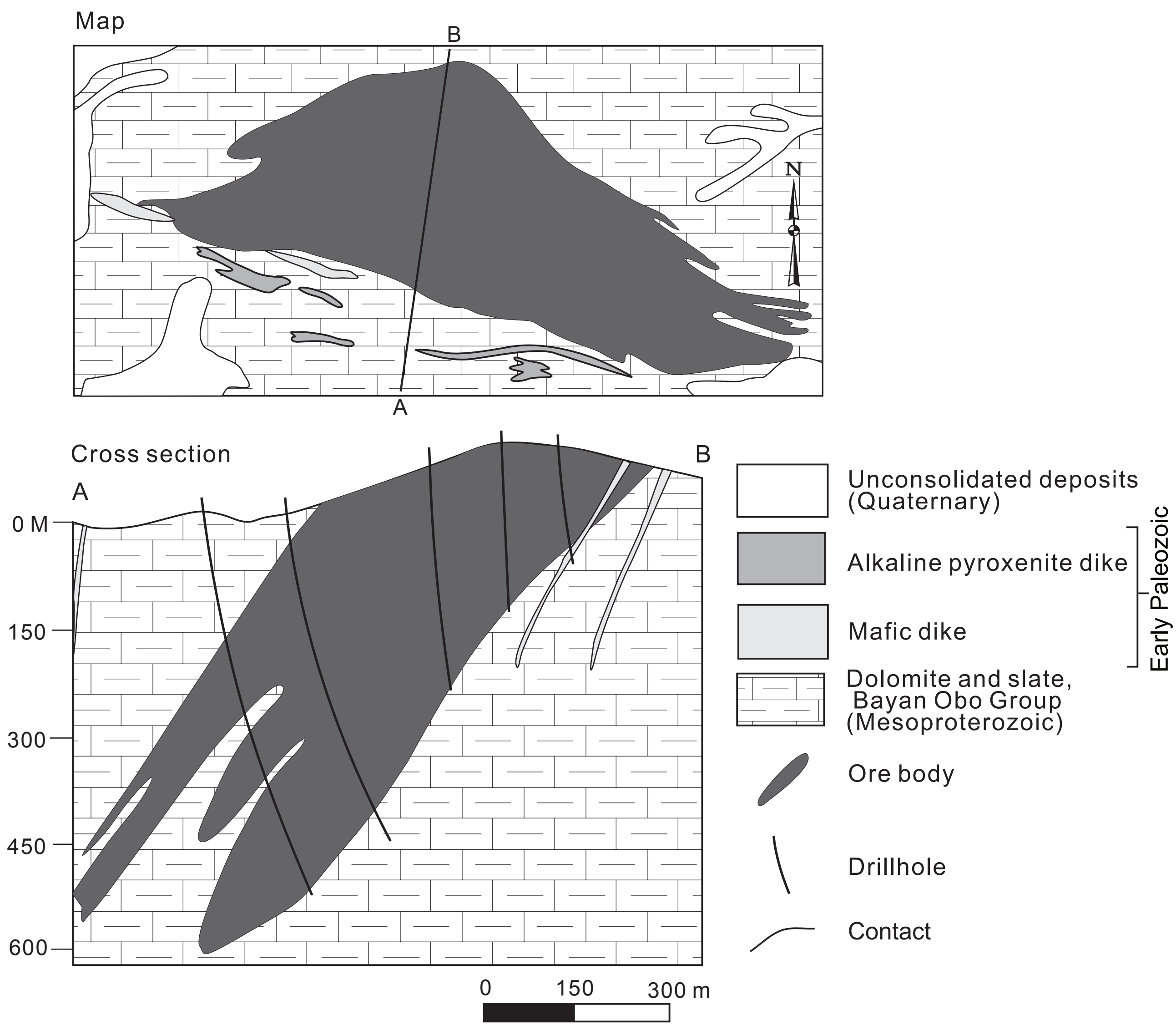


Figure 18. Bayan Obo polygenic REE-Fe-Nb deposit (Bayan-Obo type), Langshan-Bayan Obo metallogenic belt. Adapted from Li (1993).

Nb, REE, Ti, Zr, Nb, and Fe minerals and 19 new minerals such as Huanghoite and others. Besides clear features of hot water sedimentation, the deposit also exhibits Mg, Fe, Na and F metasomatism. Sm-Nd monazite isochron age for bastnaesite and riebeckite is 1200 to 1300 Ma, whereas Th-Pb and Sm-Nd age of Ba-REE-F carbonates and aeschynite is 474 to 402 Ma. In recent years Qiao and others (1997) suggest that some host strata are early Paleozoic. The deposit is superlarge and has reserves of 40.1 million tonnes and an average grade of 3 to 5.4 percent REE; Reserves of more than 1 million tonnes Nb_2O_5 have an average grade of 0.1 to 0.14 percent Nb_2O_5.

Huogeqi Sedimentary Exhalative Pb-Zn (SEDEX) Deposit

This stratiform deposit (Ge and others, 1994) occurs in the Langshan Mountains and consists of stratiform bodies hosted in phyllite, schist, and quartzite of the Proterzoic Langshan group that has a Rb-Sr isotopic age of 1100 Ma. Ore minerals are mainly chalcopyrite, pyrite, pyrrhotite, magnetite, galena, and sphalerite, with small amounts of arsenopyrite and hematite. Wall rocks are altered to silica, diopsie-grunerite, biotite, sericite, and chlorite. The deposit is large and has reserves of 0.973 tonnes Pb, 0.782 tonnes Zn, and 0.711 million tonnes Cu. Average grades of Pb, Zn, and Cu are 1.44 percent, 1.46 percent, 1.35 percent, respectively.

Origin and Tectonic Controls for Langshan-Bayan Obo Metallogenic Belt

The Bayan Obo deposit is interpreted as a SEDEX deposit related to a carbonatite magma and associated hydrothermal activity. The belt hosted in a Mesoproterozoic overlap sedimentary assemblage deposit, formed in the Zhangbei-Bayan Obo-Langshan rift along the passive continental margin of the Sino-Korean craton. The Early Mesoproterozoic overlap assemblage hosting the belt in the Yinshan Archean terrane consists of (1) metasedimentary schist, biotite gneiss, quartzite, marble, (2) metaconglomerate, quartzite, stromatolite-bearing crystalline limestone, phyllite, slate, mica schist, actinolite schist, and minor metamorphosed intermediate and siliceous volcanic rock of the Zhartai Group with an age of 1,500 to 1,600 Ma, and (3) phyllite, slate, quartzite, meta-sandstone, and dolomite of the Bayan Obo Group with an age of 1,350 to 1,650 Ma. Some authors interpret the assemblage as the Mesoproterozoic Langshan-Zhartaishan Basin that formed along the northwestern margin of North China Plate (Xu Guizhong and others, 1998). The world class Bayan Obo Fe-Nb-REE deposit is a non-conventional super-large of deposit (Tu Guangzhi, 1998) is unique in the world. The origin is still debated (Chao and others, 1992, Tu 1998). Tu (1998) suggested that Bayan Obo deposit is a SEDEX deposit related to the carbonatite magma and associated hydrothermal activity. Various studies on the Bayan Obo deposit focus on the syngenetic nature of igneous carbonatite and the epigenetic replacement of the sedimentary dolomite. These two types of processes are not strictly exclusive and both may be part of a SEDEX deposit model.

Yanliao Metallogenic Belt of Chemical-Sedimentary Fe-Mn and Sedimentary-Exhalative Pb-Zn (SEDEX) Deposits (Belt YL-2) (Northern and Northeastern China)

This metallogenic belt (fig. 8) is hosted in the Jixian Group in platform sedimentary cover rocks on the Sino-Korea craton. The belt occurs in the eastern Yanshan Mountain in the West Liaoning and Northeast Hebei Provinces, is 200 to 300 km long, more than 50 km wide, and strikes east-west. The belt is the continuation of the Yanliao Mesoproterozoic metallogenic belt. The deposits are mainly hosted in the Neoproterozoic Jixian Group with isotopic ages of 1400 to 1100 Ma. The host rocks for the deposits are variably-colored siltstone and silty shale and intercalated with limestone. The significant deposits are at Wafangzi and Gaobanhe. The main reference on the geology and metallogenesis of the belt is Wang (1985).

Wafangzi Chemical-Sedimentary Fe-Mn Deposit

This deposit (Ye and others, 1994) consists of stratiform and lensoid masses. The thickness of a single layer is only 10 to 30 cm. The deposit comprises three layers that are 1 to 2 m thick on average. These three layers are hosted in pelitic rock the middle part of the Mesoproterozoic Tieling Formation of the Jixian Group in a northeast-striking anticlinorium. The deposit occurs on the southeastern limb of the anticlinorium. The ores are divided into three types (1) sedimentary manganite and rhodochrosite with para-oolitic, banded, massive, and psephitic textures, (2) contact metamorphic ores consisting of bixbite, braunite, manganoferrite, coarse-grained rhodochrosite, Ca-rhodochrosite, Mn-olivine, Mn-garnet, diopside, and sulphides, and (3) oxidized ores consisting of massive, banded, and radiating psilomelane, pyrolusite, calcite, dolomite, and quartz. The sedimentary environment is interpreted as shallow marine or nearshore. To the west of the deposit is a group of smaller sedimentary Mn deposits. The deposit is large and has reserves of 37.69 million tonnes grading 18 to 24 percent Mn.

Gaobanhe Sedimentary Exhalative Pb-Zn (SEDEX) Deposit

This deposit (Tu and others 1989) consists of nine stratiform deposits that occur in an east-west-trending belt that is 6 km long and 3 km wide. The host rocks are Mn shale and dolomite of late Proterozoic Gaoyuzhuang Formation. Ore minerals are mainly sphalerite, galena, and pyrite, and the ore varies from massive to banded. Framboidal, colloform, and pelletoidal pyrite are common. The deposit occurs in the east-west-trending Yanliao Basin on the Sino-Korea craton. The deposit is medium size with an average grade of about 2 percent Zn and a lower concentration of Pb.

Origin and Tectonic Controls for Yanliao 2 Metallogenic Belt

The belt is interpreted as having formed in a shallow marine basin on the Sino-Korea craton and is hosted in the Middle and Neoproterozoic Hebei-Liaoning sedimentary basin. The Mesoproterozoic part of the basin consists of (1) sandy-muddy dolomite, (2) dolomite, (3) shale; (4) quartz sandstone, dolomite, and limestone, dolomitic limestone, (5) sandstone and siltstone, (6) muddy limestone. The Yanliao oceanic basin changed from a shallow sea in the Jixianan period to an epicontinental sea in the Qinbaikou period (Wang, 1985). The Mn deposits of the Wafangzi type are interpreted as having formed in a shallow oceanic basin.

Archean through Mesoproterozoic Metallogenic and Tectonic Model—General Comments

A metallogenic and tectonic model for the North Asian and the Sino-Korean cratons is developed for the Proterozoic (2.5 to 1.6 Ga), and Mesoproterozoic (1.6 to 1.0 Ga) (figs. 19-23). The model is based on the boundaries of the cratons and their relative positions at 850 Ma (Wang and others, 1991; Nokleberg and others, 2000; Kravchinsky and others, 2001) and new modeling work by C.R. Scotese presented herein. The model employs isotopic age data obtained for the Tynda and Chogar terranes of the Stanovoy region (Larin and others, 2002a,b; Karsakov, 1983), the Okhotsk terrane and the Omolon superterrane (Khil'tova and others, 1988), indicating that these terranes were part of the Sino-Korean craton. The part of the model for Sino-Korean craton is also based on the data from the Geodynamic Map of Northeast Asia (Parfenov and others, 2003).

The model is based on the assumption that during the Proterozoic, the North Asian craton was a single unit consisting of various Archean and Paleoproterozoic terranes of the Aldan-Stanovoy and Anabar shields, terranes of the buried basement of the Siberian platform, the Okhotsk terrane, and the Kolyma-Omolon superterrane, as well as various metamorphic Mesoproterozoic terranes. The relative positions of the crystalline basement blocks in the Proterozoic cratons significantly differed from their present positions.

In addition, the model employs data on the composition and age of buried terranes that are overlain by the sedimentary cover of the Siberian platform and the Verhoyansk margin of the North Asian craton (Smelov and Timofeev, 2007). These units are not depicted on the summary geodynamics map (fig. 2), but are depicted on figures 19 to 23.

Terranes Overlain by the Siberian Platform

Information about the nature of the Tunguska, Tyung, Tyryn, and Berekta terranes are buried beneath the cover rocks of the Siberian Platform is derived from petrological and isotopic-geochemical studies of basement xenoliths in various types of volcanic rocks and from intrusive rocks sampled in deep boreholes. The boundaries of the terranes are delineated from aeromagnetic studies because the tectonic mélange zones and the terrane-bounding faults generally form positive linear anomalies. The terranes themselves are characterized either by arcuate anomalies or by homogenous magnetic fields.

Tunguska Tonalite-Trondhjemite Gneiss Terrane (TGS)

This terrane occurs in the western part of the North Asian craton where aeromagnetic data provide a more detailed delineation of the terrane boundaries. However, petrographic information from drillholes is scarce and only available for the Baikit anticline and the Malo-Botuobiya kimberlite field. The rocks in these latter two areas are biotite and amphibole plagiogneiss that consists of tonalitic to trondhjemite, granite gneiss, and granodiorite gneiss with Nd model ages ranging from ~3.3 to ~2.6 Ga. The terrane is interpreted as an extension of the Near-Sayan Uplift (Sharizhalgay and Onot terranes) in the western part of the Anabar shield (Magan Terrane) and likely represents marginal parts of the Tunguska Archean craton which was reworked during a Paleoproterozoic continental collision as a part of the orogenic belts.

Tyung Terrane (TNG)

This terrane occurs along the southeastern margin of the North Asian craton and generally is interpreted as a fragment of an Archean craton (Rosen and others, 1994). However, metamorphic rock xenoliths in the kimberlite pipes in this area include two granulite facies rock units. The first unit is garnet-amphibole-clinopyroxene and amphibole schist with TNd (DM) ages ranging from ~3.3 to ~2.9 Ga, and the second unit is amphibole-two-pyroxene schist with a Nd model age of ~2.1 Ga. The latter unit is fairly close to the TNd (DM) ages of ~2.5 Ga obtained from eclogite xenoliths in the same kimberlitic pipe. Petrographic and geochemical studies reveal no differences in the metamorphic grade and degree of secondary alteration between the two rock units and suggest that the continental crust of the Tyung terrane formed in two stages, one in the Archean (~3.3 to ~2.9 Ga), and the other in the Paleoproterozoic (~2.5 to ~2.1 Ga). The closing of Sm-Nd isotopic systems in minerals of garnet-clinopyroxene amphibolite of both age groups occurred at ~1.9 to ~1.7 Ga, suggesting a long cooling period of the lower crust following granulite-grade metamorphism.

Tyryn Terrane (TRN)

This terrane is defined by geophysical data and may represent the northern part of the Batomga terrane (EBT) that is buried beneath the sedimentary cover of the Siberian Platform and the Verkhoyansk margin of the North Asian craton.

Berekta Terrane (BRK)

This terrane occurs in the northeastern part of the North Asian craton is defined from geophysical data and from basement rocks that are exposed in the arch of the Olenek Uplift, within the Sololi inlier. The terrane is overlain by flat-lying Riphean deposits of the Siberian Platform. The basement rocks of the terrane are the Aekit Series (see discussion of the Olenek Uplift above) and are coeval with the Udokan Series of the West Aldan composite terrane. Both series are interpreted as Archean gneiss complexes that are supported by the occurrence of xenoliths of amphibole leucocratic plagiogneisses with Nd model ages of ~3.3 Ga in the Obnazhonnaya kimberlitic pipe. However, samples from these units contain large $^{147}Sm/^{144}Nd$ ratios (0.1883) that are close to chondritic and depleted mantle values, and the determination of model ages is impossible.

Basement of the Verkhoyanskoy Margin of North Asian craton

The eastern margin of the North Asian craton (Yana-Indigirka superterrane) is overlain by sedimentary rock. The composition and age of the basement is determined from studies of crystalline basement rock sampled in deep drill-holes and xenoliths in various granitoid plutons that intrude Phanerozoic sedimentary rocks of the Verkhoyansk terranet. The Ivanovskaya borehole penetrated crystalline rocks, including biotite and biotite-muscovite micro-paragneiss, metasandstone, quartzite schist, and garnet-amphibole schist, at depths of 3,386 to 3,518 m below the base of overlying Permian sedimentary sequence. The crystalline rocks are metamorphosed to greenschist and lower amphibolite facies, and TNd (DM) ages of the microparagneiss fall into two groups: ~2.5 to ~2.3 Ga and ~1.5 to ~1.0 Ga. The Nd data indicate that both Paleo- and Mesoproterozoic rocks were the source of detritus for these rocks. The xenoliths of biotite-two-feldspar banded gneiss and biotite schist in granitoid rocks were metamorphosed to amphibolite facies and may reflect contact metamorphism by the surrounding granitoid pluton. They are characterized by $^{147}Sm/^{144}Nd$ ratios of 0.1080 to 0.1206 and TNd (DM) ages of about1.5 to 1.3 Ga, suggesting a Mesoproterozoic age for the source rocks from which the metasedimentary cover rocks were derived.

The occurrence of Mesoproterozoic metamorphic complexes in the basement of the Verkhoyansk terrane is also supported by U-Pb (SHRIMP) ages of ~1.5 to ~1.05 Ga from detrital zircons in the middle and upper Riphean sedimentary rocks. The Lower Carboniferous conglomerate in the northern basement of the Verkhoyanskoy terrane contains granite clasts and two-mica schist boulders with K-Ar ages of ~1.4 to ~0.9 Ga. The conglomerate is composed of granite clasts and is metamorphosed sandstone and quartzites and is interpreted to have been formed in a littoral zone that was adjacent to a basement uplift at the front of the foldbelt.

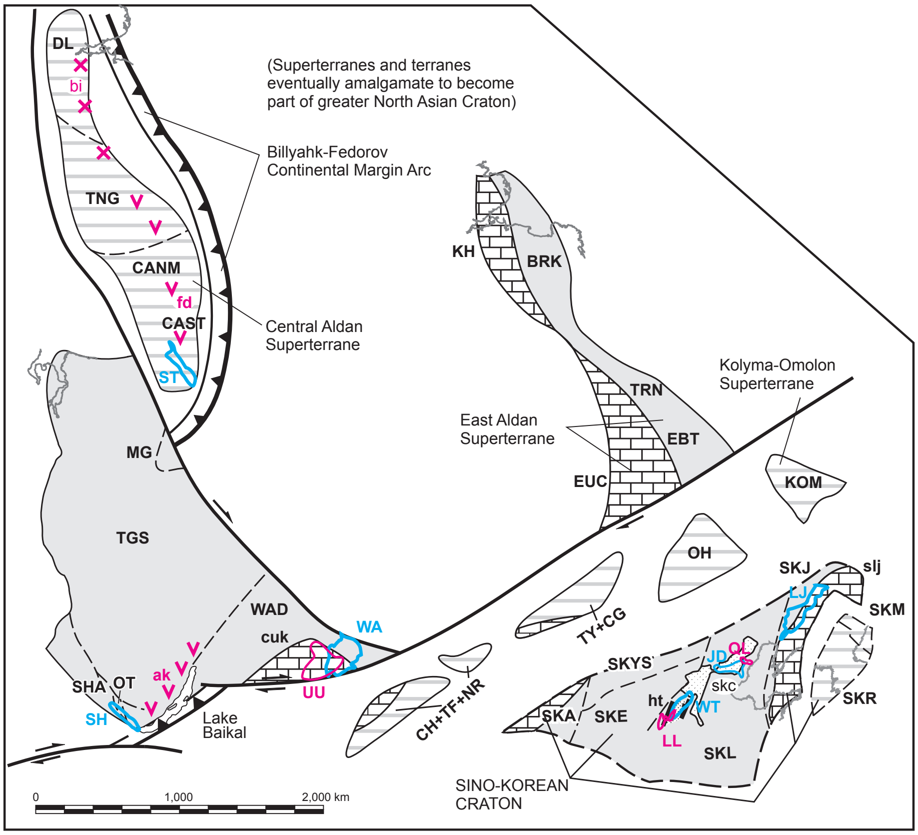
Archean and Proterozoic Metallogenic and Tectonic Model

Tectonics

At the end of Archean (≥2,500 Ma) (fig. 19), the North Asian craton was not a single structure. Various terranes, now amalgamated to form the craton, formed at several different times. The oldest terranes are the Okhotsk (OH) cratonal and the Chogar (CG) granulite-orthognesiss terranes that started to form in the Paleoarchean (3.7 to 3.5 Ga). The protoliths of the oldest rocks of the Central Aldan granulite-gneiss superterrane and the Daldyn Granulite-orthogneiss terranes formed from about 3.35 to 3.0 Ga, while protoliths of the protoliths of the West Aldan (WAD) granite-greenstone and Onod (OT) terranes formed at about 3.2 to 2.7 Ga. Protoliths of the Tynda (TY) tonalite-trondhjemite-gneiss, Chuya (CH) (granite gneiss), Tonod (TF), and Nercha (NR) terranes formed from about 2.9 to 2.5 Ga. Most of these protoliths formed in an island arc or back-arc basin environment. These terranes and superterranes were likely amalmated into the cratons or microcontinents in the late Archean. The West Aldan terrane accretion occurred at about 2.6 Ga and was accompanied by granite formation and granulite metamorphism. In all other terranes, these processes are poorly defined or highly modified by later events. Also at this time-stage, the West Aldan and probably Batomga granite-greenstone terranes were overlapped by platform cover, and parts of the Daldyn and Central Aldan granulite-gneiss terranes were forming.

In between the units that would form the North Asian craton (described above, fig. 19) and the Sino-Korean craton (described below, fig. 2) were the Chogar granulite-orthogneiss, Chuya, Kolyma-Omolon, Okhotsk, Nechera, Omolon, Tonod, and Tynda terranes (Larin and others, 2002a,b) (fig. 19). Interestingly, the ages of protoliths of the Nercha, Tonod, Chuya, Tynda, Chogar and Okhotsk terranes, that comprise part of the North Asian craton are similar to the terranes that comprise the Sino-Korean craton. At this time, no major overlap assemblages were forming or have since been eroded.

In contrast to the North Asian craton and margin terranes, the eastern Sino-Korean craton is interpreted as a single unit that contained the Yinshan, Erduosi, Jilin-Liaoning-East Shandong and, West Liaoning-Hebei-Shanxi terranes.The major Archean tectonic events in the Sino-Korean craton were (1) crustal growth of the Sino-Korean Block during the Paleoarchean through Mesoarchean (3,600 to 2,800 Ma), (2) the beginning of the Archean plate tectonic mechanism in the Early Neoarchean (2,800 to 2,700 Ma) that consisted of amalgamation of the West Liaoning-Hebei-Shanxi, the Jilin-Liaoning-Eastern Shandong, Rangnim, and Yeongnam terranes that constituted island arcs and back-arc basins, (3) the formation of tonalite-trondhjemite-gneiss belts, (4) the amalgamation of the Alashan (SKA), West



GEOLOGIC UNITS

ak - Akitkan volcanic-plutonic belt
cuk - Chara-Uchur rift system (Paleoproterozoic) - Udokan basin
bi - Billyahk plutonic belt (Paleoproterozoic)
fk - Fedorov volcanic-plutonic belt
skc - Hebei-Liaoning sedimentary basin
ht - Hutuo rift basin (Paleoproterozoic)
slj - East Shandong-East Liaoning-East Jilin rift basin (Paleoproterozoic)

North Asian Craton

BRK - Berekta Terrane (Granite-greenstone) (Late Archean)
CANM - Nimnyr terrane (Granulite-orthogneiss) (Paleoproterozoic)
CAST - Sutam terrane (Granulite-paragneiss) (Late Archean)
CG - Chogar Granulite-orthogneiss terrane (Archean)
CH - Chuja terrane (Paragneiss) (Late Archean through Neoproterozoic)
DL - Daldyn terrane (Granulite-orthogneiss) (Middle Archean)
EBT - Batomga composite terrane (Granite-greenstone) (Late Archean)
EUC - Uchur terrane (Granulite-paragneiss) (Paleoproterozoic)
KH - Khapchan terrane (Granulite-paragneiss) (Paleoproterozoic)
KOM - Kolyma-Omolon superterrane (Archean to Jurassic)
MG - Magan terrane (Tonalite-trondhjemite-gneiss) (Paleoproterozoic)
NR - Nechera terrane (Granulite-paragneiss) (Archean? and Proterozoic)
OH - Okhotsk terrane (Cratonal) (Archean through Jurassic)
SHA - Sharizhalgay terrane (Granulite-orthogneisse) (Archean through Paleoproterozoic)
TF - Tonod terrane (Greenschist) (Paleoproterozoic)
TGS - Tunguska terrane (Tonalite-trondhjemite) (Archean)
TNG - Tyung terrane (Granulite-orthogneiss) (Archean to Paleoproterozoic)
TRN - Tyryn Terrane (Granite-greenstone) (Late Archean)
TY - Tynda terrane (Tonalite-trondhjemite-gneiss) (Archean and Paleoproterozoic)
WAD - West Aldan terrane (Granite-greenstone) (Archean)

Sino-Korean Craton

SKA - Alashan terrane (Granulite-paragneiss) (Paleoproterozoic)
SKE - Erduosi terrane (Granulite-paragneiss) (Archean)
SKJ - Jilin-Liaoning-East Shandong terrane (Tonalite-trondhjemite-gneiss) (Archean)
SKL - West Liaoning-Hebei-Shanxi terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKM - Machollyong terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKR - Rangnim terrane (Granulite-paragneiss) (Archean)
SKYS - Yinshan terrane (Granite-greenstone belt) (Archean)

METALLOGENIC BELTS

Paleoproterozoic
LL - Luliangshan
QL - Qinglong
UU - Uguy-Udokanskiy

Archean
JD - Jidong
LJ - Liaoji
SH - Sharizhalgaiskiy
ST - Sutam
WA - West Aldan
WT - Wutai

Figure 19. Early Paleoproterozoic (2,500 to 2,000 Ma) time stage of metallogenic and tectonic model (with additional Archean metallogenic belts). Figure adapted from Parfenov and others (chapter 9, this volume).

EXPLANATION

Craton

Passive continental margin on subsided craton

Microcontinent

Continental slope

Intracontinental sedimentary basin

Collage of accreted terranes and overlap assemblages

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

Sea underlain by continental crust

SUBDUCTION-RELATED ISLAND-ARC AND CONTINENTAL-MARGIN ARCS

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

+ + + + Intra-plate granitoids

COLLISIONAL GRANITOIDS

⊕ ⊕ ⊕ ⊕

CONTACTS, FAULTS, AND SYMBOLS

Subduction zone and its accretionary wedge

Thrust

Strike-slip fault

Normal fault

Fold- and thrust-belt formed on the subsided craton margin

Stratigraphic contact

OH Metallogenic belt with abbreviation

Figure 19.—Continued.

Liaoning-Hebei-Shanxi (SKL), Jilin-Liaoning-Eastern Shandong (SKJ), and Rangnim (SKR) terranes to form the crystalline basement of SKC during the Late Neoarchean (2,600 to 2,500 Ma), and (5) the amalgamation of the main Archean terranes to form the crystalline basement of Yinshan (SKYS), Erdos (SKE), Western Liaoning-Hebei-Shanxi (SKL) and Jilin-Liaoning-Eastern Shandong (SKJ) terranes during the latest Neoarchean (2,500 to 2,450 Ma).

Metallogenesis

The major Archean metallogenic belts formed in a variety of tectonic environments (fig. 19, appendix C).

In the Jidong belt (JD, figs. 3, 19) the BIF deposits are interpreted as having formed in a volcanic and sedimentation basin along an unstable proto-continental margin, or in a fragment of Archean part of the Sino-Korean craton. The Au deposits are interpreted as having formed during retrograde metamorphism to greenschist facies.

In the Liaoji belt (LJ, figs. 3, 19), the host greenstone belt in the Northern Liaoning (Hunbei) area is interpreted as having formed in an active continental margin, whereas the greenstone belts in the Anshan-Benxi and Jiapigou areas are interpreted as having formed in oceanic rifts along a continental margin. The Au deposits are interpreted as having formed during retrograde metamorphism to greenschist facies. Because of the ancient ages of geologic units and the lack of detailed data, several mineral-deposit types are combined into a composite belt.

In the Sharizhalgaiskiy belt (SH, figs. 3, 19), some deposits (Kitoy group and Baikalskoye deposit) are hosted in Archean units. Other deposits (for example, the Onot group, Sosnovy Baits deposit) are hosted in Proterozoic units. Layering in ferruginous quartzite and in two-pyroxene schists is interpreted as having been derived from ferruginous volcanic and sedimentary rock sequences.

In the Sutam belt (ST, figs. 3, 19), two rock groups with BIF occur (1) magnetite-hypersthene and magnetite-pyroxene gneiss is interbedded with amphibole-pyroxene and magnetite-pyroxene-plagioclase schist, and BIF consisting of magnetite and hypersthene-magnetite quartzite occur in outer part of an antiform, and (2) feldspar quartzite interlayered with garnet- and sillimanite-bearing schist with diopside calciphyre. Also occurring are magnetite-hypersthene and garnet-magnetite hypersthene layers.

The West Aldan metallogenic belt (WA, figs. 3, 19) is interpreted as having formed in a back-arc basin and (or) in an island arc. Au occurrences are mainly in the shear zones cutting metabasalt, amphibilite, and ultramafic rock. Shear zones formed during amalgamation of terranes, or during later tectonic events. BIF (magnetite quartzite) deposits in the belt forms in stratiform layers and lenses in metabasalt and amphibolite and local siliceous metavolcanic rock and schist.

In the Wutai belt (WT, figs. 3, 19), the host Wutai greenstone belt and BIF deposits are interpreted as having formed in a nonmature to mature island arc.

Paleoproterozoic Metallogenic and Tectonic Model

Early Paleoproterozoic Tectonics

In the Early Paleoproterozoic (2,500to 2,000 Ma) (fig. 19), large granite-greenstone terranes (fragments of which were subsequently amalgamated to become craton) of the North Asian craton began converging along strike-slip faults. The major tectonic events were as follows. (1) Passive continental margins and microcontinents, such as the Daldyn and Tyung (TNG) terranes, and the Central Aldan superterrane, formed a single amalgamated block, which formed along one edge of the Billyahk-Fedorov continental nargin arc. (2) The Tunguska, Sharizhalgay, and West Aldan terranes were amalgamated and were juxtaposed against the previous block. (3) Overlying the West Aldan terrane was the Chara-Uachur rift system that formed the Udokan Basin. (4) The Khapchan terrane and the East Aldan superterrane were amalgamated and migrated towards the above terranes.

Between the above components of the North Asian craton and the below components of the Sino-Korean terrane (fig. 19), an extensive suite of terranes was starting to amgamate and subsequently to form marginal parts of the North Asian craton. These terranes included the Chuja, Okhotsk, Tonod, and Tynda terranes, and the Central Aldan and Kolyma-Omolon superterranes. The convergence of the Sino-Korean and North Asian cratons along the strike-slip fault was accompanied by initiation of the Hutuo rift basin (ht). Within the Tynda terrane, a rifting process was associated with formation of greenstone belt structures (Korsakov, 2000). In addition, various parts of the core and margins of the Sino-Korean craton were forming, including the Alashan, Erduosi, Jilin-Liaoning-East Shandong, West Liaaoning-Hebei-Shanxi, Machollyong, and Rangnim terranes.

Metallogenesis

The Uguy-Udokan sediment-hosted Cu metallogenic belt (UU) (Russia, Aldan-Stanovoy shield) is hosted by the Udokan and Uguy basins (cuk) of the Chara-Uchur rift system. The age of the belt is interpreted as Early Proterozoic. The belt includes sediment-hosted Cu deposits such as the Usuu deposit. The belt occures in the western part of the Aldan-Stanovoy shield and overlaps the West Aldan terrane and Kalar tectonic melange zone. The large Udokan Cu sandstone deposit is to the southwest of the belt, within the rift-related Udokan trough filled in with thick (up to 10 000 m) clastics and minor carbonate rocks dated at 2,200 to 1,800 Ma. The rocks corresponding to the upper part of the trough section also fill in relatively small graben-like Uguy, Oldongso, and Lower Khani basins, unconformably overlying various crystalline rocks of the West Aldan granite-greenstone composite terrane (Parfenov and others, 1999; Bogdanov and Apol'sky, 1988; Davydov and Chiryaev, 1986)

In the Luliangshan belt (LL, figs. 8, 19), the banded iron formation (BIF, Superior Fe) deposits are interpreted as having formed in a Paleoproterozoic Hutuo Basin that was superposed on the Archean Northern China craton. The Au in shear-zone and quartz-vein deposits are interpreted as having formed during later collision and regional metamorphism.

In the Qinglong belt (QL) banded iron formation (BIF) (Zhalanzhangzhi) and clastic-sediment-hosted Sb-Au (Qinglonghe) BIF are hosted in marine volcaniclastic and clastic sedimentary rocks with minor conglomerate that are metamorphosed to amphibolite and greenschist facies. The belt is interpreted as having formed in a passive continental margin or aulacogen that was subsequently regionally metamorphosed and thrusted (Zhang Yixia and others, 1986).

Middle Paleoproterozoic Tectonics

In the Middle Paleoproterozoic (2,000 to 1,900 Ma), major accretions occurred to form the North Asian craton (compare figs. 19 and 20). The left part of the craton consisted of the amalgamated TGS, SHA, and WAD terranes. The central part of the craton consisted of the DL, TNG, and Central Aldan superterrane (CAL), and the right part of the craton consisted of the KH, EUC, and EBT terranes. Along the bottom of the craton were the accreted CH, TF, NR, TY, OH, and KOM terranes. These accretions resulted in formation of the Daldyn-Aldan and Khapchan-Uchur, Sharizhalgay-Nechera and Stanovoy orogenic belts and formation of the major Kalar, Amga, and Turkanda tectonic mélange zones (figs. 2, 20).

Also in the Middle Paleoproterozoic (2,000 to 1,900 Ma), major overlap and stitch assemblages formed on the North Asia craton (not shown on figures 2 and 20) (1) Udokan and Uguy basins with ages 2,200 to 1,900 Ma, (2) the Akitkan volcano-plutonic belt, (3) the Anabar, Dzugdzur and Kalar anorthositic belts, (4) Billyahk and Ulkan plutonic belts, and (5) Kodar and Tyrkanda granitic belts.

Also at this time, amalgamation of the Sino-Korean craton to the North Asian craton (lower part of fig. 20), produced the Sharizhalgay-Nechera and Stanovoy orogenic belts. This event was accompanied by granulite facies metamorphism in some of the terranes (Nutman and others, 1992).

The major terranes forming in the Sino-Korean craton were the Machollyong, Rangnim and Yeongnam granulite-paragneiss terranes. The major overlap and stitch assemblages forming on the Sino-Korean craton were (not shown on figures 2 and 20) was the Hutuo rift. The major terrane forming in the South China craton was the Jiaonan Ultra-High Pressure terrane.

Late Paleoproterozoic Tectonics

In the first part of the Late Paleoproterozoic, (1,900 to 1,800 Ma) (fig. 21), the North Asian craton was fully formed as described in the previous section. Also at this time, displacement of the Sino-Korean craton and the southern terranes of the North Asian craton occurred relative to its northern terranes along a left-lateral strike-slip fault. The collision was probably related to the on-going formation of the supercontinent Pangea, and it resulted in the intrusion of collisional granites at about 1.85 Ga.

In the second part of the Late Paleoproterozoic (1,800 to 1,600 Ma) (fig. 21), major rift basins were initiated parallel to the zone of collision between the North Asian and Sino-Korean cratons. In addition, new major rift basins formed at this time, including the ak, cuk, and cul basins (fig. 21). Some of the rifting was accompanied by subalkaline and alkaline magmatism. In the Central Aldan and West Aldan terranes, ultrabasite and carbonatite bodies were emplaced. The major overlap and stitch assemblages forming on the Sino-Korean craton were (units ht, slj) (1) the Hutuo rift, (2) the Shandong-East Liaoning-East Jilin rift, (3) the Zhangbei-Bayan Obo-Langshan rift, and (4) the Hebei-Liaoning sedimentary basin.

Paleoproterozoic Metallogenesis

The major Paleoproterozoic metallogenic belts formed in a variety of tectonic environments (formed in a variety of tectonic environments (figs. 8, 20-21, appendix C).

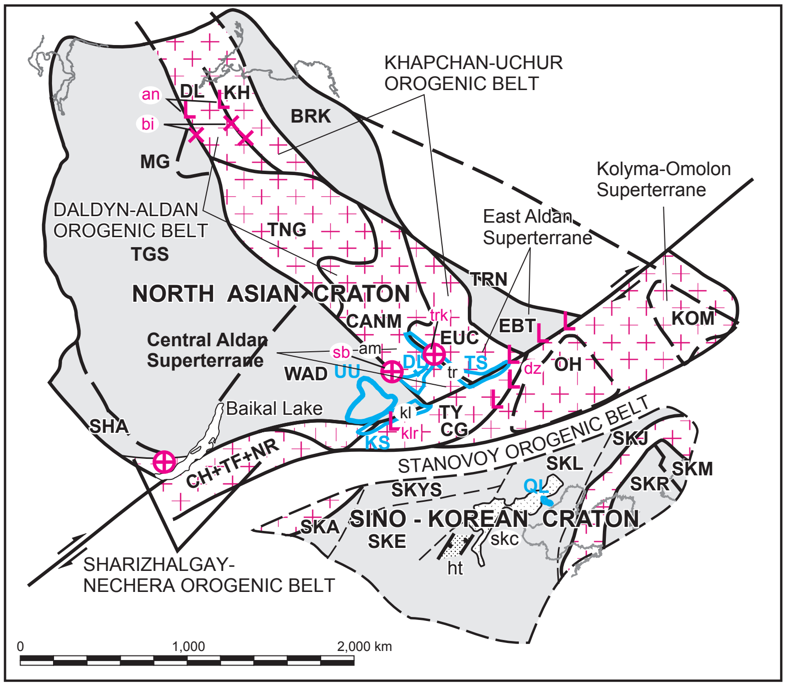
In the Baydrag belt (BD, fig. 8) the BIF deposits are interpreted as having formed in volcanic and clastic sedimentary rock basin. During the Paleoproterozoic, the host Tuva-Mongolia superterrane was far removed from the North Asian craton and is not depicted in figures 21 or 22.

In the Dyos-Legier belt (DL, figs. 8, 20) the Fe skarn deposits are interpretd as having formed from 2.0 to 1.9 Ga, during intrusion of Paleoproterozoic, late-collisional granitoids into the Aldan-Stanovoy shield that is a core part of the North Asian craton.

The Jiliaojiao belt (JLJ, figs. 8, 21) is a composite metallogenic belt that includes several mineral-deposit types, including sedimentary-metamorphic borate, sedimentary-metamorphic magnesite, talc (magnesite) replacement, banded iron formation (BIF, Superior Fe), Korean Pb-Zn massive sulfide, metamorphic graphite, and Au in shear-zone and quartz-vein deposits. The environment of formation and deposit controls are debated. The sediment-hosted deposits are herein interpreted as having formed in the East Shandong-East Liaoning-East Jilin rift. The Au in shear-zone and quartz-vein deposits are herein interpreted as having formed during metamorphism and intense deformation at about 1.9 Ga.

The Kalar-Stanovoy (KS) belt (KS, figs. 8, 20) formed from 2.0 to 1.9 Ga and contains Au in shear-zone and quartz-vein deposits that are interpreted as having formed during the collision between Tynda and West Aldan terranes in Aldan-Stanovoy region (North Asia craton) and during subsequent collapse of the orogenic belt. The cause of collision was amalgamation of terranes during the formation of the North Asia craton.

The apatite carbonatite deposits in the Nimnyr belt (NM, figs. 8, 21) formed from 1.9 to 1.6 Ga and are interpreted as



GEOLOGIC UNITS
ak - Akitkan volcanic-plutonic belt
an - Anabar anorthositic belt (Archean)
bi - Billyahk plutonic belt (Paleoproterozoic)
cuk - Chara-Uchur rift system (Paleoproterozoic) - Udokan basin
dz - Dzugdzur anorthositic belt (Paleoproterozoic)
klr - Kalar anorthosite belt (Paleoproterozoic)
ht - Hutuo rift basin (Paleoproterozoic)
sb - Subgan granite belt (Paleoproterozoic)
skc - Hebei-Liaoning sedimentary basin
tkn - Tyrkanda granite belt (Paleoproterozoic or older)

North Asian Craton

BRK - Berekta Terrane (Granite-greenstone) (Late Archean)
CANM - Nimnyr terrane (Granulite-orthogneiss) (Paleoproterozoic)
CG - Chogar Granulite-orthogneiss terrane (Archean)
CH - Chuja terrane (Paragneiss) (Late Archean through Neoproterozoic)
DL - Daldyn terrane (Granulite-orthogneiss) (Middle Archean)
EBT - Batomga composite terrane (Granite-greenstone) (Late Archean)
EUC - Uchur terrane (Granulite-paragneiss) (Paleoproterozoic)
KH - Khapchan terrane (Granulite-paragneiss) (Paleoproterozoic)
KOM - Kolyma-Omolon superterrane (Archean to Jurassic)
MG - Magan terrane (Tonalite-trondhjemite-gneiss) (Paleoproterozoic)
NR - Nechera terrane (Granulite-paragneiss) (Archean? and Proterozoic)
OH - Okhotsk terrane (Cratonal) (Archean through Jurassic)
SHA - Sharizhalgay terrane (Granulite-orthogneisse) (Archean through Paleoproterozoic)
TF - Tonod terrane (Greenschist) (Paleoproterozoic)
TGS - Tunguska terrane (Tonalite-trondhjemite) (Archean)
TNG - Tyung terrane (Granulite-orthogneiss) (Archean to Paleoproterozoic)
TRN - Tyryn Terrane (Granite-greenstone) (Late Archean)
TY - Tynda terrane (Tonalite-trondhjemite-gneiss) (Archean and Paleoproterozoic)
WAD - West Aldan terrane (Granite-greenstone) (Archean)

am - Amga tectonic melange zone
kl - Kalar tectonic melange zone
tr - Tyrkanda tectonic melange zone

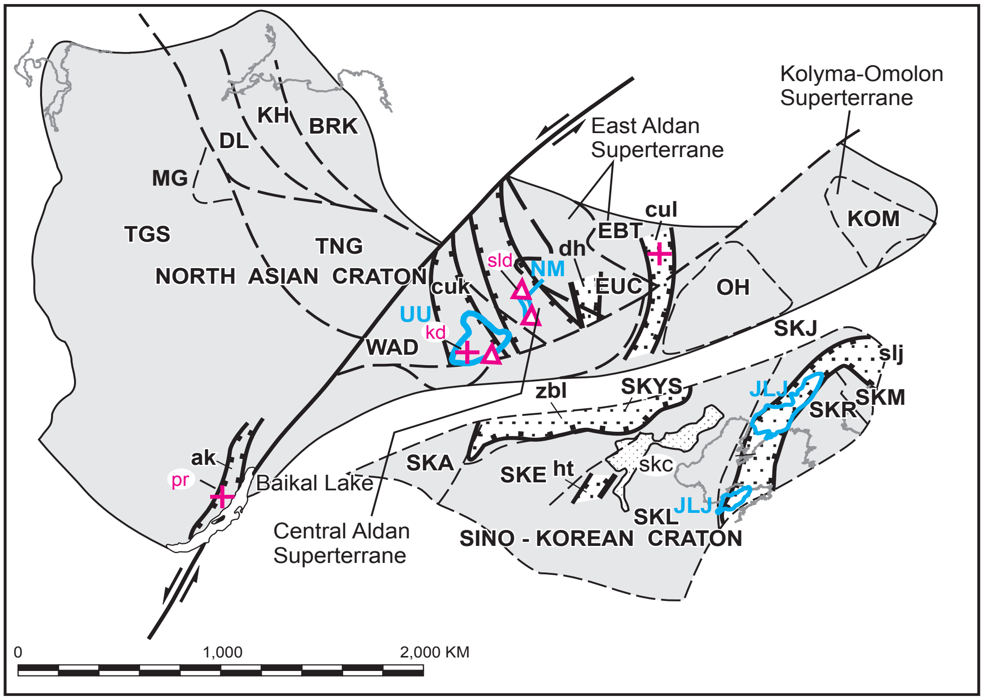
Sino-Korean Craton

SKA - Alashan terrane (Granulite-paragneiss) (Paleoproterozoic)
SKE - Erduosi terrane (Granulite-paragneiss) (Archean)
SKJ - Jilin-Liaoning-East Shandong terrane (Tonalite-trondhjemite-gneiss) (Archean)
SKL - West Liaoning-Hebei-Shanxi terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKM - Machollyong terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKR - Rangnim terrane (Granulite-paragneiss) (Archean)
SKYS - Yinshan terrane (Granite-greenstone belt) (Archean)

METALLOGENIC BELTS

DL - Dyos-Leglier
KS - Kalar-Stanovoy
NM - Nimnyr
QL - Qinglong
TS - Tyrkanda-Stanovoy
UU - Uguy-Udokanskiy

Figure 20. Middle Paleoproterozoic (2,000 to 1,900 Ma) time stage of metallogenic and tectonic Model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).



GEOLOGIC UNITS

ak - Akitkan volcanic-plutonic belt
cuk - Chara-Uchur rift system (Paleoproterozoic)
cul - Ulkan rift basin (Paleoproterozoic)
dh - Davangra-Khugda rift basin (Paleoproterozoic)
kd - Kodar granitic belt (Paleoproterozoic)
ht - Hutuo rift basin (Paleoproterozoic)
pr - Primorsky plutonic complex (Paleoproterozoic)
skc - Hebei-Liaoning sedimentary basin
sld - Seligdar plutonic belt
slj - East Shandong-East Liaoning-East Jilin rift basin (Paleoproterozoic)
zbl - Zhangbei-Bayan Obo-Langshan rift basin (Paleoproterozoic)

North Asian Craton

BRK - Berekta Terrane (Granite-greenstone) (Late Archean)
CANM - Nimnyr terrane (Granulite-orthogneiss) (Paleoproterozoic)
CAST - Sutam terrane (Granulite-paragneiss) (Late Archean)
DL - Daldyn terrane (Granulite-orthogneiss) (Middle Archean)
EBT - Batomga composite terrane (Granite-greenstone) (Late Archean)
EUC - Uchur terrane (Granulite-paragneiss) (Paleoproterozoic)
KH - Khapchan terrane (Granulite-paragneiss) (Paleoproterozoic)
KOM - Kolyma-Omolon superterrane (Archean to Jurassic)
MG - Magan terrane (Tonalite-trondhjemite-gneiss) (Paleoproterozoic)
OH - Okhotsk terrane (Cratonal) (Archean through Jurassic)
TGS - Tunguska terrane (Tonalite-trondhjemite) (Archean)
TNG - Tyung terrane (Granulite-orthogneiss) (Archean to Paleoproterozoic)
TRN - Tyryn Terrane (Granite-greenstone) (Late Archean)
WAD - West Aldan terrane (Granite-greenstone) (Archean)

Sino-Korean Craton

SKA - Alashan terrane (Granulite-paragneiss) (Paleoproterozoic)
SKE - Erduosi terrane (Granulite-paragneiss) (Archean)
SKJ - Jilin-Liaoning-East Shandong terrane (Tonalite-trondhjemite-gneiss) (Archean)
SKL - West Liaoning-Hebei-Shanxi terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKM - Machollyong terrane (Granulite-paragneiss) (Archean to Paleoproterozoic)
SKR - Rangnim terrane (Granulite-paragneiss) (Archean)
SKYS - Yinshan terrane (Granite-greenstone belt) (Archean)

METALLOGENIC BELTS

NM - Nimnyr
UU - Uguy-Udokanskiy
JLJ - Jiliaojiao

Figure 21. Late Paleoproterozoic (1,900 to 1,600 Ma) time stage of metallogenic and tectonic model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

having formed during interplate rifting in the Central Aldan superterrane that was amalgamated to the North Asian craton.

In the Qinglong belt (QL, figs. 8, 20), the banded iron formation (BIF, Algoma Fe) and clastic-sediment-hosted Sb-Au deposits are as interpreted as having formed in a passive continental margin or aulacogen that was subsequently regionally metamorphosed and thrusted. The belt is hosted in the West Liaoning-Hebei-Shanxi terrane of the Sino-Korean craton.

The Au in shear-zone and quartz-vein deposits of the Tyrkanda-Stanovoy belt (TS, figs. 8, 20, 21) formed from 2.0 to 1.9 Ga and are interpreted as having formed during collision between the Tynda composite terrane and Central Aldan and East Aldan superterranes during amalgamation of these units to the margin of the North Asian craton.

The Uguy-Udokanskiy belt (UU, figs. 8, 20, 21) formed from 2.2 to 1.8 Ga and is a composite metallogenic belt that includes several mineral deposit types, including zoned mafic-ultramafic Cu-PGE, sediment-hosted Cu, and Ta-Nb-REE alkaline metasomatite deposits that are hosted in the West Aldan terrane. The Cr and PGE deposits occur in zoned mafic-ultramafic plutons and the sediment-hosted Cu deposits are interpreted as having formed in the continental-margin rift (unit cuk). The Ta-Nb-REE alkaline metasomatite deposits are interpreted as having formed during later collision and formation of anatectic granite.

Mesoproterozoic Tectonics

In the Mesoproterozoic (1,600 to 1,000 Ma), the following major terranes were forming or continued to form (1) Gyenggi granulite-paragneiss terrane (SCG) in the South China craton, and the West Stanovoy (WST) and Mamont (CTM) metamorphic terranes, Wundurmiao WD accretionary wedge terranes. The paleogeographic position of last three terranes in the Mezoproterozoic is unknown, and the paleogeographic position of the South China craton was far removed from the region of the North Asian and Sino-Korean cratons.

In the North Asian craton, the Early Mesoproteozoic (1,600 to 1,300 Ma) (fig. 22) was marked by the initiation and development of major sedimentary basins, including the East Angarsk, Near-Kolyma, Patom, and Uchur-Maya Basins that formed along the passive continental margins along the present-day boundaries of the craton. In addition, the Nyurba rift basin formed in the inner part of the craton

In the Sino-Korean craton, the Early Mesoproteozoic (1,600 to 1,300 Ma) (fig. 22) was marked by the developomehnt of major rift basins, including the Zhangbei-Bayan Obo-Langshan rift, and the Hebei-Liaoning sedimentary basins that formed along the present-day northern boundary of the craton. The rifting and formation of passive continental margins along both cratons were the result of the onset of the breakup of the Paleoproterozoic continent Pangea.

In the North Asian craton, the Late Mesoproteozoic (1,300 to 1,000 Ma) (fig. 23 was marked by a collision between the North Asian craton and a Mesoproterozoic continent (Yana-Indigirka superterrane), which was accompanied by greenschist to amphibolite facies metamorphiasm, emplacement of collisional granites, and formation of accretionary complexes (Lena-Aldan Orogenic Belt or Near-Kolyma block) (Beus and others, 1962). The collision was synchronous with the formation of the supercontinent Rodinia, of which the North Asian craton was a part until 850 Ma. The breakup of Rodinia was marked by the initiation of rifts and formation of the passive continental margin along the northern boundary of the North Asian craton (Parfenov and others, 2003).

Mesoproterozoic Metallogenesis

The major Mesoproterozoic metallogenic belts formed in a variety of tectonic environments (figs. 8, 22-23, appendix C).

The Darvi belt (DR, fig. 8), contains sedimentary bauxite (Alag Uul) and edimentary Fe-V deposits that forming during bauxite sedimentation in Lower to Middle Riphean sedimentary basin that overlapped the Baydrag cratonal terrane and subsequent regional metamorphism of sedimentary bauxite. During this time, the Tuva-Mongolia superterrane was far removed from the North Asian craton and is not depicted in figures 22 or 23.

The Langshan-Bayan Obo belt (LB, figs. 8, 22, 23) contains sedimentary exhalative Pb-Zn (SEDEX) deposits and a large polygenic REE-Fe-Nb deposit at Bayan Obo. The Bayan Obo deposit is interpreted as a SEDEX deposit related to a carbonatite magma and associated hydrothermal activity. The belt is hosted in the Paleoproterozoic and Mesoproterozoic Zhangbei-Bayan Obo-Langshan rift basin and related metasedimentary and metavolcanic units that formed along the passive continental margin of the Sino-Korean craton.

The Yanliao belt (YL, figs. 8, 22, 23) contains chemical-sedimentary Mn (Wafangzi) and sedimentary exhalative Pb-Zn (SEDEX) deposits in the Jixian Group that are interpreted as having formed in a shallow marine basin on the Sino-Korean craton.

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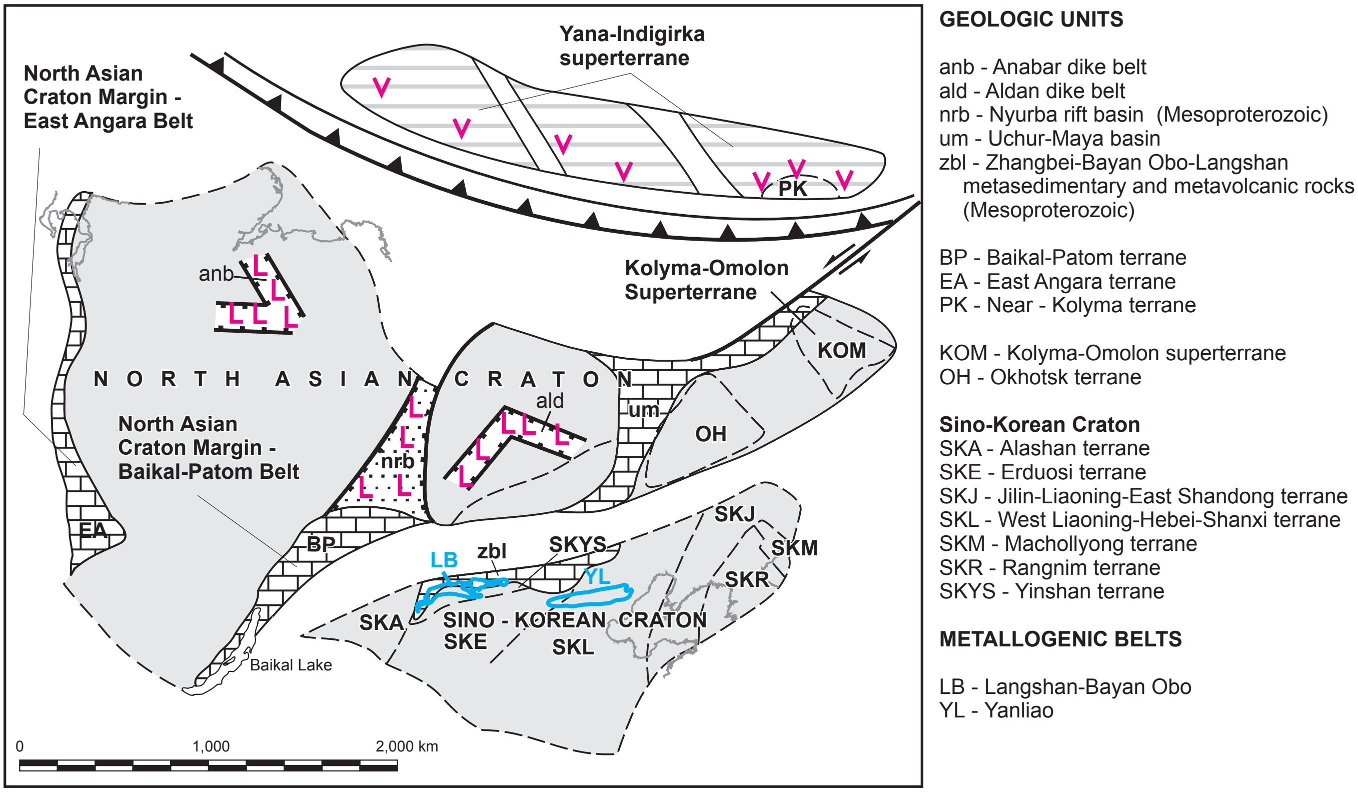

Figure 22. Early Mesoproterozoic (1,600 to 1,300 Ma) time stage of metallogenic and tectonic model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

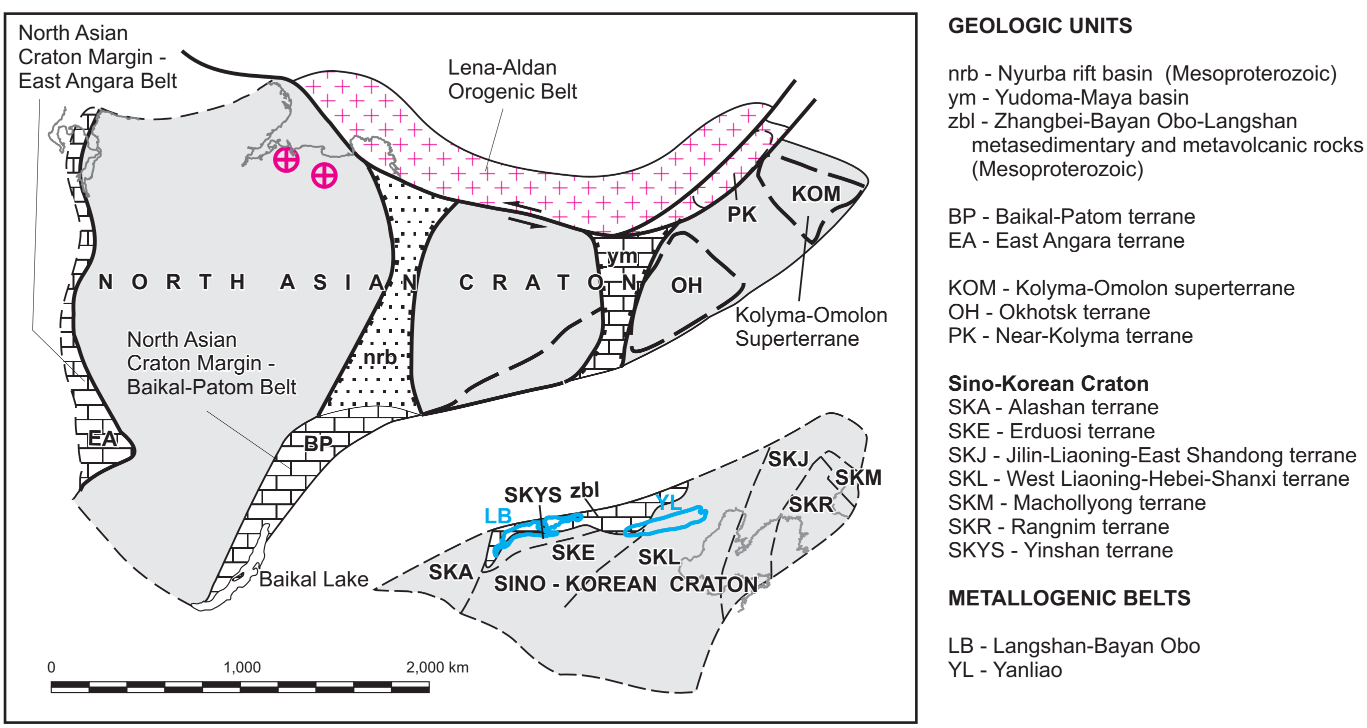

Figure 23. Late Mesoproterozoic (1,300 to 1,000 Ma) time stage of metallogenic and tectonic model. Refer to figure 19 for explanation. Figure adapted from Parfenov and others (chapter 9, this volume).

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