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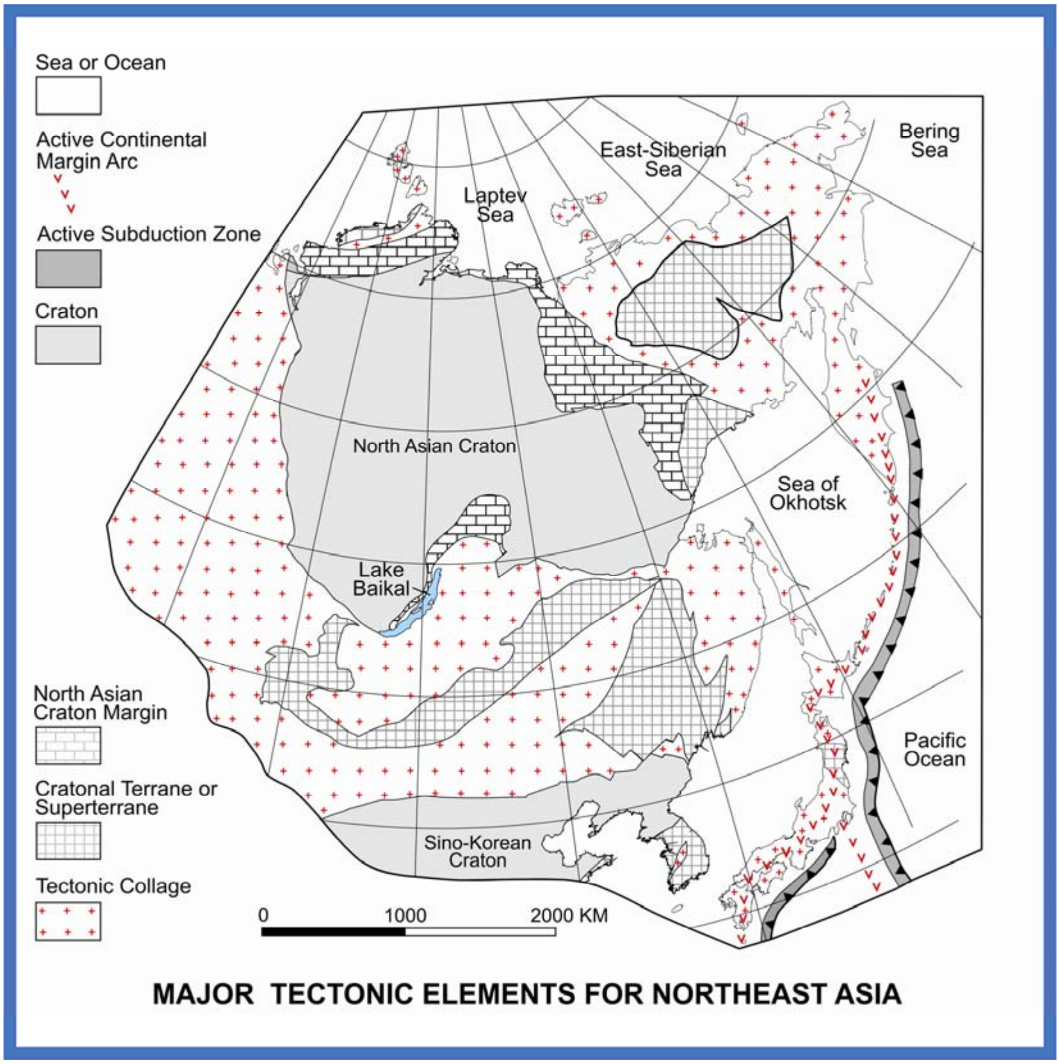

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Introduction to Regional Geology, Metallogenesis, and Tectonics of Northeast Asia

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Introduction to Regional Geology, Metallogenesis, and Tectonics of Northeast Asia

Purpose

This introduction presents an overview of the regional geology, tectonics, and metallogenesis of Northeast Asia. The major purposes are to provide a relatively short summary of these features for readers who are unfamiliar with Northeast Asia; a general scientific introduction for the succeeding chapters of this volume; and an overview of the methodology of metallogenic and tectonic analysis employed for Northeast Asia. The introduction also describes how a high-quality metallogenic and tectonic analysis, including synthesis of an associated metallogenic-tectonic model will greatly benefit refinement of mineral deposit models and deposit genesis; improvement of assessments of undiscovered mineral resources as part of quantitative mineral resource assessment studies; land-use and mineral exploration planning; improvement of interpretations of the origins of host rocks, mineral deposits, and metallogenic belts; and suggestions for new research.

The compilation, synthesis, description, and interpretation of metallogenesis and tectonics of major regions, such as Northeast Asia (Eastern Russia, Mongolia, northern China, South Korea, and Japan) and the Circum-North Pacific (Russian Far East, Alaska, and Canadian Cordillera) requires a complex methodology. The methodology includes: (1) definitions of key terms; (2) compilation of a regional geologic base map that can be interpreted according to modern tectonic concepts and definitions; (3) compilation of a mineral deposit database that enables the determination of mineral deposit models, and relations of deposits to host rocks and tectonic origins; (4) synthesis of a series of mineral deposit models that characterize the known mineral deposits and inferred undiscovered deposits of the region; (5) compilation of a series of maps of metallogenic belts constructed on the regional geologic base map; and (6) formulation of a unified metallogenic and tectonic model.

The summary 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. These studies have produced two broad types of publications. One type is a series of regional geologic, mineral deposit, and metallogenic belt maps and companion descriptions for the regions. Examples of major publications of this type are Obolenskiy and others (2003a, b, 2004), Parfenov and others (2003, 2004a, b), Nokleberg and others (2004), Rodionov and others (2004), and Naumova and others (2006). The other type is a suite of metallogenic and tectonic analyses of these same regions. Examples of major publications of this type are Rodionov and others (2004), Nokleberg and others (2000, 2004, 2005), and Naumova and others (2006).

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 U.S. Geological Survey.

The Northeast Asia project extends and build on data and interpretations from a previous project on the *Major Mineral Deposits, Metallogenesis, and Tectonics of the Russian Far East, Alaska, and the Canadian Cordillera* (below figure) that was conducted by the U.S.G.S., the Russian Academy of Sciences, the Alaska Division of Geological and Geophysical Surveys, and the Geological Survey of Canada. A summary of the major products of this project are contained on the Web at: http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.pdf and in Appendix A.

Acknowledgments

In the last three decades, many persons have assisted the authors in developing and employing the concepts of combined regional metallogenic and tectonic analysis, and in developing methods for synthesizing of a metallogenic-tectonic model. These persons include D.P. Cox, D.L. Jones, E.M. MacKevett, Jr., Ian O. Norton, D.W. Scholl, C.R. Scotese, and D.S. Singer, and D.B. Stone. We also thank managers N.L. Dobretsov, L.C. Gundersen, P.P. Hearn, K. Johnson, R. Koski, L.P. Leahy, J. Medlin, M. Power, and J.N. Weaver for their encouragement and support of the project. The constructive reviews of Charles Cunningham and Jeremy Hourigan are appreciated.

Definitions, Geologic Time Scale, and Tectonic Environments

In order to illustrate the regional geology of a large region in a page-size format, figure 2 utilizes the concept of tectonic collage that is defined as a series of linear island arcs or continental-margin arcs and tectonically-linked (companion) accretionary wedge (subduction) zones, and (or) fore-arc and back-arc basins that formed in a major tectonic event during a relatively narrow geologic time span. A few collages consist of fragments of craton margin and cratonal terranes that were amalgamated before accretion to a continent. This definition of tectonic collage enables (1) a readily-understood conceptual framework for understanding the geology and tectonics of large regions; (2) the depiction at small scales of major geologic units and structures that formed in a single tectonic event; and (3) the depiction of the major metallogenic belts related to tectonic collages.

Definitions of other key terms for analysis of regional geology and metallogenesis are provided in table 1. The definitions are adapted from Howell and others (1985), Jones and others (1983), Nokleberg and others (2000, 2004, 2005), or from cited references. Geologic time scale units are according to the IUGS Global Stratigraphic Chart (Remane, 1998). For this study, for descriptions of some Proterozoic geologic units in Russia, the term *Riphean* is used for the Mesoproterozoic to middle Neoproterozoic (1600 to 650 Ma), and the term *Vendian* is used for Neoproterozoic III (650 to 540 Ma).

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

Regional Geologic Map – A Basis for Metallogenesis

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

For the synthesis and interpretation of the Northeast Asia region, a regional geodynamics map was compiled at a scale of 1:5,000,000 in order to display major features of host rock geology and structures (Nokleberg and others, 1997b, c; Parfenov and others, 2003, 2004a, b) and major belts of mineral and fuel resources. For illustration of the major geodynamic features on a page-size illustration (fig. 2), a summary regional geodynamics map was synthesized in order to display: (1) the regional surface extent of major geologic units (cratons, craton margins, tectonic collages of island arc, continental-margin arc, accretionary wedge, and passive continental margin terranes, volcanic and plutonic igneous arcs); (2) major fault and rift systems; and (3) active subduction zones. The summary map also contains a list of the major host-rock geologic units in the explanation and a description of the major geologic units in an Appendix. The regional geologic map also provides descriptive data on the tectonic origin of major host-rock geologic units (e.g., explanation for figure 2) that are needed to establish the geologic controls for formation of metallogenic belts.

The Northeast Asia summary geodynamics map (fig. 2) is at a scale of about 1:34,000,000 and is derived from: (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004a); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North Pacific tectono-stratigraphic terrane map at 5 and 10 million scales (Nokleberg and others, 1994, 1997c). The tectonic interpretations are derived from the major interpretative publications of the collaborative international studies on Northeast Asia (Nokleberg and others, 2004) and the Circum-North Pacific (Nokleberg and others, 2000, 2004). The descriptions of geologic units are adapted from Nokleberg and others (2000, 2004) and Parfenov and others (2004).

Methodology of Regional Geologic and Tectonic Analysis

The methodology employed for synthesizing the summary geodynamics map consists of the following three steps: (1) correlation of major geologic units; (2) tectonic linking (pairing) of major geologic units; and (3) alignment of coeval arc and tectonically-linked subduction zones into curvilinear complexes. This methodology was originally established for the tectonic synthesis of the Circum-North Pacific by Nokleberg and others (2000) and modified for Northeast Asia by Parfenov and others (1998). The methodology is explained in detail in chapter 2 of this book.

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

For step 2, tectonic linking (pairing) is accomplished between: (1) subduction-related igneous arcs, now preserved as various igneous-arc terranes or overlap assemblages, with former subduction zones, now preserved as subduction-zone terranes; (2) belts of anatectic-related igneous rocks and major faults (sutures) that bound the collisional margins of terranes with each other or terranes with a craton margin; and (3) belts of igneous rocks that are coeval with, and occur along major transpressional fault zones. These pairings are based on examination of the detailed geology and ages (fossil and geochronologic) of units, and the interpretation of an originally adjacent loci.

The first type of tectonic linking is based on: (1) interpreting an original physical proximity between an arc and subduction zone; (2) determining the similarity in age of formation of an igneous-arc and subduction-zone terrane, (3) determining a subduction polarity from tectonic transport direction in a melange for subduction-zone terranes, where not disrupted by later deformation, and (4) recognizing the occurrence of disrupted layers of arc-derived volcanic or volcaniclastic units from a specific igneous arc in the melange of the linked subduction zone terrane.

The second type of tectonic linking is based on the spatial and temporal (age) association of collisional (S-type) granitic plutons and associated volcanic rocks with (1) major fault zones (sutures) between terranes or between a terrane and a craton margin, and (or) (2) belts of highly deformed, regional-grade metamorphic rocks that occur along the fault zones. Collision-related igneous belts are interpreted as forming either during accretion of one terrane to another or during the accretion of one or more terranes to a craton or craton margin.

The third type of tectonic linking is based on the spatial and temporal (age) association of mainly intermediate and silicic igneous belts that are coeval with, and intrude along major transpressional fault zones.

For step 3, terranes and overlap assemblages are grouped into larger entities that were probably once continuous and coeval igneous arcs and companion subduction-zones. This grouping of units is based, to varying degrees, on (1) similar stratigraphy, fauna, rock-unit age, and structure, (2) paleomagnetic data, to a lesser degree, and (3) an assumption of simplicity rather than complexity. The result of these groupings is the alignment of coeval igneous-arc overlap assemblages and igneous-arc terranes, and tectonically-linked (companion) subduction-zone terranes into coeval, curvilinear arc-subduction-zone complexes that herein are termed *tectonic collages*. One result of this grouping is the interpretation of single rather than multiple continental-margin- or island arc-subduction-zone complexes.

Summary of Regional Geology and Tectonics

The major geologic and tectonic units of Northeast Asia are cratons, craton margins; cratonal terranes and superterranes; tectonic collages; overlap and transform continental-margin arcs; island arcs, and sea and ocean units (fig. 2). Detailed descriptions of geologic units are provided by Nokleberg and others (2000, 2004) and Parfenov and others (2004b). Abbreviations in parentheses in the below list of geologic units refer to units on the summary geodynamics map (fig. 2). More detailed descriptions of map units are given in Appendix B. Two geologic ages are staged for each collage, one for the age of formation of the units in a collage, and another age for the time of accretion (formation) of the collage to another terrane, superterrane, or continent.

Major Cratons and Craton Margins

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

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

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

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

The South Taimyr Craton Margin (ST) consists chiefly of a thick wedge of Ordovician to Jurassic craton margin deposits and deep basin deposits.

The Verkhoyansk (North Asian) Craton Margin (VR) consists chiefly of a thick wedge of Devonian to Jurassic miogeoclinal deposits.

Cratonal Terranes and Superterranes

Three cratonal terranes occur along the margins of the North Asian and Sino-Korean Cratons and are interpreted as rifted and reaccreted fragments of 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 to Cambrian Argun-Idermeg superterrane (AR) consists of the Paleoproterozoic to 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-Myra island arc described below.

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

Tectonic Collages Between North Asian and Sino-Korean Cratons

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

The tectonic collages between the North Asian and Sino-Korean Cratons are as follows.

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

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

(3) The Altai collage (Vendian to Ordovician age and accreted in Late Silurian) consists of the Vendian to Early Ordovician Salair island arc and various fragments of arc-related turbidite terranes, subduction zone terranes, metamorphic terranes derived from arc-related units, thick Cambrian and Ordovician overlap turbidite units that formed on a continental slope and rise, and fragments of originally-adjacent oceanic terranes. The collage is interpreted as an island arc system that was active near the southwest margin (present-day coordinates) of the North Asian Craton and Margin and previously-accreted terranes.

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

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

(6) The South Mongolia-Khingan collage (SM) *(*Ordovician to Carboniferous age and accreted in Late Carboniferous or Early Permian) consists of the South Mongolia-Khingan arc and tectonically-linked subduction zone terranes. The collage is interpreted as a major island-arc system that formed southwest and west (present-day coordinates) of the North Asian Craton and Margin and previously accreted terranes. The collage was separated from the North Asian Craton by a large back-arc basin.

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

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

And (9) the Solon collage (SL) (Carboniferous to Permian age and accreted in Late Paleozoic to Early Mesozoic) consists of several subduction zone terranes: (1) Carboniferous and Early Permian North Margin terrane; (2) Late Carboniferous to Permian Solon terrane; (3) Devonian Imjingang terrane; (4) Paleozoic Ogcheon terrane; and (5) Silurian through Permian Sangun-Hidagaien-Kurosegawa terrane. Parts of the collage are interpreted as fragments of the Solon Ocean plate that were subducted to form the South Mongolian, Lugyngol, Gobi-Khankaisk-Daxing'anling, and Jihei continental-margin arcs. Other parts of the collage are interpreted as fragments of the Solon Ocean plate that were subducted to form the North Margin continental-margin arc on the Sino-Korean Craton.

Tectonic Collages East of North Asian and Sino-Korean Cratons

To the east of the North Asian and Sino-Korean Cratons are a series of tectonic collages that were successively accreted from west to east (older to younger) during closures of parts of the Ancestral Pacific and modern Pacific Oceans, and older oceans in the region. Because of successive accretions from west to east, the ages of collages generally young from west to east. However, this pattern is locally disrupted because some collages have been interspersed by subsequent strike-slip faulting

Except for the first two collages (Verkhoyansk-Kolyma and Chukotka) the other tectonic collages contain one or more island arcs or continental-margin arcs and tectonically-linked subduction zones. Following are the tectonic collages that occur east of the North Asian and Sino-Korean Cratons.

(1) The Verkhoyansk-Kolyma collage (VK) (Late Paleozoic to Early Jurassic age and accreted in Late Jurassic to early Early Cretaceous) consists of a deformed passive continental margin, accreted ophiolites, and subduction zone and is interpreted as forming during accretion of the outboard Kolyma-Omolon superterrane.

(2) The Chukotka collage (CH) (Paleozoic to Triassic age and accreted in Late Jurassic to Early Cretaceous) consists of passive continental-margin terranes that formed along the long-lived Neoproterozoic to early Mesozoic North American Continental Margin. After subsequent rifting of the North American Craton Margin in the Late Jurassic and Early Cretaceous and translation, the collage was accreted to the northern Verkhoyansk-Kolyma collage in the Late Cretaceous.

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

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

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

(6) Honshu-Sikhote-Alin collage (HS) (Jurassic and Early Cretaceous age and accreted in Cretaceous). Consists of fragments of island arc, continental-margin turbidite (flysch), and subduction zone terranes. The collage is interpreted as forming along a transform continental margin.

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

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

(9) The West Kamchatka collage (WK) (Mid-Cretaceous to early Tertiary age and accreted in Early Cenozoic) consists of late Paleozoic to Cretaceous subduction zone terranes in the Russian Northeast. The collage was tectonically linked to Okhotsk-Chukotka continental-margin arc.

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

(11) The Olyutorka-Kamchatka collage OK) (Late Cretaceous and Paleocene age and accreted in Early Cenozoic) consists of the Olyutorka island arc and tectonically-linked subduction zone terranes to the east.

And (12) the East Kamchatka Peninsula collage (EP) (mainly Paleocene age and accreted in Pliocene) consists of the Kronotskiy island arc and associated ophiolite.

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

Several major continental-margin arcs occur on previously-accreted terranes south of the North Asian Craton and on the Sino-Korean Craton. These arcs are interpreted as related to subduction of the late Paleozoic and early Mesozoic Solon Ocean plate beneath the North Asian and Sino-Korean Cratons. This ocean occurred between the Argun-Idermeg superterrane to the north and the Sino-Korean Craton to the south (present-day coordinates). The arcs are described from older to younger.

(1) The Altay arc (at) (Devonian and early Carboniferous) occurs on the Altay and Yenisey-Transbaikal collages. The arc is interpreted as forming along an active continental margin in an oblique subduction zone environment.

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

(3) The South Mongolian arc (sm) (Middle Carboniferous through Triassic) overlies and intrudes the South Mongolian collage and Atasbogd collage. The arc is interpreted as forming during subduction of the northern part of Solon Ocean plate under the Argun-Idermeg superterrane.

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

(5) The Jihei arc (ji) (Permian) occurs on the South Mongolia-Khingan collage. The arc intrudes the Bureya-Jiamusi supterterrane and South Mongolia-Khingan collage and is interpreted as forming during subduction of the northern part of Solon Ocean plate under the southern margin (present-day coordinates) of the Bureya-Jiamusi supterterrane and adjacent units.

And (5) the North Margin arc (nn) (Late Carboniferous to Permian) occurs on the northeastern margin (present-day coordinates) of Sino-Korean Craton. The arc is interpreted as forming during subduction of the southern part of Solon Ocean plate under the northeastern margin (present-day coordinates) of Sino-Korean Craton.

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

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

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

(2) The Hangay arc (ha) (Late Carboniferous to Early Permian) occurs on the Yenisey-Transbaikal collage and Mongol-Okhotsk collage. The arc is interpreted as forming during subduction of the northern part of Mongol-Okhotsk Ocean plate under the North Asian Craton Margin and previously-accreted terranes.

(3) The Selenga arc (se) (Permian to Jurassic) overlies and intrudes the Yenisey-Transbaikal collage and Tuva-Mongolia superterrane. The arc is interpreted as forming during oblique subduction of the Mongol-Okhotsk Ocean plate under the North Asian Craton Margin and previously-accreted terranes.

And (4) the Uda-Murgal and Stanovoy arcs (us) (Jurassic to Early Cretaceous) occur on the southern margin of the North Asian Craton. The arcs are interpreted as forming during final stage of subduction of the Mongol-Okhotsk Ocean plate.

Jurassic and Early Cretaceous Island Arcs Occurring On or Adjacent to Kolyma-Omolon Superterrane

The major island arcs occurring on the Kolyma-Omolon superterrane are the Late Jurassic to Early Cretaceous Uyandina-Yasachnaya island arc and the Late Jurassic Oloy island arc.

(1) The Uyandina-Yasachnaya arc (uy) (Late Jurassic to Early Cretaceous) occurs along the margin of the Kolyma-Omolon superterrane. The arc is interpreted as forming during subduction of the Oimyakon Ocean plate between the North Asian Craton Margin and the Kolyma-Omolon superterrane. Remnants of the Oimyakon oceanic crust are preserved in small obducted ophiolites along the western margin of superterrane. This ocean occurred between the Verkhoyansk (North Asian) Craton Margin to the southwest and the Kolyma-Omolon to the northeast (present-day coordinates).

And (2) the Oloy arc (ol) (Late Jurassic) occurs along the margin of the Kolyma-Omkolon superterrane. The arc is interpreted forming on the Kolyma-Omolon superterrane during subduction of the South Anyui Ocean plate beneath the superterrane to form the South Anyui subduction-zone terrane. This ocean formed north of the Kolyma-Omolon superterrane (present-day coordinates).

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

A series of Jurassic through early Tertiary continental-margin arcs and granite belts occur along the eastern margin of the North Asian and Sino-Korean Cratons and outboard accreted terranes to the east. From older to younger, the arcs and belts are as follows.

(1) The Umlekan-Ogodzhin arc (uo) (Jurassic and Cretaceous) occurs along the margin of the Kolyma-Omkolon superterrane. The arc is interpreted as forming during subduction of the Ancestral Pacific Ocean plate to form the Badzhal and Nadanhada terranes in the Badzhal collage.

(2) The South Verkhoyansk granite belt (sv) (Late Jurassic to mid-Cretaceous) occurs in central Russian Far east. The belt extends longitudinally along the central part of the South Verkhoyansk synclinorium in the Verkoyansk (North Asian) Craton Margin. The belt is interpreted as forming during the accretion of the outboard Okhotsk terrane.

(3) The Main granite belt (ma) (Late Jurassic) occurs along the adjacent margins of the North Asian Craton Margin and Kolyma-Omolon superterrane. The belt is interpreted as forming during and immediately after collision of the Kolyma-Omolon superterrane onto the North-Asian Craton Margin.

(4) The Transverse granite belt (tv) (Early Cretaceous) radiates outwards from the southwestern bend of the Kolyma-Omolon superterrane. The belt is interpreted as forming during the late stage of accretion of Kolyma-Omolon superterrane.

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

(6) The Khingan-Okhotsk arc (ko) (Early and mid-Cretaceous) occurs in the Russian Southeast and consists of the Khingan-Okhotsk volcanic-plutonic belt. The arc was tectonically paired to the Early Cretaceous Zhuravlevsk-Amur River and Kiselevka-Manoma subduction-zone terranes, part of the Honshu-Sikhote-Alin collage.

(7) The Okhotsk-Chukotka arc (oc) (Late Cretaceous to early Tertiary) occurs along the eastern margin of central and northern Russian Far East. The arc is interpreted as forming during subduction of the Ancestral Pacific Ocean plate with formation of the West Kamchatka, Ekonay, and Yanranay subduction zone terranes.

And (8) the East Sikhote-Alin arc (ea) (Late Cretaceous to early Tertiary) occurs along the margin of southern Russian Far East. The arc is interpreted as forming during subduction of the Ancestral Pacific Ocean plate with formation of the older part of the Hidaka subduction zone, the younger part of the Aniva subduction-zone terrane, and the Nabilsky, and Tokoro subduction-zone terranes.

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

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

(1) The Izu-Bonin arc (ib) (Miocene through Present) occurs south of southern Japan and consists of a volcanic arc composed chiefly of basalt to rhyolite, associated volcaniclastic rock, and intercalated hemipelagic mudstone. The arc is interpreted as forming from subduction of the Philippine Sea Plate with creation of the Nankai subduction zone.

(2) The Japan arc (ja) (Miocene through Present) occurs along the Japan Islands and consists of extensive Quaternary volcanic and associated rock. The arc is interpreted as forming during subduction of the Pacific Ocean and Philippine Sea Plates with formation of the Japan Trench and Nankai subduction zones.

And (3) the Kuril-Kamchatka arc (kk) (Miocene through Present) occurs along Kamchatka Peninsula and Kuril Islands and consists of the Pliocene to Quaternary Central Kamchatka volcanic belt, central Kamchatka volcanic and sedimentary basin, and the East Kamchatka volcanic belt. The arc is interpreted as forming during subduction of the Pacific Ocean Plate with formation of the Japan Trench subduction zone.

Transpressional Arcs (Devonian through Cretaceous)

Three major transpressional arcs occur along the margins of the North Asian Craton and previously accreted terranes to the south. The arc formations are associated with a combination of strike-slip faulting along and local compression and extension.

(1) The South Siberian arc (ss) (Early Devonian) occurs in Southern Siberia. The arc is interpreted as forming along the southern margin of the North Asian Craton and Craton Margin during Early Devonian rifting that successively evolved into a continental-margin transform margin and subsequently into a convergent margin.

(2) The Mongol-Transbaikal arc (mt) (Late Triassic to Early Cretaceous) occurs in northern Mongolia and southern Siberia. The arc is interpreted as forming during strike-slip faulting and rifting along the Mongol-Okhotsk fault during and after the final closure of the Mongol-Okhotsk Ocean.

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

Regional Metallogenesis of Northeast Asia

Synthesis of Mineral Deposit Models

A modern metallogenic analysis of a large region requires that mineral deposit models that are appropriate for the region be characterized, synthesized, and grouped so that they can be correlated with the regional tectonic processes that formed the known mineral deposits. The beginning of this type of correlation between models and tectonic process is evident in many of the classic compilations of mineral deposits models (Eckstrand, 1984; Cox and Singer, 1986; Singer, 1993). As an example of mineral deposit models employed for a large region, table 2 lists the mineral deposit models that were defined and described for the metallogenic analysis of Northeast Asia. For this large and complex region, a suite of 122 mineral deposit models was sufficient to describe the characteristic features of the 1674 lode deposits and 75 placer districts (Obolenskiy and others, 2003, this volume). The models include previous descriptions from Eckstrand (1984); Cox and Singer (1986), Nokleberg and others (1997a), with modifications by Obolenskiy and others (2003; this volume).

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

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

Summary of Methodology of Metallogenic and Tectonic Analysis

The methodology for metallogenic and tectonic analysis is illustrated in figures 3A and 3B (derived from Nokleberg and others, 2005). Figure 3A is a schematic map that portrays a suite of metallogenic belts that are hosted in several geologic units, including cratons, terranes, and overlap assemblages, or along major faults between terranes. Figure 3B is a series of stratigraphic columns for the units depicted in Figure 3A and illustrates the stratigraphic and metallogenic history of the map area.

The steps in this theoretical example are as follows.

(1) A regional geologic base map is constructed. Figure 3A, a map view of an orogenic belt (consisting of two cratons and several intervening terranes), portrays two major cratons (A, B), several fault-bounded terranes (1, 2, 3, 4) between the two cratons, one accretionary assemblage (a), and four postaccretion overlap assemblages (b, c, d, e). In a schematic fashion, Figure 3A depicts the regional geology Northeast Asia, with craton B representing the North Asian Craton, craton A representing the Sino-Korean craton, terranes 1-4 representing the tectonic collages of terranes between the cratons, and overlap assemblages a-e representing the major arcs overlying cratons and collages.

(2) A series of mineral deposit models appropriate for the geology are identified and defined, and a mineral deposit database is prepared. For this theoretical example, the major mineral deposit models are low-sulfide Au quartz vein, ironstone, Au epithermal vein, porphyry Cu, bedded barite, and kuroko massive sulfide.

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

(4) The genesis of bedrock geologic units, structures, and contained metallogenic belts and mineral deposits is interpreted using modern tectonic concepts. Examples are: kuroko massive sulfide deposits forming in an island arc environment; porphyry Cu and low-sulfide Au quartz vein deposits forming in a collisional environment; and epithermal Au vein deposits forming in a continental-margin igneous arc environment.

And (5) by carefully defining each metallogenic belt to be the geologically-favorable area for a group of coeval and genetically-related mineral deposits, a predictive character is established within each belt for undiscovered deposits.

Synthesis of Metallogenic Belt Maps

Many metallogenic maps display major mineral deposits and (or) districts on a regional geologic base map. These maps are often quite complicated because of a high density of deposits. In order to simply data presentation, and to increase understanding of regional patterns, the concept of a metallogenic belt map was developed for the studies of Northeast Asia and the Circum-North Pacific (Nokleberg and others, 1997b, c; Obolenskiy and others, 2003, 2004a, b). As an example of the power of a modern-day metallogenic belt map, the major Archean metallogenic belts for Northeast Asia are illustrated in figure 4 that contains the summary geodynamics map as a basal layer. Besides displaying important summary map data, figure 4 also illustrates that how the origins of metallogenic belts can be related to the major geologic units or structures containing the belts. This relation arises from the definition of a metallogenic belt (a group of coeval and genetically-related, significant lode and placer deposits that can be interpreted as forming in a single major geologic or tectonic event). For additional information, summary descriptions of the characteristics and interpretations of the major metallogenic belts for the region are provided in Appendix C.

Benefits of Performing a Combined Regional Metallogenic and Tectonic Analysis

As described above, a high-quality metallogenic and tectonic analysis, including synthesis of a metallogenic and tectonic model, will greatly benefit other mineral resource studies (fig. 3), including: (1) synthesis of mineral deposit models (Eckstrand, 1984; Cox and Singer, 1986; Singer and Cox, 1988); (2) assessment of undiscovered mineral resource resources as a part of quantitative mineral resource assessment studies (Cox, 1993; Singer, 1993, 1994); (3) improvement of land-use and mineral exploration plans; (4) improvement of interpretations of genesis of mineral deposits and host rocks; and (5) suggestions for new research.

Following are three examples of these benefits. (1) The in-depth understanding of the tectonic and metallogenic origins of potential host rocks for mineral deposits make enable the prediction of undiscovered mineral deposits according to favorable host rock geology. It is crucial to have this capability because for a mineral resource assessment, the outlines of permissive tracts (i.e., areas with potential for undiscovered mineral deposit types) must be drawn for each mineral deposit type according to a favorable geologic environment. (2) Regional metallogenic and tectonic analyses, such as those performed for Northeast Asia and the Circum-North Pacific, enable the identification and location of continuations of ore-hosting terranes and permissive tracts around the world that were separated by various tectonic processes that have operated throughout the Earth's long history. Suppose that a suite of metallogenic belts containing porphyry Cu deposits is hosted in various fragments of island-arc terranes that are now dispersed in a collage of terranes in the center of a continent. Tectonic analysis of the origin of the island-arc terranes and correlations with each other will result in grouping of these terranes and their contained metallogenic belts into an originally continuous island-arc and a single, large metallogenic belt. This enlargement of the host rock area and contained metallogenic belt will provide a larger data set that should greatly improve the quality of metallogenic analysis and mineral resource assessment. And (3) an understanding of the metallogenic setting and history of host rocks and ore-forming processes often is important for estimating numbers of undiscovered mineral deposits in a permissive tract for a mineral resource assessment. For example, the number of volcanogenic massive sulfide deposits estimated in a permissive tract containing poorly exposed and poorly described mafic to felsic volcanic rocks may vary depending on whether the tract is located in a volcanic fore-arc, axial arc, or back-arc tectonic setting. Conversely, no deposits of this type might be estimated for a tract of similar rocks in an extensional cratonic setting.

Summary of Major Metallogenic Belts in Northeast Asia

The summaries of major metallogenic belts in the below time-span sections are adapted from detailed descriptions of metallogenic belts in Rodionov and others (2004). Summary description of metallogenic belts are given in Appendix C and detailed descriptions of lode deposits in each belt are available in Ariunbileg and others (2003).

Major Archean Metallogenic Belts

The major Archean (>2500 Ma) metallogenic belts are the Jidong, Liaoji, Sharizhalgaiskiy, Sutam, West Aldan belts, and Wutai (fig. 4, 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 forming 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 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 this region.

Major Paleoproterozoic Metallogenic Belts

The major Paleoproterozoic (2500 to 1600 Ma) metallogenic belts are the Baydrag, Jiliaojiao, Kalar-Stanovoy, Luliangshan, Nimnyr, Qinglong, Tyrkanda-Stanovoy, and Uguy-Udokanskiy belts (fig. 5, Appendix C).

Metallogenic Belts Related to Sedimentary Basins formed on Craton or Craton Margins

Three 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 banded iron formation (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 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 cratons and locally in rift basins.

Metallogenic Belts Related to Rifting or Terrane Collision

Two 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 formed during rifting of craton or cratonal terranes. The isotopic ages of the 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 derived form the North Asian Craton 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, 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 occurring during terrane collision.

Major Mesoproterozoic Metallogenic Belts

The major Mesoproterozoic (1600 to 1000 Ma) metallogenic belts are the Darvi, Langshan-Bayan Obo, and Yanliao belts (fig. 5, Appendix C).

All three belts possess geologic units favorable for major stratiform sediment-hosted deposits, including the Darvi belt (with sedimentary bauxite and sedimentary Fe-V deposits), Langshan-Bayan Obo belt (with sedimentary exhalative Pb-Zn (SEDEX) and polygenic REE-Fe-Nb deposits), and Yanliao belt (with chemical-sedimentary Fe-Mn and sedimentary exhalative Pb-Zn (SEDEX)) 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.

Major Neoproterozoic Metallogenic Belts

The major Neoproterozoic metallogenic belts are the Angara-Pit, Baikalo-Muiskiy, Bodaibinskiy, Bokson-Kitoiskiy, Central-Yenisei, Hovsgol, Jixi, Kyllakh, Lake, Pribaikalskiy, Prisayanskiy, and Vorogovsko-Angarsk belts (fig. 6, Appendix C).

Metallogenic Belts Related to Sedimentary Basins formed on Craton Margins

Several belts possess geologic units favorable for major stratiform sediment-hosted deposits, including the Angara-Pit belt (with sedimentary siderite Fe and volcanogenic-sedimentary Fe deposits), Bodaibinskiy and Central-Yenisei belt (with Au in black shale deposits), Bokson-Kitoiskiy belt (with sedimentary bauxite deposits), Hovsgol belt (with sedimentary phosphate, volcanogenic-sedimentary Mn, and sedimentary Fe-V deposits), Jixi belt (with Banded iron formation (BIF, Algoma Fe deposits), Kyllakh and Pribaikalskiy belts (with carbonate-hosted Pb-Zn deposits), and Vorogovsko-Angarsk belt (with sedimentary exhalative Pb-Zn (SEDEX), and carbonate-hosted Pb-Zn (Mississippi valley type) deposits). Where known, the fossil or isotopic ages of host rocks or deposits range from Riphean to Vendian. These deposits are hosted either in sedimentary units on the North Asian Craton Margin (Angara Pit, Bodaibinskiy, Central-Yenisei, and Kyllakh belts), or in sedimentary basins deposited on passive continental-margin terranes that were possibly derived from the Craton Margin (Hovsgol and Vorogovsko-Angarsk belts). These favorable geologic units and deposits formed during sedimentation on continental shelves or during rifting of a continental shelf.

Metallogenic Belts Related to Island Arcs

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

Metallogenic Belts Related to Terrane Accretion

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

Major Cambrian through Silurian Metallogenic Belts

The major Cambrian through Silurian metallogenic belts are the Bayanhon-gor-1, Bedobinsk, East Liaoning, Govi-Altai, Hovd, Hunjiang-Taizihe, Jinzhong, Kiyalykh-Uzen, Kizir-Kazyr, Martaiginsk, Ozerninsky, South Khingan, and Uda-Shantar belts (fig. 7, Appendix C).

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

Several metallogenic belts possess geologic units favorable for major granitoid-hosted or related deposits, including the Bayanhon-gor belt (with Au in shear zone and quartz vein, granitoid-related Au vein, Cu-Ag vein, Cu skarn deposits), the Hovd belt (with granitoid-related Au vein, Au skarn, and Cu skarn deposits), the Kizir-Kazyr belt (with Fe skarn and granitoid-related Au vein deposits), and the Martaiginsk belt (with granitoid-related Au vein and Au skarn deposits). The isotopic ages of the deposits or hosting units range from 490 to 420 Ma. The favorable geologic units and deposits are in the Altai and Yenisey-Transbaikal collage and are interpreted as forming in a continental-margin arc or associated continental-margin turbidite terranes, back-arc basin associated with continental-margin arc magmatism, transform continental-margin faulting, island arc, or terrane accretion. The Kiyalykh-Uzen belt (with Cu skarn, W skarn, Fe skarn, W-Mo-Be greisen, stockwork, and quartz vein deposits) and the Martaiginsk belt (with granitoid-related Au vein and Au skarn deposits) contain collisional granitoids that are interpreted as having been intruded during transpressive (dextral-slip) movement along the Kuznetsk Alatau fault or during terrane accretion.

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

Several metallogenic belts possess geologic units favorable for major volcanic-rock hosted deposits, including the Govi-Altai, Ozerninsky, and Uda-Shantar belts (with volcanogenic-sedimentary Fe, volcanogenic-sedimentary Mn, volcanogenic-hydrothermal-sedimentary massive sulfide, and sedimentary phosphate deposits). The fossil ages of the deposits or host units range from Cambrian to Silurian. The favorable geologic units and deposits are in the Mongol-Okhotsk, South Mongolia-Khingan, and Yenisey-Transbaikal collages and are interpreted as forming in either continental-margin or island arcs, or in sea floor sedimentation. The Bedobinsk belt with sediment-hosted Cu deposits is hosted in early Paleozoic sedimentary units of the North Asia Craton and is interpreted as forming in an inland-sea basin during post-saline stage of rock deposition.

Kimberlite Diamond Metallogenic Belts

Three metallogenic belts possess unique favorable geologic units for diamond-bearing kimberlite deposits in the Sino-Korean Craton (East Liaoning belt), evaporite sedimentary gypsum deposits in platform sedimentary cover on the Sino-Korean Craton (Hunjiang-Taizihe and Jinzhong belts), and banded iron formation (BIF) deposits in continental-margin sedimentary cover on the Sino-Korean Craton (South Khingan belt). The latter two belts formed during sedimentation along a craton margin. The origin of the diamond-bearing kimberlite deposits is not well known.

Major Devonian through Early Carboniferous Metallogenic Belts

The major Devonian through Early Carboniferous metallogenic belts are the Botuobiya-Markha, Bayangovi, Daldyn-Olenyok, Edrengiin, Edren-Zoolon, Hongqiling, Kizhi-Khem, Mamsko-Chuiskiy, Rudny Altai, Salair, Sette-Daban, Sorsk, Tsagaan-suvarga, Udzha, Ulziit, and Yaroslavka belts (fig. 8, Appendix C).

Metallogenic Belts Related to Continental-Margin or Island Arcs

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

Metallogenic Belts Related to Terrane Accretion

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

Metallogenic Belts Related to Rifting

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

Metallogenic Belts Related to Transpressional Faulting

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

Unique Metallogenic Belts

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

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

Major Late Carboniferous through Middle Triassic Metallogenic Belts

The major Late Carboniferous through Middle Triassic metallogenic belts are the Angara-Ilim, Altay, Barlaksk, Battsengel-Uyanga-Erdenedalai, Buteeliin nuruu, Central Mongolia, Duobaoshan, Harmagtai-Hongoot-Oyut, Hitachi, Kalatongke, Kolyvansk, Kureisko-Tungsk, Maimecha-Kotuisk, Mino-Tamba-Chugoku, Norilsk, Orhon-Selenge, and Shanxi belts (fig. 9, Appendix C).

Metallogenic Belts Related to Superplume

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

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

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

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

Metallogenic Belts Related to Island Arcs

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

Metallogenic Belt Related to Collision of Cratons

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

Metallogenic Belt Related to Weathering

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

Metallogenic Belt Related to Oceanic Crust

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

Major Late Triassic through Early Jurassic Metallogenic Belts

The major Late Triassic through Early Jurassic metallogenic belts are the Central Hentii, Delgerhaan, Govi-Ugtaal-Baruun-Urt, Harmorit-Hanbogd-Lugiingol, Kalgutinsk, Mongol Altai, North Hentii, North Kitakami, North Taimyr, and Sambagawa-Chichibu-Shimanto belts (fig. 10, Appendix C).

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

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

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

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

Metallogenic Belts Related to Oceanic Crust

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

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

Major Middle Jurassic through Early Cretaceous Metallogenic Belts

The major Middle Jurassic through Early Cretaceous metallogenic belts are the Allakh-Yun, Ariadny, Bindong, Chara-Aldan, Chybagalakh, Djeltulaksky, Dzid-Selenginskiy, Daxinganling, East Mongolian-Priargunskiy-Deerbugan, Govi-Tams, Hartolgoi-Sulinheer, Jiliaolu, Kitakami, Kondyor-Feklistov, Kular, Nerchinsky, North Bureya, North Jilin, North Stanovoy, Onon-Turinskiy, Polousny, Samarka, Shilkinsko-Tukuringrskiy, South Verkhoyansk, Taebaegsan, Tompo, Verkhne-Ingodinsky, Verkhoyansk, Yana-Adycha, and Yanshan belts (fig. 11, Appendix C).

Metallogenic Belts Related to Trans-Baikalian-Daxinganling Transpressional Arc

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

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

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

Metallogenic Belts Related to Uda-Stanovoy Continental-Margin Arc

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

Metallogenic Belts Related to Transpression

Four metallogenic belts possess geologic units favorable for a wide variety of transpressional granitoid-related deposits, including the Jiliaolu, North Jilin, Samarka, and Yanshan belts (with Au-Ag epithermal vein, Cu skarn W skarn, fluorspar vein, granitoid-related Au vein, polymetallic Pb-Zn vein and stockwork, polymetallic volcanic-hosted metasomatite, porphyry Cu and Cu-Mo, W skarn, and Zn-Pb skarn deposits). The isotopic ages for the granitoids hosting the deposits range from 186 to 110 Ma. The granitoids and veins intrude either overlap assemblages on the Sino-Korean Craton or the Samarka subduction zone terrane (part of Honshu-Sikhote-Alin collage). The metallogenic belts are interpreted as having formed during intrusion of granitoids along transpressional zones along micro plate boundaries, underthrusting of the Kula oceanic ridge, and formation of bimodal igneous rocks along a transform continental margin, or during interplate magmatism associated with extensional tectonism related to oblique subduction of the Pacific Oceanic Plate beneath Eurasian Plate.

Unique Metallogenic Belts

Five unique metallogenic belts formed during this time span. (1) The Kondyor-Feklistov belt with zoned mafic-ultramafic Cr-PGE deposits is hosted in mafic-ultramafic intrusions and is interpreted as having formed during intrusion of mafic-ultramafic plutons along a deep-seated fault that formed along the North Asian Craton margin during collision and accretion of outboard terranes. (2) The North Bureya belt with Au-Ag epithermal vein and granitoid-related Au vein deposits is hosted in the Umlekam-Ogodzhin volcanic-plutonic belt. The belt is interpreted as forming during formation of Umlekan-Ogodzhin continental-margin arc that formed during subduction of part of Ancestral Pacific Ocean plate. (3) The Ariadny belt with mafic-ultramafic rock-related deposits is hosted in Middle Jurassic and Early Cretaceous plutons intruding the Samarka subduction zone terrane, part of the Honshu-Sikhote-Alin collage. The belt is interpreted as forming during generation of ultramafic and gabbroic plutons during underthrusting of the Kula oceanic ridge and formation of bimodal igneous rocks along a transform continental margin. (4) The Taebaegsan belt with a wide assortment of granitoid-related deposits is hosted in the Daebo granite and is as forming during intrusion of granitoids associated with Late Jurassic to Early Cretaceous Daebo granite. The granitioid are interpreted as part of a continental-margin arc that was linked to subduction of the Ancestral Pacific Ocean plate. And (5) the Kitakami belt with Cu skarn and granitoid-related Au deposits is hosted in the Early Cretaceous Hiroshima granite belt (with isotopic ages of 120 to 110 Ma) and is interpreted as having formed during intrusion of granitoids associated with a continental-margin arc and siliceous magmatism.

Major Cenomanian through Campanian Metallogenic Belts

The major Cenomanian through Campanian metallogenic belts are the Badzhal-Komsomolsk, Central Polousny, Chelasin, Chokhchur-Chekurdakh, Eckyuchu-Billyakh, Gyeongnam, Gyeongpuk, Hidaka, Inner Zone Southwest Japan, Khandyga, Kukhtuy-Uliya, Luzhkinsky, Malo-Khingan, Pilda-Limuri, Preddzhugdzhursky, Selennyakh, Sergeevka-Taukha, South Verkhoyansk, Tumnin-Anyuy, and Upper Uydoma belts (fig. 12, Appendix C).

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

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

Metallogenic Belts Related to Opening of Eurasia Basin

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

Metallogenic Belts Related to Khingan Continental-Margin Arc

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

Unique Metallogenic Belts

Four unique metallogenic belts formed during this time span.

(1) The Gyeongpuk and Gyeongnam belts (with polymetallic Pb-Zn vein and stockwork, Au in shear zone and quartz vein, porphyry Mo, W-Mo-Be greisen, stockwork, and quartz vein, Sn-W greisen, stockwork, and quartz vein, Fe skarn, and polymetallic Ni vein deposits) have isotopic ages of Cenomanian through Campanian, and are hosted in the Cretaceous Bulgugsa granite that intrudes the Sino-Korean Craton. The belt and deposits are interpreted as having formed in a continental-margin arc during subduction of the Ancestral Pacific Ocean Plate.

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

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

Major Maastrichtian through Oligocene Metallogenic Belts

The major Maastrichtian through Oligocene metallogenic belts are the Kema, Lower Amur, and Popigay belts (fig. 13, Appendix C).

Two metallogenic belts possess geologic units favorable for a wide variety of vein and replacement and granitoid-related deposits, including the Kema and Lower Amur belts (with Ag-Au epithermal vein, porphyry Cu-Mo, porphyry Cu, porphyry Au, porphyry Mo, Au-Ag epithermal vein, epithermal quartz-alunite, and Sn-W greisen, stockwork, and quartz vein deposits). The isotopic ages for the granitoids hosting or associated with the deposits range from Late Cretaceous to Paleocene. The belts and deposits are hosted in granitoids in the East Sikhote-Alin volcanic-plutonic belt that is a major overlap assemblage in the Russian Far East. The belt is interpreted to be part of a very extensive continental-margin arc that formed along the eastern margin (present-day coordinates) of the North Asian Craton and Craton Margin and previously-accreted terranes to the east. The arc is interpreted as having formed during subduction of the Ancestral Pacific Ocean Plate.

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

Major Miocene through Quaternary Metallogenic Belts

The major Miocene through Quaternary metallogenic belts are the Kyushu, Northeast Hokkaido, Hokuriku-Sanin, Northeast Japan, and Outer Zone Southwest Japan belts (fig. 13, Appendix C).

All five major metallogenic belts possess geologic units favorable for a wide variety of volcanic-rock-related deposits. These belts contain a wide variety of deposits, including Au-Ag epithermal vein, cassiterite-sulfide-silicate vein and stockwork, chemical-sedimentary Fe-Mn, clastic sediment-hosted Hg±Sb, clastic-sediment-hosted Sb-Au, Ag-Sb and Hg-Sb-W vein and stockwork, limonite from spring water, Mn vein, polymetallic Pb-Zn vein and stockwork, polymetallic volcanic-hosted metasomatite, Sn skarn; Sn-W greisen, stockwork, and quartz vein, sulfur-sulfide, volcanic-hosted Hg; Ag-Sb vein, volcanogenic Zn-Pb-Cu massive sulfide, volcanogenic-sedimentary Mn, W-Mo-Be greisen, stockwork, and quartz vein, and Zn-Pb skarn deposits. The isotopic ages of the igneous rocks hosting the deposits range from 15 to 0.3 Ma. The belts and deposits are hosted in the Quaternary Japan volcanic belt and the Neogene Japan sedimentary basin that are interpreted as part of the modern-day Japan continental-margin arc. This arc is tectonically related to subduction of the Pacific Ocean and Philippine Sea Plates beneath the East Asia continental margin.

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

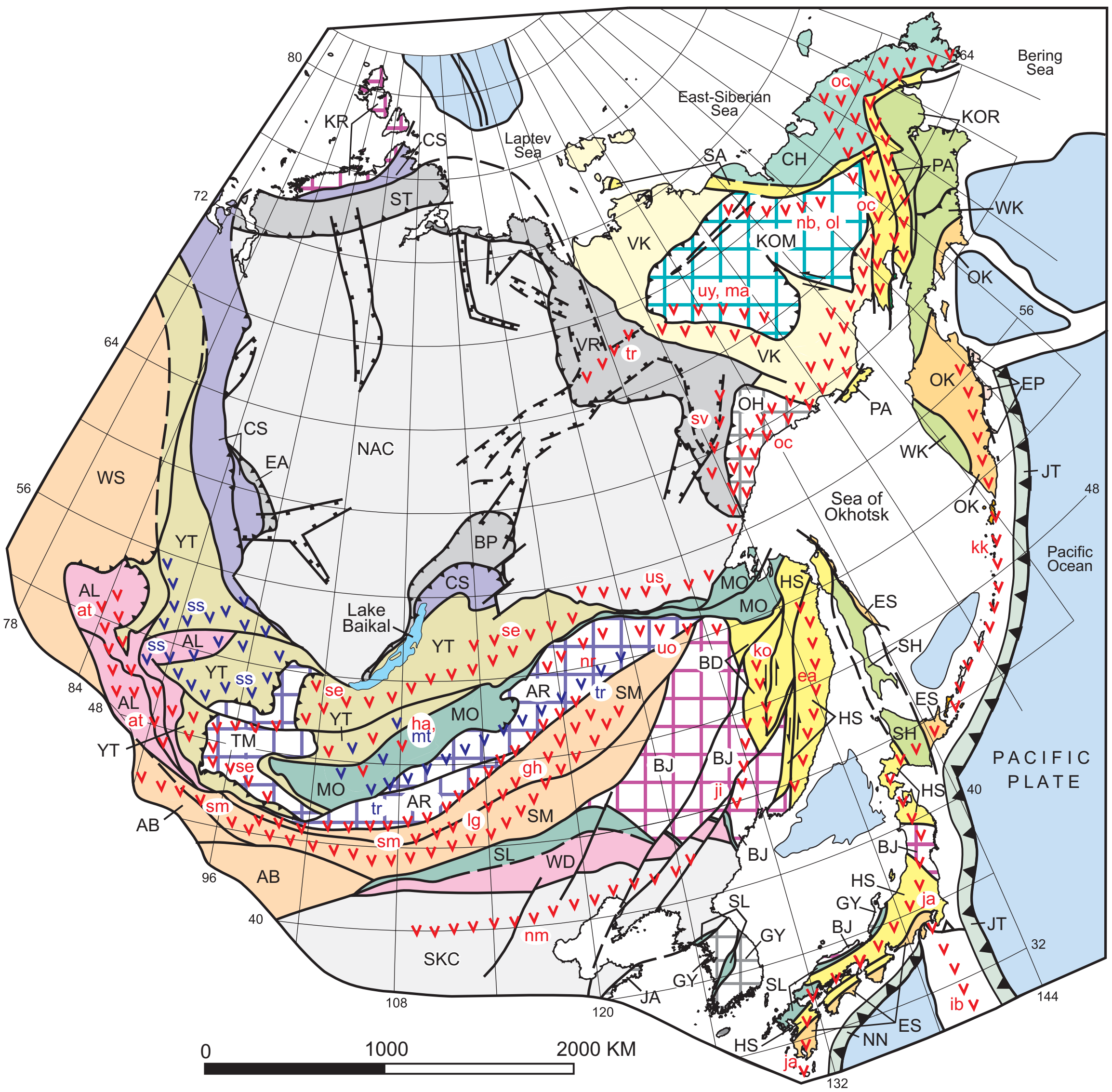

Figure 2A. Northeast Asia summary geodynamics map. Map is derived from: (1) a Generalized Northeast Asia Geodynamics Map at 10 million scale (Parfenov and others, 2004); (2) a more detailed Northeast Asia Geodynamics Map at 5 million scale (Parfenov and others, 2003); and (3) the western part of a Circum-North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

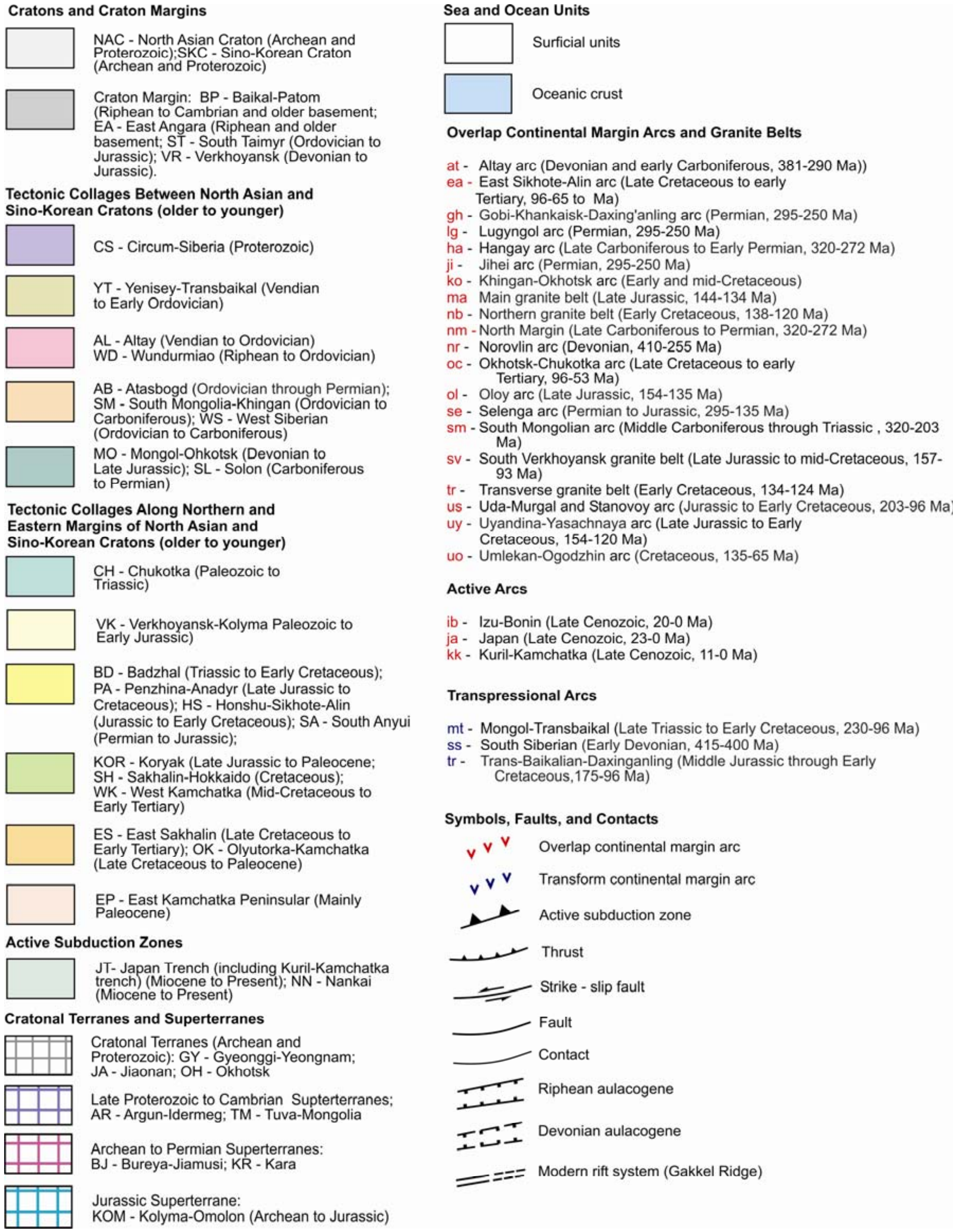

Figure 2B. Explanation for Northeast Asia geodynamics map.

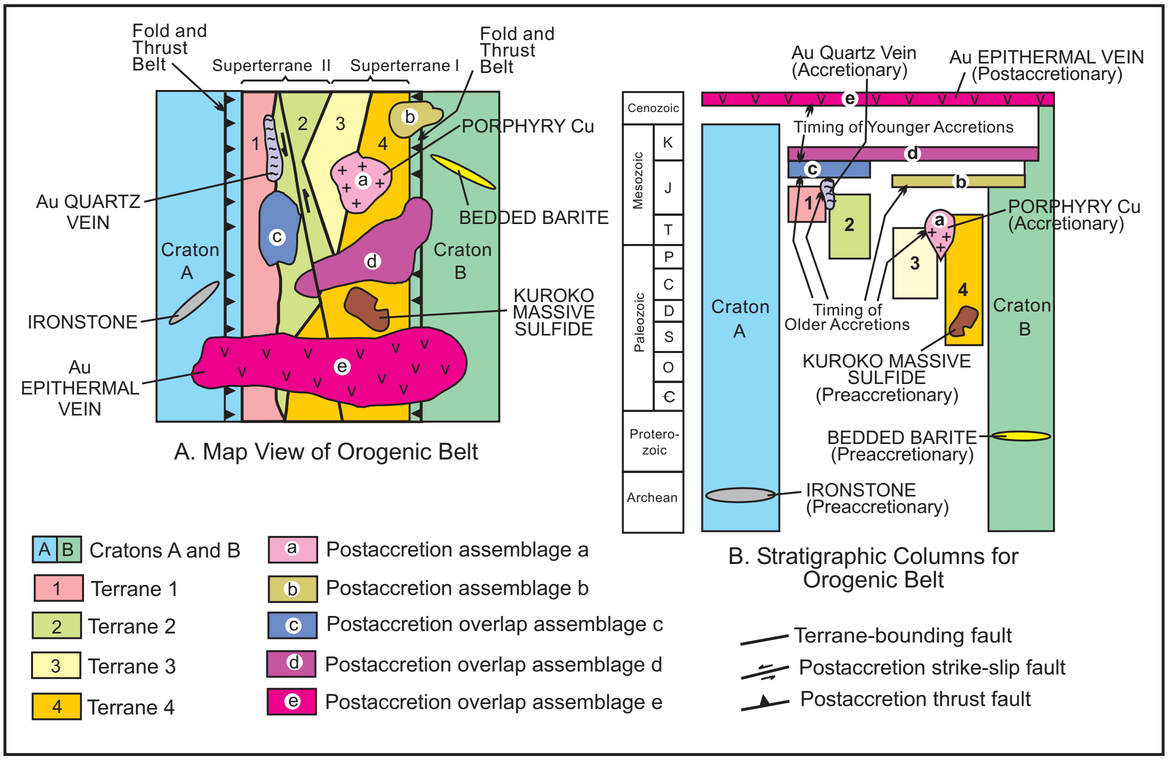

Figure 3. Schematic and figure illustrating the methodology for metallogenic analysis of cratons, terranes, accretionary assemblages, overlap assemblages, and contained metallogenic belts. A. Map view of orogenic belt. B. Stratigraphic columns for orogenic belt. Adapted from Parfenov and others (1998). Refer to text for discussion.

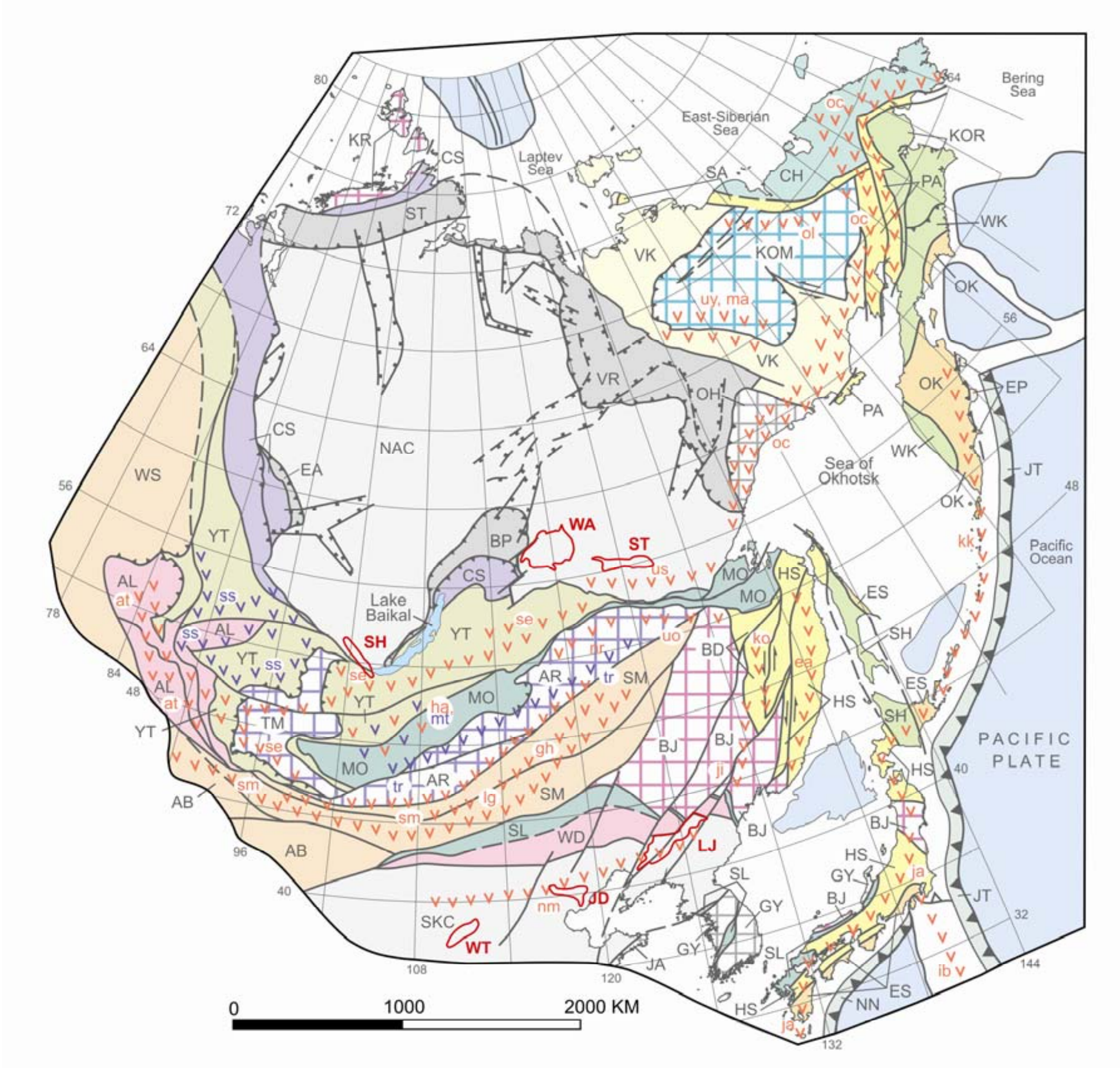

Figure 4. Generalized map of major Archean metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and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

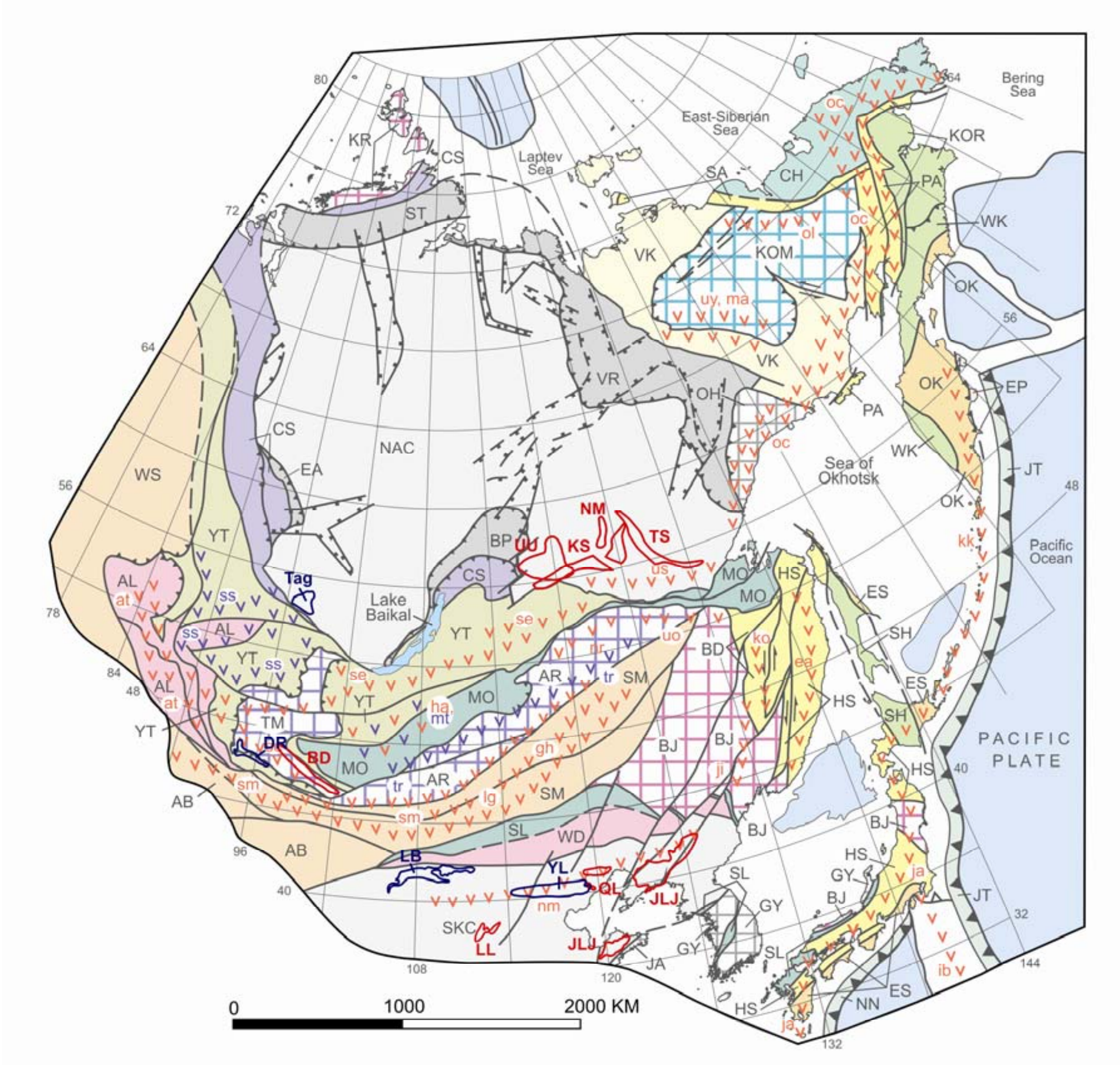

Figure 5. Generalized map of major Paleoproterozoic and Mesoproterozoic metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

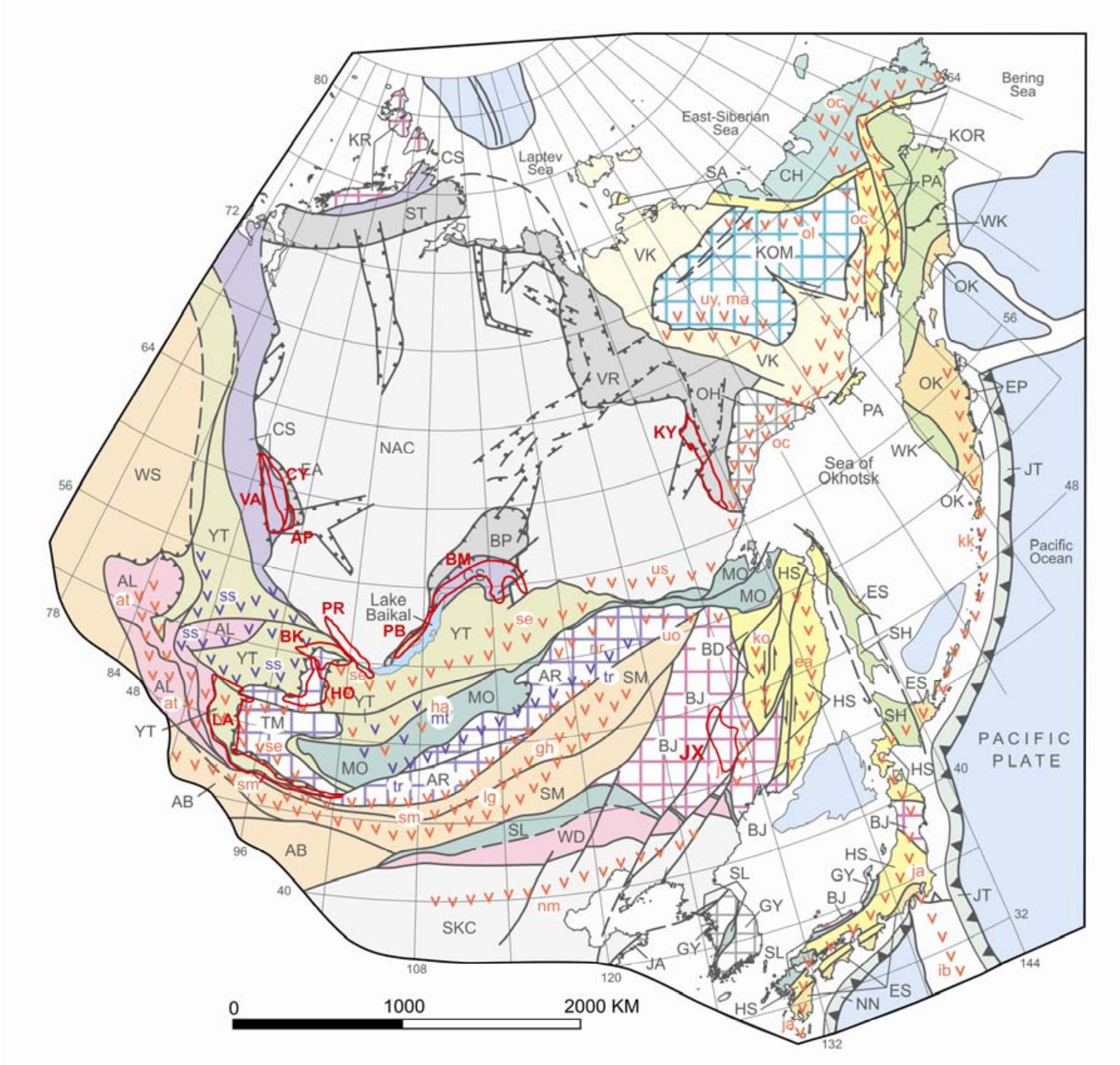

Figure 6. Generalized map of major Neoproterozoic metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

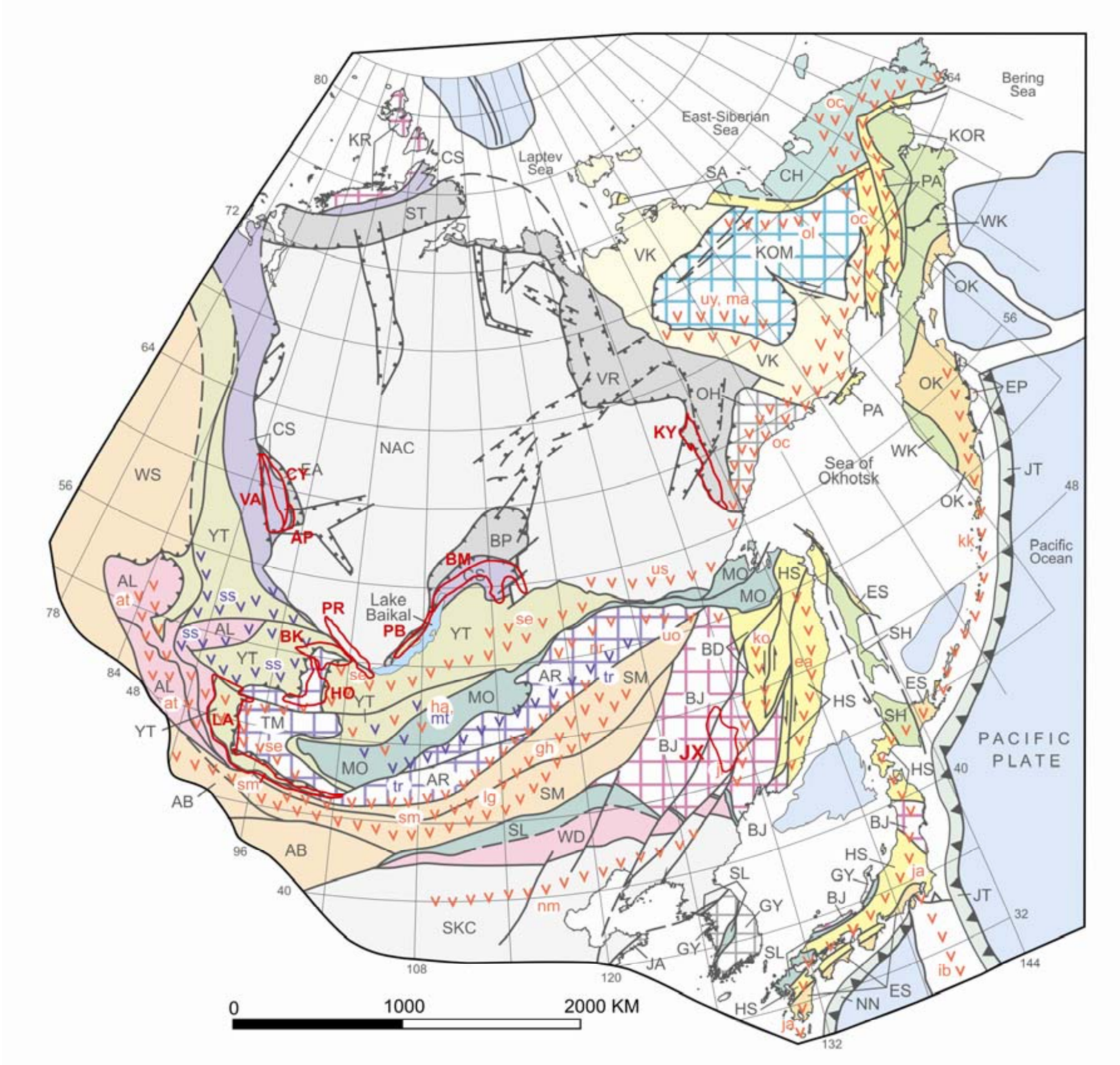

Figure 7. Generalized map of major Cambrian through Silurian metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

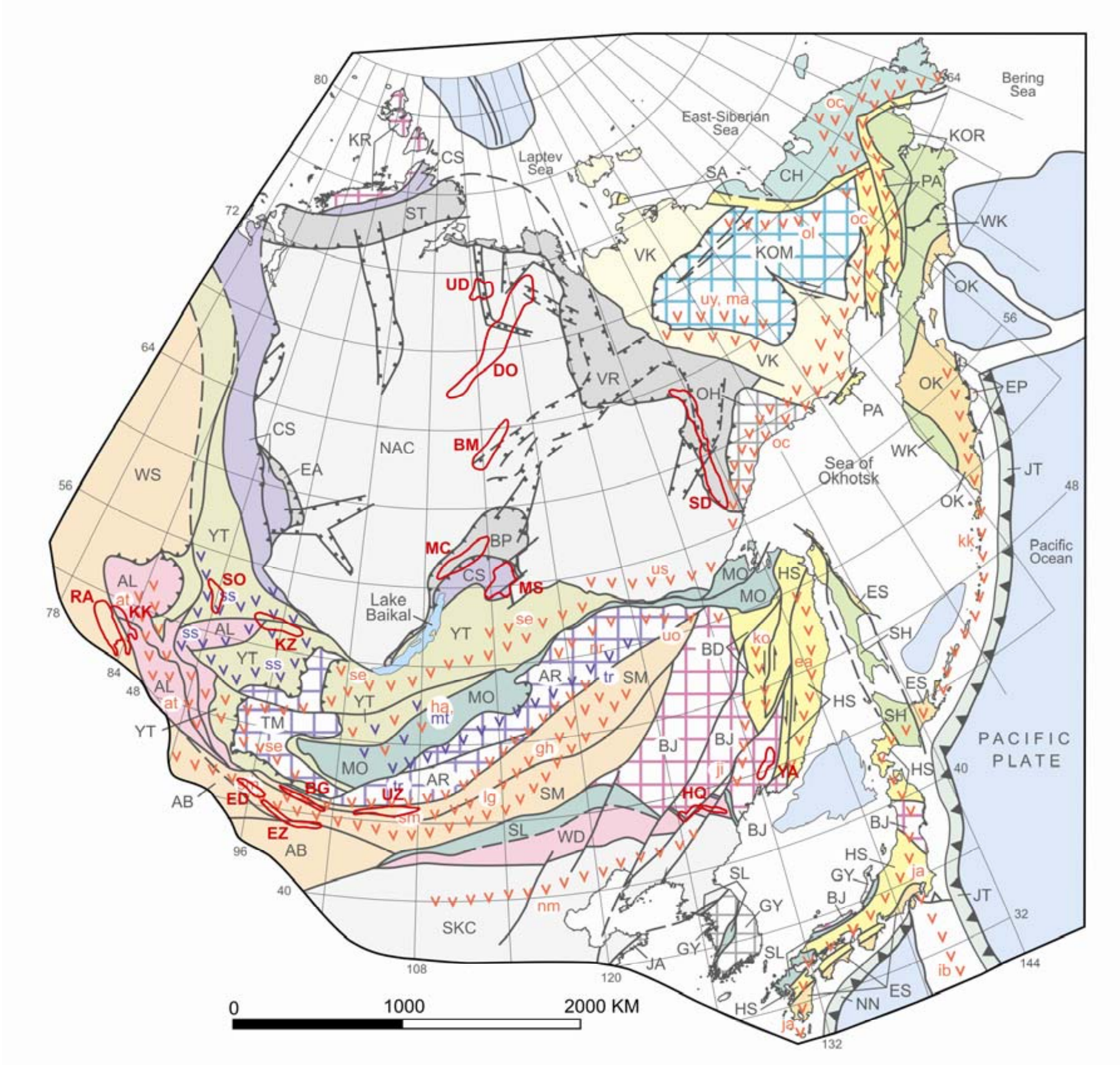

Figure 8. Generalized map of major Devonian through Early Carboniferous metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

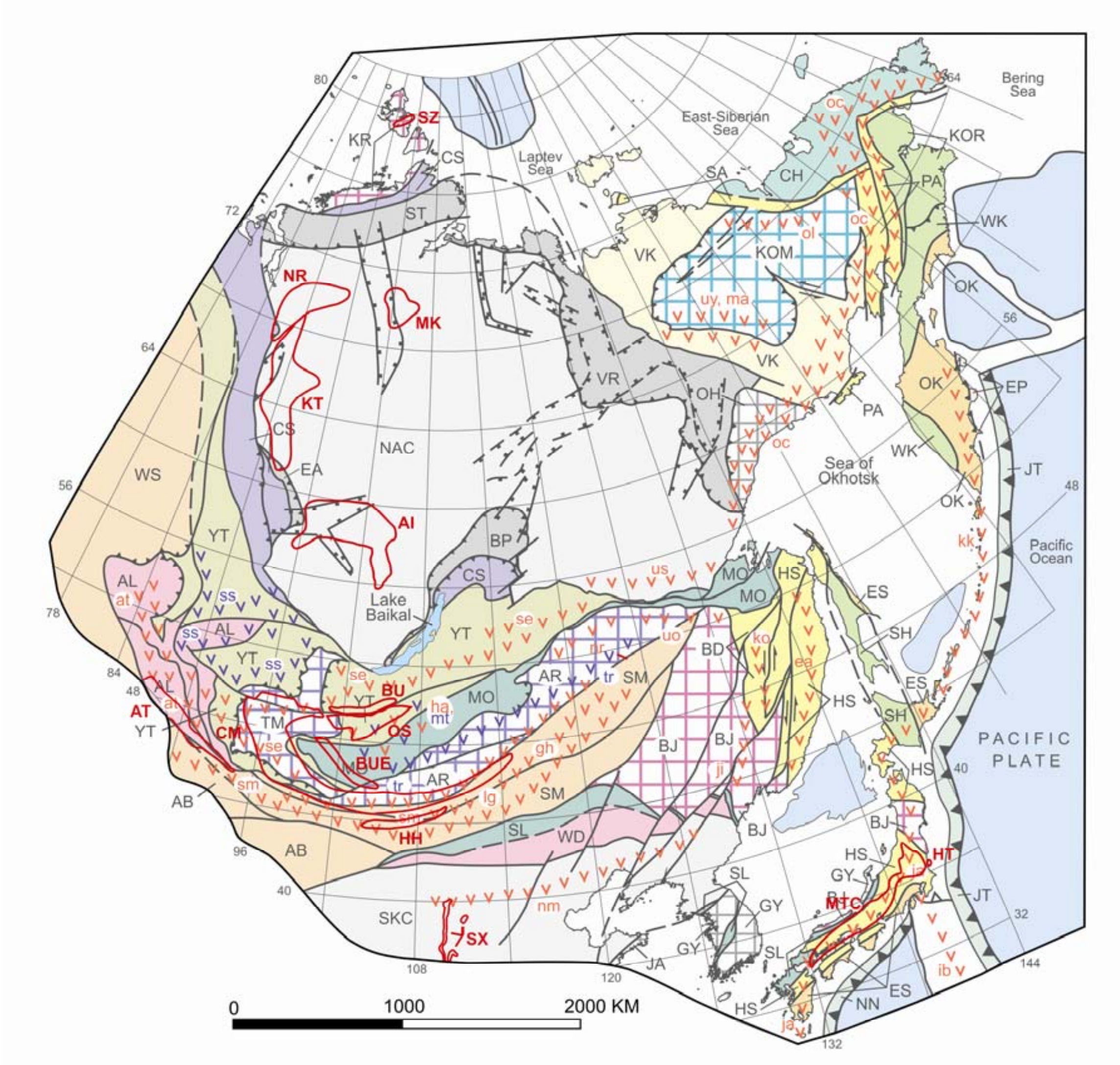

Figure 9. Generalized map of major Late Carboniferous through Middle Triassic metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

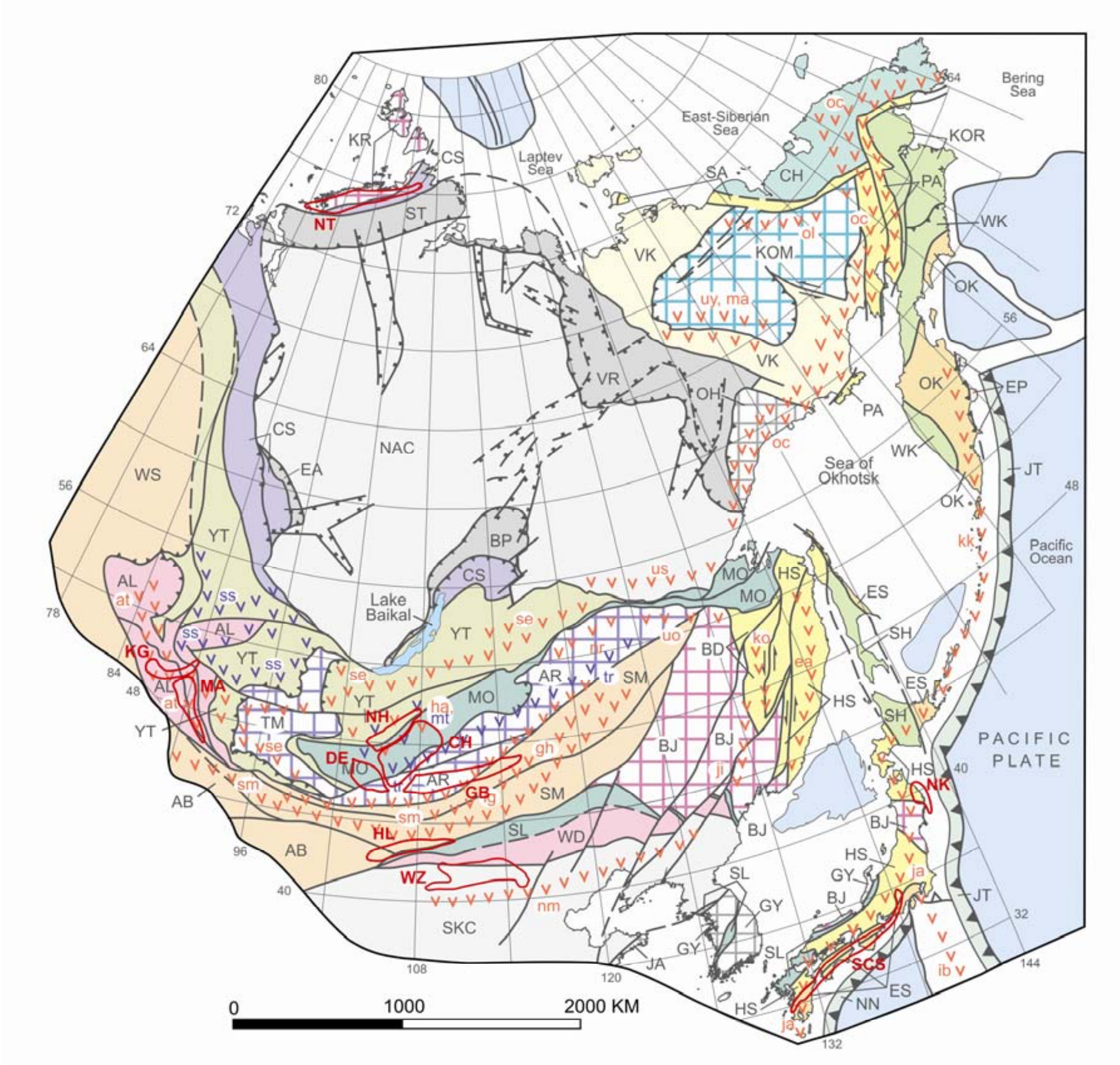

Figure 10. Generalized map of major Late Triassic through Early Jurassic metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

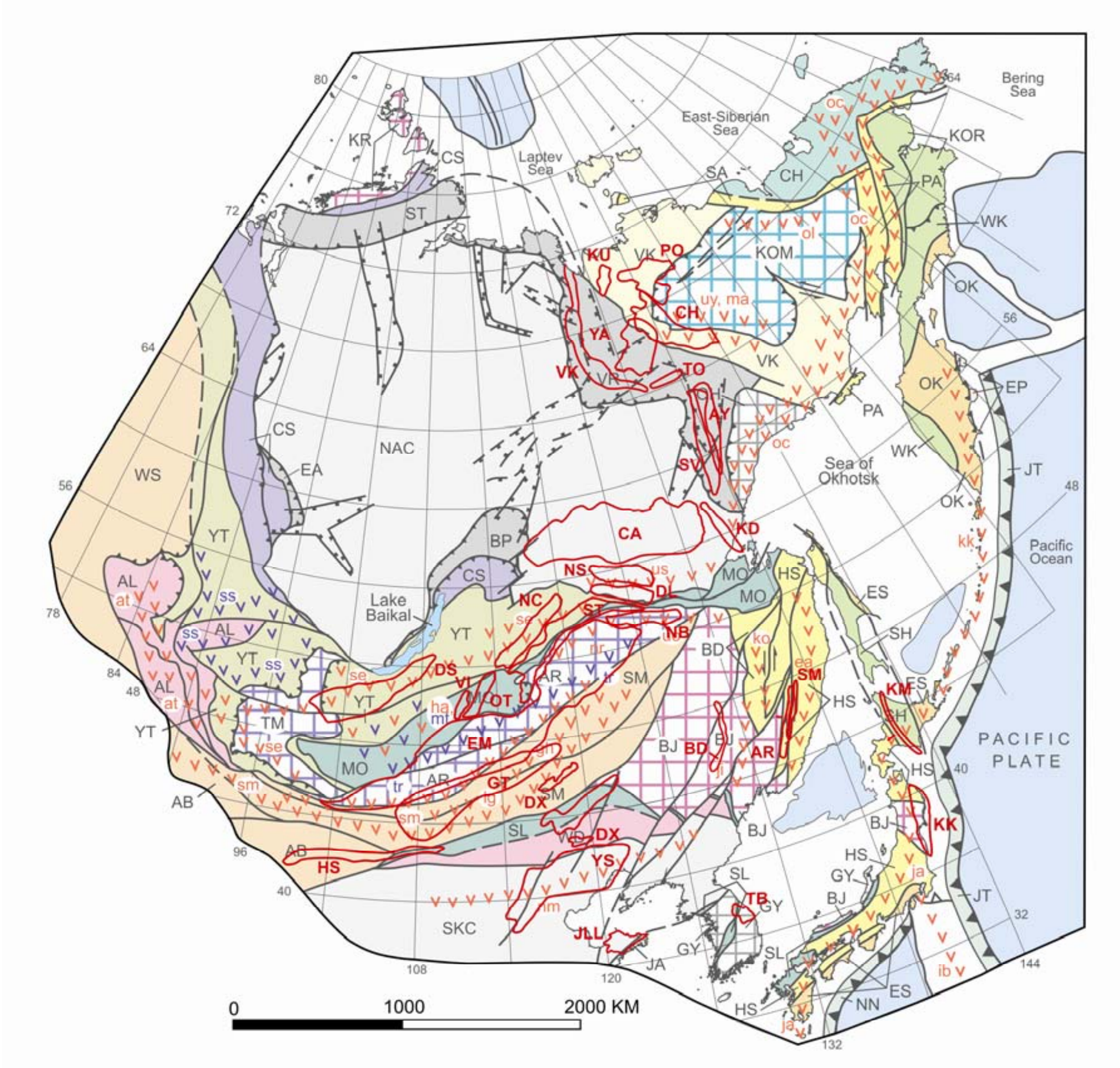

Figure 11. Generalized map of major Middle Jurassic through Early Cretaceous metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

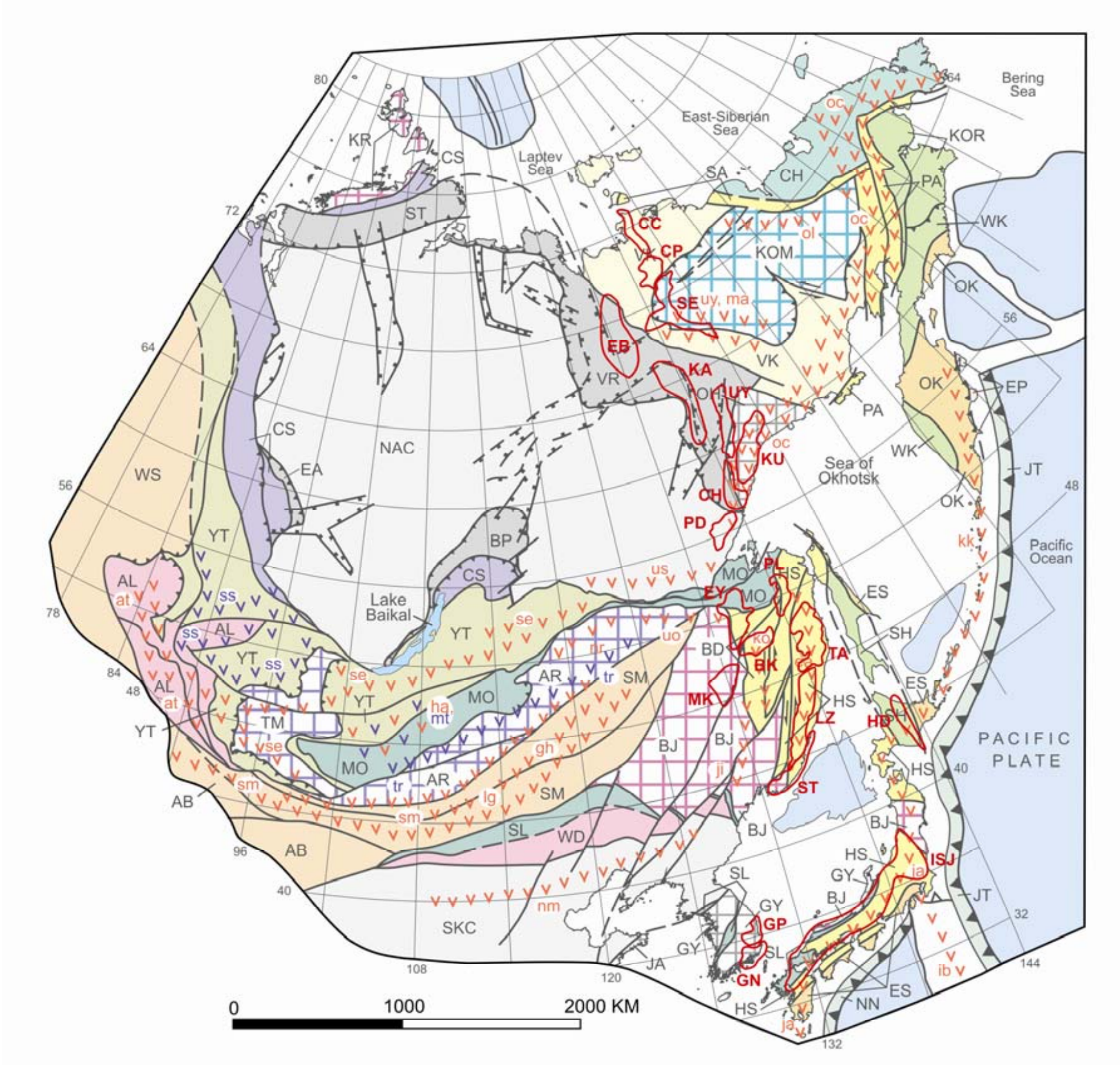

Figure 12. Generalized map of major Cenomanian through Campanian metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

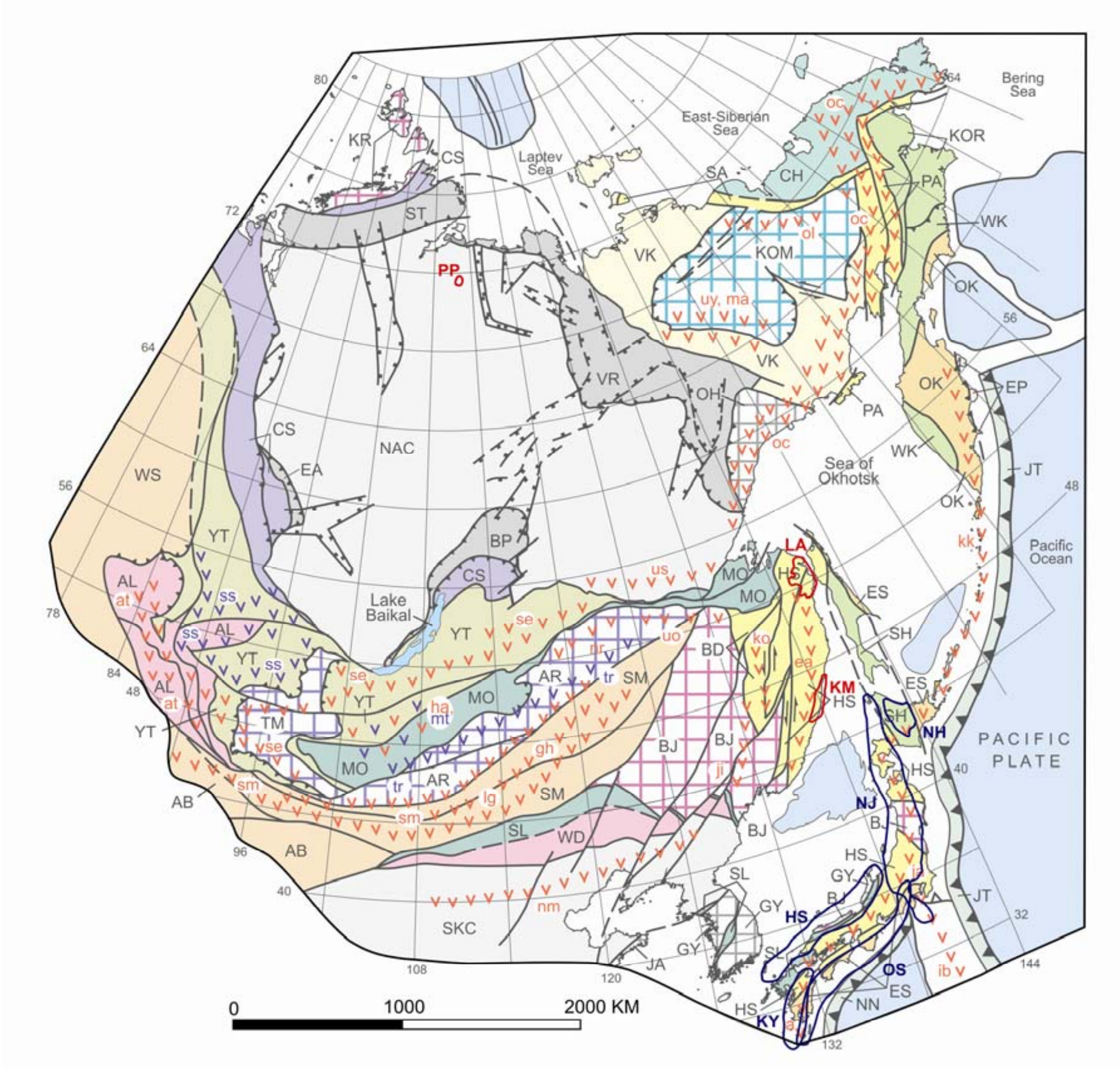

Figure 13. Generalized map of major Maastrichtian through Quaternary metallogenic belts and major geologic units for Northeast Asia. Refer to text and Appendix C for summary descriptions of belts. Refer to figure 2 for explanation of geologic units. Metallogenic belt outlines adapted from Obolenskiy and others (2003, 2004) and Parfenov and others (2003, 2004). Metallogenic belts for area to east of 144 E (eastern boundary of Northeast Asia project area) are described and interpreted by Nokleberg and others (2003).

Table 1. Definitions of key terms for analysis of regional geology and metallogenesis. Adapted from Howell and others (1985), Jones and others (1983), Nokleberg and others (2000, 2005), or cited references.

Term	Definition
Accretion	Tectonic juxtaposition of terranes to a craton or continental margin. Accretion of terranes to one another or to a craton margin also defines a major change in the tectonic evolution of terranes and craton margins.
Accretionary-wedge terrane	Fragment of a mildly to intensely deformed complex consisting of varying amounts of turbidite deposits, continental-margin rocks, oceanic crust and overlying units, and oceanic mantle. Units are interpreted to have formed during tectonic juxtaposition in a zone of major thrusting of one lithosphere plate beneath another, generally in zones of thrusting along the margin of a continent or an island arc. May include large fault-bounded fragments with a coherent stratigraphy. Many subduction-zone terranes contain fragments of oceanic crust and associated rocks that exhibit a complex structural history, occur in a major thrust zone, and possess blueschist-facies metamorphism.
Amalgamation	Tectonic juxtaposition of two or more terranes before accretion to a continental margin.
Craton	Chiefly regionally metamorphosed and deformed shield assemblages of Archean and Early Proterozoic sedimentary, volcanic, and plutonic rocks, and overlying platform successions of Late Proterozoic, Paleozoic, and local Mesozoic and Cenozoic sedimentary and lesser volcanic rocks.
Continent	A large section of continental crust surrounded by oceans on all sides, which consist, in its core, of one or more cratons framed by younger tectonic collages (accretionary and collisional orogenic belts).
Continental-margin arc terrane	Fragment of an igneous belt of coeval plutonic and volcanic rocks and associated sedimentary rocks that formed above a subduction zone dipping beneath a continent. Inferred to possess a sialic basement.
Craton	Chiefly regionally metamorphosed and deformed shield assemblages of Archean, Paleoproterozoic, and Mesoproterozoic sedimentary, volcanic, and plutonic rocks, and overlying platform successions of Paleoproterozoic, Paleozoic, and local Mesozoic and Cenozoic sedimentary and lesser volcanic rock.
Craton margin	Chiefly Neoproterozoic to Jurassic sedimentary rocks deposited on a continental shelf or slope. Consists mainly of platform successions. Locally has, or may have had an Archean and Early Proterozoic cratonal basement.
Cratonal terrane	Fragment of a craton.
Island-arc system	An island arc and tectonically linked subduction zone terranes.
Island-arc terrane	Fragment of an igneous belt of plutonic rocks, coeval volcanic rocks, and associated sedimentary rocks that formed above an oceanic subduction zone. Inferred to possess a simatic basement.
Metallogenic belt	A geologic unit (area) that either contains or is favorable for a group of coeval and genetically-related, significant lode and placer deposit models. A metallogenic belt has the following characteristics: (1) is favorable for known or inferred mineral deposits of specific type or type; (2) may be irregular in shape and variable in size; (3) need not contain known deposits; and (4) is based on a geologic map as the primary source of information for delineation of areas that are favorable for specific deposit models. An essential part of the definition is that a belt is defined as the geologically-favorable area for a group of coeval and genetically-related mineral deposit models. This definition provides a predictive character for undiscovered deposits in each belt.
Metamorphic terrane	Fragment of a highly metamorphosed or deformed assemblage of sedimentary, volcanic, or plutonic rocks that cannot be assigned to a single tectonic environment because the original stratigraphy and structure are obscured. Includes intensely deformed structural melanges that contain intensely deformed fragments of two or more terranes.
Mine	A site where valuable minerals have been extracted.
Mineral deposit	A site where concentrations of potentially valuable minerals for which grade and tonnage estimates have been made. In this study, also used as a general term for any mineral deposit, mineral occurrence, or prospect.
Mineral occurrence	A site of potentially valuable minerals on which no visible exploration has occurred, or for

	which no grade and tonnage estimates have been made.
Oceanic crust, seamount, and ophiolite terrane	Fragment of part or all of a suite of deep-marine sedimentary rocks, pillow basalt, gabbro, and ultramafic rocks (former eugeoclinal suite) that are interpreted as oceanic sedimentary and volcanic rocks and the upper mantle. Includes both inferred offshore oceanic and marginal ocean basin rocks, minor volcaniclastic rocks of magmatic-arc derivation, and major marine volcanic accumulations formed at a hotspot, fracture zone, or spreading axis.
Overlap Assemblage	A postaccretion unit of sedimentary or igneous rocks deposited on, or intruded into, two or more adjacent terranes.
Passive continental-margin terrane	Fragment of a craton (continental) margin.
Subduction zone terrane	Fragment of a mildly to intensely deformed complex consisting of varying amounts of turbidite deposits, continental-margin rocks, oceanic crust and overlying units, and oceanic mantle. Units are interpreted to have formed during tectonic juxtaposition in a zone of major thrusting of one lithosphere plate beneath another, generally in zones of thrusting along the margin of a continent or an island arc. May include large fault-bounded fragments with a coherent stratigraphy. Many subduction-zone terranes contain fragments of oceanic crust and associated rocks that exhibit a complex structural history, occur in a major thrust zone, and possess blueschist-facies metamorphism.
Superterrane	A fault-bounded geologic entity or fragment that is characterized by a distinctive geologic history that differs markedly from that of adjacent terranes (Jones and others, 1983; Howell and others, 1985).
Tectonic collage	A series of linear island arcs or continental margin arcs and tectonically-linked (companion) subduction zones, and (or) fore-arc and back-arc basins that formed in a major tectonic event during a relatively narrow geologic time span. The collages of igneous arcs and companion subduction zone terranes have been successively accreted to the margins of major cratons. The ages of collages with subduction zone units are for time of active formation of an accretionary wedge in a subduction zone, rather than the older range of units that comprise the accretionary wedge. A few collages consist of fragments of craton margin and cratonal terranes that were amalgamated before accretion to a continent.
Tectonic linkage	A genetic relation of a continental margin arc or an island arc with a companion accretionary wedge that formed in a subduction zone that was adjacent to, and was underthrusting the arc.
Tectonostratigraphic terrane (terrane)	An aggregate of terranes that is interpreted to share either a similar stratigraphic kindred or affinity, or a common geologic history after accretion (Jones and others, 1983; Howell and others, 1985). An approximate synonym is composite terrane (Plafker and Berg, 1994).
Turbidite terrane	Fragment of a basin filled with deep-marine clastic deposits in either an orogenic forearc or back-arc setting. May include continental-slope and continental-rise turbidite deposits, and submarine-fan turbidite deposits deposited on oceanic crust. May include minor epiclastic and volcaniclastic deposits.

Table 2. List of lode mineral deposit models employed for metallogenic analysis of Northeast Asia. Adapted from Obolenskiy and others (2003, this volume).

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

	Ni-Co arsenide vein
	Silica-carbonate (listvenite) Hg
	Trap related Fe skarn (Angara-Ilim type)
	Au-Ag epithermal vein
	Ag-Pb epithermal vein
	Au potassium metasomatite (Kuranakh type)
	Barite vein
	Be tuff
	Carbonate-hosted As-Au metasomatite
	Carbonate-hosted fluorspar
	Carbonate-hosted Hg-Sb
	Clastic sediment-hosted Hg±Sb
	Epithermal quartz-alunite
	Fluorspar vein
	Hydrothermal-sedimentary fluorite
	Limonite
	Mn vein
	Polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite
	Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite
	Rhyolite-hosted Sn
	Sulfur-sulfide (S, FeS_2)
	Volcanic-hosted Au-base-metal metasomatite
	Volcanic-hosted Hg
	Volcanic-hosted U
	Volcanic-hosted zeolite
Deposits related to hydrothermal-sedimentary	Bedded barite
sedimentary processes	Carbonate-hosted Pb-Zn (Mississippi valley type)
	Sediment-hosted Cu
	Sedimentary exhalative Pb-Zn (SEDEX)
	Chemical-sedimentary Fe-Mn
	Evaporate halite
	Evaporate sedimentary gypsum
	Sedimentary bauxite
	Sedimentary celestite
	Sedimentary phosphate
	Sedimentary Fe-V
	Sedimentary siderite Fe
	Stratiform Zr (Algama Type)
	Polygenic REE-Fe-Nb deposits (Bayan-Obo type)
Deposits related to metamorphic processes	Banded iron formation (BIF, Algoma Fe)
	Homestake Au
	Sedimentary-metamorphic borate
	Sedimentary-metamorphic magnesite
	Au in black shale
	Au in shear zone and quartz vein
	Clastic-sediment-hosted Sb-Au
	Cu-Ag vein
	Piezoquartz
	Rhodusite asbestos
	Talc (magnesite) replacement
	Metamorphic graphite
	Metamorphic sillimanite
	Phlogopite skarn

Deposits related to surficial proceses	Bauxite (karst type) Laterite Ni Weathering crust Mn (±Fe) Weathering crust and karst phosphate Weathering crust carbonatite REE-Zr-Nb-Li Placer and paleoplacer Au Placer diamond Placer PGE Placer Sn Placer Ti-Zr REE and Fe oolite
Exotic deposits	Impact diamond

Table 3. Summary of major areas, major tectonic environments (events), and associated major lode mineral deposit models. Derived from metallogenic analyses of Northeast Asia, the Russian Far East, Alaska, and the Canadian Cordillera. Adapted from Nokleberg and others (2003), Scotese and others (2001), and Rodionov and others (2004).

Areas	Tectonic Environment(s) (Event)	Major Mineral Deposit Models
Northeast Asia and North American Cratons and Craton Margins	Rifting	Sedimentary-exhalative Zn-Pb, polygenic REE, Cyprus massive sulfide, volcanogenic massive sulfide, carbonate-hosted sulfide.
Ocean	Sea-floor spreading	Cyprus massive sulfide, volcanogenic massive sulfide, podiform chromite.
North Asian and North American continental margins	Continental-margin arc and back-arc	Porphyry, epithermal vein, polymetallic vein, skarn, greisen, pegmatite, volcanogenic massive sulfide, Besshi massive sulfide.
Ocean	Island arc and back-arc	Porphyry, epithermal vein, polymetallic vein, granitoid-related Au vein, skarn, zoned mafic-ultramafic Cr-PGE, mafic-ultramafic related Cu-Ni-PGE.
North Asian and North American continental margins	Collision	Low-sulfide Au quartz vein, granitoid-related Au, porphyry, skarn, Au in black shale.
North Asian and North American continental margins	Transform-continental margin faulting and associated bimodal volcanic-plutonic belt	Zoned mafic-ultramafic PGE, Cr, and Ti; W skarn, porphyry Cu-Mo, Au-Ag epithermal vein, Au quartz vein, basaltic copper, Cu-Ag quartz vein.
North Asian and North American cratons	Plume intrusion	Mafic-ultramafic related Cu-Ni-PGE, Fe-Ti and REE carbonatite, skarn, metamorphic graphite, diamond-bearing kimberlite, porphyry, pegmatite,