Metallogenesis and Tectonics of Northeast Asia
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Chapter 3

Mineral-Deposit Models for Northeast Asia

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Introduction

Metalliferous and selected nonmetalliferous lode and placer deposits of Northeast Asia (Eastern Russia, Mongolia, northern China, South Korea, and Japan) are herein classified into various models or types because of the complex array of mineral-deposit models in the region that are not fully described in the current literature. The mineral-deposit models used in this chapter are based on both descriptive and genetic information that is systematically arranged to describe the essential properties of a given class of deposits. Some types are descriptive whereby the various attributes are recognized as essential even though their relations are unknown, for example basaltic Cu in which the empirical datum of a geologic association of Cu sulfides with relatively Cu rich metabasalt or greenstone is the essential attribute; other types are genetic (theoretical) whereby attributes are related through some fundamental concept, for example W skarn in which the process of contact metasomatism is the genetic attribute. For additional information on the methodology of mineral-deposit models, see the discussions by Eckstrand (1984) and Cox and Singer (1986).

We use three main principles are utilized for classifying mineral deposits: (1) ore-forming processes are closely related to rock-forming processes, and mineral deposits originate as a result of mineral mass differentiation under their constant circulation in sedimentary, magmatic, and metamorphic cycles of the formation of rocks and geologic structures; (2) the classification must be understandable for the user; and (3) the classification must be open, so that new mineral deposit types can be added in the future.

The mineral-deposit models used in this volume are subdivided into four large groups according to major geologic rock-forming processes: (1) deposits related to magmatic processes; (2) deposits related to hydrothermal-sedimentary processes; (3) deposits related to metamorphic processes; and (4) deposits related to surficial processes. A separate group of exotic ore-forming processes is also defined. Each group includes several classes; for example, the group of deposits related to magmatic processes includes two classes: (1) those related to intrusive rocks; and (2) those related to extrusive rocks. The most detailed subdivisions are for deposits related to magmatic processes because they are the most abundant in the region. In this classification, lode deposit models that share a similar origin, such as magnesian and (or) calcic skarn or porphyry deposits, are grouped together under a single genus with several types (or species) within the genus.

This chaper was prepared by a large group of Russian, Chinese, Mongolian, South Korean, Japanese, and U.S. geologists who are members of a joint international project on Major Mineral Deposits, Metallogenesis, and Tectonics of Northeast Asia conducted by the Russian Academy of Sciences, the Mongolian Academy of Sciences, the Mongolian

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National University, the Mongolian Technical University, the Mineral Resources Authority of Mongolia, the Geological Research Institute, Jilin University, the China Geological Survey, the Korea Institute of Geoscience and Mineral Resources, the Geological Survey of Japan, and the U.S. Geological Survey. More information about major goals and all publications produced by the project is contained in the introduction to this volume (see chap. 1). The major publications for this project are: (1) a compilation of significant metalliferous and selected nonmetalliferous lode deposits and selected placer districts in Northeast Asia (Ariunbileg and others, 2003); (2) a series of mineral-deposit location and metallogenic-belt maps of Northeast Asia (Obolenskiy and others, 2003a,b, 2004; Nokleberg and others, 2004); (3) a description of the metallogenic belts in Northeast Asia (Rodionov and others, 2004); and (4) a Geographic Information Systems (GIS) spatial data compilation of all these maps, descriptions, and databases (Naumova and others, 2006). A summary of the major publications of this project is posted on the World WideWeb at URL: http://pubs.usgs.gov/of/2006/1150/PROJMAT/RFE-Ak-Can_Cord_Proj_Pamph.doc and provided in Appendix A.

Classification of Mineral Deposits

Three main principles are utilized for classifying mineral deposits in this study: (1) ore-forming processes are closely related to rock forming processes (Obruchev, 1928), and so mineral deposits originate as thae result of mineral mass differentiation under their constant circulation in sedimentary, magmatic, and metamorphic cycles of formation of rocks and geological structures (Smirnov, 1969); (2) the classification must be understandable for the user; and (3) the classification must be open, so that new mineral-deposit types can be added in the future (Cox and Singer, 1986).

The classification below is a further development of the mineral deposit classifications by Smirnov (1969), Eckstrand (1984), Cox and Singer (1986), Kirkham (1993), and Nokleberg and others (1997). In Smirnov (1969)'s classification, the mineral deposits are grouped into six hierarchical levels of metallogenic taxons, according to such stable features as: (1) environment of formation of host and genetically-related rocks, (2) genetic features of the deposit, and (3) mineral and (or) elemental composition of the ore. The six hierarchical levels are as follows.

1. Group of deposits.
    2. Class of deposits.
        3. Clan of deposits.
            4. Family of deposits.
                5. Genus of deposits.
                    6. The deposit types (models).

A hierarchial ranking of mineral deposit models according to these levels is listed in table 1; for simplicity, this classification in this table omits the family and genus levels.

The mineral-deposit models used in this volume (table 1) are subdivided into four groups, according to major geologic rock-forming processes: (1) deposits related to magmatic processes; (2) deposits related to hydrothermal-sedimentary processes; (3) deposits related to metamorphic processes; and (4) deposits related to surficial processes. A separate group of exotic ore-forming processes is also defined. Each group includes several classes. For example, the group of deposits related to magmatic processes includes two classes: (1) those related to intrusive rocks; and (2) those related to extrusive rocks; each class includes several clans and so on. The most detailed subdivisions are for deposits related to magmatic processes because they are the most abundant type in the region. In the classification below, lode deposit types that share a similar origin, such as magnesian and (or) calcic skarn, or porphyry deposits, are grouped together under a single genus with several types (or species) within the genus.

Some of the mineral-deposit models below differ from the published descriptions; for example, the Bayan Obo deposit was described previously as carbonatite-related. However, modern isotopic, mineralogic, and geologic data recently obtained by Chinese geologists have resulted in a new interpretation of the origin of this deposit. These new data indicate that the Bayan Obo deposit consists of minerals which formed during Mesoproterozoic sedimentary-exhalative (*SEDEX*) processes, along with coeval metasomatic activity, and sedimentary diagenesis of dolomite, and alteration. The SEDEX process consisted of both sedimentation and metasomatism. Later deformation, especially during the Caledonian orogeny, further enriched the ore. Thus, the Bayan Obo mineral-deposit type is herein described as related to SEDEX processes, not to magmatic processes, although magmatic processes also played an important role in deposit formation. Consequently, this deposit model is part of the family of polygenetic carbonate-hosted deposits. Similar revisions were made for carbonate-hosted Hg-Sb and other mineral-deposit models.

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text.

- Deposits related to magmatic processes
  - Deposits related to intrusive magmatic rocks
    - I. Deposits related to mafic and ultramafic intrusions
      - A. Deposits associated with rift related differentiated mafic-ultramafic complexes
        - Mafic-ultramafic-related Cu-Ni-PGE
        - Mafic-ultramafic-related Ti-Fe(±V)
        - Zoned mafic-ultramafic Cr-PGE
      - B. Deposits associated with ophiolitic complexes
        - Podiform chromite
        - Serpentinite-hosted asbestos
      - C. Deposits associated with anorthosite complexes
        - Anorthosite Ti-Fe-P-apatite
      - D. Deposits associated with kimberlite
        - Diamond-bearing kimberlite
    - II. Deposits related to intermediate-composition and felsic intrusions
      - A. Pegmatite
        - Muscovite pegmatite
        - REE-Li pegmatite
      - B. Greisen and quartz vein
        - Fluorite greisen
        - Sn-W greisen, stockwork, and quartz vein
        - W-Mo-Be greisen, stockwork, and quartz vein
      - C. Alkaline metasomatite
        - Ta-Nb-REE alkaline metasomatite
      - D. Skarn (contact metasomatic)
        - Au skarn
        - B (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, W) skarn
      - E. Porphyry and granitoid pluton-hosted deposit
        - 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

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text. —Continued

- III. Deposits related to alkaline intrusions
  - A. Carbonatite-related deposits
    - Apatite carbonatite
    - Fe-REE carbonatite
    - Fe-Ti(±Ta, Nb, Cu, apatite) carbonatite
    - Phlogopite carbonatite
    - REE (±Ta, Nb, Fe) carbonatite
  - B. Alkaline-silicic intrusion-related deposits
    - Alkaline complex-hosted Au
    - Peralkaline granitoid-related Nb-Zr-REE
    - Albite syenite-related REE
    - Ta-Li ongonite
  - C. Alkaline-gabbroic intrusion-related deposits
    - Charoite metasomatite
    - Magmatic and metasomatic apatite
    - Magmatic graphite
    - Magmatic nepheline

Deposits related to extrusive rocks

- IV. Deposits related to marine extrusive rocks
  - A. Massive sulfide deposits
    - Besshi Cu-Zn-Ag massive sulfide
    - Cyprus Cu-Zn massive sulfide
    - Volcanogenic Cu-Zn massive sulfide (Urals type)
    - Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types)
  - B. Volcanogenic-sedimentary deposits
    - Volcanogenic-hydrothermal-sedimentary Pb-Zn (±Cu) massive sulfide
    - Volcanogenic-sedimentary Fe
    - Volcanogenic-sedimentary Mn
- V. Deposits related to subaerial extrusive rocks
  - A. Deposits associated with mafic extrusive rocks and dike complexes
    - Ag-Sb vein
    - Basaltic native Cu (Lake Superior type)
    - Hg-Sb-W vein and stockwork
    - Hydrothermal Iceland spar
    - Ni-Co arsenide vein
    - Silica-carbonate (listvinite) Hg
    - Trapp-related Fe skarn (Angara-Ilim type)
  - B. Deposits associated with felsic to intermediate-composition extrusive rocks
    - Au-Ag epithermal vein

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text. —Continued

			Ag-Pb epithermal vein
			Au K 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 processes			
	VI. Stratiform and stratabound deposits		
		Bedded barite	
		Carbonate-hosted Pb-Zn (Mississippi Valley type)	
		Sediment-hosted Cu	
		Sedimentary exhalative (SEDEX) Pb-Zn	
		Korean Pb-Zn massive sulfide	
	VII. Sedimentary rock-hosted deposits		
		Chemical-sedimentary Fe-Mn	
		Evaporate halite	
		Evaporate sedimentary gypsum	
		Sedimentary bauxite	
		Sedimentary celestite	
		Sedimentary phosphate	
		Sedimentary Fe-V	
		Sedimentary Fe-siderite	
		Stratiform Zr (Algama type)	
	VIII. Polygenic carbonate-hosted deposits		
		Polygenic REE-Fe-Nb (Bayan-Obo type)	
Deposits related to metamorphic processes			

Table 1. Hierarchical ranking of mineral deposit models according to hierarchial levels discussed in text. —Continued

	IX. Sedimentary-metamorphic deposits	
		Banded iron-formation (Algoma type)
		Banded iron-formation (Superior type)
		Homestake Au
		Sedimentary-metamorphic borate
		Sedimentary-metamorphic magnesite
	X. Deposits related to regionally metamorphosed rocks	
		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		
	XI. Residual deposts	
		Bauxite (karst type)
		Laterite Ni
		Weathering-crust Mn (±Fe)
		Weathering-crust and karst phosphate
		Weathering-crust REE-Zr-Nb-Li carbonatite
	XII. The depositional deposits	
		Placer and paleoplacer Au
		Placer diamond
		Placer PGE
		Placer Sn
		Placer Ti-Zr
Exotic deposits		
	Impact diamond	

Deposits Related to Intrusive Magmatic Rocks

I. Deposits Related to Mafic and Ultramafic Intrusions

A. Deposits Associated with Rift-related Differentiated Mafic-Ultramafic Complexes

Mafic-Ultramafic-Related Cu-Ni-PGE (Eckstrand, 1984; Page, 1986c; Dyuzhikov and others, 1988)

Mafic-ultramafic-related Cu-Ni-PGE deposits consist of magmatic Cu-Ni sulfide deposits in differentiated layered mafic-ultramafic intrusions that generally occur in a cratonic setting commonly in association with intracontinental rifts and flood basalts. Mafic and ultramafic phases of layered intrusive complexes include peridotite, pyroxenite, gabbro, norite, picrite, troctolite, gabbro, and diabase. The deposits may occur either in the footwall below the main intrusion or near the bottom of the intrusion. Conformable layers or lenses commonly occur in a local depression or embayment, at or near the base of the host intrusion. Minerals are massive sulfides, sulfide-matrix breccias, interstitial sulfide networks, and disseminated sulfides. In well-preserved deposits, the rich areas of deposit minerals occur close to the base, and are overlain by sparse disseminated sulfides. Sulfide veins and dissemination commonly penetrate footwallrocks. Minerals are complex, contain Ni and Cu along with PGE, Co, Se, Te, and Au, and include pentlandite, chalcopyrite, cubanite, millerite, pyrrhotite, various PGE minerals, pyrite, sphalerite, and marcasite in association with plagioclase, hypersthene, augite, olivine, hornblende, biotite, quartz, and a variety of alteration minerals. The main deposit minerals are syngenetic with the host intrusions. The depositional environment consisted of emplacement of multiple ore-bearing mafic magmas (probably mantle derived) in upper-crustal levels in tensional environments associated with rifting. Contamination of the magma was an important factor for sulfur saturation and formation of a sulfide phase. Examples of this mineral-deposit type are Norilsk I and II (fig. 1) and Talnakh, Russia; and Hongqiling, Jilin Province, China, Kalatongke; and Xinjiang, China.

Mafic-Ultramafic Related Ti-Fe ($\pm$V) (Lee and others, 1965; Eckstrand, 1984; Page, 1986a; Sinyakov, 1988)

Mafic-ultramafic related Ti-Fe (+V) deposits consist of layers and lenses, and disseminated titanomagnetite or V-magnetite, with minor amount of ilmenite and chromite, in differentiated gabbroic intrusions. Host rocks are mainly

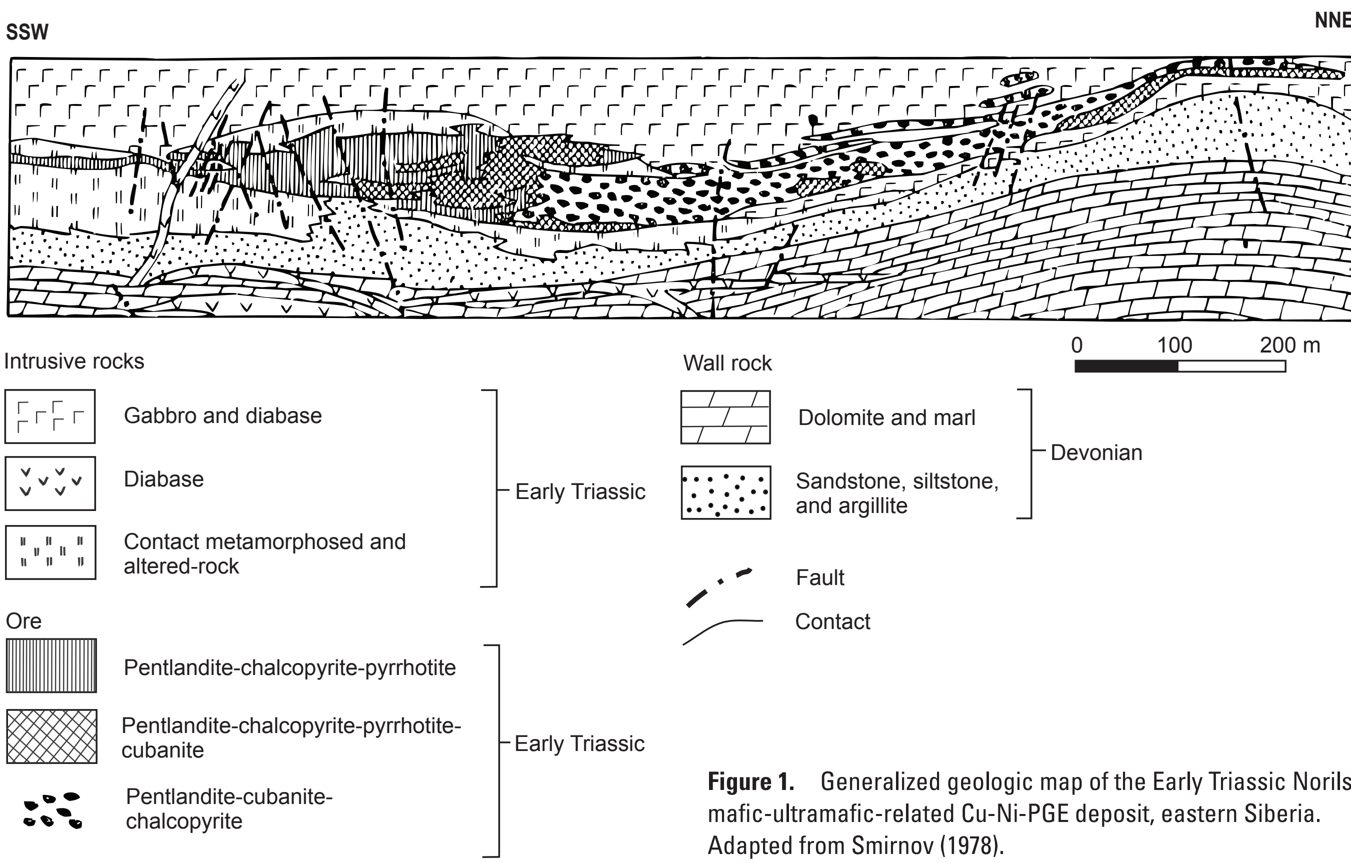


Figure 1. Generalized geologic map of the Early Triassic Norilsk mafic-ultramafic-related Cu-Ni-PGE deposit, eastern Siberia. Adapted from Smirnov (1978).

norite, gabbronorite, dunite, harzburgite, peridotite, pyroxenite, troctolite, anorthosite, gabbro, and diabase. The deposit minerals occur near the tops of intrusions as stratiform or irregular bodies consisting of disseminated and interstitial Fe-Ti-V oxide minerals. Pipes and ilmenite-rich veins may cut layers. Massive ore is generally more important economically than disseminated ore. The principal ore minerals are titanomagnetite and (or) V-magnetite; asociated minerals are ilmenite, hematite, spinel, and sulfides (pyrite, pyrrhotite, chalcopyrite). Rock-forming minerals are plagioclase, olivine, pyroxene, apatite, and sphene, as well as Fe-Ti oxide phases that formed by crystal settling or filter pressing during crystallization of anorthosite or gabbro magmas, thereby forming syngenetic layers and segregations, as well as massive oxide autointrusions in partially solidified gabbro and genetically related host rocks. The depositional environment consisted of intrusions of gabbro-anorthosite, dunite-pyroxenite-gabbroic and gabbro-diabasic magmatic associations with magmatic layering of host intrusions. Mafic-ultramafic rocks commonly intrude granitic gneiss, or volcanic-sedimentary rocks. An association exists between the ore-bearing, layered plutons and deep-fault zones. The deposits are generally Precambrian but may be as young as Tertiary. Locally, the Precambrian deposits may be highly metamorphosed with occurrence of deposits in hornblende schist as at the Soyonpyong deposit on the Korean Peninsula, where the depositional environment consisted of stratiform to irregular mafic to ultramafic plutons in continental margin or island arcs. Examples of this mineral-deposit type are Kavakta (fig. 2) and Lysanskoye, Russia, and Damiao, Hebei Province, China.

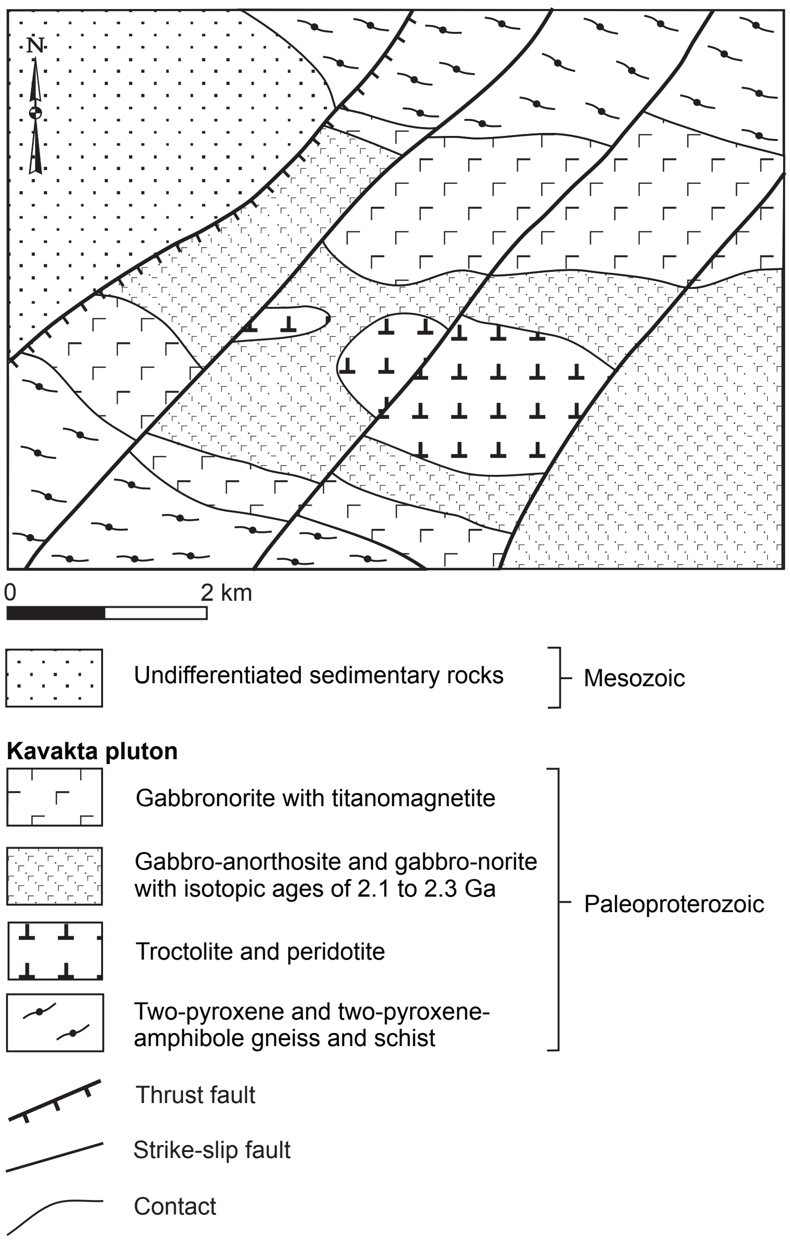


Figure 2. Generalized geologic map of the Paleoproterozoic Kavakta mafic-ultramafic related Ti-Fe(V) deposit, Yakutia, Russia. Adapted from Stogniy (1998).

Zoned Mafic-Ultramafic Cr-PGE (Page and Gray, 1986; Kosygin and Prikhod'ko, 1994; Malich, 1999)

Zoned mafic-ultramafic Cr-PGE deposits consist of zoned ultramafic to mafic plutons containing Cr and PGE minerals. The central part of the pluton is generally composed of dunite and the peripheral parts consist of pyroxenite, koswite, and rare gabbro. The zoned plutons are commonly intruded by sills and dikes of gabbro, diorite, monzonite, and various alkaline rocks. The mafic and ultramafic rocks composing the pluton, as well as the host metamorphosed sedimentary-calcareous rocks, may be locally altered to feldspar-pyroxene metasomatite and skarn. The deposit minerals in the zoned plutons are chromite, native PGE, various PGE minerals and alloys, and Ti-V-magnetite, with local accessory pentlandite, pyrrhotite, bornite, and chalcopyrite. The deposit minerals generally occur in dunite in the top-central part of the pluton. Small to large (up to 3 kg and more) platinum nuggets may occur in peripheral placer deposits. The depositional environment consisted of zoned mafic to ultramafic plutons that formed the lower parts of island-arc or continental margin arc systems. An example of this mineral-deposit type is at Kondyor, Russia (fig. 3).

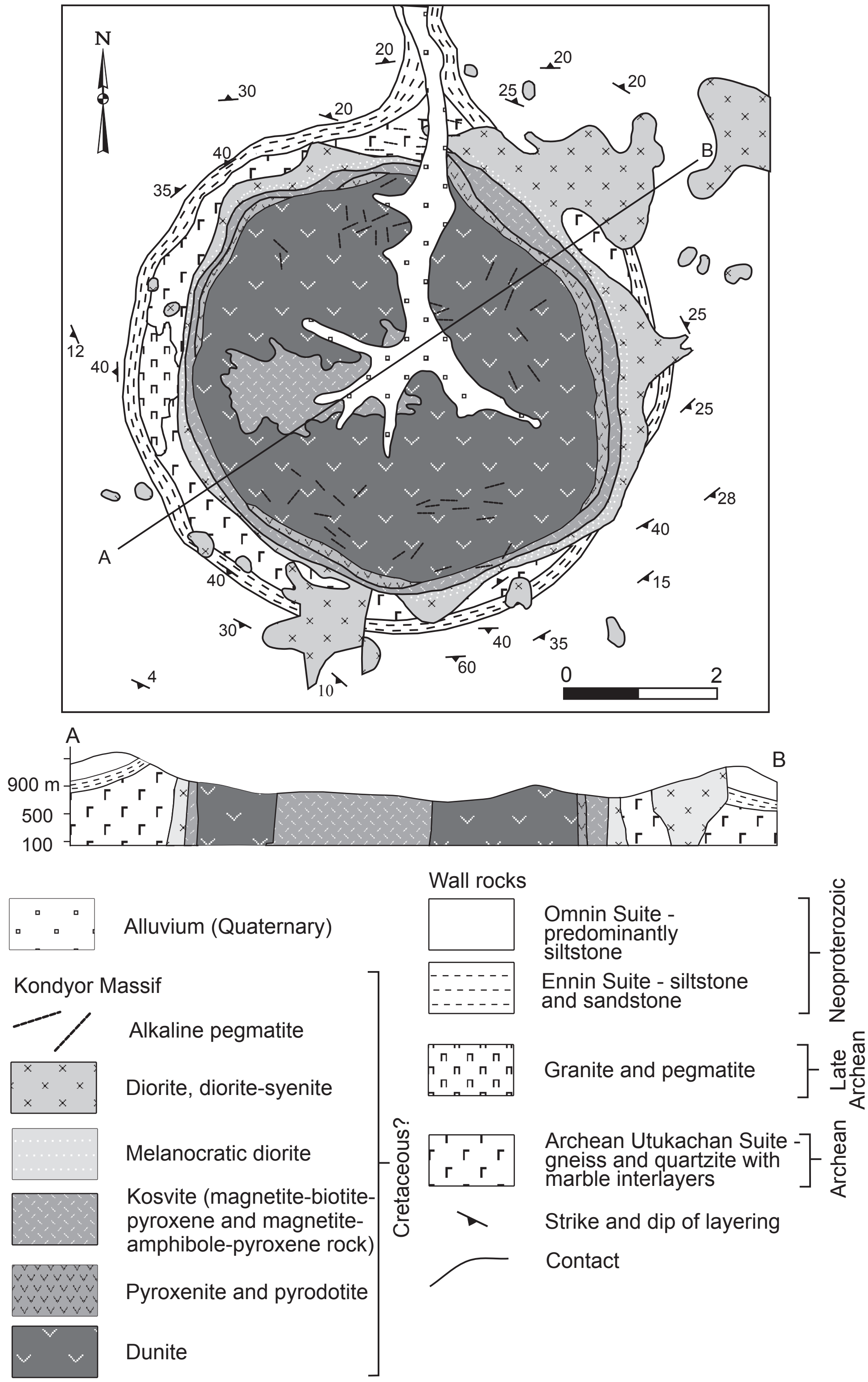


Figure 3. Generalized geologic map of the Early Cretaceous Kondyor zoned mafic-ultramafic Cr-PGE deposit, Russian Southeast. Adapted from G.V. Andreev, A.A. El'yanov, and A.N. Mil'to, written commun., 1974).

B. Deposits Associated with Ophiolitic Complexes

Podiform Chromite (Eckstrand, 1984; Albers, 1986)

Podiform chromite deposits consist of pods or lenses of chromite in the ultramafic parts of ophiolite complexes (alpine peridotites) that may locally be intensely faulted and dismembered. The host rocks are mainly dunite and harzburgite, commonly serpentinized, with local troctolite. The principal ore mineral is chromite with associated olivine, pyroxene, serpentine, magnetite, clinopyroxene, and plagioclase, as well as magnetite and PGE minerals and alloys. The deposits generally consist of lenticular bodies of massive to heavily disseminated chromite.; tabular, rod-shaped and irregular bodies may also occur. Nodular textures and foliation and banding are common. A specific deposit may consist of several individual pods, commonly in linear zones or, in some places, in echelon arrays. The depositional environment consisted of magmatic cumulates in elongate magma pockets along oceanic ridges or the basal parts of island arcs. Examples of this mineral-deposit type are Khalzan uul and Sulinheer group, Mongolia;, Hegenshan 3756, Inner Mongolia, China; and Ganbi, Japan.

Serpentinite-Hosted Asbestos (Cho and others, 1970; Zolojev, 1975; Eckstrand, 1984; Page, 1986b)

Serpentinite-hosted asbestos deposits consist of chrysotile developed in stockworks in serpentinized olivine-rich ultramafic rocks that consist mainly of harzburgite, dunite, wehrlite, and pyroxenite. The serpentinized ultramafic rocks may be locally intruded by pegmatite dikes, as in the central Korean Peninsula. Associated minerals are magnetite, brucite, talc, and tremolite. The major deposits occur in allochthonous bodies of serpentinized ophiolitic or alpine ultramafic rocks in Phanerozoic orogenic belts. The depositional environment consisted of ultramafic rocks that form the basal part of ophiolite sequences obducted onto a continental margin, or parts of a subduction-zone complex. Examples of this mineral-deposit type are Molodezhnoye and Sayanskoye, Russia, and Ikh nart, Mongolia.

C. Deposits Associated with Anorthosite Complexes

Anorthosite Ti-Fe-P-Apatite (Sang and Shin, 1981; Kosygin and Kulish, 1984; Force, 1986a; Jeong and others, 1998)

Anorthosite Ti-Fe-P-apatite deposits occur in anorthosite plutons composed of andesine and andesine-labradorite. The anorthosite plutons are highly alkalic and are associated with gabbro, ferrodiorite, syenite, alkalic granite, and, in some places, mangerite. The plutons generally intrude granulite-facies country rocks. Principal deposit minerals are apatite, titanomagnetite, and ilmenite that occur either: (1) as disseminations near melanocratic gabbro, pyroxenite, and dunite along the margins of the anorthosite pluton; or (2) as rich apatite (nelsonite) veins in tectonically weak zones; lesser associated minerals are ilmenite and magnetite. The depositional environment consisted of intrusion into the basal part of a continental crust or craton under hot, dry conditions. Examples of this mineral-deposit type are Dzhaninskoe, Gayumskoe, and Maimakanskoe, Russia.

D. Deposits Associated with Kimberlite

Diamond-Bearing Kimberlite (Zhang and Xu, 1995; Khar'kiv and others, 1997)

Diamond-bearing kimberlite deposits consist of pipes and dikes made of kimberlite breccia. The deposits occur mostly near secondary branches of giant, deep, long, extensional faults in a stable craton, for example, the Tanlu Fault belt in the eastern part of the North China platform. The pipes are rounded or elongated with diameters of few hundred meters. In the North Asian craton, the kimberlite pipes range in age from Devonian through early Tertiary. Within a few hundred meters of the surface, the pipe is commonly funnel-shaped, and at greater depths (down to about 1,500 m), is cylindrical, and at still greater depths may have the shape of a feeder dike. The kimberlite dikes generally range from 0.3 to 20 m wide, are 100 to 800 m long and several hundred meters long downdip. Most kimberlites are concentrated in fields, generally less than 1 ha in area and from several kilometers to 20 km apart. The kimberlite breccia consists of fragments of sedimentary cover rocks, including limestone, sandstone, shale, schist, granulite, and gneiss that are parts of Precambrian cratonal basement, as well as dunite, garnet lherzolite, garnet saxonite, picotite lherzolite, massive phlogopite, diamond–bearing ultramafic rocks, eclogite, spinel-rich and spinel-free ultramafic rocks, and pyroxenite. The ultramafic and associated rocks are interpreted as mantle derived. Inclusions of Phanerozoic sedimentary cover and cratonal basement rocks are abundant at the margins of kimberlite pipes and dikes which commonly contain inclusions of mantle-derived minerals that range from 1 to 10 cm across, including Cr-pyrope and picotite. The breccia is cemented by tuff with xenocrysts of altered olivine (group I), pyrope, picroilmenite, Cr spinel, Cr diopside, and rare large (maximum 2 cm) diameter) grains of gem-quality zircon. The minerals are embedded in a carbonate-serpentine matrix including olivine II, picroilmenite II, Cr-spinel II, phlogopite, and perovskite. Secondary minerals, such as serpentine, carbonate, and chlorite, compose the bulk of the kimberlite in both the upper and lower parts of pipes; rare minerals are Cr-diopside, picrotanite, morssanite, rutile, oysanite, and zircon. Kimberlite intrudes under hypabyssal conditions, as indicated by typically massive structures and pseudomorphs of coarse olivine crystals scattered in a fine-grained matrix of phlogopite, serpentine, calcite, and perovskite. Only parts of kimberlite pipes and dikes contain industrial diamonds. Indicator minerals for diamond in kimberlite are Cr-diopside and picotite and associated diamond placer deposits. The depositional environment consisted of kimberlite magma interpreted as forming during deep-level subduction of oceanic crust and mantle metasomatism in cratonal regions. The kimberlite magmas are erupted along various shear-fault systems to near-surface levels during uplift of the craton; subsequent younger uplift resulted in the erosion of the kimberlite and exposure of the root systems, including pipes and dikes. Examples of this mineral-deposit type are Ingashinskoye, Mir (fig. 4), and Yubileinaya, Russia.

II. Deposits Related to Intermediate-Composition and Felsic Intrusions

A. Pegmatite

Muscovite Pegmatite (Sokolov, 1970; Chesnokov, 1975; Vasil'eva, 1983)

Muscovite pegmatite deposits consist of pegmatite veins containing high-quality foliated muscovite that occurs in schist that is metamorphosed to amphibolite facies. Pegmatite veins are generally concentrated in apical parts of large granite-migmatite domes and are mainly confined to horizons of Al-silicate rocks (for example, biotite-muscovite granite gneiss, two-mica schist). Groups or fields of pegmatite veins may be hosted in the hinge areas of anticlines and flexures in schist that are multiply deformed. The shape of the deposits is diverse, and crosscutting dikes with numerous tongues are dominant. The pegmatite minerals are plagioclase (oligoclase, oligoclase-andesine), microcline-perthite, quartz, biotite, muscovite, tourmaline, and rare beryl and almandine garnet. Veins with plagioclase, plagioclase-microcline, and microcline are dominant. High-grade muscovite typically occurs in quartz masses that contain corroded feldspar crystals. The depositional environment consisted of pegmatite fields in regional metamorphic and granitic belts that occur along the periphery of ancient cratons. Many muscovite pegmatite fields, some with REE minerals (including allanite, apatite, bastnaesite, cerite, fluorite, monazite, titanite, tourmaline, topaz, xenotime, and zircon) occur in some pegmatite belts and may extend for several hundred kilometers. Examples of this mineral-deposit type are Chuyskoye, Lugovka, Mamsko-Chuiskiy (fig. 5), Sogdiondonskoye, and Vitimskoye, Russia.

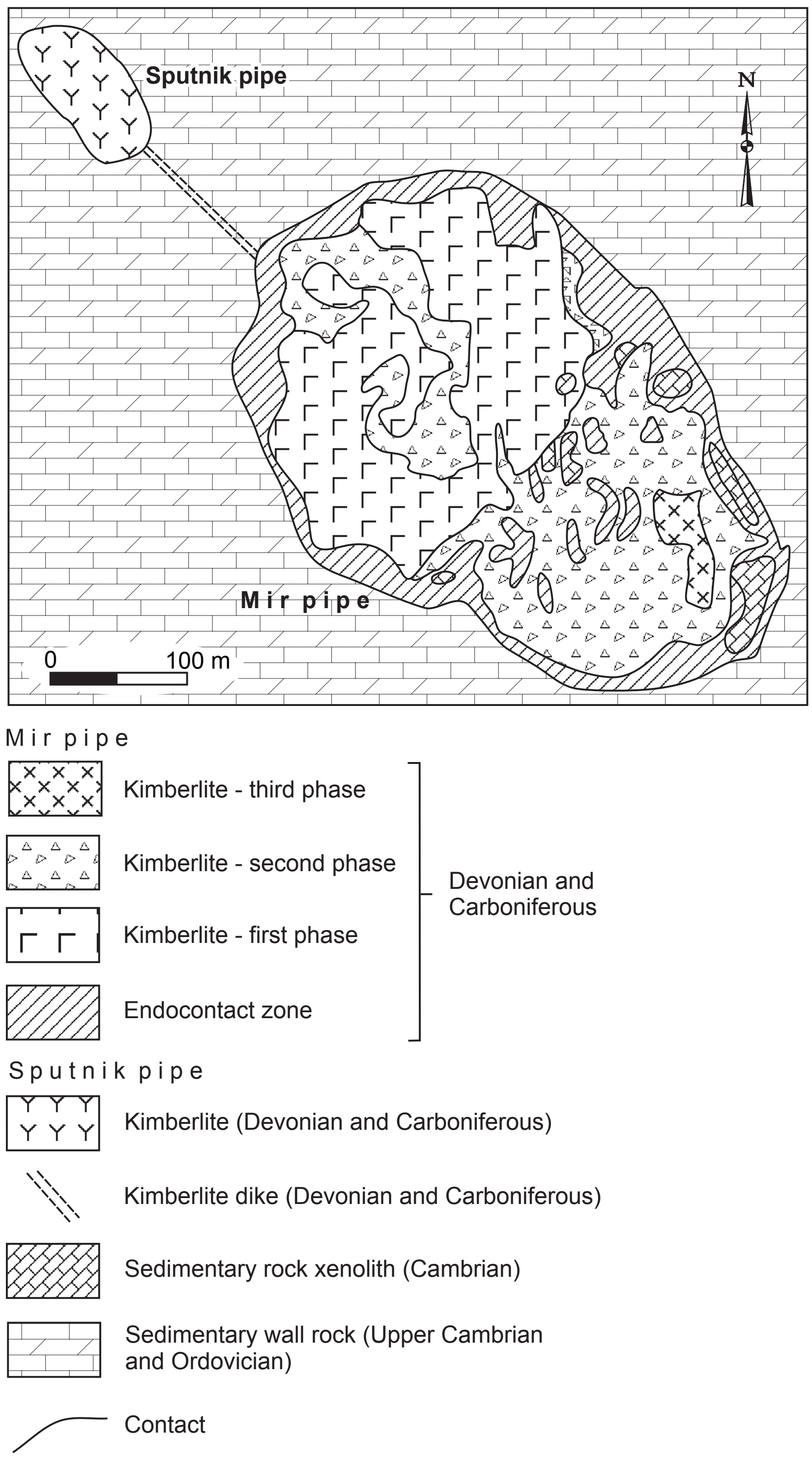


Figure 4. Generalized geologic map of the Devonian through Carboniferous Mir diamond-bearing kimberlite deposit, Yakutia, Russia. Adapted from Khar'kiv, Zinchuk, and Zuev (1997).

REE-Li Pegmatite (Lee, 1959; Kovalenko and Koval, 1984; Kim, and Park, 1986; Rundqvist, 1986; Zagorskiy and others, 1997; Lin and others, 1994)

REE-Li pegmatite deposits consist of two subtypes. The first subtype consists of REE spodumene granite pegmatite that is mainly associated with two-mica granite. The pegmatite deposits generally occur along the exocontact zones of granitic intrusions, generally within 1 to 3 km of contacts and intrude metamorphosed carbonaceous and clastic rocks. Pegmatite bodies are commonly clustered in elongate belts along regional faults. Many pegmatite veins occur along feather joints. Two morphologic types of pegmatite bodies are defined: (1) elongate and persistent veins and vein systems that occur at depth; and (2) single and small vein-shaped bodies. Major minerals are albite, oligoclase, spodumene, quartz, microcline, muscovite, beryl, helvite, columbite-tantalite, fluorite, tourmaline, cassiterite, and zircon; lesser minerals are various sulfides, including pyrite, molybdenite, and galena. The major REE minerals include allanite, apatite, bastnaesite, cerite, fluorite, monazite, titanite, tourmaline, topaz, xenotime, and zircon. The principal metal is Li along with associated Ta, Nb, Sn, Be, Mo, and W. Mineral zonation is typical in large pegmatite bodies. The Keketuohai pegmatite No. 3 (Xinjiang Province, China) consists of a large cupola-like body that is about 250 m long, 150 m wide, and 250 m high.

The second subtype consists of REE pegmatite that is mainly associated with calc-alkaline, Li-F leucocratic granite. Three varieties are defined: (1) Li-mica pegmatite; (2) muscovite (muscovite-albite) pegmatite; and (3) muscovite-microcline pegmatite. The first two varieties are Ta bearing, and the third contains cassiterite and wolframite. Li-mica pegmatite contains Ta-Nb minerals, cassiterite, Li-mica, quartz, albite, microcline, apatite, tourmaline, topaz, and

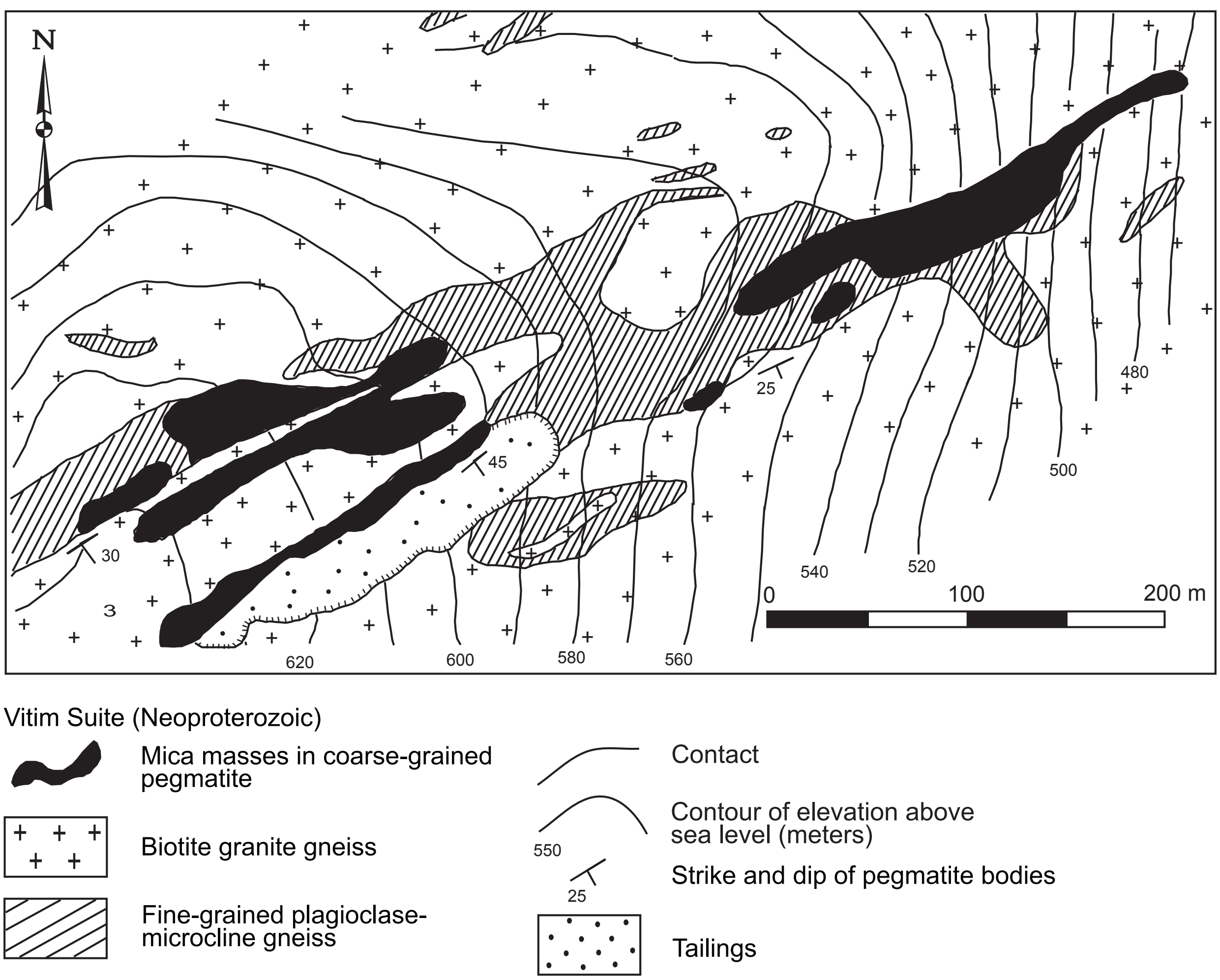


Figure 5. Generalized geologic map of the Devonian through Early Carboniferous Mamsko-Chuiskiy muscovite pegmatite deposit, TransBaikal, Russia. Adapted from Markov (1937).

beryl; and muscovite-albite pegmatite contains columbite, tantalite, quartz, albite, microcline, and muscovite. Muscovite-microcline pegmatite includes cassiterite, wolframite, quartz, microcline, and muscovite. REE-Li pegmatite deposits form dikelike or lenticular bodies that range from a few meters to hundreds of meters in length, and from 1 to 10 m width. Associated Li-Sn-Be pegmatite contains Li-mica, and Ta and Sn-W minerals. The depositional environment consisted of REE-Li pegmatite and associated granitic rocks in postaccretionary intrusions that postdate the peak of batholith emplacement. Associated granite is mainly calc-alkaline and Li-F leucogranite and related, coeval volcanic and subvolcanic rocks. Examples of this mineral-deposit type are Vishnyakovskoye, Russia; and Keketuohai (fig. 6), Kelumute, and Xinjiang, China.

B. Greisen and Quartz Vein

Fluorite Greisen (Govorov, 1977)

Fluorite greisen deposits consist of fine-grained, dark-violet rocks composed of fluorite (from 63 to 66 volume percent) and micaceous minerals, mainly muscovite (25 to 35 volume percent), along with lesser ephesite and phlogopite; subordinate minerals are (in decreasing order) tourmaline, sellaite, cassiterite, topaz, sulfides, and quartz. The deposits generally occur in veins in gneiss (as on the Korean Peninsula), or in limestone or marble (as in the Khanka area, Russian Southeast). The veins in limestone or marble occur concordant to limestone layers, and form lenticular and

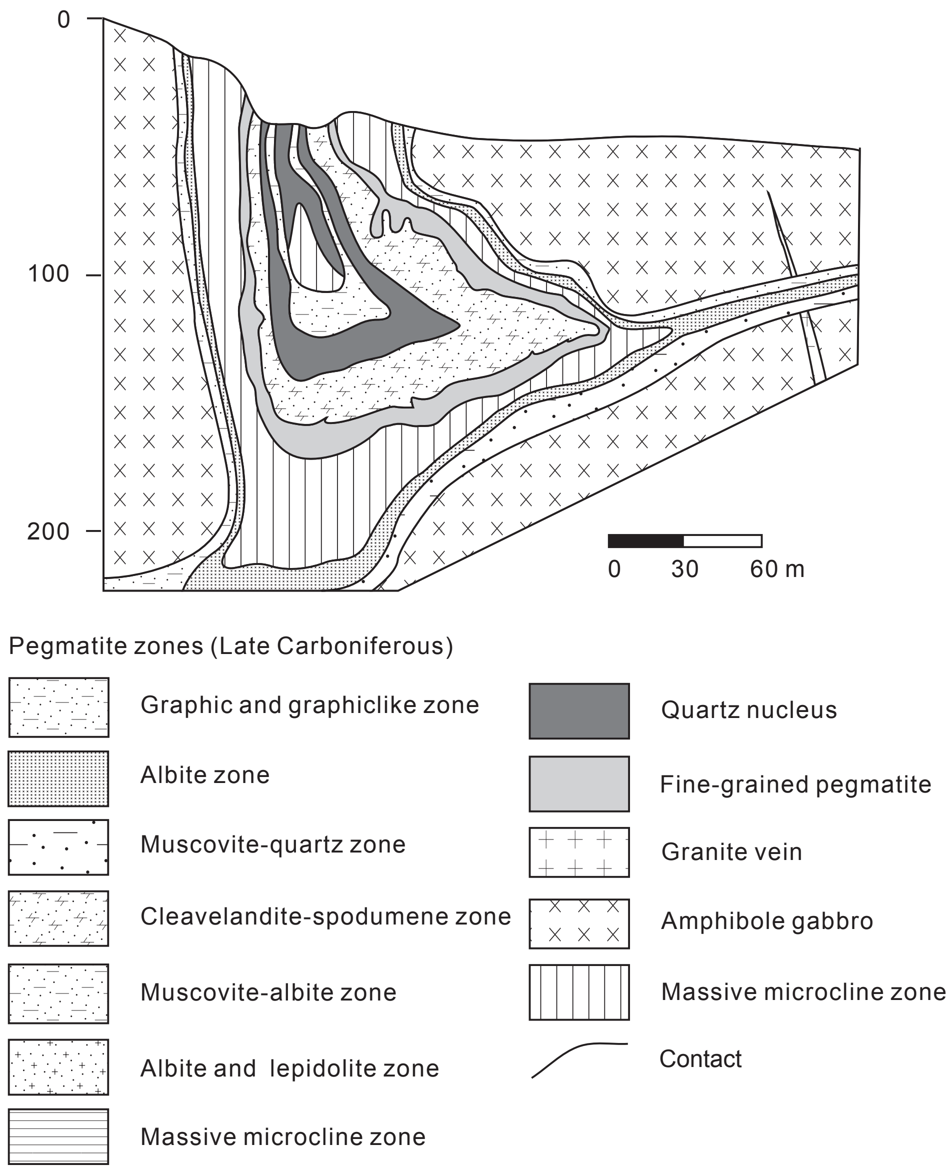


Figure 6. Generalized geologic map of the Late Carboniferous Altay REE-Li-pegmatite Kehketuohai deposit, northern China. Adapted from Lin and others (1994).

flame-shaped bodies of apocarbonate greisen that occurs in limestone intruded by Li-F, S-type granite. Metasomatic rocks replacing limestone occur at and above contacts with granitic intrusions. Muscovite-quartz pegmatite veins containing molybdenite-cassiterite-diopside, vesuvianite-diopside-andradite, and scapolite skarn also occur near intrusive contacts; these veins are interpreted as having formed before fluorite-mica greisen. B isotopic analysis of tourmaline indicates a primary evaporite source (V.V. Ratkin, written commun., 1994), suggesting that deep-seated evaporites in zones of granitic magma generation were the source of fluorine. Alternatively, some fluorine may be derived from the volatile phase of granitic magma. Scarce quartz and the absence of paragenetic calcite suggest an extremely high fluorine activity in silica-poor solutions. The depositional environment consisted of thick clastic limestone sequences or carbonate gneiss in cratonal or continental-margin terranes that were intruded by continental-margin-arc plutonic rocks. Examples of this mineral-deposit type are Preobrazhenovskoye and Voznesenka-II (fig. 7), Russia.

Sn-W Greisen, Stockwork, and Quartz Vein (Rodionov and others, 1984; Reed, 1986b)

Sn-W greisen, stockwork, and quartz vein deposits consist of disseminated cassiterite, cassiterite- and wolframite-bearing veinlets in stockworks, lenses, pipes, and breccia in granite that has been altered to greisen. The granite is mainly biotite and (or) muscovite leucogranite emplaced in mesozonal to epizonal environments. The deposits are commonly associated with cupolas and domes of silicic and ultra-silicic, F-enriched rocks of late-stage, fractionated granitic magmas. The deposits generally consist of simple to complex quartz-cassiterite±wolframite and rare sulfides in fissure fillings or replacement lodes that occur in or near felsic plutonic rocks. The veins are associated with mineralized greisen zones. Main deposit minerals are cassiterite, wolframite, arsenopyrite, scheelite, rare molybdenite, beryl, and pyrite wit associated chalcopyrite, various Bi-minerals, and rare galena, stannite, and sphalerite. Mineralogic and metal zonation may occur on a small scale (within single veins or vein systems) and (or) on a larger scale (within ore districts). An inner zone of cassiterite±wolframite is commonly bordered by Pb, Zn, Cu, and Ag sulfides. The depositional environment generally consisted of mesozonal to epizonal (hypabyssal) silicic plutons containing felsic dike swarms, and the typical tectonic environment consisted of zones of accreted terranes that intruded late-stage to postorogenic granitoids which ascended from deep-seated magmatic chambers. Examples of this mineral-deposit type are Deputatskoye and Zimnee (fig. 8), Russia, and Mungon-Ondur and Tugalgatain nuruu, Mongolia.

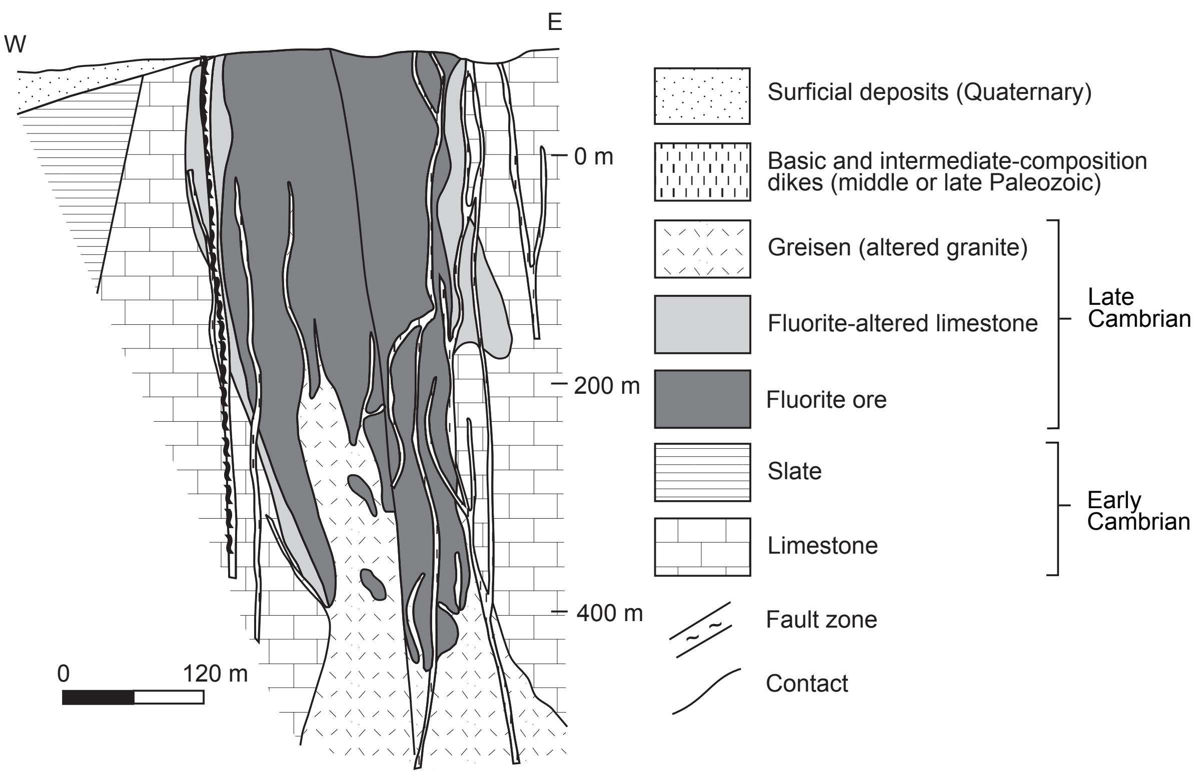


Figure 7. Generalized geologic map of the Late Cambrian though Devonian Voznesenka-II fluorite greisen deposit, Russian Southeast. Adapted from Ryazantzeva (1998).

W-Mo-Be Greisen, Stockwork, and Quartz Vein (Kim and Koh, 1963; Malinovskiy, 1965; Kuznetsov and others, 1966; Sotnikov and Nikitina, 1971; Park and others, 1980; Cox and Bagby, 1986; Kolonin, 1992)

W-Mo-Be greisen, stockwork, and quartz vein deposits consist of veins and stockworks of W, Mo-W, and Be-Mo-W minerals that occur within endo- and exocontact zones of multistage granitoid intrusions. The deposits generally occur in cupolas and domes of silicic and ultrasilicic granitic rocks and the deposits consist of elongate quartz veins and vein systems, stockworks, and greisen cupolas. Quartz-scheelite stockworks are common in exocontact zones and disseminated wolframite and molybdenite occur in greisen, quartz veins, and veinlets. Other minerals are bismuthinite, pyrite, pyrrhotite, arsenopyrite, bornite, chalcopyrite, scheelite, cassiterite, beryl, galena, sphalerite, and various Bi minerals; gangue minerals are quartz, muscovite, K-feldspar, fluorite, lepidolite, and rare tourmaline. Veins occur at the upper-level apices of granitic plutons, including alaskite, and in peripheral zones of contact-metamorphosed sandstone and shale. Associated hydrothermal alteration includes greisen with albite, and rare chlorite and tourmaline with Li, Nb, and Ta minerals. The deposits may be associated with Sn-W vein and Sn greisen deposits. The depositional environment consisted of tensional fractures in epizonal granitoid plutons that intruded sedimentary or metasedimentary rocks, and the typical tectonic setting consisted of anatectic granitic plutonic belts related to collisional zones and (or) interplate strike-slip-fault zones. Examples of this mineral-deposit type are Dzhidinskoe (fig. 9) and Okunevskoye, Russia, and Lednikovy-Sarmaka, Ondortsagan, and Tsunkheg, Mongolia.

C. Alkaline metasomatite.

Ta-Nb-REE Alkaline Metasomatite (Solodov and others, 1987)

Ta-Nb-REE alkaline metasomatite deposits concist of Ta-, Nb-, and REE-bearing alkaline metasomatite that replaces multistage alkali REE granites and host rocks that are generally composed of marble, gneiss, or amphibolite. The

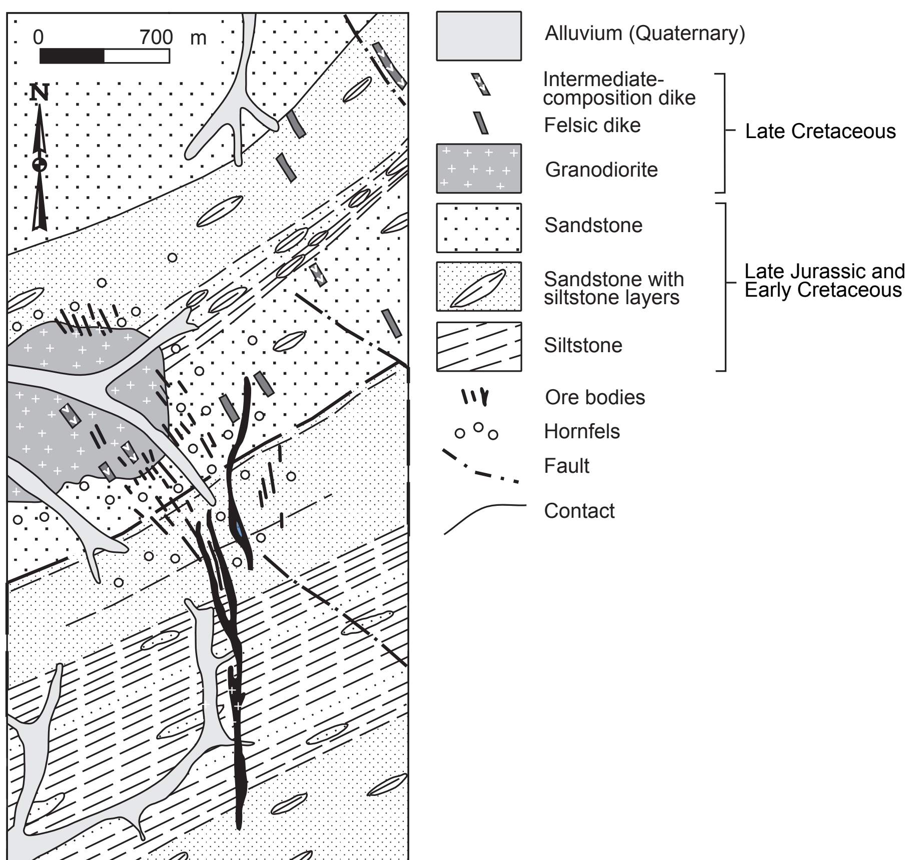


Figure 8. Generalized geologic map of the mid-Cretaceous through early Tertiary Luzhkinsky Sn-W greisen, stockwork, and quartz vein deposit, Russian Southeast. Adapted from A.N. Ivakin and V.V. Orlovsky (written commun, 1978).

deposits are composed of fine- and medium-grained quartz-albite-microcline. Ta-Ni minerals (for example, columbite and pyrochlore), zircon, and thorite are widespread along with REE minerals. Columbite and zircon are of practical significance. Important accessory minerals are REE minerals, including gagarinite, yttrofluorite, monazite, bastnaesite, and xenotime. Mineral zonation of metasomatic bodies is characteristic. Complex multistage metasomatic processes, which occur in the apical part of granite massive and in rocks within shear zones, consisted of microcline, albite, muscovite, and silica alterations. Relatively rich deposits occur in columns and lenticular planar bodies that extend to depths of hundreds of meters. The deposits consistute a unique resource of Ta, Ni, Zr, Hf, and Th, along with Li, REE, and U. The depositional environment consisted of deposit-hosting intrusions and metasomatic deposits that occur along major shear zones connected with intraplate and continental-marginal rift and strike-slip faults. Examples of this mineral-deposit type are Katuginskoye, Ulug-Tanzek (fig. 10), and Zashikhinskoe, Russia, and Khalzanburegtei, Mongolia.

D. Skarn (Contact Metasomatic)

Au Skarn (Hwang and Kim, 1963; Vachrushev, 1972; Theodore and Hammarstrom, 1991)

Au skarn deposits consist of veinlet-disseminated and masses of Au-sulfides that are superimposed on hydrothermally altered calc-silicate and Mg-silicate skarn. The various skarns replace carbonates and coeval volcanic rocks along intrusive contacts with andesite stocks, diorite, granodiorite, granite, and granite porphyry. The deposits are generally small and irregular but may persist at the depth. Minerals are garnet, pyroxene, wollastonite, vesuvianite, magnetite, epidote, actinolite, quartz, pyrite, chalcopyrite, bornite, sphalerite, and native gold. Gold formed simultaneously with or after deposition of sulfides, sometimes in association with hydrothermal alteration that formed epidote, chlorite, and silica. The depositional environment consisted of contacts of calcareous-volcanic sequences intruded by gabbrodiorite-granitic complexes in continental margin or island-arc systems. Examples of this

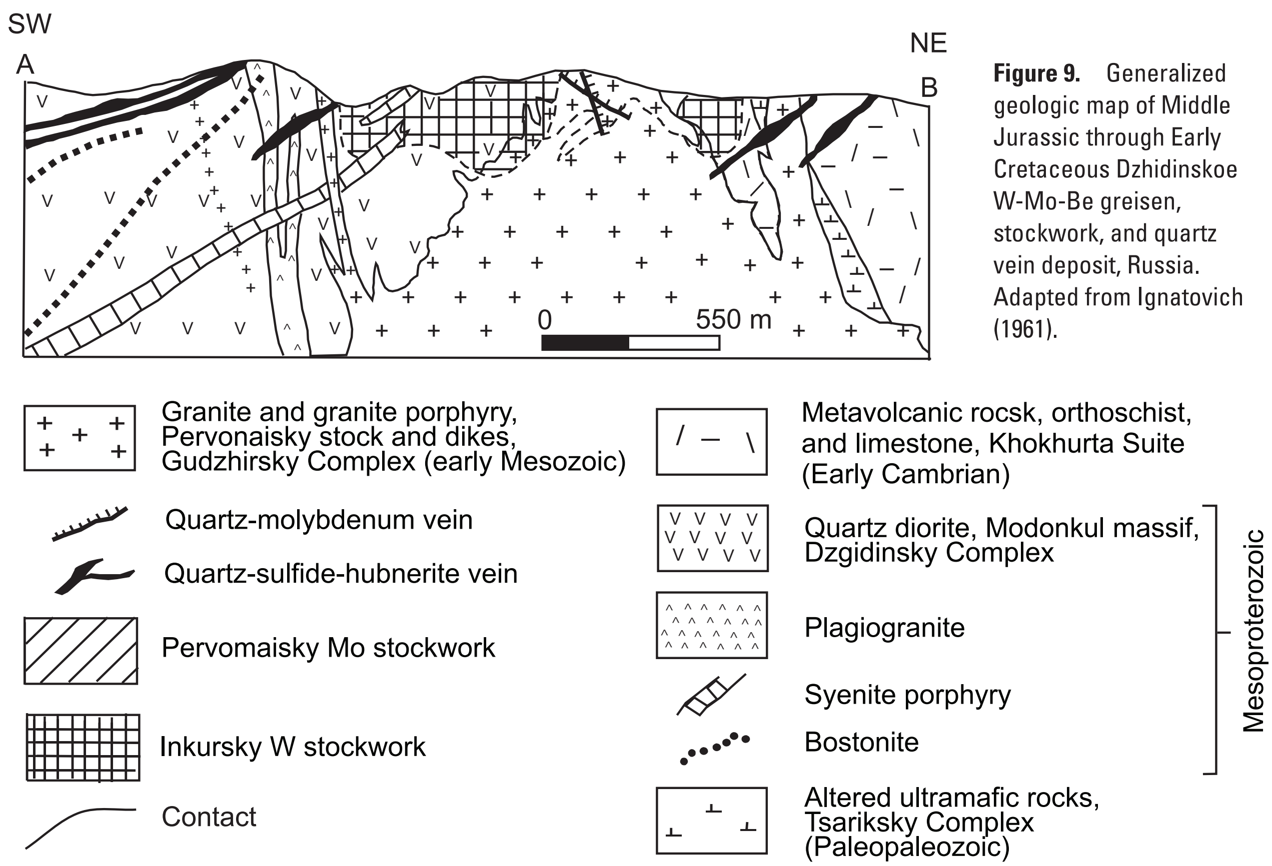


Figure 9. Generalized geologic map of Middle Jurassic through Early Cretaceous Dzhidinskoe W-Mo-Be greisen, stockwork, and quartz vein deposit, Russia. Adapted from Ignatovich (1961).

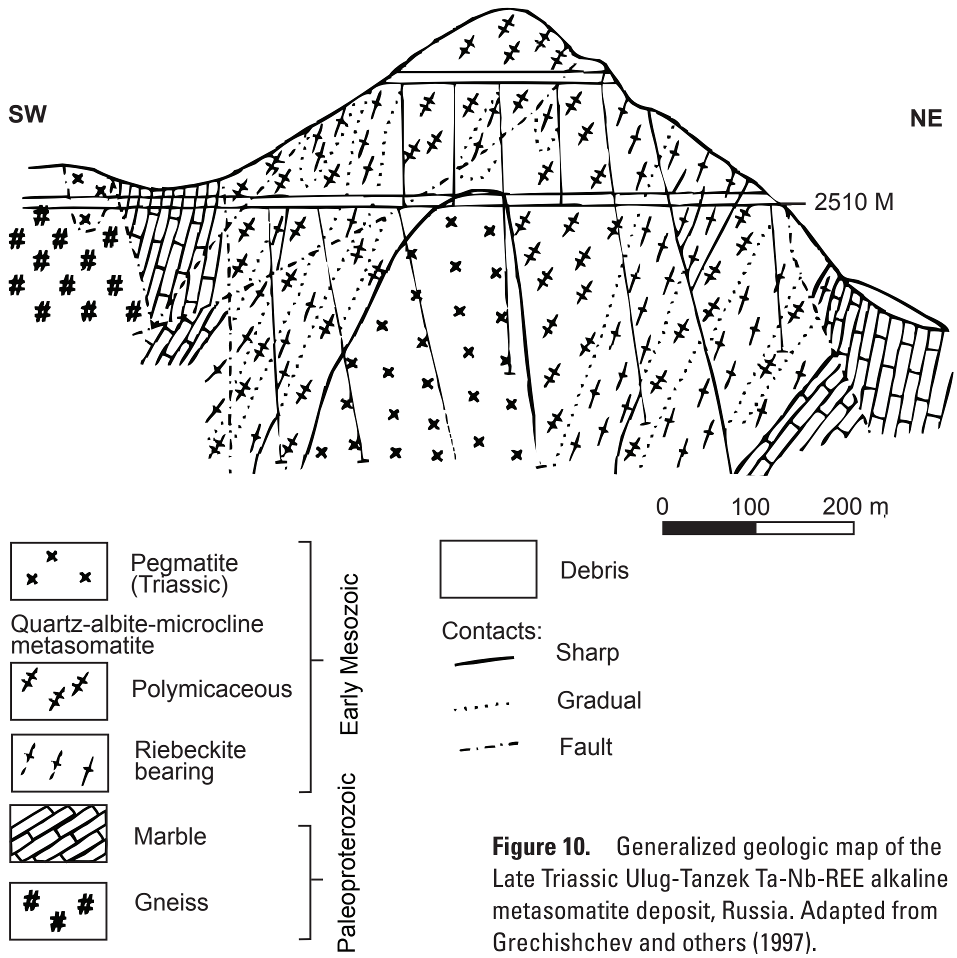


Figure 10. Generalized geologic map of the Late Triassic Ulug-Tanzek Ta-Nb-REE alkaline metasomatite deposit, Russia. Adapted from Grechishchev and others (1997).

mineral-deposit type are Boltoro, Mongolia, and Andryushkinskoe and Sinyukhinskoye, Russia.

B (Datolite) Skarn (Nosenko and others, 1990; Ratkin and others, 1992; Ratkin and Watson, 1993)

B (datolite) skarn deposits consist of danburite and datolite skarn associated with garnet-hedenbergite-wollastonite skarn. The skarn is interpreted as having formed during successive metasomatic replacement of limestone by wollastonite, grossularite-andradite, and hedenbergite and by danburite, datolite, axinite, quartz, and calcite. The deposits are characterized by thin-banded wollastonite that forms kidney-shaped aggregates of pyroxene and datolite in walls of paleohydrothermal cavities in marble. The hydrothermal cavities occur to depths of 500 m from the paleosurface, above a metasomatic zone of wollastonite and grossularite. The central part of these cavities (0.5 to 50 m across) is filled with danburite druse. Danburite formed after a second, B metasomatism, and boron was redeposited at higher paleogypsometric levels in datolite associated with garnet-hedenbergite skarn. Genesis of neighboring Pb-Zn deposits is associated with formation of the later skarn. B isotopic data suggest that the source of dissolved boron was a deep-seated granitoid intrusion. The depositional environment consisted of early formation of grossular-wollastonite skarn, followed by formation of thin-banded wollastonite aggregates with datolite and danburite simultaneously with eruption of a postaccretionary ignimbrite sequence that overlay an accretionary wedge complex containing large limestone xenoliths (dimensions of 0.5 by 2.0 km) in a highly deformed siltstone and sandstone matrix. The only example of this deposit type is the large Dalnegorsk boron mine (fig. 11) in the Russian Southeast that constitutes the main source of boron in Russia.

Carbonate-Hosted Asbestos (Wrucke and Shride, 1986)

Carbonate-hosted asbestos deposits occurs along the contacts between mafic dikes and sills that intruded silicified carbonates. Major rock types are serpentinite, diabase, gabbro, chert-bearing dolomite, and marl. The deposits are commonly stratiform, lensoid, or irregular, and are concordant with the host carbonates. The industrial minerals are serpentine asbestos, massive serpentine, calcite, and dolomite. Varied and distinct metasomatic structures also occur. Major alteration minerals are serpentinite, talc, tremolite, diopside, and carbonate. Alteration zoning is not apparent. The deposition environment was metasomatism associated with mafic intrusions into impure carbonates. The deposits may be of any age, but in Northeast Asia they are mainly Mesoproterozoic. The tectonic environment was mafic plutons forming parts of continental-margin arcs. The best example of this mineral-deposit type is at Chaoyang, Liaoning Province, China.

Co Skarn (Nekrasov and Gamyanin, 1962; Bakharev and others, 1988; Lebedev, 1986)

Co skarn deposits occur along the contacts between siltstone and limestone during contact metamorphism associated with intrusion of granodiorite, syenite-diorite, and granite plutons and small intrusions (stocks and dikes) of alkali gabbro. The skarn typically consists of pyroxene and grossularite-andradite garnet and lesser axinite and scapolite. The deposits consist of small masses of Co-pyrite, sulfoarsenides, and arsenides along with gersdorffite, arsenopyrite, lollingite, and cobaltite. Native gold occurs in association with Bi and Te minerals, including native bismuth, joseite, hedleyite, and bismuthine. Examples of this mineral-deposit type are Karagem and Vladimirovskoye, Russia.

Cu (±Fe, Au, Ag, Mo) Skarn (Cox and Theodore 1986; Nokleberg and others, 1997)

Cu (±Fe, Au, Ag, Mo) skarn deposits consist of chalcopyrite, magnetite, and pyrrhotite in calc-silicate skarn that replaces carbonates along intrusive contacts with plutons ranging in composition from quartz diorite to granite and from diorite to syenite. Zn-Pb-rich skarn generally occurs farther from the intrusion, whereas Cu- and Au-rich skarn generally occur closer. Major minerals are pyrite, hematite, galena, molybdenite, sphalerite, and scheelite. Mineralization is multistage. The deposit type is commonly associated with porphyry Cu-Mo deposits. The depositional environment consisted mainly calcareous sedimentary sequences intruded by felsic to intermediate-composition granitic plutons that form parts of continental-margin arcs. Examples of this mineral-deposit

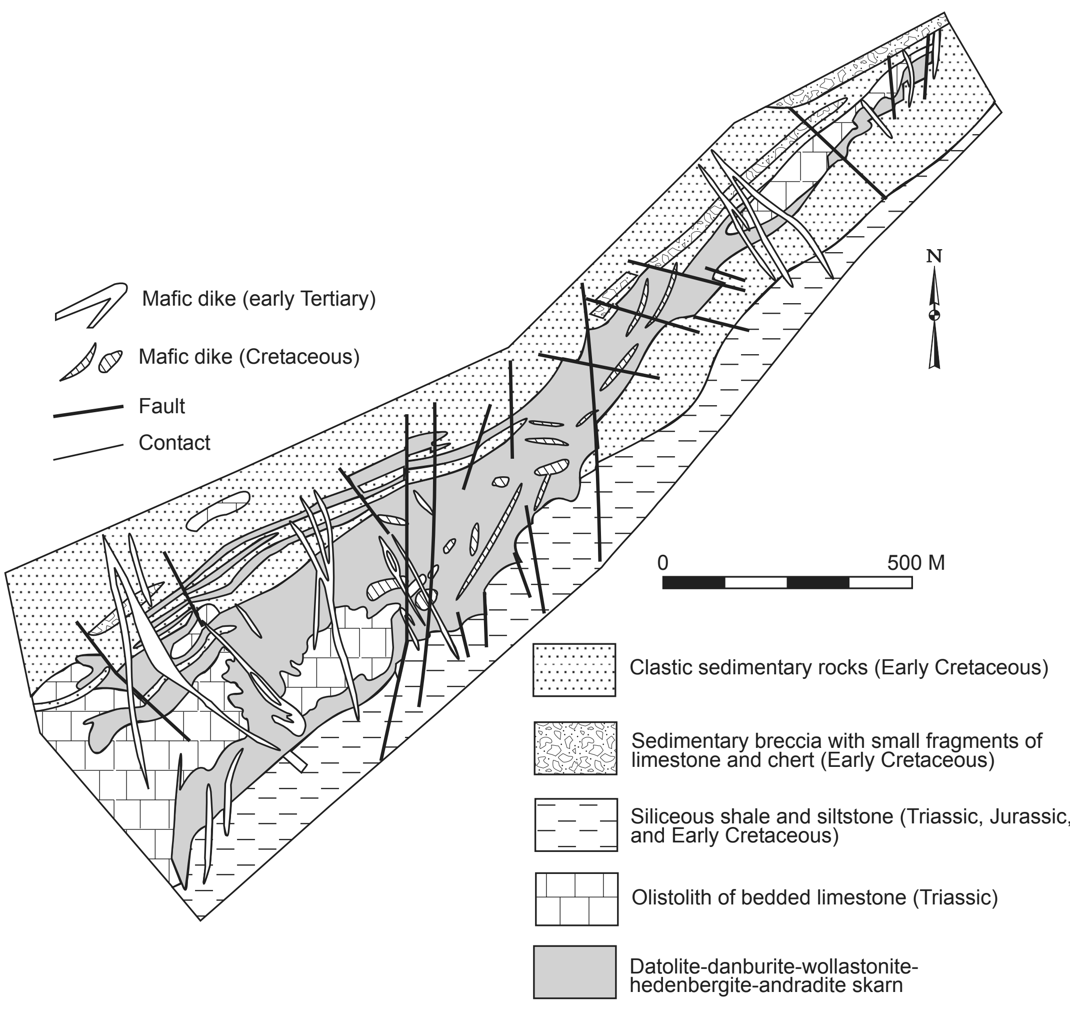


Figure 11. Generalized geologic map of the Late Cretaceous through early Tertiary Dalnegorsk boron (datolite) skarn deposit. Adapted from Ratkin (1991).

type are Boltoro, Kuma, and Muromets, Russia, Khokhbulgiin khondii, Mongolia, and Kamaishi, Japan (fig. 12).

Fe Skarn (Mazurov, 1985; Cox, 1986d; Sinyakov, 1988)

Fe skarn deposits consist of dispersed magnetite in calc-silicate or Mg- silicate skarn that replaces carbonates, tuffaceous carbonates, or calcareous clastic rocks near the contact of intrusive rocks range vary from gabbro and diorite to granodiorite and granite. Coeval volcanic rocks occur locally. Associated minerals are relatively rare chalcopyrite, pyrite, and pyrrhotite. Metasomatic replacements consist of a wide variety of calc-silicate and related minerals. The main skarn minerals are Mg-silicates, calc-silicates, albite, scapolite, chlorite, and amphibole. The depositional environment consisted of metavolcanic and metasedimentary sequences, including dolomite, dolostone, and rare limestone that were intruded by gabbro to granite in island arcs, continental marginal arcs, or rifted continental margins. Examples of this mineral-deposit type are Abakanskoye, Beloretskoye, Inskoye, Lavrenovskoye, Tabratskoye, and Timofeevskoe, Russia, and Tomor tolgoi (fig. 13), Mongolia.

Fe-Zn Skarn (Bakhteev and Chizhova 1984; Podlessky and others, 1984, 1988)

Fe-Zn skarn deposits consist of sphalerite and associated minerals in calcic skarn that typically occurs along the pre-intrusive tectonic-lithologic contacts between uplifted blocks of calcareous metasedimentary rocks intruded by granitoids. The intrusive rocks are mainly potassic subalkaline granite and leucogranite. The skarn occurs in lenses or in layers, and range from tens to hundreds of meters in thickness and several hundreds meters along strike. The intrusive rocks display little or no alteration. Major minerals are sphalerite and magnetite, and lesser chalcopyrite, hematite, bismuthinite, molybdenite, pyrite, and galena. Gangue minerals are andradite-grossularite garnet, hedenbergite, magnetite, epidote, and feldspar. Typical and common zonation consists of epidote-feldspar, epidote-andradite, andradite-magnetite, andradite-pyroxene-magnetite, and pyroxene-magnetite. Typical retrograde minerals are actinolite, quartz, calcite, and chlorite. Fe and Zn mineral distribution is irregular and occurs mostly in garnet and garnet-pyroxene skarn. Pb/Zn/Cu ratios are about 0.2/4.5/0.1. The deposit typically exhibits four stages of mineralization: garnet-pyroxene

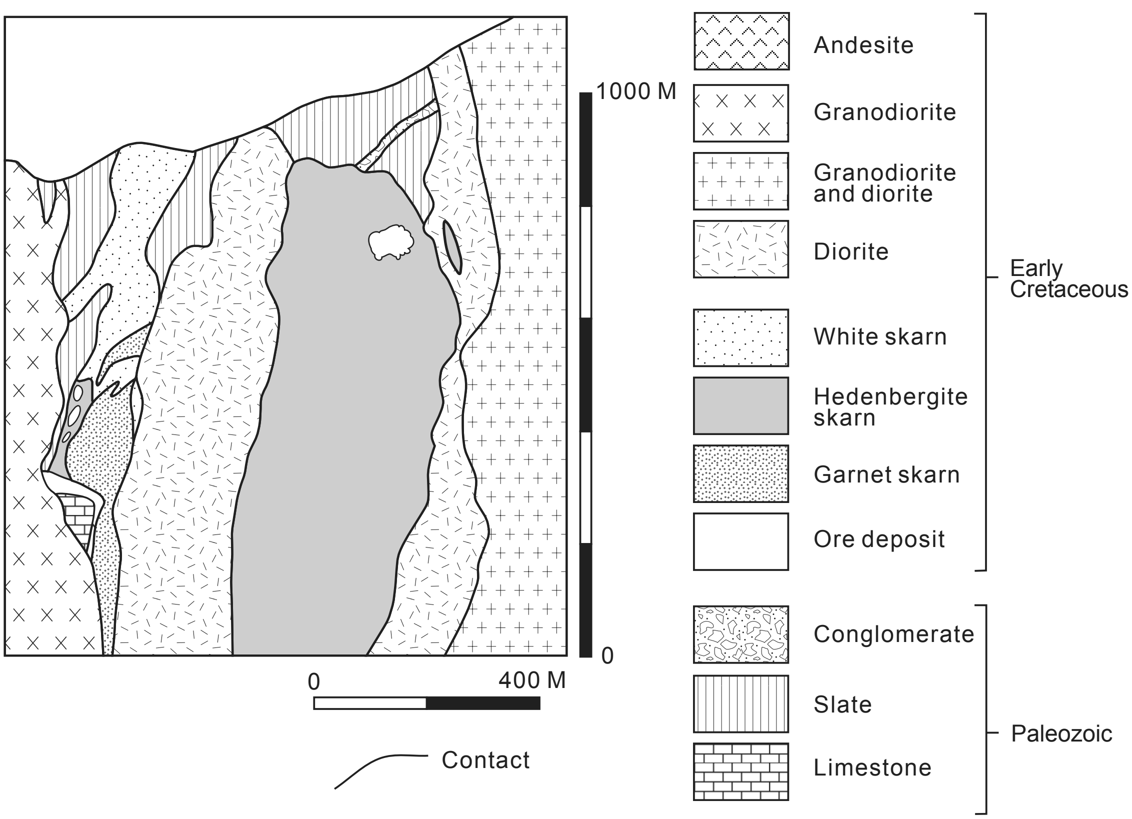


Figure 12. Generalized geologic map of the Early Cretaceous Kamaishi Cu(±Fe, Au, Ag, Mo) skarn deposit, Japan. Adapted from Nittetsu Mining Co. (1981).

skarn, andradite-magnetite aposkarn, sulfide, and quartz-carbonate. The depositional environment consisted of metamorphosed calcareous rock sequences including dolomite, dolostone, and rare limestone that were intruded by granitoids in island or continental marginal arcs. Examples of this mineral-deposit type are Khol khudag, Tumurte, and Tumurtiin-Ovoo, Mongolia, and Jinling, Shandong Province, China.

Sn Skarn (Reed, 1986c; Nokleberg, and others, 1997)

Sn skarn deposits consist of Sn, W, and Be minerals in skarn, veins, stockworks, and greisens near intrusive contacts between generally epizonal(?) granitic plutons and limestone. The deposit minerals include cassiterite, and local scheelite, sphalerite, chalcopyrite, pyrrhotite, magnetite, and fluorite. Alteration consists of greisen near granite margins, and metasomatic andradite, idocrase, amphibole, chlorite, chrysoberyl, and mica in skarn. The depositional environment consisted of epizonal granitoid plutons that intruded calcareous sedimentary or metasedimentary rocks and the typical tectonic setting was backarc granitoids interpreted as having formed in continental-margin arcs, or anatectic granitoids in collisional zones and (or) interplate strike-slip-fault zones. Examples of this mineral-deposit type are Haobugao and Huanggan, Inner Mongolia, China.

Sn-B (±Fe) Skarn (Ludwigite Type) (Lisitsin, 1984; V.I. Shpikerman in Nokleberg and others, 1997)

Sn-B (±Fe) skarn (ludwigite type) deposits consist of metasomatic replacement of dolomite by mainly ludwigite and magnetite adjacent to granitoids. Ludwigite constitutes as much as 80 percent of the deposits, and Sn occurs as an isomorphic admixture in ludwigite. Other minerals are magnetite, suanite (Mg_2B_5O), ascharite, kotoite, datolite, harkerite, monticellite, fluoroborite, clinohumite, calcite, periclase, forsterite, diopside, vesuvianite, brucite, garnet, axinite, phlogopite, serpentine, spinel, and talc. The deposits consist of limestone metasomatically replaced by pyroxene-garnet-calcite skarns that is commonly altered to greisen to form Sn skarn. Mg and associated calcic skarn generally form near highly irregular (convoluted) contacts of granite plutons and in large xenoliths of carbonates. The depositional environment consisted of epizonal granitoid plutons that intruded calcareous sedimentary or metasedimentary rocks, and the typical tectonic setting consisted of backarc granitoids forming in continental-margin arcs, or of anatectic granitoids in collisional zones and (or) along interplate strike-slip-fault zones. No notable examples of this deposit type occur in the region.

W±Mo±Be Skarn (Beus, 1960; Kuznetsov and others, 1966; Cox, 1986j)

W±Mo±Be skarn deposits consist of scheelite and (or) scheelite-helvite in pure or altered (greisen or silica alteration) calc-silicate skarn that replaces carbonates or calcareous sedimentary rocks, along or near intrusive contacts with quartz diorite to granite plutons. Skarn forms irregular and vein-shaped bodies and layers. Associated minerals are molybdenite, pyrrhotite, sphalerite, bornite, pyrite, and magnetite. Two subtypes are defined: (1) scheelite skarn containing disseminated W minerals and (2) scheelite-helvite skarn with disseminated W and Be minerals. Skarn typically contains garnet, vesuvianite, pyroxene, epidote, actinolite fluorite, helvite, scheelite, beryl, quartz, muscovite, and rare sulfides. Replacement of wallrocks consists of a wide variety of calc-silicate and related metasomatic minerals. Scheelite also occurs in quartz-topaz and quartz-mica greisen interpreted as having formed by replacement of skarn. The depositional environment consisted of contact zones along the margins of granitic intrusions in continental-margin or island arcs, or adjacent to anatectic granitoids intruding

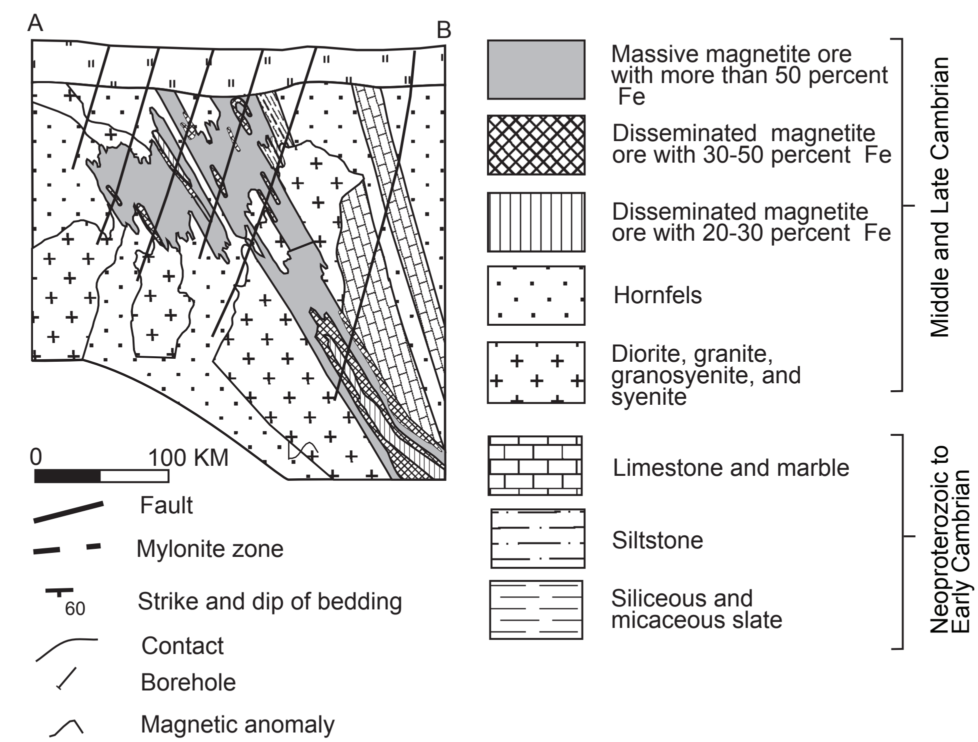


Figure 13. Generalized geologic map of the Middle through Late Cambrian Tomor tolgoi Fe skarn deposit, Mongolia. Adapted from (Marinov, Khasin, and Khurts (1977).

collisional zones. Examples of this mineral-deposit type are Lermontovsky and Vostok 2 (fig. 14), Russia, and Sangdong, South Korea.

Zn-Pb (±Ag, Cu, W) Skarn (Cox, 1986k; Eckstrand, 1984; Nokleberg, and others, 1997)

Zn-Pb (±Ag, Cu, W) skarn deposits consist of sphalerite and galena in calc-silicate skarn that replaces carbonates or impure calcareous sedimentary rocks along intrusive contacts with plutons varying in composition from quartz diorite to granite and from diorite to syenite. Zn-Pb-rich skarns generally occur farther from the intrusion relative to Cu- and Au-rich skarns. The deposits may occur at a considerable distance from the source granitic intrusion. Associated minerals are pyrite, chalcopyrite, hematite, magnetite, bornite, arsenopyrite, and pyrrhotite. The deposits vary from stratiform skarn that occurs parallel to limestone bedding near plutonic contacts, to discordant bodies that commonly occur at lithologic and structural contacts at some distance from pluton and dike contacts. The deposits are rather narrow but may extend downdip to 1-km depth and they may be controlled by ring faults around volcanic-tectonic depressions. The depositional environment consisted of mainly calcareous sedimentary sequences intruded by felsic to intermediate-composition granitic plutons in continental margin arcs. Examples of this mineral-deposit type are Savinsky 5, Russia (fig. 15); Baiyinnuoer and Xiaoyingzi, Inner Mongolia;, Huanren, Liaonig Province, China, and Kamioka Tochibora, Japan.

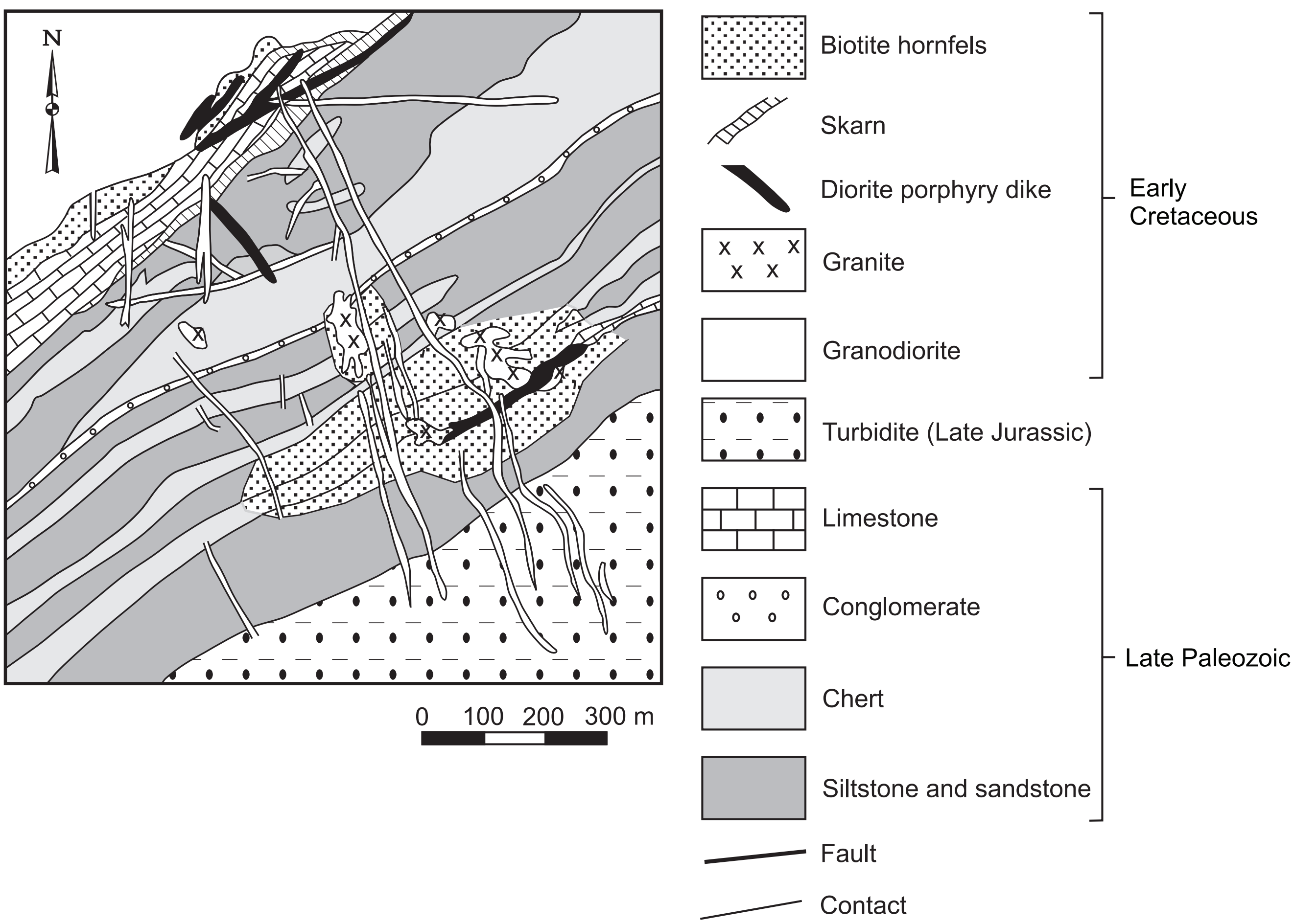


Figure 14. Generalized geologic map of the Early Cretaceous through mid-Cretaceous Vostok 2 W±Mo±Be skarn deposit, Russian Southeast. Adapted from Stepanov (1977).

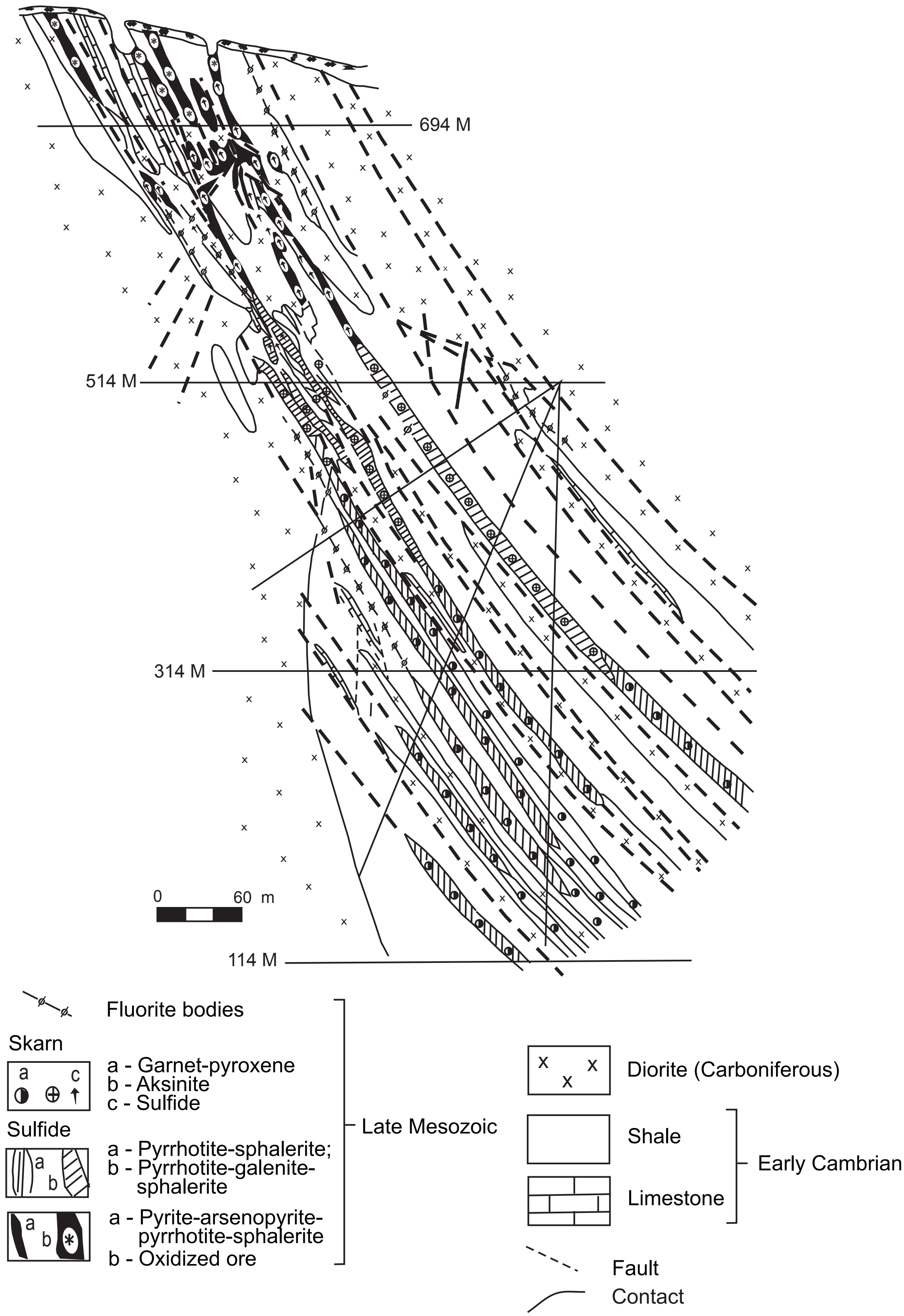


Figure 15. Generalized geologic map of the Middle Jurassic through Early Cretaceous Savinsky 5 Zn-Pb(Ag, Cu, W) skarn deposit, TransBaikal, Russia. Adapted from Arkhangelskaya (1963).

E. Porphyry and Granite Pluton-Hosted Deposits

Cassiterite-Sulfide-Silicate Vein and Stockwork (Kim and Shin, 1966; Lugov and others, 1972; Ontoyev, 1974; Seminsky, 1980; Togashi, 1986; S.M. Rodionov, this study)

Cassiterite-sulfide-silicate vein and stockwork deposits consist of linear zones, veins, and stockworks containing cassiterite, wolframite, scheelite, and various sulfides in a gangue of quartz with siderophyllite, tourmaline, sericite, and chlorite. The deposits occur in or adjacent to hypabyssal multistage intrusive massifs (stocks and laccoliths), subvolcanic bodies that intrude sedimentary, volcanic or metamorphic rocks. Associated intrusive rocks range in composition from gabbro through diorite and granodiorite to granite. The deposits typically contain abundant simple and complex veins and zones that are controlled by large crosscutting faults, or occur in various elements of concentric or radial faults surrounding volcanic-plutonic complexes. Stock with greisen is relatively older and scarce. Many deposits commonly contain stockwork minerals of the same composition as veins and zones. Minerals are cassiterite, arsenopyrite, chalcopyrite, galena, sphalerite, pyrite, pyrrhotite, scheelite, wolframite, fluorite, native bismuth, argentite, native gold, bismuthine, and complex sulfosalts; gangue minerals are quartz, tourmaline, sericite, chlorite, and rare muscovite and feldspar. Typical alteration assemblages are quartz-tourmaline, quartz-siderophillite, quartz-sericite, and quartz-chlorite. High-sulfide (cassiterite-sulfide) and low-sulfide (cassiterite-silicate) deposits may also occur. Several stages of mineralization may be evident with horizontal zonation. The depositional environment consisted of backarc zones of continental-margin arcs. Examples of this mineral-deposit type are Deputatskoye, Khapcheranga (fig. 16), Sherlovogorskoye, and Ulakhan-Egelyakh, Russia.

Felsic Plutonic U-REE (Nokleberg and others, 1997)

Felsic plutonic U-REE deposits consist of disseminated U, Th, and REE minerals in fissure veins and alkalic granite dikes in or along the margins of alkalic and peralkalic granitic plutons, or in granitic plutons, including granite, alkalic granite, granodiorite, syenite, and monzonite. The deposit minerals include allanite, thorite, uraninite, bastnaesite, monazite, uranothorianite, xenotime, and some with galena and fluorite. The depositional environmentconsisted mainly of the margins of epizonal to mesozonal granitic plutons in the backarc zones of continental-margin arcs. Examples of this mineral-deposit type are Chergilen, Diturskoe, and Neozhidannoye, Russia.

Granitoid-Related Au Vein (Eckstrand, 1984; Firsov, 1985; Cherezov and others, 1992)

Granitoid-related Au vein deposits consist of fissure veins and veinlet-stockwork zones containing disseminated gold and and some sulfides that generally occur in small, complex granitic intrusions. Plutonic rocks consist mainly of calc-alkalic and subalkalic diorite, granodiorite, and granite. The deposits may consist of disseminated gold that occurs at the apices of plutons, or in contact metamorphic aureoles. Minerals are native gold, Au-bearing telluride, and sulfides, and associated quartz, tourmaline, muscovite, sericite, chlorite, feldspar, carbonates, and fluorite. Disseminated sulfides in wallrocks, especially arsenopyrite, are commonly enriched in Au and Ag. Alteration to berizite-listvenite is common, with the formation of quartz, sericite, tourmaline, and chlorite. The depositional environment consisted of epizonal plutons that intruded miogeoclinal sedimentary rocks, some of which were regionally metamorphosed and deformed before intrusion. The plutons commonly occur in backarcs of a continental-margin arcs. The deposits display a similar mineralogy and chemical environment and are commonly associated with polymetallic vein deposits containing disseminated Au-bearing sulfides. Examples of this mineral-deposit type are Boroo, Mongolia (fig. 17), Linglong, Shandong Province, Sanshandao, Xincheng, Shandong Province, China; and Tuanjiegou, Heilongjiang Province, China.

Polymetallic Pb-Zn ± Cu (±Ag, Au) Vein and Stockwork (Hwang and Kim, 1962; Moon, 1966; Cox, 1986e; Wang, 1989; Mironov and others, 1989; Tian and Shao, 1991)

Polymetallic Pb-Zn ± Cu (±Ag, Au) vein and stockwork deposits consist of quartz-carbonate veins containing base metal sulfides and associated Ag-minerals and gold. The deposits are related to hypabyssal bodies that intruded volcanic, sedimentary, and metamorphic rocks, including interbedded calcic siltstone, siliceous marble, and rhyolite. The intrusions range in composition from calcalkaline to alkaline diorite to granodiorite, and from monzonite to monzogranite and occur in small plutons and dike swarms. Some deposits are controlled by faults along contacts between host rocks and felsic intrusions and range from stratiform or vein to lensoid. The deposits are locally large and are concordant with the bedding of host rocks (for example, Au-Ag polymetallic vein deposits in Jilin Province, China). Au vein deposits are generally sulfide poor (total sulfide content less than 5 percent), and generally occur in masses, disseminations, or veinlets. Minerals are native silver, galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, arsenopyrite, argentite, Ag sulfosalts, native gold, and Cu and Sn sulfides. Vein minerals are quartz, carbonate, barite, and fluorite. Metallic zoning is very common and consists of Pb, Zn (Au and Ag) at depth, Au, Ag (Pb, Zn) at middle horizons, and Ag (Au) at upper levels. Similar metallic zoning patterns also occur horizontally. Alteration consists of wide propylitic zones, and narrow sericite and argillite zones. For Au vein deposits, the most intense host-rock alterations are silica and berizite (pyrite+sericite+carbonate) alterations. Silica alteration commonly occurs adjacent to deposit minerals, and successive outward are are sericite and propylite alterations. Alteration zones range from several tens to 100 meters in width. The depositional environment consisted of zones of

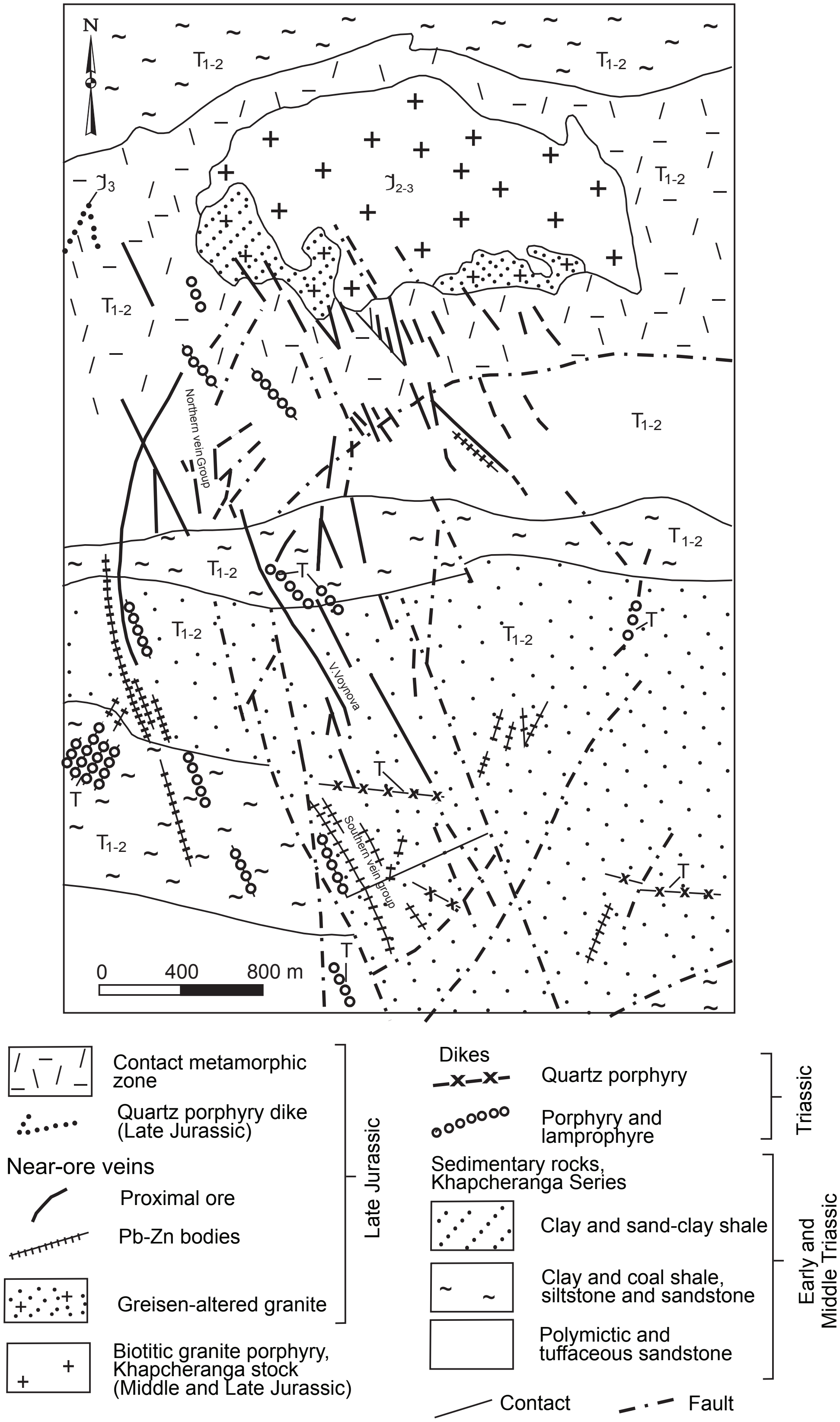


Figure 16. Generalized geologic map of the Middle Jurassic through Early Cretaceous Khapcheranga cassiterite-sulfide-silicate vein and stockwork deposit, TransBaikal, Russia. Adapted from Ontoev (1974).

local domal uplift in continental margin arc and island-arc volcanic-plutonic belts. Examples of this mineral-deposit type are Kuolanda, Prognoz, and Tsav (fig. 18), Russia, Khartolgoi, Mongolia; and Lianhuashan, Inner Mongolia and Meng'entaolegai, Inner Mongolia, China.

Porphyry Au (Fogelman, 1964, 1965; Eckstrand, 1984; Gamyanin and Goryachev, 1990, 1991; Sillitoe, 1993b; Dejidmaa, 1996)

Porphyry Au deposits consist of stockwork zones and disseminated gold with local sulfides that generally occur in simple to complex granitic intrusions, or in breccia pipes associated with volcanic-plutonic complexes. Related intrusive rocks are calc-alkalic and subalkalic granodiorite or granite. Breccia, if present, contains fragments of host rocks (flows, tuffs, granitoids, and sedimentary rocks), and other hypabyssal and subvolcanic rocks. Minerals are native gold, Au-bearing tellurides, and sulfides; accessory minerals are quartz, tourmaline, muscovite, sericite, chlorite, feldspar, carbonates, and fluorite. Two subtypes are defined: (1) a low-sulfide subtype with chalcedony veins and (2) a high-sulfide subtype with abundant disseminated sulfides. Within breccia pipes, gold generally occurs in the cement (matrix) as disseminations or stringer disseminations, along with disseminated sulfides (pyrite, sphalerite, galena, arsenopyrite, and chalcopyrite). Disseminated sulfides in wallrocks, especially arsenopyrite, are commonly enriched in Au and Ag. Host rocks exhibit chlorite, argillite, and quartz alteration. Advanced argillic alteration is widespread in the shallow parts of deposits; sericite alteration is typically minor. Stock and associated volcanic rocksrange in composition from low-K calc-alkalic through high-K calc-alkalic to K-alkalic. The deposits are commonly associated with polymetallic vein, Au-Ag epithermal vein, and porphyry Cu deposits. The depositional environment consisted of subduction-related continental-margin or island arcs with

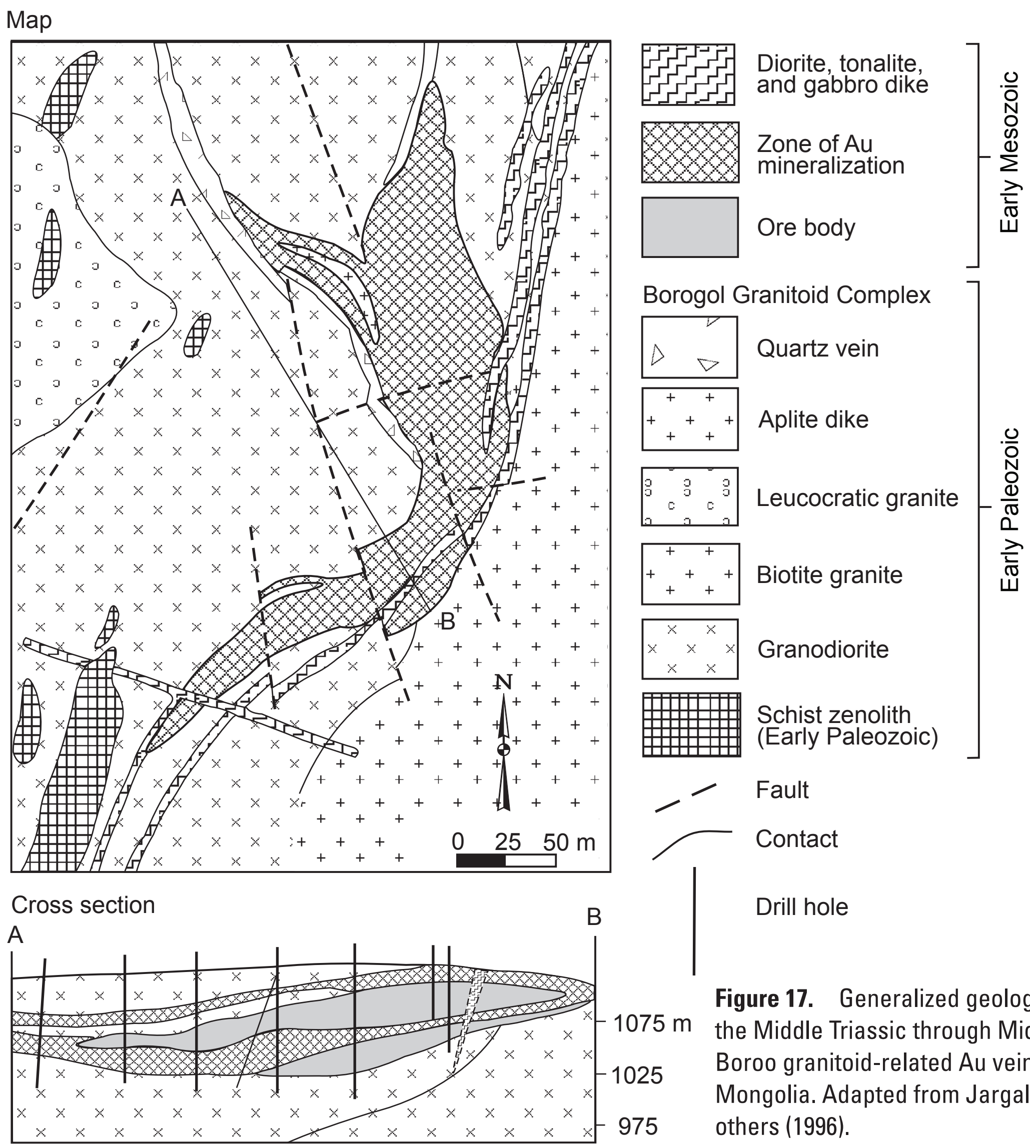


Figure 17. Generalized geologic map of the Middle Triassic through Middle Jurassic Boroo granitoid-related Au vein deposit, Mongolia. Adapted from Jargalsaihan and others (1996).

composite epizonal porphyry stocks that intruded coeval volcanic piles and adjacent passive continental-margin sedimentary rocks, some of which were regionally metamorphosed and deformed before intrusion. Examples of this mineral-deposit type are Ara-Ilinskoe, Russia, Delmachik, Russia, and Naozhi, Jilin Province, China.

Porphyry Cu (± Au) (Cox, 1986g; Sukhov and Rodionov, 1986; Evstrakhin, 1988)

Porphyry Cu (± Au) deposits consist of stockwork veinlets and rare veins of chalcopyrite, bornite, and magnetite in porphyry intrusions and coeval volcanic rocks. The host intrusive rocks vary in composition from tonalite and monzogranite to syenite and monzonite. Coeval volcanic rocks consist of dacite and andesite flows and tuffs. High-K, low-Ti volcanic rocks (shoshonite) may also be common. Minerals are chalcopyrite and bornite with associated magnetite, pyrite, rare native gold, electrum, sylvanite, and hessite, and rare PGE minerals; gangue minerals are quartz, K-feldspar, biotite, sericite, and chlorite, and rare actinolite, anhydrite, calcite, and clay minerals. A general, systematic alteration consists of (1) an inner zone of quartz, biotite, rare K-feldspar, chlorite, actinolite, and anhydrite; (2) an outer alteration zone of propylitic minerals; and (3) late-stage quartz-pyrite-white mica-clay minerals that overprint early feldspar alteration. The deposit mineral veinlets and mineralized fractures are closely spaced. The deposits are generally cylindrically or bell-shaped and are centered on a volcanic-intrusive center. Highest-grade ore commonly occurs at the level where stock divides into branches. The depositional environment consisted of subduction-related continental margin or island arcs with porphyry stocks, dikes, and large-scale breccia intruding coeval volcanic rocks nearby volcanic center and adjacent passive-continental-margin sedimentary rocks. Granitoids hosting the deposits generally intruded durint the waning stage of a volcanic cycle. Examples of this mineral-deposit type are Khongoot and Oyu Tolgoi (fig. 19), Mongolia, and Xiaoxinancha, Jilin Province, China.

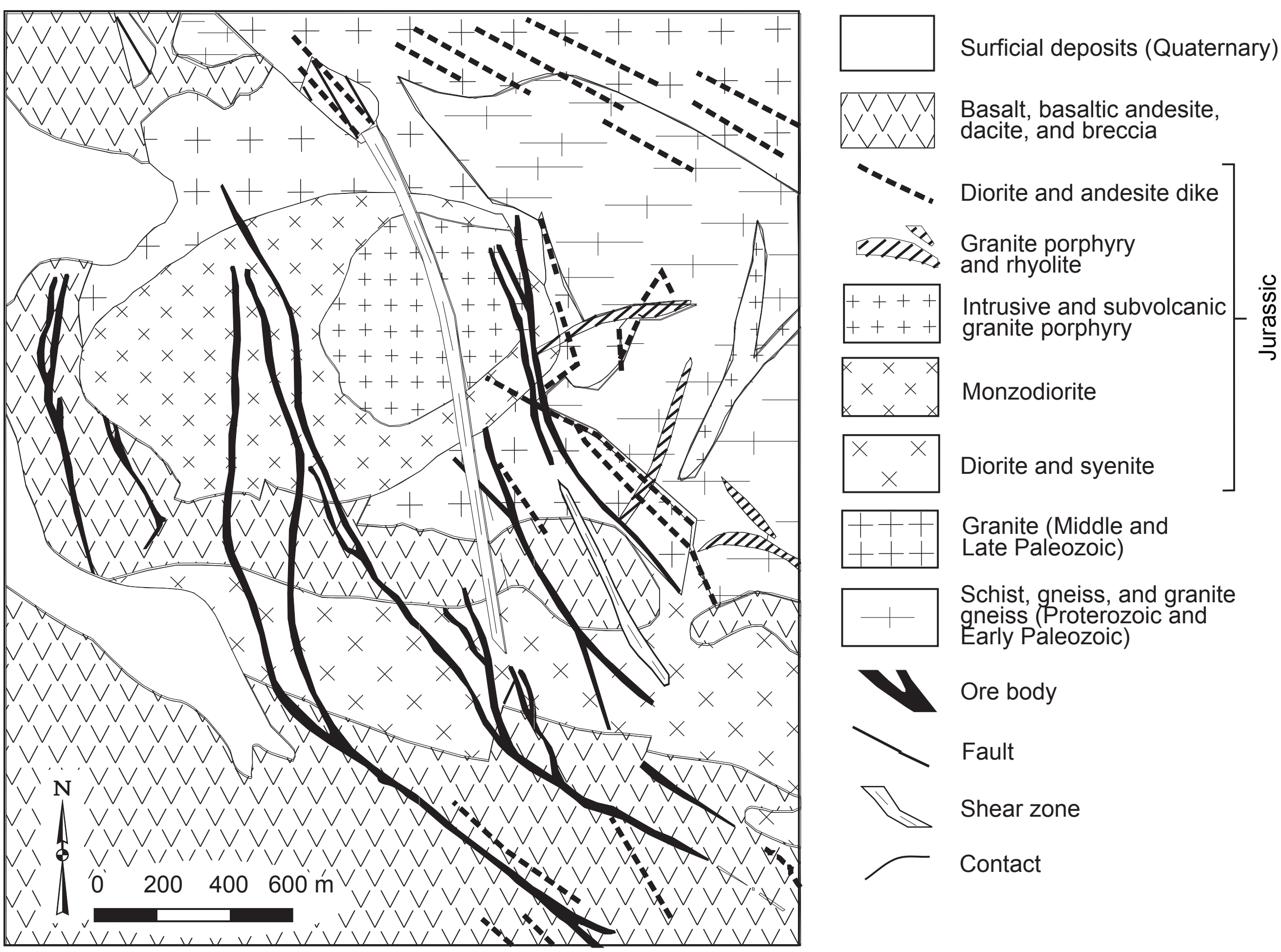


Figure 18. Generalized geologic map of the Middle Jurassic through Early Cretaceous Tsav polymetallic Pb-Zn±Cu(±Ag, Au) vein and stockwork deposit, Mongolia. Adapted from Jargalsaihan and others (1996).

Porphyry Cu-Mo (± Au, Ag) (Sotnikov and others, 1977, 1985; Cox, 1986h; Sukhov, and Rodionov, 1986; Nokleberg and others, 1997)

Porphyry Cu-Mo (± Au, Ag) deposits consist of stockwork veinlets and veins of quartz, chalcopyrite, and molybdenite in or near porphyritic intrusions. The host igneous rocks are felsic and calc-alkalic, predominantly tonalite to monzogranite plutons occurring mainly in stocks that intrude granitic, volcanic, or sedimentary rocks. Breccia pipes (including pebble breccia) and dikes are common. Veinlets and veins contain mainly quartz and carbonates. Minerals are chalcopyrite, molybdenite, pyrite, sphalerite, Ag-rich galena, and gold; alteration minerals are quartz, K-feldspar, sericite, and biotite or chlorite. Anhydrite occurs in the deeper levels of the deposits. Most deposits exhibit varying degrees of hypogene alteration, including sodic, potassic, and phyllic alteration. The earlier mineralization stage commonly starts with alkaline metasomatism (microclinization), followed by metasomatic deposition of molybdenite and later overprinting by

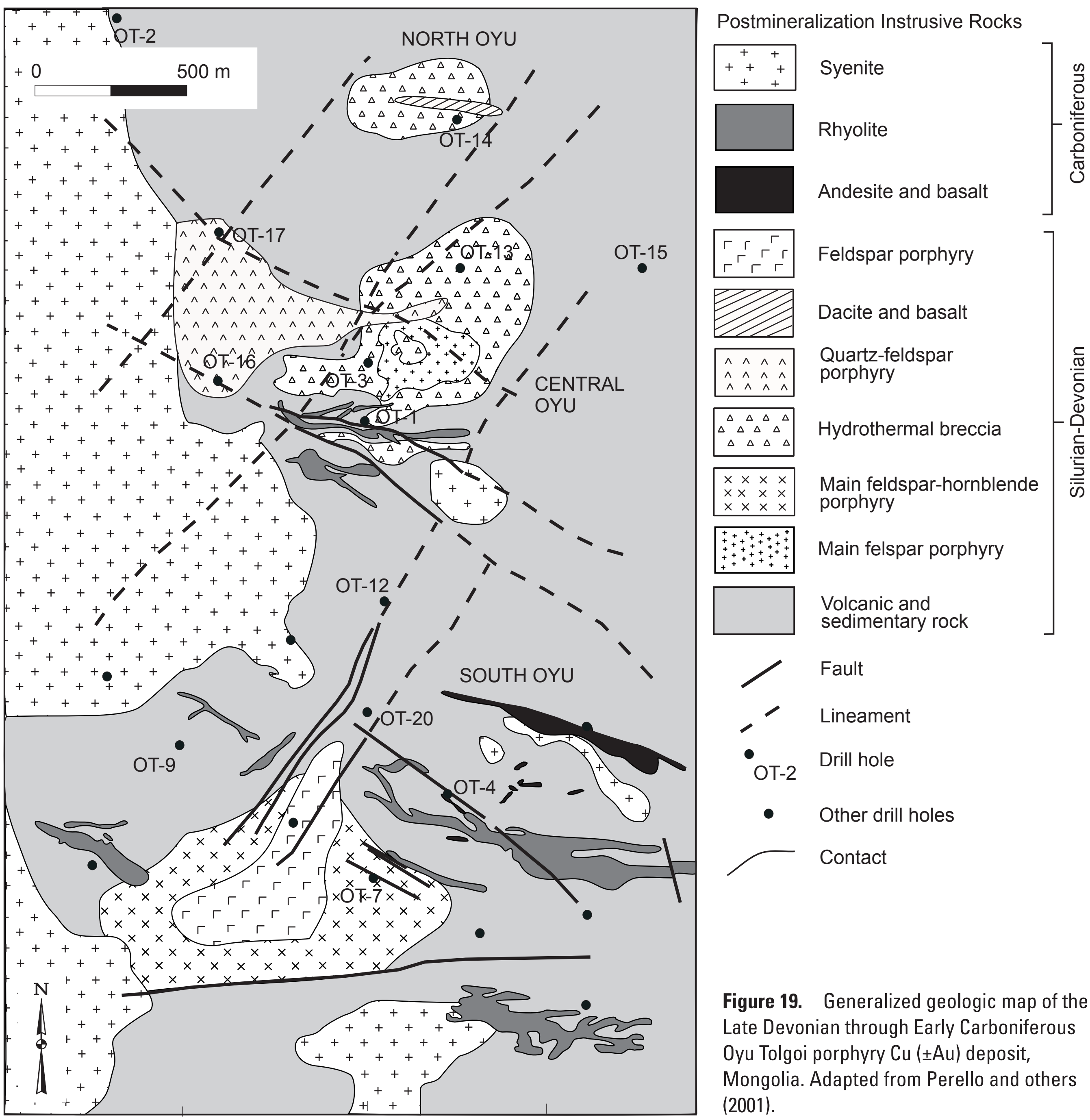


Figure 19. Generalized geologic map of the Late Devonian through Early Carboniferous Oyu Tolgoi porphyry Cu (±Au) deposit, Mongolia. Adapted from Perello and others (2001).

sericite alteration with subsequent deposition of Cu sulfides, sometimes in open-space filling veins and veinlets. Alteration zones, from inner to outward, are sodic-calcic, potassic, phyllic, and argillic to propylitic. Widespread, episodic development of abundant joints in intrusions and wallrocks is typical. The depositional environment consisted of shallow porphyry intrusions that were contemporaneous with abundant dikes, faults, and breccia pipes associated with andesite stratovolcanoes in the backarc zones of subduction-related continental-margin or island arcs. Examples of this mineral-deposit type are Erdenetiin Ovoo (fig. 20) and Tsagaan Suvarga, Mongolia, Duobaoshan, Heilongjiang Province and Wunugetushan, Inner Mongolia, China.

Porphyry Mo (± W, Sn, Bi) (Sotnikov and others, 1977, 1985; Theodore, 1986; Pokalov, 1992; Ludington, 1986; Nokleberg, and others, 1997)

Porphyry Mo (± W, Sn, Bi) deposits consist of quartz-molybdenite stockwork in felsic porphyries and adjacent country rock. The porphyries range in composition from granite-rhyolite, (>75 percent SiO_2) to tonalite, granodiorite, and monzogranite. Radial silicic dikes and small breccia pipes are common. Associated minerals are pyrite, scheelite, and chalcopyrite, rare cassiterite, wolframite, and tetrahedrite; gangue minerals are quartz, K-feldspar, biotite, calcite, and white mica. Some deposits are high F, and have larger

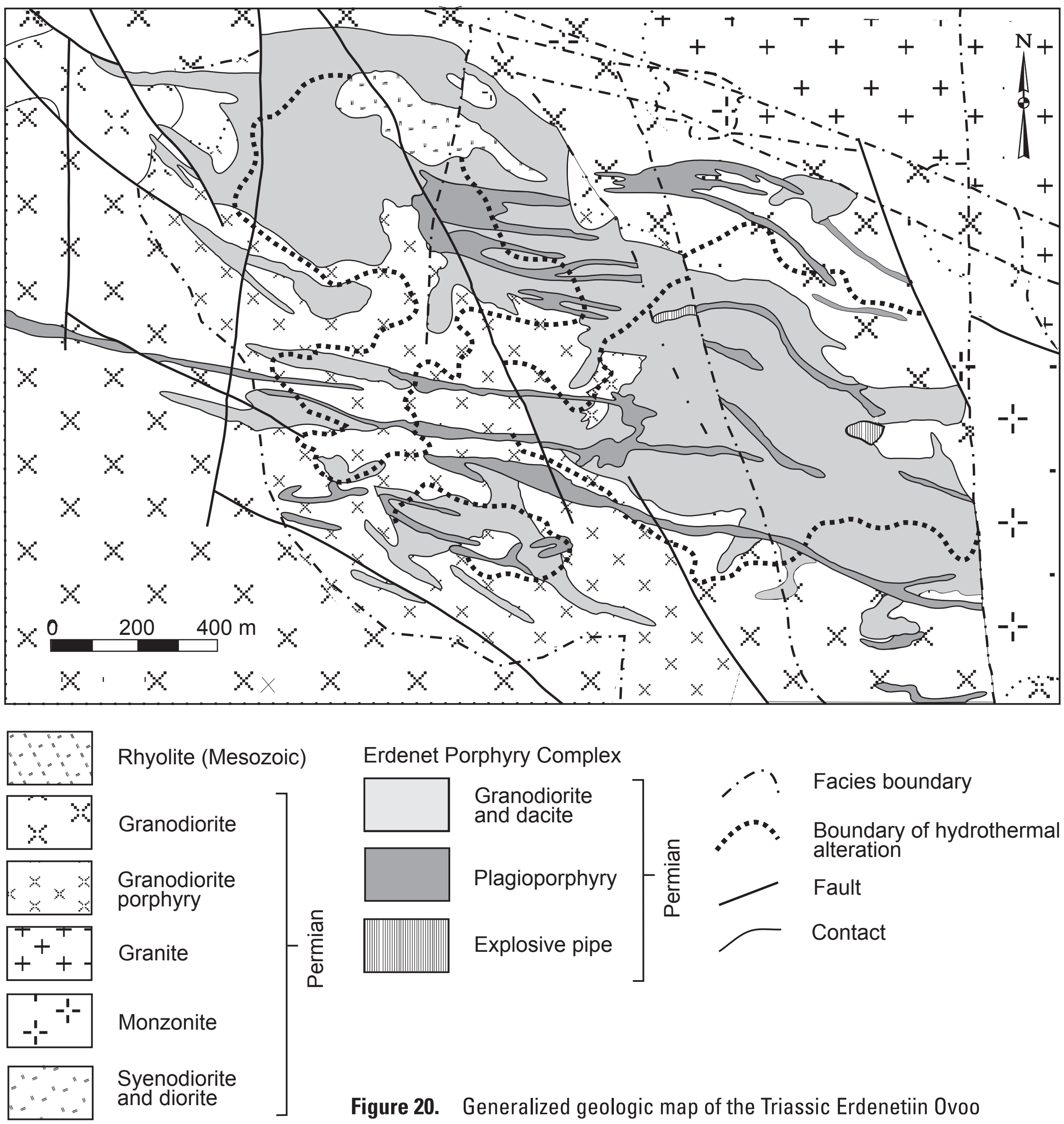


Figure 20. Generalized geologic map of the Triassic Erdenetiin Ovoo porphyry Cu-Mo deposit, Mongolia. Adapted from Gavrilova and others (1989).

tonnages and higher average grades than the low-F deposits hosted in quartz monzonite. Alteration consists of potassic grading outward to propylitic, sometimes with phyllic and argillic overprints. Intense quartz and quartz-feldspar veins are typical for F-rich deposits. Minor greisen veins may occur below the ore body. According to mineralogy and tectonic setting, two subtypes are defined: (1) high-grade, rift-related deposits with multistage F-rich, highly evolved granite to rhyolite stocks that constitute a high-silica, alkalic rhyolite suite; and (2) low-grade, continental-margin arc-related deposits hosted in F-poor, calc-alkalic stocks or plutons that form a differentiated monzogranite suite. The high-grade, F-rich deposits are also associated with intraplate alkaline igneous rocks. The depositional environment consisted of shallow, epizonal porphyry intrusions in the backarc zones of subduction-related, continental-margin arcs that were built on thick continental crust. Examples of this mineral-deposit type are Birandzha, Melginskoye, Metrekskoye, Sorskoye (fig. 21), and Zhirekenskoye, Russia; and Daheishan 2, Jilin Province, China; and Lanjiagou, Liaoning Province, China.

Porphyry Sn (Reed, 1986a; Rodionov, 1990; Nokleberg and others, 1997)

Porphyry Sn deposits consist mainly of cassiterite and associated minerals in stockworks, veinlets, and disseminations that occur in complex, subvolcanic, multiphase granitic plutons, granitic porphyry or quartz porphyry stocks, and subvolcanic and volcanic rhyolite breccias, and as well as in coeval volcanic rocks and surrounding clastic rocks. The subvolcanic host rocks range in composition from intermediate to silicic (quartz-latite, dacite, rhyodacite); cogenetic volcanic rocks consist of calc-alkaline pyroclastic rocks and lava (quartz-latite to rhyodacite). Closely related intrusions are mainly strongly-altered and brecciated quartz porphyry. Magmatic-hydrothermal breccia and extensive metasomatic propylitic and phyllic alterations are typical, accompanied by quartz, tourmaline, sulfides, and sericite. Minerals are cassiterite, quartz, pyrrhotite, pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, stannite, wolframite, muscovite, sericite, chlorite, albite, adularia, siderite, rhodochrosite, calcite, topaz, fluorite, sulfostannates, and Ag and Bi minerals. Alteration zones, from interior to periphery, are

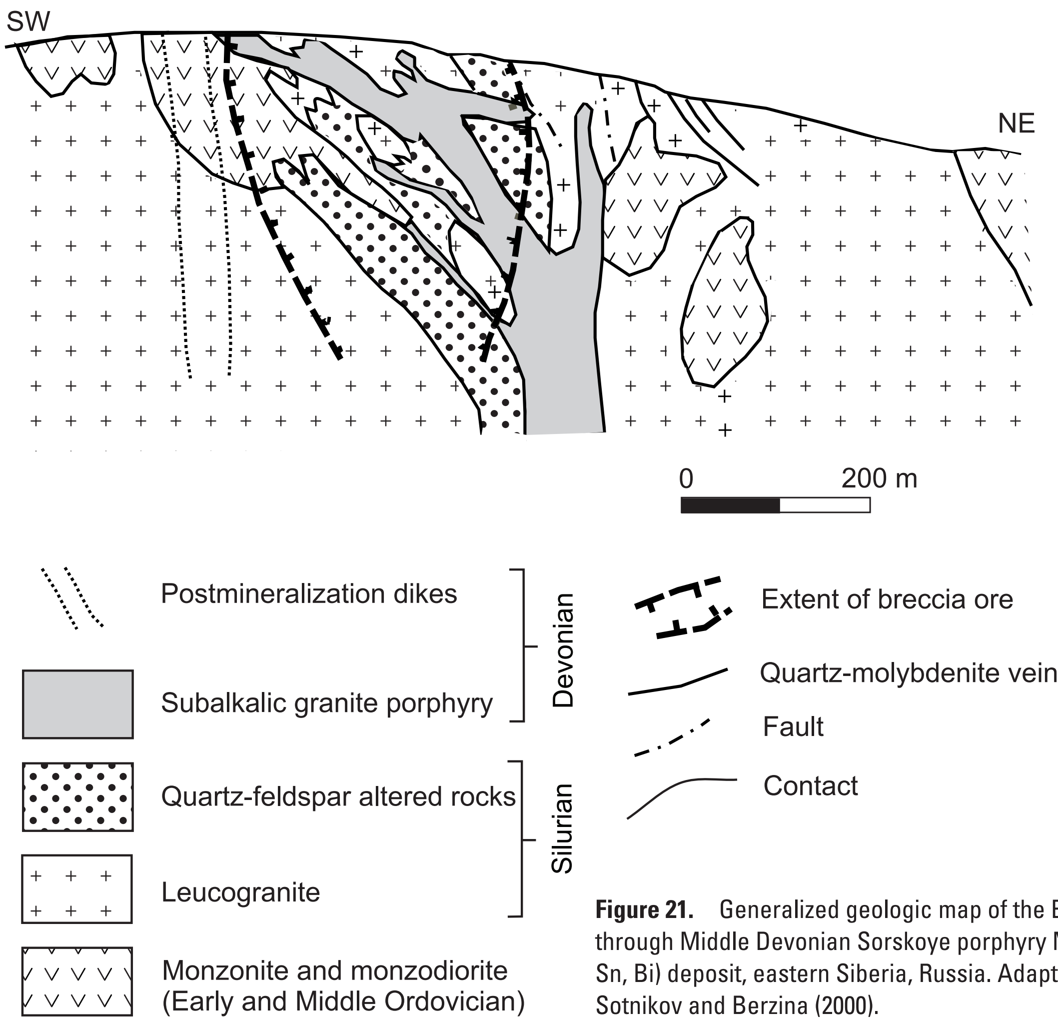


Figure 21. Generalized geologic map of the Early through Middle Devonian Sorskoye porphyry Mo(±W, Sn, Bi) deposit, eastern Siberia, Russia. Adapted from Sotnikov and Berzina (2000).

tourmaline (±adularia), phyllic, propylitic, and argillic. Some deposits exhibit a quartz-tourmaline core with a peripheral zone of sericite. The deposits are commonly associated with Sn- and Ag-bearing polymetallic veins. The depositional environment consisted mainly of shallow subvolcanic stocks emplaced from 1 to 3 km beneath or within vents of stratovolcanoes in the backarc zones of subduction-related continental-margin arcs. Examples of this mineral-deposit type are Mokhovoye, Mopau, Surkho, Yantarnoe, and Zvezdnoe, Russia.

III. Deposits Related to Alkaline Intrusions

A. Carbonatite-Related Deposits

Apatite Carbonatite (Smirnov, 1982; Entin and others, 1991)

Apatite carbonatite deposits consist of apatite-carbonate, apatite-quartz-carbonate, martite-apatite-quartz-carbonate assemblages, martite-apatite-carbonate, and apatite-carbonate-quartz assemblages in asymmetric early- and late-stage stocks. Early-stage carbonatites form veins, vein zones, and stockworks in mafic complexes intruded into crystalline basement. The veins range from a few centimeters to 30-40 m wide and from a few meters to 500 m long, rarely as much as 1.5 km. Early-stage apatite carbonatite contains apatite, carbonates (calcite, dolomite), K-feldspar, phlogopite, martite, and serpentine. Apatite occurs as large (maximum of 20 cm diameter) acicular crystals with coarse cracks filled with breakdown products, including mica, serpentine, and martite. Intergrowths of martite, serpentine, and phlogopite, and serpentine and martite that rim apatite grains are common. Apatite may also contain microcrystals of monazite. Late-stage carbonatite, which occurs as dikes and stocks intruding the early-stage carbonatite, consists of dolomite, anhydrite, apatite, quartz, chlorite, minor barite and martite, and rare tourmaline, fluorite, and sulfate-apatite. Typically intergrowths of apatite and hematite, visually resembling jaspilite, are replaced by apatite, martite, and carbonates. Apatite in late-stage carbonatite occurs as subparallel acicular crystals in a carbonate matrix, lacks coarse cracks, and is intergrown with martite, serpentine, and phlogopite; carbonate inclusions are insignificant. The depositional environment consisted of generation of alkalic mafic magmas during rifting of cratons or cratonal terranes. An example of this mineral-deposit type is at Seligdar, Russia.

Fe-REE Carbonatite (Kim and others, 1965; Nevskiy and others, 1972; Sinyakov, 1988; Park and Hwang, 1995)

Fe-REE carbonatite deposits consist of magnetite, calcite, hematite, limonite, chalcopyrite, pyrite, siderite, rhodochrosite, apatite, REE minerals, fluorite, barite, and siderite. The deposits occur in complex featherjoint systems associated with large faults. Host rocks are alkali mafic magmas that intrude mainly gneiss-schist complexes and clastic sedimentary rocks. Hornblendite dikes occur locally (for example, Hongcheon mine, Korean Peninsula). Minerals are siderite, barite, fluorite, hematite, magnetite, bastnaesite, parisite, REE minerals, and sulfides. REE minerals also occur in siderite, barite, and fluorite. Extensive hydrothermal alteration consists of ankerite-calcite-siderite metasomatite. Ore-bearing breccia zones form steeply dipping columns. The deposit minerals form complex mixtures of magnetite, monazite, apatite, and strontianite that occur in carbonates mostly composed of Fe-rich dolomite, ankerite, and siderite with anomalous P, Sr, Nb, La, Ce, Nd, Sm, and Ba contents. Apatite is associated with magnetite, dolomite, strontianite, and barite. Also occurring is REE monazite that forms myrmekitic intergrowths with dolomite and strontianite. Minor chalcopyrite and molybdenite occur as disseminations in ore and carbonaceous host rocks. Magnetite and monazite are commonly fractured by cataclastic deformation. Pyrite is a common sulfide in alteration zones. The deposits range in structure from breccia to massive to locally banded. High Fe deposit minerals are interpreted as forming during hydrothermal replacement of argillaceous sedimentary rocks. The depositional environment consisted of generation of alkalic mafic magmas during rifting of craton or cratonal terranes. Examples of this mineral-deposit type are Karasugskoye and Ulatayskoye, Russia.

Fe-Ti (±Ta, Nb, Fe, Cu, Apatite) Carbonatite (A.A. Frolov in Pokalov, 1984; Singer, 1986a)

Fe-Ti (±Ta, Nb, Fe, Cu, apatite) carbonatite deposits consist of ferrous carbonatite spatially and genetically related to circular alkali-ultramafic plutons that tend to occur adjacent to deep fault zones. Zoned plutons are characteristic and consist of dunite, pyroxenite, jacupirangite, melteigite, ijolite, urtite, nepheline syenite, and carbonatite. Two subtypes are defined: perovskite-titanomagnetite and apatite-magnetite. The first subtype consists of pyroxenite and dunite with disseminations, branches, lenses, and veinlets of minerals, mianly titanomagnetite, perovskite, olivine, and pyroxene. The second subtype consists of magnetite, apatite, baddeleite, pyrochlore, forsterite, calcite, dolomite, phlogopite, clinohumite, zircon, and Cu-Ni sulfides. The deposits commonly occur in linear or ring-shaped veins, pipelike bodies, and stockworks that occur in both the central and in peripheral parts of plutons. The depositional environment consisted of generation of alkalic mafic-ultramafic magmas during rifting of cratons or cratonal terranes. Examples of this mineral-deposit type are Esseiy 1, Gulinskoye 1, Iriaas 1, and Kugda 1, Russia.

Phlogopite Carbonatite (Eckstrand, 1984; Epstein, 1994)

Phlogopite carbonatite deposits consist of phlogopite bodies and disseminations hosted in alkalic ultramafic plutons. Phlogopite occurs in carbonatite in association with autoreactional skarns. Both endoskarn and exoskarn occur. endoskarn consists of metasomatic ijolite and nepheline-pyroxene rock; and exoskarn consists of melonite-pyroxene, calcite-diopside, diopside-wollastonite-calcite, and calcite-magnetitem pegmatite masses. Phlogopite also occurs in (1) veins and lenses of garnet, nepheline, and pyroxene; (2) disseminations in carbonate-diopside rock; and (3) veins in dunite. The deposits are zoned with (1) a peripheral zone composed of garnet-pyroxene-nepheline pegmatoid rock; (2) a core vein zone composed of apatite-pyroxene and calcite-phlogopite rock. Phlogopite distribution is irregular. The depositional environment consisted of a carbonatite-alkali-ultramafic complex that intruded along major faults during intracraton rifting. This deposit type is associated with Fe-Ti carbonatite and REE-Ta-Nb carbonatite deposits. Examples of this mineral-deposit type are Gulinskoye 3 and Odikhincha 1, Russia.

REE (±Ta, Nb, Fe) Carbonatite (Smirnov, 1969; Nevskiy and others, 1972; Samoilov and Kovalenko, 1983; Eckstrand, 1984; Sinyakov, 1988; Epstein, 1994; Kovalenko and Yarmolyuk, 1995)

REE (±Ta, Nb, Fe) carbonatite deposits consist of stockworks, metasomatic veins, breccias, columnar bodies, and lenses of various size containing REE, Ta-Nb, and Fe minerals in complexly zoned alkalic ultramafic carbonatite igneous complexes that occur in (1) zoned pluglike stocks, (2) lopolith-type conical massifs, (3) circular or semi-circular structures, and linear dikes occurring in conical and radial faults, and (4) complexly shaped intrusions combining the three previous structures. The complexes tend to cluster near major faults. The zoned carbonatite complexes and stocks commonly contain two or more of the following rock types: pyroxenite, gabbro, urtite, ijolite, foyaite, nephelinite, alkaline syenite, carbonatite melanephelinite, melaleucitite, phonolite, trachyte, eruptive trachyte breccia with a carbonatite matrix, latite, trachybasalt, and syenite. The carbonatites generally consist of various assemblages of augite-diopside-calcite, forsterite-calcite, aegirine-dolomite, aegirine-ankerite, calcite, and ankerite. Zonation consists of a central zone of carbonatite, a medial zone of ultramafic rocks, and a peripheral zone of ijolite and nepheline syenite; the zonation sequence may be locally reversed or complex. Igneous and nearby host rocks are commonly intensively altered, along with the obscuration of the distinction between igneous and country rocks. Alteration assemblages include combinations of pyroxene, feldspar, nepheline, alkaline amphibole, ankerite, calcite, siderite, magnetite, apatite, and bastnaesite. Minerals, which occur in alkaline metasomatic rock, are pyrochlore, baddeleyite, perovskite, knopite, dysanalite, synshysite, bastnaesite, parisite, zircon, monazite, columbite, apatite, yttrialite, melanocerite, yttrotitanite, hydrothorite, siderite, barite, strontianite, fluorite, hematite, magnetite, celestine, cerrusite, apatite, monazite, and sulfides. REE's also occur in siderite, barite, and fluorite. The depositional environment consisted of intrusion of alkalic mafic magma during rifting of cratons or cratonal terranes. Examples of this mineral-deposit type are Beloziminskoye, Gornoye Ozero (fig. 22), and Gulinskoye 2, Russia, and Mushgai hudag, Mongolia.

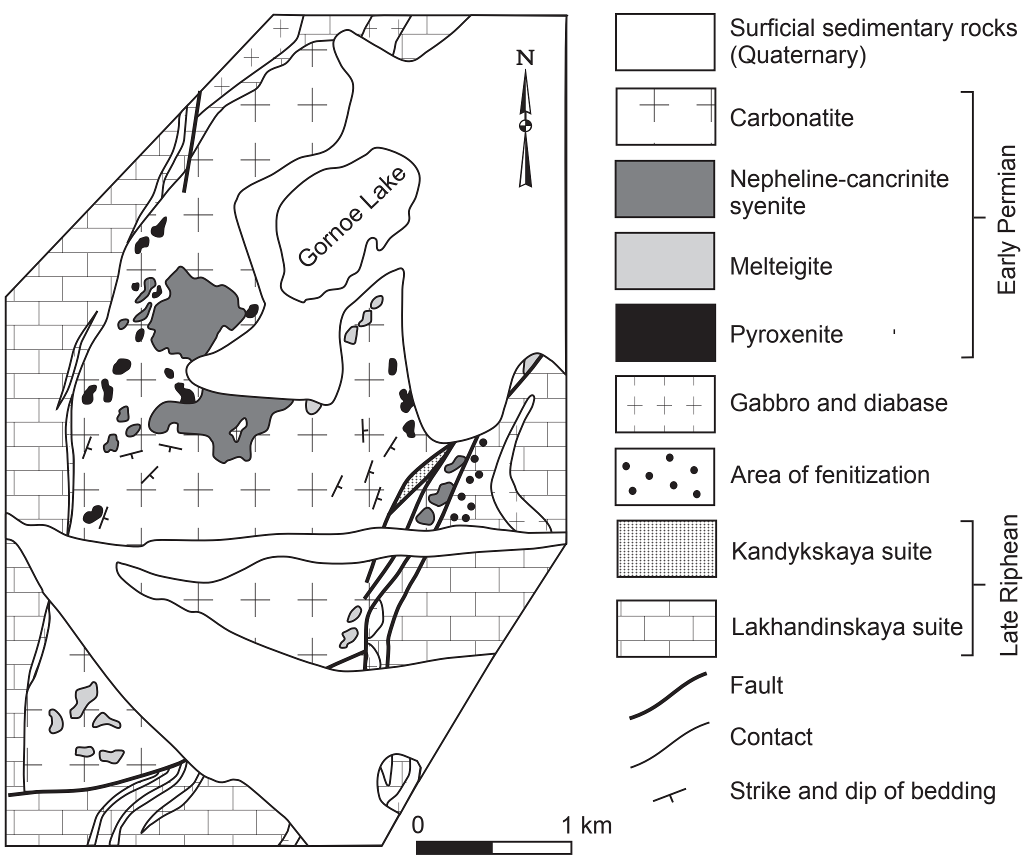


Figure 22. Generalized geologic map of the Middle Devonian through Early Carboniferous Gornoye Ozero REE (±Ta, Nb, Fe) carbonatite deposit, Russian Southeast. Adapted from Korostylyov (1982).

B. Alkaline-Silicic Intrusions-Related Deposits

Alkaline Complex-Hosted Au (Song and others, 1996; Shi and Xie, 1998)

Alkaline complex-hosted Au deposits occur in alkaline igneous complexes and peripheral country rocks. Three subtypes are defined: (1) most common Au-bearing potassic and silica-altered rocks; (2) more common, Au quartz veins associated with potassium alteration envelope; and (3) less common Au quartz veins. Minerals, which comprise less than 3 percent of the host rock, are mainly gold and pyrite, and lesser magnetite, chalcopyrite, galena, altaite, and others; gangue minerals are mainly quartz and lesser feldspar, sericite, chlorite, epidote, and others. Gold ranges in fineness ranges from 935 to 978. Wallrocks are altered to K-feldspar, silica, pyrite and sericite. The host alkaline igneous complex (for example at Dongping, Hebei Province, China) consists of alkali feldspar syenite, alkali feldspar quartz syenite, pyroxene-hornblende-alkali feldspar syenite, pyroxene-hornblende syenite, and hornblende-alkali-feldspar syenite. Alkaline complexes occur in elongated zones that typically intrude Archean metamorphic gneiss along major faults. The depositional environment consisted of intrusion of alkalic mafic magma during rifting or strike-slip faulting of cratons or cratonal terranes. Examples of this mineral-deposit type are Akalakhinskoye, Russia, Dongping (fig. 23) and Hougou Chicheng, Hebei Province, China.

Peralkaline Granitoid-Related Nb-Zr-REE (Vladykin, 1983; Kovalenko and others, 1985, 1995)

Peralkaline granitoid-related Nb-Zr-REE deposits consist of peralkaline granitic rocks containing REE-Zr-Nb minerals that generally occur in the apical parts of cupolas, generally in association with highly fractionated magmatic phases, including peralkaline pegmatite. The host granite is composed of K-feldspar, quartz, albite, arfvedsonite, aegirine, fluorite, and various REE minerals, such as elpidite, gittinsite, zircon, pyrochlore, monazite, REE fluorcarbonate, and polylitihonite. Alteration consists of replacement by epidote, orthoclase, and postmagmatic albite. The deposits are generally hosted in microcline-albite granite and metasomatic rocks composed of quartz, albite, pyroxene, and microcline. Quartz-epidote metasomatite contains zircon, fergusonite, allanite, chevkinite and titanite in veinlike zones; fergussonite and zircon with REE's and Y also occur. Accessory minerals are amphibole, magnetite, zircon, epidote, ilmenite, fluorite, beryl, chevkinite, pyrite, and galena. Associated deposit types are REE pegmatite and quartz-fluorite veins. The depositional environment consisted of intrusion of peralkaline granitic rock into miogeoclinal or island arc assemblages. Examples of this mineral-deposit type are Ulaantolgoi, Mongolia and China, and Baerzhe, Inner Mongolia, China.

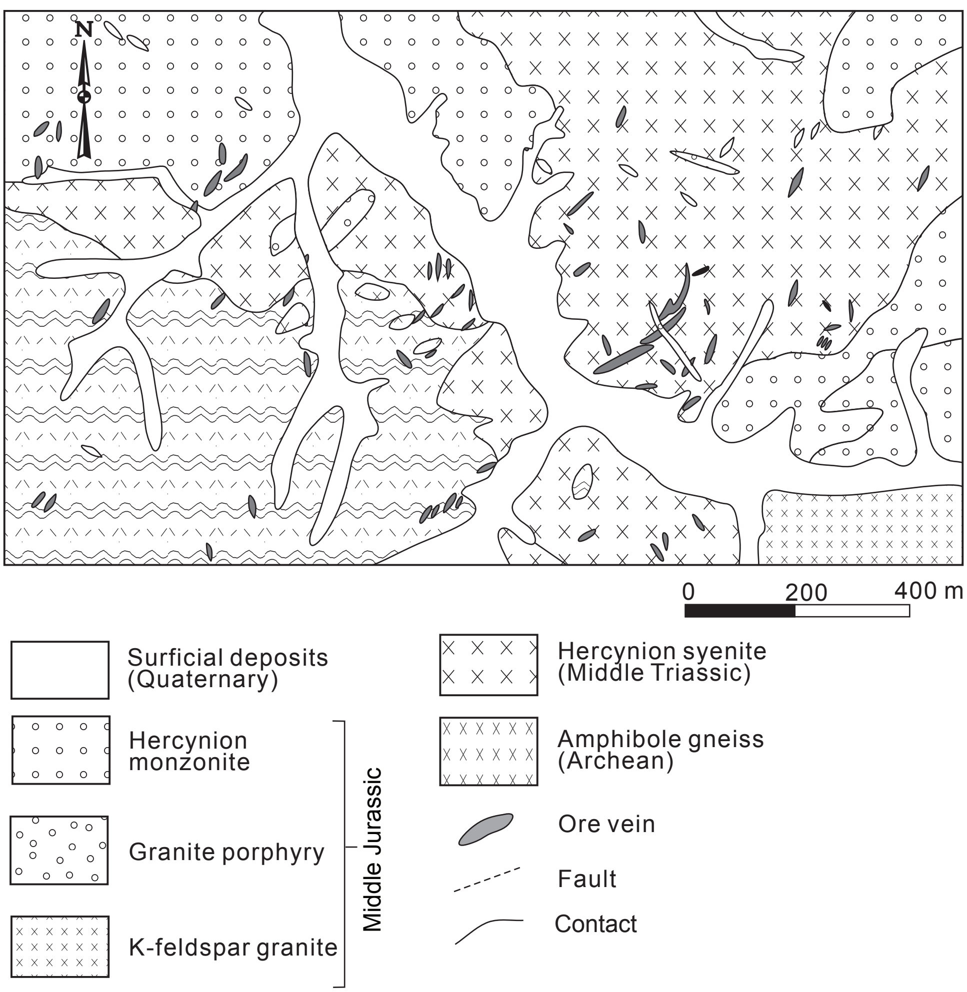


Figure 23. Generalized geologic map of the Middle Jurassic Dongping alkaline complex-hosted Au deposit, northern China. Adapted from Song and Zhao (1996).

Albite Syenite-Related REE (Andreev and others, 1994; Kempe and others, 1994; Kovalenko and Yarmolyuk, 1995)

Albite syenite-related REE deposits occur in (1) endocontacts of alkaline plutons composed of metasomatically altered alkaline syenite (nordmarkite) and (2) peralkaline volcanic rocks (comendite, pantellerite, peralkaline trachydacite, trachyrhyolite and trachybasalt) intruded by REE-albite nepheline syenite. Minerals are various REE-Zr-Nb minerals. An example of this deposit type is at Maikhan Uul, Mongolia.

Ta-Li Ongonite (Kovalenko and others, 1971; Kovalenko and Kovalenko, 1986)

Ta-Li ongonite deposits are subdivided into volcanic and plutonic facies. The igneous rocks are porphyritic with phenocrysts of albite, quartz, K-feldspar, topaz, and Li-fengite in a fine-grained matrix of REE minerals. Main minerals contain Ta, Rb, Nb, Be, Li, and Sn. Plutonic ongonite is rich in Ta (maximum of 130 ppm with an average concentration of 88 ppm), and Li (average concentration of 2,780 ppm), and Rb (average concentration of 2,380 ppm). Volcanic ongonite (for example, Teg Uul, Mongolia) contains less REE's (average concentrations of 37 ppm Ta, 170 ppm Nb, 1,040 ppm Rb, and 90 ppm Be) and occurs in large bodies, including volcanic cones, stratified bodies, and sheets. Igneous rocks contain an average of 0.05 to 0.8 percent Li, 0.5 to 5.0 percent Zr, and 0.3 to 4.5 percent REE. High Li, Be, Sn, and Zn contents are characteristic. The Teg Uul deposit, Mongolia, is large (over 1 km^2) and composed of a tuff unit that ranges from 10 to 20 m in thickness. Associated rocks are late Mesozoic rhyolite and ongorhyolite that occur in volcanic necks. Other examples of this mineral-deposit type are Ulkanskoe, Russia, and Ongon Khairkhan, Mongolia.

C. Alkaline-Gabbroic Intrusion-Related Deposits

Charoite Metasomatite (Konev and others, 1996)

Charoite metasomatite deposits consist of breccia-like, veinlike, stratified bodies of charoite hosted in Archean and Proterozoic fenitized gneiss, quartz sandstone, and dolomite. Charoite is interpreted as having formed during the final intrusive stage of ultrapotassic alkaline syenite; however, interpretations vary about its genesis. One interpretation is a metasomatic origin and the other interpretation is magmatism that resulted in charoite metasomatic replacement of host rocks Mineral composition is diverse, ranging from almost monomineralic charoite to complex mixtures of aegirine, pectolite, K-feldspar, quartz, tinaksite, fedorite, canasite, and calcite. As many as 50 minerals are known in the deposits. Morphology consists of dense monoliths with shell-like fractures, pegmatoid, coarse-crystalline, schistose, and gneissic. Charoite ranges in color from purple to brown, and to colorless. Charoite composition is similar to canasite and the chemical formula is $(Na, K)_5Ca[(OH,F)_3]Si_{10}O_{25}$ with Ba and Sr. The only example of this mineral-deposit type is at Murunskoe, Russia.

Magmatic and Metasomatic Apatite (Arkhangelskaya, 1964; Litvinovsky and others, 1998)

Magmatic and metasomatic apatite deposits consists of two subtypes: magmatic deposits and metasomatic apatite deposits. The first subtype occurs in sheeted plutonic or stratiform complexes with alternating, conformable lenses, plates, and dikes that are composed of medium- and coarse-grained alkaline gabbro, melanocratic alkaline gabbro, or alkaline-feldspar syenite. Apatite is concentrated in alkaline gabbro (average 4 percent P_2O_5) and forms equally spaced tabular grains, short prisms, needles, discrete cumulate minerals, poikilitic inclusions in pyroxene and amphibole, phenocrysts in microgabbro dikes, and lenses and nests with hornblende and titanomagnetite. Hornblende-feldspar pegmatite also occurs with numerous apatite inclusions. Host rocks for the intrusions are commonly gneissic granite and gneiss.

The second subtype consists of large metasomatite zones in zoned plutons of alkaline nepheline syenite and pseudoleucite syenite containing as much as 19 percent K_2O and 23 percent Al_2O_3. The metasomatite mainly occurs along syenite contacts and in linear fracture zones. Early stage melanocratic metasomatite consists of ijolite, fayalite, and micaceous shonkinite. The melanocratic metasomatite bodies varies from several meters, to dozens to hundreds of meters thick and from dozens to hundreds of kilometers long. Melanocratic metasomatite is enriched in Ca, Mg, Fe, and P with a high apatite content of 3 to 10 percent. Apatite is unevenly distributed; deposits rich in apatite consist of pyroxene, biotite, apatite, orthoclase, nepheline, plagioclase, magnetite (locally up to 10 to 20 percent), and sphene. Apatite content ranges from 5 to 10 to 80 percent. Apatite-rich areas, as much as several dozen square meters in area, occur in synnyrite that contains mainly apatite with lesser orthoclase, biotite, pyroxene, and magnetite. The depositional environment of both subtypes consisted of intrusion of alkaline syenite magma during rifting or strike-slip translation of cratons or cratonal terranes. Examples of this mineral-deposit type are Murunskoe, Oshurkovskoye, and Synnyrskoye, Russia, and Fanshan, Hebei Province, China.

Magmatic Graphite (Lobzova, 1975; Eremin, 1991)

Magmatic graphite deposits consist of masses of graphite in alkaline plutonic rocks, including syenite and nepheline syenite. The graphite occurs in irregular lenses, stocks, and veins. The host rock limestone forms complex xenoliths in the marginal parts of the alkaline plutons. Altered rock is skarn and fenite that occur in, or adjacent to contact zones. Banded deposit minerals consist of alternating graphite and graphite-pyroxene-calcite layers; associated minerals include feldspar, apatite,and aegirine. Examples of this mineral-deposit type are Kureiskoye 2, Russia, Guangyi, Muling, and Yangbishan, Heilongjiang Province, China.

Magmatic Nepheline (A.N. Sucharina, in Kuznetsov, 1982)

Magmatic nepheline deposits consist of high-grade nepheline minerals hosted in alkalic gabbro that intrudes orogenic zones and accreted terranes. The deposits and intrusive host rocks occur along or adjacent to major fault zones. Host rocks for the ore-bearing intrusions are mainly carbonates and carbonaceous pyroclastic rocks. Minerals are urtite containing as much as 90 percent nepheline that occur in dikes and complex alkalic gabbro plutons; associated minerals are titanaugite and lesser apatite, aegirine-augite, titanomagnetite, and pyrrhotite. Examples of this mineral-deposit type are Dahu-Nurskoye and Kharlinskoye, Russia, and Beltesin gol, Mongolia.

IV. Deposits Related to Marine Extrusive Rocks

A. Massive Sulfide Deposits

Besshi Cu-Zn-Ag Massive Sulfide (Cox, 1986c; Slack, 1993, M. Ogasawara, this study)

Besshi Cu-Zn-Ag massive sulfide deposits consist of thin sheets of massive to well-laminated pyrite, pyrrhotite, chalcopyrite and sphalerite, and sulfides with lesser magnetite, galena, bornite, and tetrahedrite. Gangue minerals are quartz, carbonates, albite, white mica, and chlorite. The deposits occur in thick sequences of clastic sedimentary rocks and intercalated basalt, which is volumetrically subordinate to the sedimentary rocks. Thinly laminated chert and black shale occur locally. Wallrocks may include sericite and chlorite schist, coticule, tourmalinite, and albitite lenses that commonly form stratabound bodies or envelopes around massive sulfides, and may extend as much as 5 to 10 meters into adjacent host rocks. Coticule, tourmalinite, and albitite lenses may occur as stratiform layers that extend laterally for hundreds of meters beyond the massive sulfide deposit. Wallrocks exhibit hydrothermal alteration and (or) chemical sedimentation that was coeval with deposition of the massive sulfides. Alteration is sometimes difficult to recognize because of subsequent metamorphism. The deposits typically consist of stratiform lenses and sheetlike accumulations of semi-massive to massive sulfides. Footwall feeder zones may occur. The type example is the Besshi deposit in southwestern Japan that occurs in the Sambagawa metamorphic terrane. The depositional environment consisted of submarine hot springs related to the deeper zones of submarine basaltic volcanism along spreading oceanic ridges or backarc spreading centers, possibly in areas where a spreading oceanic ridge occurs near a continental margin that is supplying clastic detritus. Examples of this mineral-deposit type are Besshi (fig. 24), Iimori, Kune, Makimine, Minenosawa, and Shimokawa, Japan.

Cyprus Cu-Zn Massive Sulfide (Eckstrand, 1984; Singer, 1986b)

Cyprus Cu-Zn massive sulfide deposits consist of massive sulfides in submarine, predominantly mafic tholeiitic or calc-alkaline volcanic rocks that occur in ophiolite sequences or greenstone belts. Minerals are mainly pyrite, chalcopyrite, and sphalerite, and lesser marcasite and pyrrhotite. Sulfides occur in pillow basalt associated with tectonized dunite, harzburgite, gabbro, sheeted diabase dikes, and fine-grained sedimentary rocks that form part or all of an ophiolite assemblage. Locally beneath massive sulfide bodies is a stockwork composed of pyrite, pyrrhotite, minor chalcopyrite, and sphalerite. Some sulfides may be brecciated and recemented. Alteration in the stringer zone consists of abundant quartz, chalcedony, chlorite, and lesser illite and calcite. Some deposits are overlain by Fe-rich and Mn-poor ochre. The depositional environment consisted of submarine hot springs along an axial graben in oceanic or backarc spreading ridges, or hot springs related to submarine volcanoes in seamounts. Examples of this mineral-deposit type are Mainskoye, Russia, Nergui, Mongolia, and Okuki, Japan.

Volcanogenic Cu-Zn Massive Sulfide (Urals type) (Borodaevskaya and others, 1985)

Volcanogenic Cu-Zn massive sulfide (Urals type) deposits consist of massive to disseminated Zn-Cu sulfide minerals hosted in island-arc volcanic belts. The volcanic rocks consist of bimodal rhyolite and basalt, andesite, dacite, and rhyolite with subordinate felsic rocks. Ore-controlling structures are volcanotectonic depressions, calderas, domes, and synvolcanic faults. The most widespread are lens-shaped deposits that are concordant with host rocks. Less abundant deposits are funnel-shaped or T-shaped deposits. Apophyses of massive sulfides in lenses in footwalls may grade downward into discordant stringers. Multilevel deposits are typical. Minerals are mainly pyrite, chalcopyrite, and sphalerite with minor galena, tennantite, tetrahedrite, and bornite; gangue minerals are quartz, sericite, chlorite, and carbonate. The volcanic and sedimentary host rocks are widely altered. The root-zones consist of sericite-quartz metasomatite grading upward and outward into quartz-sericite-chlorite and quartz-carbonate-sericite-chlorite with albite and epidote zones. Silica, epidote, and hematite alterations are widespread above deposits. Sulfides are zoned with Cu and Zn enrichment from footwall to hanging-wall and from core to periphery. Most minerals are massive but locally may be banded or brecciated, or may occur in stringers on the flanks of deposits. Formation of thick gossan in weathering zones of deposits is typical. The depositional environment consisted of an ensimatic island arc constructed on oceanic crust containing differentiated basalt and other volcanic rocks. The deposit type is a variant of Cyprus Cu-Zn massive sulfide deposits. Examples of this mineral-deposit type are Khariuzikhinskoye 1, Russia, and Borts Uul, Mongolia.

Volcanogenic Zn-Pb-Cu Massive Sulfide (Kuroko, Altai types) (Lambert and Sato, 1974, Jakovlev, 1978; Singer, 1986c)

Volcanogenic Zn-Pb-Cu massive sulfide (Kuroko, Altai types) deposits consist of Zn-Pb-Cu massive sulfides hosted in marine felsic to intermediate-composition volcanic, pyroclastic, and bedded volcanic and sedimentary rocks.

The deposits consist typically of massive stratiform and stockwork parts. The massive stratiform part is typically oval shaped in plan view and is underlain by a stockwork part; the stockwork part is typically funnel shaped, commonly occurs in silicified rhyolite, and is interpreted as a feeder zone for hydrothermal fluids. From stratigraphic bottom to top, the deposits are characterized by the following zones: (1) siliceous stockwork ore (pyrite-chalcopyrite-quartz), (2) yellow ore (stratiform pyrite-chalcopyrite), (3) black ore (stratiform sphalerite-galena-chalcopyrite-pyrite-barite), (4) barite ore, and (5) thin beds of ferruginous chert. Lenticular or irregular masses of gypsum and (or) anhydrite may also occur. Main minerals are pyrite, sphalerite, galena, chalcopyrite, and lesser tennantite, tetrahedrite, bornite, electrum, stromeyerite, argentite, native silver, and enargite; other minerals are barite, gypsum, anhydrite, calcite, dolomite, quartz, chlorite, and sericite. The stratigraphic footwall and locally the stratigraphic hanging wall are hydrothermally altered. Sericite, montmorillonite, and Mg-chlorite alteration envelops stratiform deposits. Associated with the stockwork

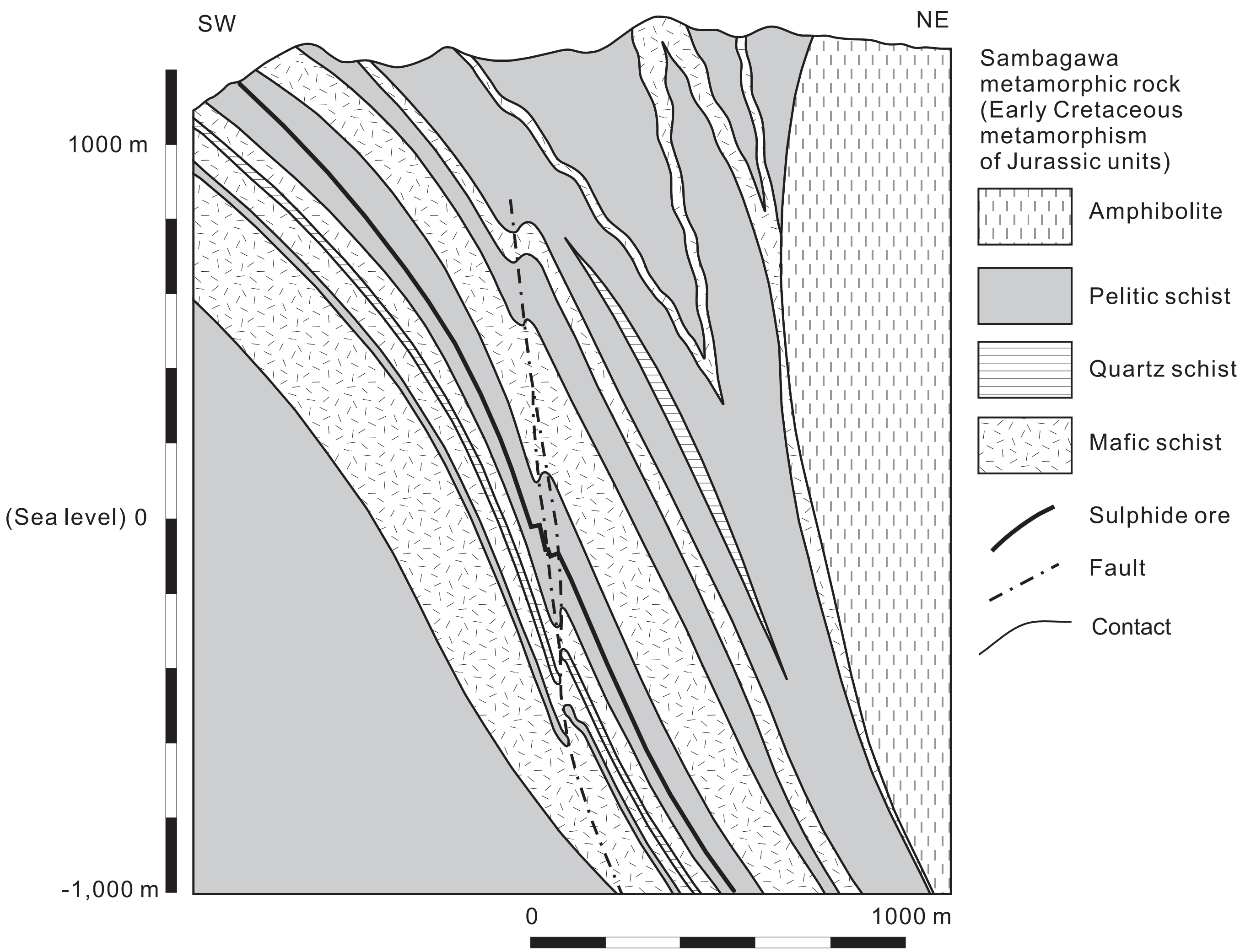


Figure 24. Generalized geologic map of the Early Jurassic through Campanian Besshi Cu-Zn-Ag massive sulfide deposit, Japan. Adapted from Sumitomo Metal Mining Co. (1981).

is quartz, sericite, and Mg-chlorite alteration. The Kuroko-type deposits in the Hokuroku area, northeastern Japan, formed in the middle Miocene during backarc rifting. The depositional environment consisted of discharge of solutions from high temperature submarine hydrothermal systems onto or near the sea floor along continental-margin or island arcs or backarc basins; discharge sites were fracture controlled. Examples of this mineral-deposit type are Khotoidokh and Korbalihinskoye (fig. 25), Russia.

B. Volcanogenic-Sedimentary Deposits

Volcanogenic-Hydrothermal-Sedimentary Pb-Zn, (±Cu) (Distanov, 1977; Distanov and others, 1982a,b; Eckstrand, 1984)

Volcanogenic-hydrothermal-sedimentary Pb-Zn, (±Cu) deposits consist of massive to stratiform Pb-Zn sulfide deposits of hydrothermal-sedimentary origin hosted in basinal assemblages of clastic, volcanic, and carbonates that are intruded by shallow basaltic magmas. Sulfides occur in basins in rhythmic, multistage sheets or layers that are hosted in tuffaceous, clastic, carbonate, and black shale. The deposits exhibit lateral and concentric zoning, massive to layered structures, and little or no wallrock hydrothermal alteration. Mineral aggregates are well laminated and consist of fine-grained quartz and sulfides, or quartz, siderite, and sulfides. The sulfides are Pb-Zn-rich, with little or no Cu. Main minerals are pyrite, sphalerite, galena, minor chalcopyrite arsenopyrite, tetrahedrite, burnonite, and pyrrhotite; gangue minerals are quartz, siderite, calcite, and ankerite. Rhythmic layers are typical, and sedimentary sulfide breccia is locally widespread. Two subtypes are defined: slightly metamorphosed (Ozernoje type) and highly metamorphosed (Kholodninskoje type). Metamorphism resulted in recrystallization and partial redistribution of minerals and

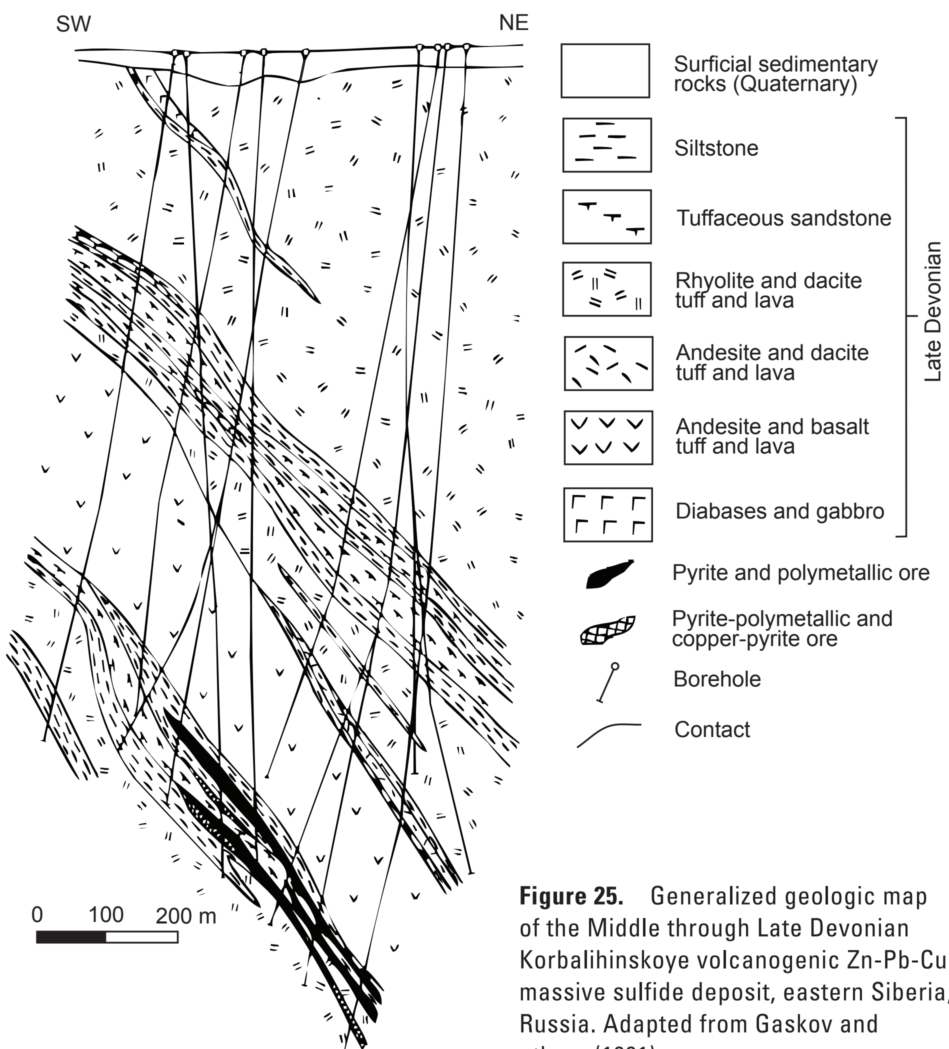
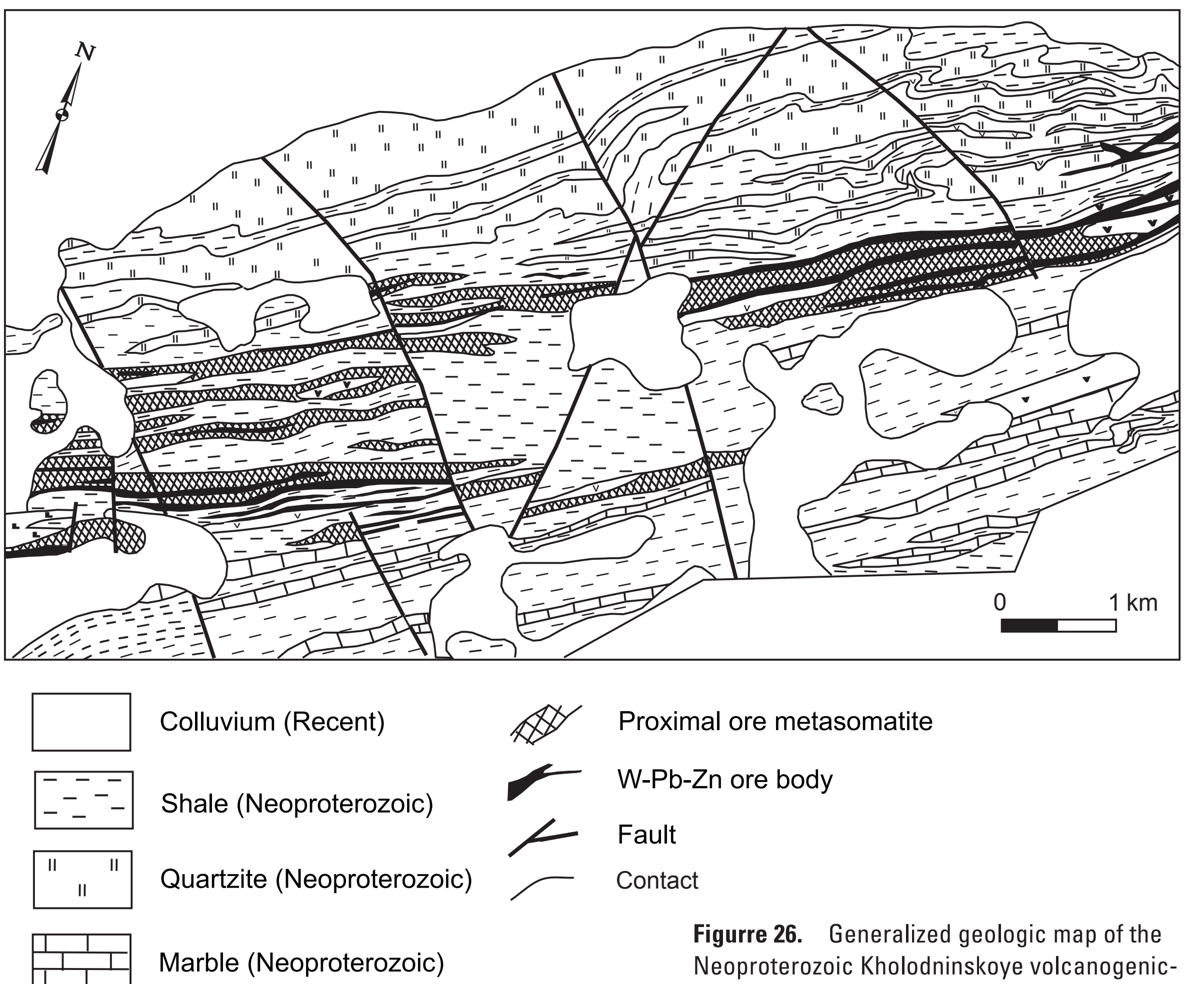


Figure 25. Generalized geologic map of the Middle through Late Devonian Korbalihinskoye volcanogenic Zn-Pb-Cu massive sulfide deposit, eastern Siberia, Russia. Adapted from Gaskov and others (1991).

changes in texture and structures but did not significantly influence the scale of deposit. The depositional environment consisted of either continental-margin rifting or intra-island-arc basins. Deep-seated faults are interpreted having formed conduits for mafic magmatism and hydrothermal systems. Basinal depressions are a deposit control and also resulted in burial of the deposits. Examples of this mineral-deposit type are Kholodninskoye (fig. 26) and Ozernoye 2, Russia, and Xiaoxilin, Heilongjiang Province, China.

Volcanogenic-Sedimentary Fe (Eckstrand, 1984; Sinyakov, 1988)

Volcanogenic-sedimentary Fe deposits consist of sheeted magnetite-hematite accumulations in volcanogenic and sedimentary sequences. The deposits are stratiform, and beds of iron formation are interlayered with volcanic rock, greywacke, and shale. The deposits occur from near to far from extrusive centers in submarine volcanic belts associated with deep fault systems and rift zones. The volcanic rocks are mainly siliceous with lesser mafic rocks, including rhyolite, siliceous porphyry, trachyrhyolite, trachyandesite, and basalt that are interlayered with pyroclastic, sedimentary, and siliceous exhalative rocks and metamorphic analogs. Main minerals are magnetite, hematite, siderite, Mn-siderite, pyrite, and pyrrhotite; associated minerals are chert, quartz, Fe-silicates, Fe-carbonates, chlorite, amphibole, biotite, feldspar, and chalcopyrite. Mineral distribution is a function of primary sedimentary facies. Oxide, silicate, carbonate, and sulfide facies commonly consist of thin, alternating layers or beds of silica and Fe-rich minerals interbedded with clastic sedimentary and volcanic rocks. Two subtyptes are defined: unmetamorphosed hematite-magnetite and metamorphosed



Figurre 26. Generalized geologic map of the Neoproterozoic Kholodninskoye volcanogenic-hydrothermal-sedimentary massive sulfide Pb-Zn(±Cu), TransBaikal, Russia. Adapted from Distanov and others (1982).

actinolite-magnetite. Metamorphic-mineral assemblages reflect the mineralogy of primary sedimentary facies. Some studies of the Fe skarn deposits in Altai-Sayan, Russia, and elsewhere suggest metamorphic derivation from volcanogenic-sedimentary Fe deposits. The depositional environment consisted of eruption of siliceous with lesser mafic volcanic rock in fault-controlled marine basins associated with island arcs, backarcs, or rifts. Examples of this mineral-deposit type are Belokitatskoye, Eloguiskoye, Gar, Kholzunskoye, Turukhanskoye, and Udorongovskoye, Russia.

Volcanogenic-Sedimentary Mn (Watanabe and others, 1970; Varentsov and Rakhmanov, 1978; Koski, 1986)

Volcanogenic-sedimentary Mn deposits consist of sheets and lenses of braunite, hausmannite, rhodochrosite, and oxidized braunite intercalated with shale, chert, jasper, limestone, marine basalt flows, mafic tuff, spilite, and siliceous keratophyre. The mafic volcanic host rocks differ from normal tholeiitic basalt in their relatively higher content of K, Na, and Ti. The deposits generally occur in sequences with abundant chert and sedimentary rocks, rather than in sequences dominated by volcanic rock; are commonly associated with volcanogenic Fe deposits; and may contain complex oxidized ferromanganese minerals. Abundant secondary Mn oxides (todorokite, psilomelane, amorphous MnO_2) typically occur at the surface and along fractures. Deposits in Japan are mainly hosted in chert in a Jurassic accretionary-wedge complex and do not contain volcanic rocks; however, a volcanogenic-sedimentary origin is interpreted. The depositional environment consisted of marginal basins associated with island arcs or young intraplate rift basins. Examples of this mineral-deposit type are Bidzhanskoe (Kabalinskoe), Mazulskoye, and Usinskoye, Russia, and Saihangol, Mongolia.

V. Deposits Related to Subaerial Extrusive Rocks

A. Deposits Associated with Mafic Extrusive Rocks and Dike Complexes

Ag-Sb Vein (Borisenko and others, 1992)

Ag-Sb vein deposits consist of siderite and quartz-siderite veins and vein systems containing Ag-sulfosalts hosted in carbonaceous clastic black shale sequences that are commonly contact metamorphosed. The main minerals are Sb-, Cu-, Pb-, and Ag sulfosals, including tetrahedrite, freibergite, schwatzite, chalcostibite, zinkenite, jamesonite, boulangerite, and Bi sulfosalts, chalcopyrite, antimony, arsenopyrite, and pyrite. The main gangue minerals are siderite, quartz, calcite, ankerite, barite, and fluorite. Associated carbonate and argillic alteration may have occurred. The depositional environment consisted of accumulation of black shale near fault-controlled basins and backarc basins in interplate rift zones. The mineral deposit type is commonly associated with epithermal vein deposits. Examples of this mineral-deposit type are Kyuchyus, Russia, and Asgat, Mongolia (fig. 27).

Basaltic Native Cu (Lake Superior type) (Lee and Kim, 1966; Eckstrand, 1984; Kutyrev, 1984; Cox, 1986b)

Basaltic native Cu (Lake Superior type) deposits consist of stratabound disseminated Cu minerals in basalt lava erupted into shallow coastal-marine basins, and less onto subaerial oceanic volcanic islands. The volcanic rocks are generally interbedded with red sandstone, conglomerate, and siltstone. The basalt is generally potassic or alkalic and may include shoshonite and trachybasalt. Major minerals are native copper, chalcocite, bornite, chalcopyrite, and native silver, both in the matrix of, and as amygdules in the porous roofs of basalt flows, and in veinlets within the basalts. Minerals occur as disseminations, stringers, lenses, and irregular patchy accumulations. Wallrocks are altered mainly to epidote, calcite, chlorite, and zeolite. The largest deposits generally are concordant or peneconcordant and occur along specific rock types, such as amygdaloidal flow-top breccia, pyroclastic tuff and breccia, and interlayered conglomerate, carbonaceous sandstone, and siltstone; smaller deposits occur as veins or irregular stringer zones in fissures and faults, and in fault breccias. The depositional environment consisted of continental, rift-related, flood-basalt sequences, and continental-margin and island arcs. This mineral-deposit type is commonly associated with sediment-hosted Cu deposits. Examples of this mineral-deposit type are Arylakhskoye, Russia, and Zuunturuu gol, Mongolia.

Hg-Sb-W Vein and Stockwork (Scheglov, 1959; Borovkov and Gaivoronsky, 1995)

Hg-Sb-W vein and stockwork deposits consist of small veins and stockworks of low-temperature, hydrothermal chalcedony-like quartz, and ferberite-scheelite, stibnite, and cinnabar. The deposits occur in Neoproterozoic and Paleozoic metamorphic rocks (shale and quartzite) along major fractures or crosscutting faults in schist, in platy stockwork with pseudostratification. The deposits occur far from intrusive bodies and are associated with deep faults along the edges of late Mesozoic intermountaine basins, or are associated with Late Cretaceous explosive extrusive siliceous volcanism. Minerals are ferberite and local stibnite, cinnabar, scheelite, pyrite, chalcopyrite, sphalerite, siderite, fluorite, native sulfur, and lesser pyrolusite; gangue minerals are chalcedony-like quartz, fine-grained quartz, and hydromica. Three subtypes are defined: (1) ferberite, stibnite, and cinnabar; (2) scheelite; and (3) stibnite and ferberite. The deposit textures are breccia, kidney-shaped, colloform, and banded. Scarce hydromica wallrock alteration may occur. Examples of this mineral-deposit type are Ryushoden and Yamatosuigin, Japan.

Hydrothermal Iceland Spar (Kievlenko, 1974)

Hydrothermal Iceland spar deposits consist of low temperature hydrothermal Iceland spar that occurs in crystalline

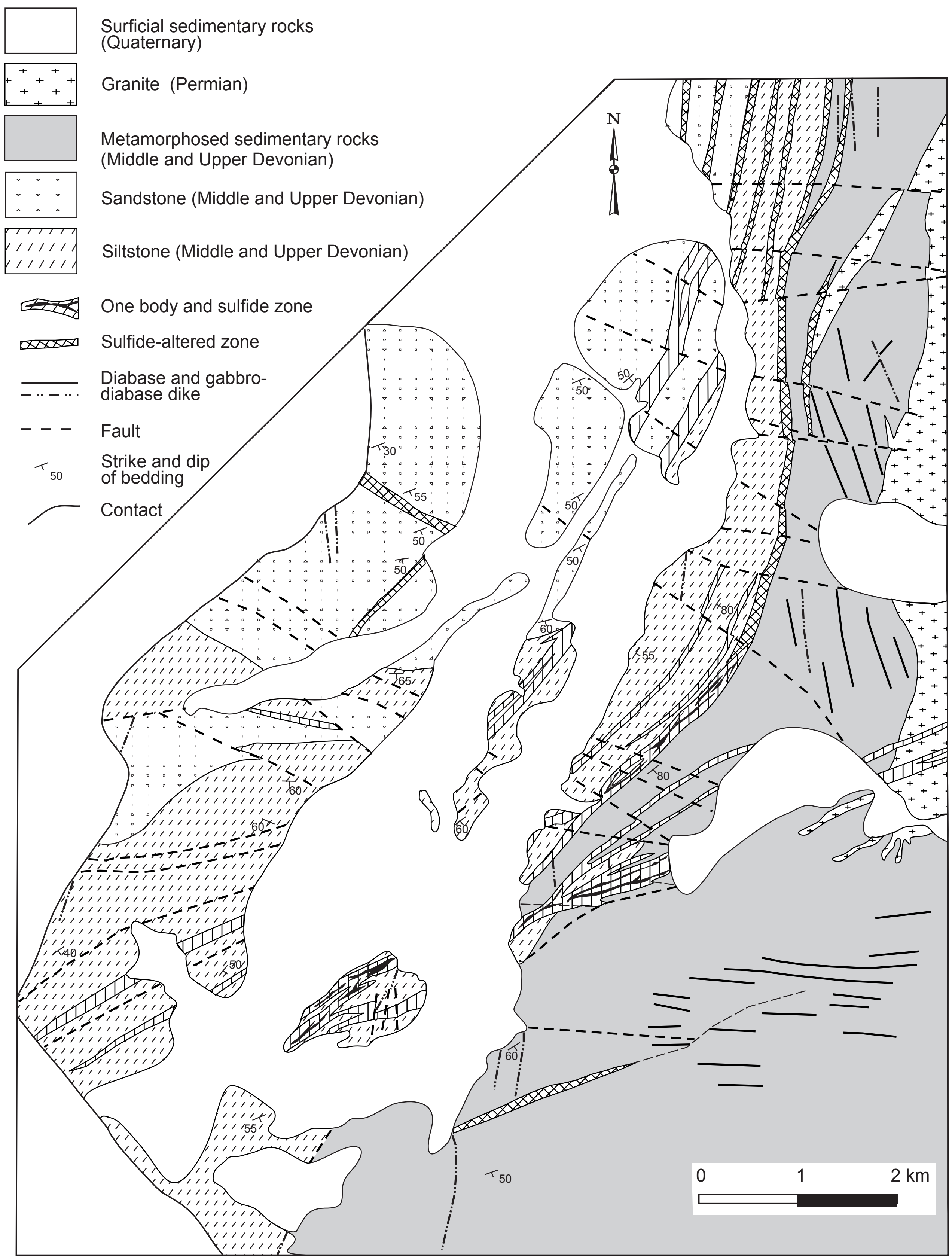


Figure 27. Generalized geologic map of the Early and Middle Jurassic Asgat Ab-Sb vein deposit, Mongolia. Adapted from Borisenko and others (1986).

masses in traps in pillow basalt, amygdaloidal basalt, tuffaceous rocks and subvolcanic dolerite. Iceland spar occurs in cavities, fractures, and fissures in basalt and dolerite, and in fractures in tuff; associated minerals are zeolite, analcite, chalcedony, chlorite, montmorillonite, and hydromica. Alteration to chlorite and montmorillonite may occur. Examples of this mineral-deposit type s are Khrustalnoye and Skala Suslova, Russia.

Ni-Co Arsenide Vein (Krutov, 1978; Borisenko and others, 1984; Eckstrand, 1984)

Ni-Co arsenide vein deposits consist of carbonate and quartz-carbonate-chlorite veins containing Ni-Co arsenides and Cu, Bi, and Ag sulfosalts. Another name is five-metal (Ag-Co-Ni-Bi-U) arsenide ore association. The deposits occur along steeply dipping vein and vein systems in deep-seated faults and conjugate fractures in association with basalt and alkalic basalt dikes. Host rocks are mainly siltstone, shale, schist, mafic and felsic volcanic rocks, contact metamorphic rocks, and relatively older mafic and ultramafic granitoids. Minerals are Ni-Co-Cu-Ag-Bi arsenides, sulfoarsenides, and sulfosalts including skutterudite, smaltite, chloanthite, safflorite, rammelsbergite, nickeline, gersdorfite, argentite, and native silver; gangue minerals are dolomite, calcite, ankerite, quartz, barite, fluorite, and chlorite. Two subtypes are defined: Ni-Co arsenide and Cu-Co sulfoarsenide-sulfosalt. The first subtype exhibits colloform and incrustate structures, and the second subtype exhibits disseminated and streaky-disseminated structures. Minor zones of talc-carbonate-chlorite alteration, and quartz-carbonate-hydromica metasomatic alteration occur in the wallrock. The depositional environment consisted of hydrothermal fluids ascending deep faults and fractures in intraplate areas undergoing tectonic and magmatic reactivation. Examples of this mineral-deposit type are Hovu-Aksinskoye, Russia, and Teht, Mongolia.

Silica-Carbonate (Listvinite) Hg (Kuznetsov, 1974; Obolenskiy, 1985; Rytuba, 1986b)

Silica-carbonate (listvinite) Hg deposits consist of cinnabar and associated minerals along contacts of serpentinite, siltstone, graywacke, and limestone that occur in major thrust zones. Minerals are mainly cinnabar, stibnite, pyrite, realgar, orpiment, arsenopyrite, and some Ni and Co minerals; gangue minerals are mainly dolomite, breunnerite, and ankerite in association with quartz, calcite, dickite, fuchite, and talc. The deposits occur in masses, veins, and disseminations in irregular lenses, in veins in crush breccia and mylonite zones, and in adjacent sedimentary rocks. Cinnabar is closely associated with silica-carbonate (listvinite) and argillic alteration. The depositional environment consisted of zones of thrust faults containing lenses of serpentinite, ultramafic rocks, and graywacke. The deposits generally occur in subduction-zone terranes and are commonly reactivated by younger interplate movement. Examples of this mineral-deposit type are Chagan-Uzunskoye and Krasnogorskoye 1, Russia.

Trapp-Related Fe Skarn (Angara-Ilim type) (Mazurov and Bondarenko, 1997)

Trapp-related Fe skarn (Angara-Ilim type) deposits consist of magnesian magnetite skarn formed during mafic trapp magmatism. The deposits occur mainly in the North Asia craton in connection with late Paleozoic and early Mesozoic tectonism and magmatism. Spatial distribution of the deposits is controlled by deep basement faults, trapp magmatic centers, and occurrence of dolomite and evaporate sequences in lower parts of the crust. The occurrence of evaporite and Ca-Na brines are important. Four subtypes are defined: (1) steeply dipping ore shoots containing brecciated skarn in diatreme, (2) gently dipping, stratabound deposits occurring under dolerite sills and interlayered sills in calcareous rock, (3) steeply dipping veins, and (4) layered deposits in caldera depressions. The main deposits occur in explosion pipes that extend to depths of 1,000 to 1,200 m. Calc-silicate and Mg-silicate skarn are widespread, along with epidote, chlorite-amphibole, serpentine-chlorite, and calcite metasomatite. The main part of magnesian magnetite deposits is associated with hydrothermal alteration. The deposits contain halite, anhydrite, typical oolitic hematite, and magnetite that occur in lenses in massive and banded ore. The depositional environment consisted of intrusion of Trapp-related mafic magma into evaporate horizons with brine. Examples of this mineral-deposit type are Kapaevskoye, Korshunovskoe, Nerjundinskoye, and Rudnogorskoe, Russia.

B. Deposits Associated with Felsic to Intermediate Extrusive Rocks and Dike Complexes

Au-Ag Epithermal Vein (Berger, 1986a; Mosier and others, 1986b; Park and others, 1988; Sillitoe, 1993a; Yurgenson and Grabeklis, 1995; Hedenquist and others, 1996; Nokleberg and others, 1997; Rodionov and Khanchuk, 1997; Yan and others, 2000)

Au-Ag epithermal vein deposits consist of gently to steeply dipping quartz veins, stockworks, and disseminations hosted mainly in volcanic rocks. Associated igneous rocks are commonly subaerial, calc-alkaline, volcanic rock (andesite, dacite, and rhyolite, as well as porphyritic shoshonite dikes or alkalic igneous rocks in continental-crustal sequences (> 20 km thick) and in island arcs. Two subtypes are defined - low sulfidation Au-Ag epithermal vein and high sulfidation Au epithermal vein. The subtype includes the Comstock Au, Creede, and Sado epithermal vein deposits, which contain electrum, native gold, pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, arsenopyrite, tellurides, and pyrargyrite; gangue minerals are quartz, adularia, illuite, calcite, and chalcedony. Fine-grained chalcedony-like quartz, grading into chalcedony, occurs in laminated and thin-banded colloform textures. The deposits are typically open-space-filling veins. Hydrothermal alteration adjacent to veins consists of illite and smectite. The deposits are interpreted as having formed from low sulfidation hydrothermal solutions with a neutral pH.

The second subtype contains disseminated native gold, pyrite, and enargite-luzonite that occur in silicified (vuggy) quartz bodies and in zones of quartz-alunite (advanced argillic) alteration and replacement. Other deposit minerals are precious-metal tellurides, covellite, tennantite, tetrahedrite, chalcopyrite, sphalerite, and galena. The occurrence of high-sulfidation sulfosalts, such as enargite and luzonite, and relatively high sulfidation tennantite characterizes this subtype. Replacements are also common. Gangue minerals are mainly quartz, alunite, kaolinite, pyrophyllite, diaspore, illite, and barite that also occur in peripheral alteration zones. The deposits are interpreted as having formed from acidic and oxidized hydrothermal fluids. Closely related mineral-deposit types are epithermal quartz-alunite Au, acid-sulfate Au, and enargite Au.

Locally, Au-Ag epithermal vein deposits may occur in volcanic-tectonic grabens associated with strike-slip faults. Associated porphyry deposits may occur. The deposits may be overlain by either barren areas, acid-leached zones, or silicified horizons. The deposits are associated with felsic volcanic centers that formed over sedimentary rocks or older volcanic and plutonic rocks. The depositional environment consisted of subduction-related continental-margin or island arc generally within 100 km of active volcanic fronts. Subduction-related magmatism and associated hydrothermal activity tended to shift trenchward over time. Examples of this mineral-deposit type are Chaganbulagen and Erentaolegai, Inner Mongolia, China; and Hishikari (fig. 28), Konomai, Kushikino, and Sado, Japan.

Ag-Pb Epithermal Vein (Batjargal and others, 1997; Dorjgotov and others, 1997)

Ag-Pb epithermal vein deposits consists o quartz-sulfide veins and mineralized zones in various rock types intruded by mafic dikes. The deposits extend along strike for several hundreds meters, extend downdip to 300 m, and are as much as several tens of meters thick. Two subtypes are defined: quartz-carbonate-sulfide and carbonate-sulfide. Major minerals are galena, arsenopyrite, stibnite, and Ag minerals, with subordinate chalcopyrite, sphalerite, cinnabar, and pyrite. Gangue minerals are quartz, siderite, chalcedony, kaolin, calcite, barite, and fluorite. Main wallrock alterations are quartz, chalcedony, kaolinite, and chlorite. The deposits exhibit three major stages: quartz-galena, quartz-fluorite, and quartz-carbonate. The depositional environment consisted of intrusion of mafic dikes along active, deep-seated faults in areas of rifting of continental-margin arcs. Examples of this mineral-deposit type are Boorch and Dulaan khar uul, Mongolia.

Au K-Metasomatite (Kuranakh type) (Kazarinov, 1967; M.B. Boradoevskaya and I.S. Rozhkov in Smirnov, 1974; Fredericksen, 1998; Fredericksen and others, 1999)

Au potassium metasomatite deposits occur along contacts between lamprophyre dikes with calcareous rocks and sandstone adjacent to high-angle faults. Host rocks may be underlain by Precambrian metamorphic rocks. The hydrothermal activity, that formed the metasomatite was associated with igneous activity that resulted in intrusion of dike swarms and (or) small plugs and sills of bostonite, microgabbro, and minette. Gold is spatially related to dikes and may occur in both early and late stages. The deposits consist of several subhorizontal, blanket- or ribbon-like bodies, as much as several dozen meters thick, that occur mainly along, and (or) locally above or below contacts between calcareous footwallrocks and overlying clastic rocks along narrow, long fault zones. Two subtypes are defined: quartz-adularia and quartz replacing adularia. Main deposit minerals are quartz, pyrite, marcasite, native gold, silver, bismuth, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite, carbonate, and barite. Gold occurs with pyrite, arsenopyrite, sphalerite, and galena; however, total sulfides constitute only a few percent of the total rock mass. The deposits are intensely oxidized and only traces of arsenopyrite and pyrite occur. Gold occurs primarily as grains smaller than 5 microns, commonly in friable grains of porous goethite. Fluid-inclusion studies indicate homogenization temperatures of 80° to 220°C, averaging from 110° to 160°C. Mineralization was controlled by interpolate-rifting structures. In many places, the deposits are complicated by karst formation, which resulted in formation of secondary rubble ore and surficial weathering of ore and gold. The depositional environment consisted of intrusion of lamprophyre into passive continental margins during rifting. Examples of this mineral-deposit type are Kuranakh, Russia, and Hadamengou, Inner Mongolia and Wulashan, Inner Mongolia, China.

Barite Vein (Marinov, Khasin, and Khurts, 1977)

Barite vein deposits consist of quartz-barite and barite veins and veinlets in stockwork in quartz porphyry, diabase, porphyry, tuff, and biotite granite. The deposits commonly occur along contacts of volcanic and sedimentary rocks, commonly in association with fluorite deposits. Examples of this mineral-deposit type are Chapsordag and Taptan-Turazy, Russia and Bayan Khoshuu, Mongolia.

Be Tuff (Kovalenko and Koval, 1984)

Be tuff deposits consist of bedded and graded-bedded tuff containing fragments of ongorhyolite, rhyolite, quartz, feldspar, fluorite, and Be-bearing bertrandite. Be content averages about 0.05 percent. The depositional environment consisted of extrusive centers with rhyolite and ongorhyolite. Examples of this mineral-deposit type are Dorvon Dert and Teg uul, Mongolia.

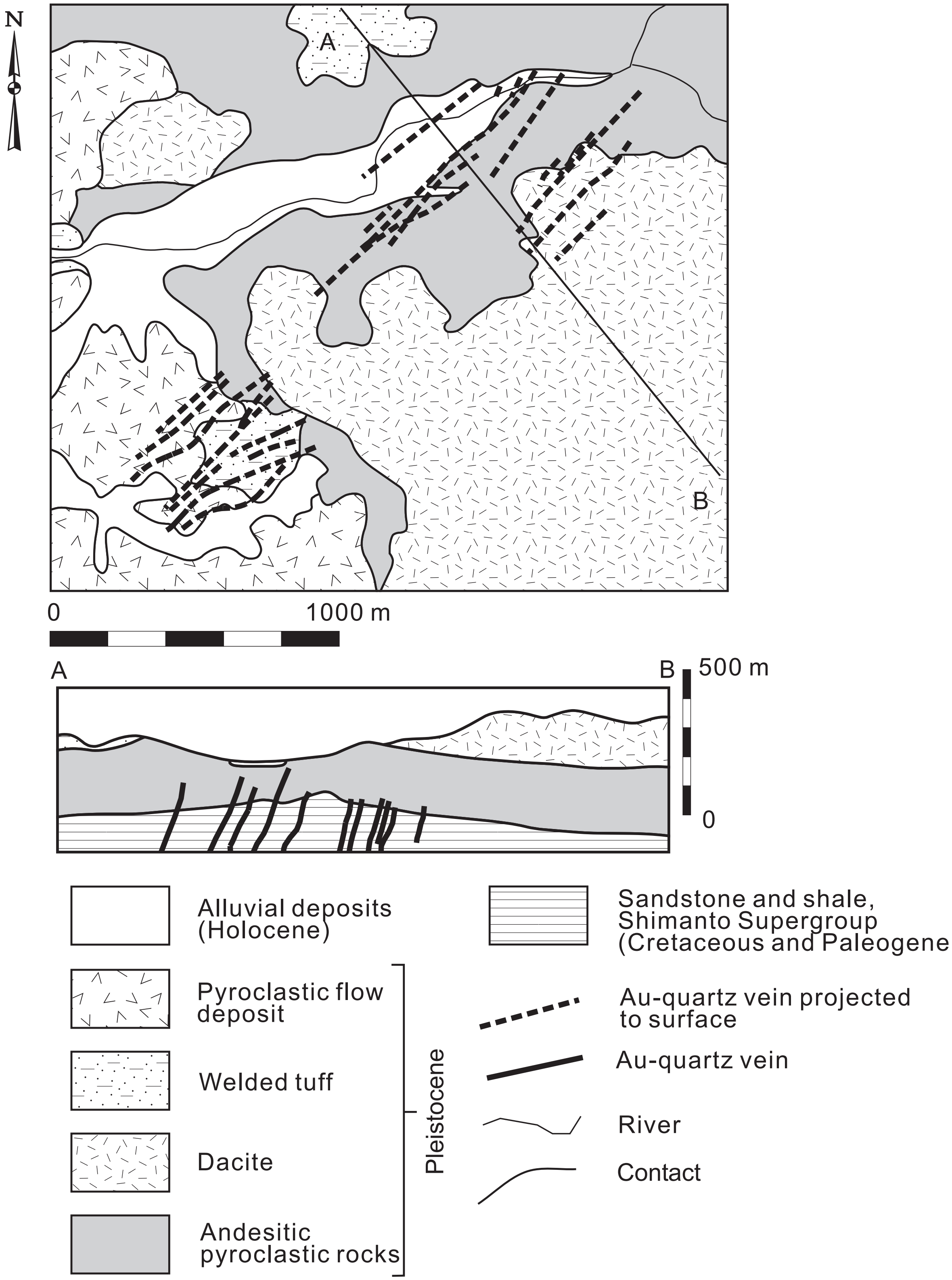


Figure 28. Generalized geologic map of the Pliocene through Quaternary Hishikari Au-Ag epithermal vein deposit, Japan. Adapted from Ibaraki and Suzuki (1993).

Carbonate-Hosted As-Au Metasomatite (Smirnov, 1961, Zavorotnykh and Titov, 1963)

Carbonate-hosted As-Au metasomatite deposits consist of quartz veins, vein zones, and lenses, nests, and veins in metasomatite bodies in limestone that is intruded by dikes of granite porphyry, granodiorite porphyry, diorite porphyry, or lamprophyre. Major minerals are arsenopyrite, pyrite, minor galena, sphalerite, marcasite, and chalcopyrite, and local gold; main gangue minerals are quartz, calcite, and dolomite. Wallrock alteration consists of quartz, dolomite, ankerite, serpentine, chlorite, sericite, talc, and kaolinite. The deposits generally contain galena, and sphalerite. The depositional environment consisted of intrusion of granite porphyry or lamprophyre into miogeoclinal sequences during continental collisions. Examples of this mineral-deposit type are Gurulevskoe and Oktjabrskoye, Russia.

Carbonate-Hosted Fluorspar (Ivanova, 1974; Bulnaev, 1995)

Carbonate-hosted fluorspar deposits consist of cocrystallized quartz and fluorite metasomatite that occurs in sheets, mineralized fracture zones, or veins in sequences of shale, limestone, and dolomite which form small xenoliths in granitoid plutons. The deposits exhibit gradational contacts with host rocks and consist of fine-grained bands, spots, and masses of fluorite, quartz, and calcite with relic dolomite, limestone, and carbonaceous rocks. The deposit layering is concordant with layering in host rock. The deposit margin generally contains quartz, fluorite, and calcite druse; calcite forms festoon ore with numerous layers. Shale contains mainly fluorite stringers. Breccia zones occur along contacts of rocks of contrasting lithology. The deposits are associated with hydrothermal veins that intrude various aluminosilicate rocks. The depositional environment consisted of intrusion of granite into shale, limestone, and dolomite in continental-margin arcs. Examples of this mineral-deposit type are Egitinskoye (fig. 29) and Urgen 2, Russia.

Carbonate-Hosted Hg-Sb (Smirnov and others, 1976; Obolenskiy, 1985)

Carbonate-hosted Hg-Sb deposits consist of stratabound lenses and nests in dolomite-limestone breccia and in layers in siliceous carbonates and jasperoid (silicified, dolomitized carbonate breccia) intercalated with clay and coal-clay shale. The sedimentary rocks are cut by dikes of quartz porphyry, diabase, and lamprophyre. The calcareous host rocks were subsequently altered to dolomite and brecciated during diagenesis and karst formation. Other wall-rock alterations consist of jasperoid, and quartz and calcite veinlets. The deposit type is commonly confined to thrust zones and localized under impermeable clay layers; clear boundaries do not occur. Major minerals are cinnabar and stibnite, and lesser pyrite, marcasite, sphalerite, stibnite, realgar, and orpiment, and rare chalcopyrite, cassiterite, arsenopyrite, chalcostibite, kermesite, servantite, gold, schwatzite, aktascite, galkhaite, and fluorite. The depositional environment consisted of an epithermal system in deep-fault zones in passive-continental-shelf margins and interplate rifts. Examples of this mineral-deposit type are Aktashskoye and Kelyanskoye, Russia.

Clastic-Sediment-Hosted Hg±Sb (Kuznetsov, 1974; Smirnov, Kuznetsov, and Fedorchuk, 1976; Khasin and Suprunov, 1977)

Clastic-sediment-hosted Hg±Sb deposits consist of simple and complex ladder and concordant carbonate-quartz and quartz veins and veinlets, and mineralized breccia. Host rocks are terrigenous and volcanic-terrigenous rocks in accretionary-wedge terranes, including flysch composed of siltstone, shale, sandstone, and conglomerate. Wallrocks are altered to quartz, carbonate, pyrite, and rare argillite and sericite. Minerals are cinnabar, pyrite, stibnite, arsenopyrite, chalcopyrite, and rare gold, galena, sphalerite, tetrahedrite, realgar, orpiment, native arsenic, native mercury, and Sb oxides that occur in disseminations, nests, and stringers. Stibnite and Sb oxides locally form Sb deposits without mercury. Gangue minerals are mainly quartz, carbonates, and dickite. The deposits occur in stockworks, lenses, layers, irregular bodies, breccia, and simple and (or) complex veins in fault zones that are associated with regional strike-slip faults and in some thrust fault zones. In thrust-fault zones, extensive alteration occurs, and the zones generally contain vertical quartz-carbonate veins of high-grade Sb and moderate-grade Au. The deposit types may occur in linear fold belts with ladder and concordant carbonate-quartz veins with higher Au than Sb grade. The deposits are structurally controlled by fracture sets and feathering major faults, anticlines, and domes, and commonly contain several ore horizons that occur in saddle-shaped veins and bodies; associated igneous rocks are mainly rare alkalic basalt dikes. The depositional environment consisted of low-temperature hydrothermal fluids that originated in deep magmatic chambers. Examples of this mineral-deposit type are Zagadka and Zvyozdochka, Russia.

Epithermal Quartz-Alunite

Epithermal quartz-alunite deposits occur in volcanic cones, caldera ring fractures, and areas of igneous activity underlain by sedimentary evaporate; associated rocks are felsic hypabyssal intrusions and volcanic rocks, including dacite, quartz latite, rhyodacite, and rhyolite. Large deposits occur in zones of intensely altered host rocks. Early-stage, high temperature mineral assemblage is quartz-alunite-pyrophyllite with corundum, diaspore, andalusite, and zunyite. Depending on extent of alunite, deposits are zoned with an inner zone of quartz-alunite, a surrounding intermediate zone of quartz-alunite-kaolinite-montmorillonite, and an outer zone of pervasive chlorite-calcite from propylitic alteration. Ammonium-bearing clay may occur. The deposit type is closely related to epithermal Au, porphyry Cu, and polymetallic volcanic-hosted metasomatite deposit type. An example of this mineral-deposit type is Iskinskoe (Askum), Russia.

Fluorspar Vein (Ivanova, 1974; Bulnaev, 1976)

Fluorspar vein deposits consist of fluorspar in steeply-dipping veins and brecciated zones and, less commonly, of metasomatite in carbonates, granite, and volcanic and volcanic-sedimentary sequences. Main mineral assemblages are quartz-fluorite, quartz-calcite-fluorite, barite-quartz-calcite-fluorite, and pyrite-marcasite-fluorite; minerals are fluorspar and quartz with barite, calcite, pyrite, marcasite, and clay. Argillic hydrothermal alteration is common in aluminosilicate host rocks, and silicification is common in limestone. The deposits are structurally controlled by fractures and breccia and form linear belts related to intraplate rifting in reactivated areas. Some deposits occur in volcanic belts in continental-marginal arcs, mainly in trachyrhyolite and trachybasalt of subaerial volcanic-plutonic belts. The depositional environment consisted of either along the flanks or in the inner parts of volcanic rift depressions. Examples of this mineral-deposit type are Naranskoye, Russia and Anas, Berkh 1, Bujgar, Bilkh-Uul, and Chuluut tsagaan del, Mongolia.

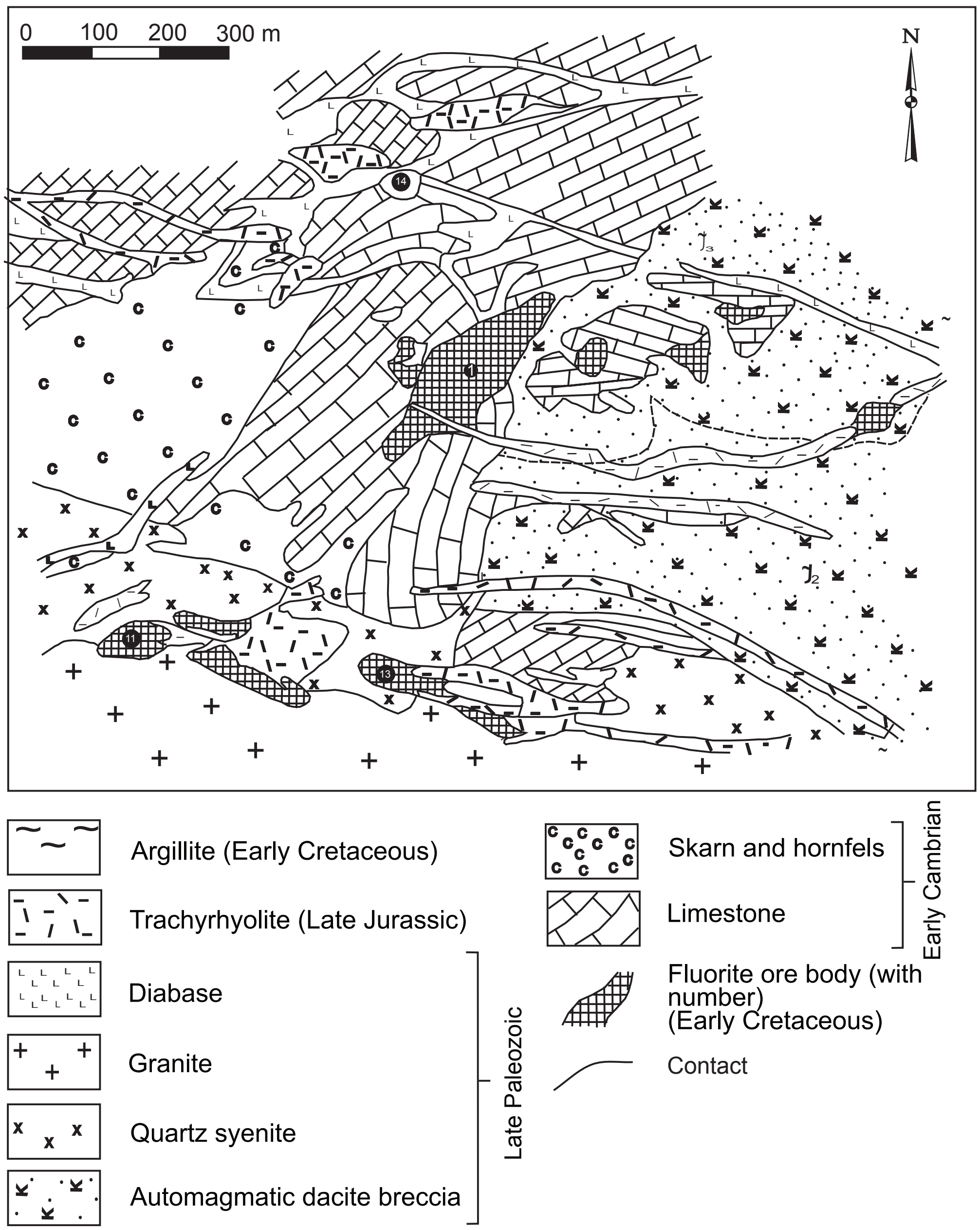


Figure 29. Generalized geologic map of the Middle Jurassic through Early Cretaceous Egitinskoye carbonate-hosted fluorspar deposit, TransBaikal, Russia. Adapted from Bulnaev (1995).

Hydrothermal-Sedimentary Fluorite (Cheng and others, 1994)

Hydrothermal-sedimentary fluorite deposits consist of multilayered fluorite and associate minerals that occur conformably in layered volcanic and sedimentary rocks, including limestone, slate, rhyolite, and dacite. Minerals occur in layers, bands, and breccia. Major deposit mineral is fluorite with minor clay and carbonates. The homogenization temperature of fluid inclusions in fluorite is about 85 to 270° C. Quartz grains are both angular and rounded, suggesting that the fluorite formation was related to volcanism. The depositional environment consisted of late Paleozoic volcanic island arcs. Examples of this mineral-deposit type are Aobaotu and Sumochaganaobao, Inner Mongolia, China.

Limonite from Spring Water (Shiikawa, 1970)

Limonite deposits consist of bedded limonite formed on mountain slopes and in valleys in areas of volcanic activity, with Fe precipitation from acidic ferruginous spring water associated with volcanic activity. The deposits are principally composed of aggregates of amorphous and (or) crystalline hydrated Fe_2O_3. Main mineral is goethite with lesser hydrohematite, akaganeite, lepidocrocite, xanthosiderite, and stilpnosiderite; jarosite, scorodite, and siderite may also occur, along with clays, including kaolinite and hydrated halloysite. Some deposits exhibit megascopic and microscopic textures and structures that are pseudomorphs after various plants, indicating that a biochemical process caused Fe_2O_3 precipitation from spring water. The deposit forms by chemical precipitation during neutralization of acidic water containing ferrous sulphate. Examples of this mineral-deposit type are Gumma and Tokushunbetsu, Japan.

Mn Vein (Mosier, 1986a)

Mn vin deposits occur as Mninerals in epithermal veins that occur along faults and fractures in subaerial volcanic rocks Host rocks are rhyolite, dacite, andesite, and basalt flows, tuffs, breccia, and agglomerate. Minerals are rhodochrosite, manganocalcite, calcite, quartz, chalcedony, barite, and zeolite that occur in veins, masses, stringers, and disseminations. Kaolinite alteration is most common. The depositional environment consisted of penetrative-fracture systems in volcanic centers in continental-margin arcs. Examples of this mineral-deposit type are Inakuraishi, Jokoku, and Yakumo, Japan.

Polymetallic (Pb, Zn ± Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite (Distanov, 1977)

Polymetallic (Pb, Zn ± Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposits consist of hydrothermal-metasomatic polymetallic sulfides that occur in volcanic and sedimentary rocks. Intensely deformed and sheared rocks are the most favorable replacement site. The deposits consist of complex lenses and stockworks containing massive, vein, and disseminated minerals. Host rocks are commonly felsic to mafic extrusive rocks, tuff, and volcanic rocks, most commonly hypabyssal quartz rhyolite and dacite porphyry intrusions and diabase porphyry dike swarms. Metasomatic alteration is intensive and consists of quartz-sericite, quartz-sericite-chlorite metasomatite, and silica and barite alterations. Aluminosilicates are more extensively altered. Three subtypes are defined: (1) barite-polymetallic, (2) pyrite-polymetallic, and (3) Cu-sulfide epigenetic. Early-stage pyrite and barite-sulfide-polymetallic minerals, and late-stage quartz-carbonate-sulfides are typical. Main minerals are mainly pyrite, sphalerite, galena, tennantite, tetrahedrite, chalcopyrite, and lesser arsenopyrite, bornite, electrum, argentite, magnetite, hematite, and native gold; gangue minerals are barite, quartz, carbonate, albite, sericite, chlorite, and rare fluorite. Main ore controlling structures are shears in deep-level fault zones in basement. Steep fault zones locally are important. The deposits are associated with small porphyry intrusions and mafic dikes. The depositional environment consisted of active continental-margin arcs built on zones of accreted terranes. Examples of this mineral-deposit type are Krasnogorskoye 2 (fig. 30), Salairskoye, and Urskoye district, Russia, and Jiawula, Inner Mongolia, China; and Sanmen, Jilin Province, China.

Polymetallic (Pb, Zn, Ag,) Carbonate-Hosted Metasomatite (Gorzhevskiy and others, 1970; Morris, 1986; Sinyakov, 1994)

Polymetallic (Pb, Zn, Ag) carbonate-hosted metasomatite deposits consist of hydrothermal-metasomatic polymetallic Pb-Zn minerals hosted mainly in limestone and dolomite. The deposits and districts are controlled by folds and fractures, with major faults, companion fractures, and shear zones. The deposits are structurally complicated, including layered, lenticular, and commonly vein, stock, or pipelike bodies. Major mineral assemblages are galena-sphalerite; boulangerite-galena-arsenopyrite; and sphalerite-pyrite. Abundant pyrite and Pb-Sb sulfides are typical. The deposit minerals occur in masses, layers, and breccia. Associated magmatic rocks are small intrusions and dikes of quartz porphyry, granite porphyry, and lamprophyre. The depositional environment consisted of active continental-margin arcs built on carbonate sequences overlying continental crust. Examples of this mineral-deposit type are Leiba, Lugovoye, and Vozdvizhenskoye, Russia.

Rhyolite-Hosted Sn (Reed and others, 1986)

Rhyolite-hosted Sn deposits consist of cassiterite and wood tin that occur in discontinuous veinlets and stockworks and in disseminations in rhyolite flow-dome complexes. Other minerals are hematite, cristobalite, fluorite, tridymite, opal, chalcedony, adularia, and zeolite; accessory minerals are topaz, fluorite, bixbyite, pseudobrookite, and beryl. Associated wallrock alteration minerals are mainly cristobalite, fluorite, smectite, kaolinite, and alunite. Host rhyolite commonly contains more than 75 percent SiO_2 and is K-rich. Controlling fracture and breccia zones occur in the most permeable, upper parts of flow-dome complexes. The depositional environment consisted of felsic volcanic rocks erupted onto continental crust. An example of this mineral-deposit type is at Dzhalinda, Russia.

Sulfur-Sulfide (S, FeS_2) (Vlasov, 1976; Mukaiyama, 1970; M. Ogasawara, this study)

Sulfur-sulfide deposits consist of three subtypes: (1) sublimation, consisting of surficial sulfur deposited from gas and solution; (2) sedimentary, consisting of lacustrine deposits formed in volcanic craters; and (3) replacement, the most valuable subtype, consisting of replacement metasomatic sheets and irregular bodies in porous and fractured rocks. All three subtypes are genetically and spatially associated with andesite. Minerals are generally diverse and consist mainly of sulfur and pyrite, with lesser variable realgar, orpiment, metacinnabar, stibnite, sphalerite, and molybdenite. Sulfide content increases with depth and grades into massive sulfide. Host rocks generally are hydrothermally altered to opal, pyrite, alunite, and kaolinite. Example of this mineral-deposit type are Kusatsu-Shirane, Matsuo, and Shojingawa, Japan.

Volcanic-Hosted Au-Base-Metal Metasomatite (Kormilitsyn and Ivanova, 1968; Sanin and Zorina, 1980; Tauson, Gundobin, and Zorina, 1987)

Volcanic-hosted Au-base-metal metasomatite deposits consist of metasomatic listvinite-beresite zones containing sulfides. The zones, which occur in propylitically altered trachyandesite and latite are intruded by small stockworks and dikes of diorite porphyry, granodiorite porphyry, and granite porphyry, extend as far as several kilometers along strike, are as much several hundred meters thick, and exhibit gradational boundaries with volcanic host rocks. The deposits occur in pipes, nests, lenses, veins, and echelonlike fractures; both continuous veins and disseminations occur. Massive deposits are uncommon, but contain 60 to 80 percent pyrite, galena, and sphalerite along with sulfosalts, quartz, and dolomite. The deposits range in texture from massive through layered, densely disseminated, and spotted, to colloform. Veinlets and disseminations form haloes around the massive deposit minerals, but generally form independent bodies with an irregular distribution of sulfides. The following mineral assemblages are recognized: (1) tourmaline and pyrite, and local arsenopyrite, chalcopyrite, and gold; (2) pyrite,

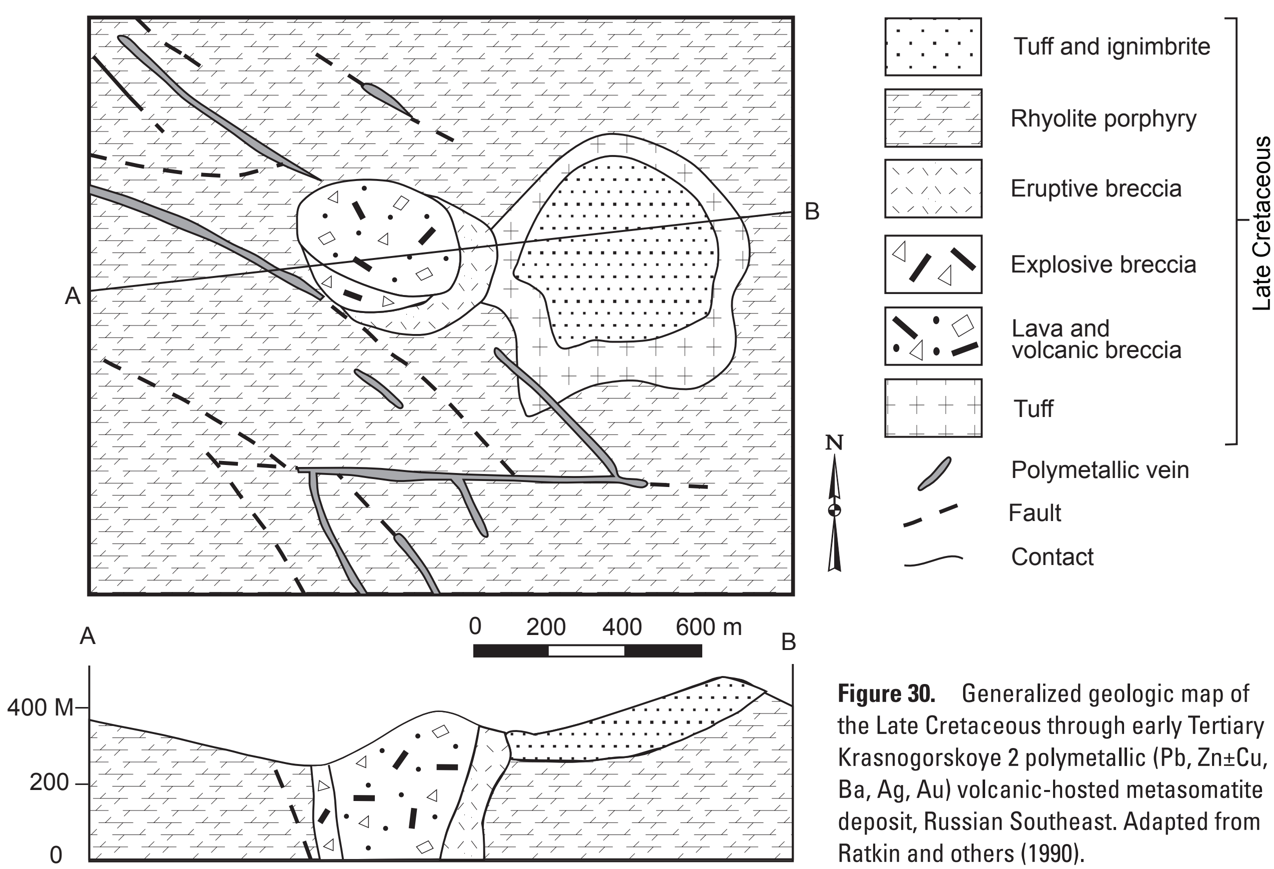


Figure 30. Generalized geologic map of the Late Cretaceous through early Tertiary Krasnogorskoye 2 polymetallic (Pb, Zn±Cu, Ba, Ag, Au) volcanic-hosted metasomatite deposit, Russian Southeast. Adapted from Ratkin and others (1990).

galena, and sphalerite with gold, quartz, and carbonates; (3) sulfosalts (fahl ore, tetrahedrite, schwatzite, tennantite, cleiophane), gold, and dolomite; and (4) realgar-stibnite with gold, Hg-barite, and stibnite. Gold is finely dispersed and occurs in sulfides. The depositional environment consisted of intrusion of intermediate-composition to siliceous granitoids into the hypabyssal parts of collisional zones and extrusion of associated andesite and latite. Examples of this mineral-deposit type are Shirokinskoye (fig. 31), Russia; Bupyoung, South Korea; and Yixingzai, Fanshi, Shanxi Province, China.

Volcanic-Hosted Hg (Kuznetsov, 1974; Babkin, 1975; Smirnov, Kuznetsov, and Fedorchuk, 1976)

Volcanic-hosted Hg deposits consist of disseminated and local masses of cinnabar in veinlets and breccia in layers, lenses, and irregular bodies. The deposits are hosted in felsic, and lesser intermediate-composition and mafic volcanic rocks or along contacts between subvolcanic intrusive and volcanic rocks. Other common minerals are stibnite, pyrite, and marcasite, with subordinate or rare arsenopyrite, hematite, lead, Zn and Cu sulfides, tetrahedrite, schwatzite, Ag sulfosalts, gold, realgar, and native mercury; gangue minerals are mainly quartz, chalcedony, hydromica, kaolinite, dickite, alunite, carbonate, chlorite, and solid bitumen. Minerals may occur in multiple layers. Wallrocks may be altered to propylite and argillite with various combinations of quartz, sericite, kaolinite, and epidote. Mercury was deposited mainly during intense metasomatic replacement and, to a lesser extent, in open fissures and voids. The depositional environment consisted of tectonic boundaries of major volcanic depressions and calderas related to active continental margin arcs and interplate rifts. This deposit type is similar to the hot-spring Hg model of Rytuba (1986a). Examples are Dogdo and Terligkhaiskoye, Russia, and Itomuka, Japan.

Volcanic-Hosted U (Bagby, 1986)

Volcanic-hosted U deposits consist of U minerals in pervasive fractures and breccias that occur along the margins of shallow intrusives. Common minerals are coffinite, uraninite, and brannerite; other minerals are pyrite, realgar-orpiment, leucoxene, molybdenite, fluorite, quartz, adularia, and barite. Uraninite is commonly encapsulated in silica. Common host rocks are high-silica alkali rhyolite, potassic trachyte, and peralkaline and peraluminous rhyolite, altered to kaolinite, montmorillonite, and alunite. Wallrocks are altered to silica and adularia. The deposits occur in subaerial to subaqueous, near-surface volcanic complexes that are associated with shallow intrusive rocks. The depositional environment consisted of continental rifts and associated calderas. Examples of this mineral-deposit type are Dornod and Gurvanbulag, Mongolia.

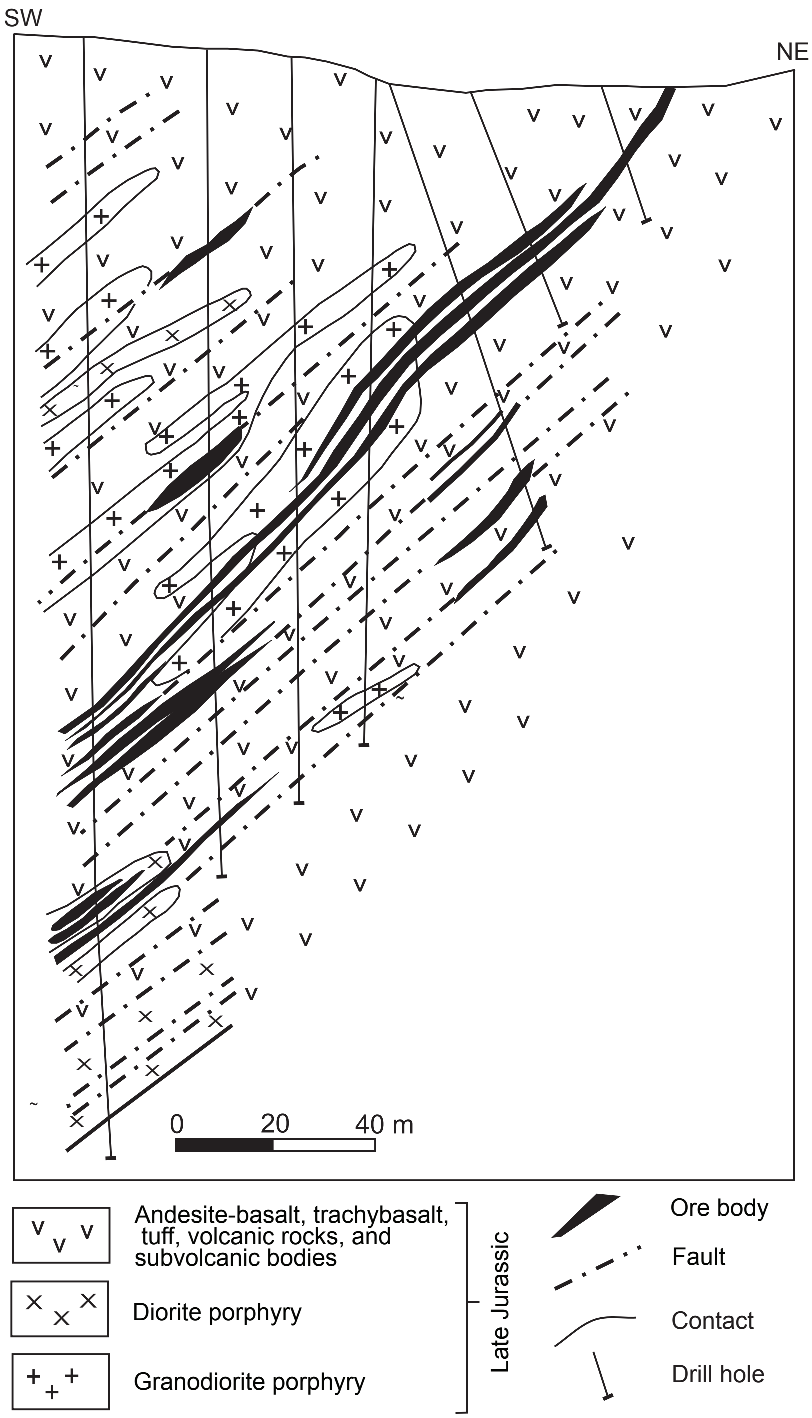


Figure 31. Generalized geologic map of the Middle Jurassic through Early Cretaceous Shirokinskoye volcanic-hosted Au-base-metal metasomatite deposit, TransBaikal, Russia. Adapted from Zorina (1980).

Volcanic-Hosted Zeolite (Gottardi and Galli, 1985; Zhamoitsina and others, 1992)

Volcanic-hosted zeolite deposits consist of concordant beds and lenses of zeolite-altered tuff in epicontinental basins and lacustrine volcanic and sedimentary rock sequences. The deposits were formed by replacement of siliceous tuff, and volcanic breccia composed of trachyrhyolite and trachydacite. Minerals are clinoptilolite, mordenite, and lesser heulandite, analcime, montmorillonite, quartz, calcite, adularia, and hydromica. Clinoptilolite and mordenite occur in siliceous tuff, and fillipsite and analcime occur in mafic tuff. Diagenetic and sedimentary zeolite are widespread. Zeolites were formed by isochemical alteration of porous vitric tuff permeated by low-temperature water of normal salinity and alkalinity. Zeolite beds are homogeneous and zoned as a function of temperature gradient. The depositional environment consisted of volcanic depressions in epicontinental volcanic belts or continental margin arcs. Examples of this mineral-deposit type are Pezasskoye, Russia, and Tsagaantsav, Mongolia.

Deposits Related to Hydrothermal-Sedimentary Processes

VI. Stratiform and Stratabound Deposits.

Bedded Barite (Orris, 1986)

Bedded barite deposits consist of stratiform, massive, and nodular barite interbedded with marine chert and calcareous sedimentary rocks, mainly dark chert, shale, mudstone, and dolomite. The deposits are commonly associated with Zn-Pb sedimentary exhalative (SEDEX) massive sulfide deposits. Alteration consists of secondary barite veining and local, weak to moderate sericite replacement. Associated minerals are minor witherite, pyrite, galena, sphalerite, quartz, and carbonate. The depositional environment consisted of epicratonal marine basins or embayments, commonly with smaller local restricted basins. Examples of this mineral-deposit type are Martyuhinskoye, Sorminskoye, and Tolcheinskoye, Russia.

Carbonate-Hosted Pb-Zn (Mississippi Valley Type) (Eckstrand, 1984; Briskey, 1986b; Ponomarev and Zabirov, 1988)

Carbonate-hosted Pb-Zn deposits consist of stratabound Pb- and Zn-sulfides hosted in carbonates with both primary and secondary porosity that commonly formed on reefs on paleotopographic highs. The deposits are hosted mainly in dolomite and limestone, but are locally hosted in sandstone, conglomerate, and calcareous shale. Minerals are mainly galena, sphalerite, pyrite, marcasite, dolomite, calcite, and barite, with minor chalcopyrite, siegenite, bornite, tennantite, bravoite, digenite, covellite, and arsenopyrite. Alteration consists of regional dolomitization. Also common is disseminated secondary carbonate gangue, massive in some places, that occurs in coarsely crystalline aggregates. The deposits are highly irregular in shape, stratiform or commonly discordant a local scale but stratabound on a district scale. Minerals occur mainly in open-space fillings in highly brecciated dolomite. Sphalerite commonly exhibits a colloform texture. The deposits commonly occur at the margins of clastic basins, generally on orogenic foreland carbonate platforms. Some deposits occur in carbonate sequences in foreland thrust belts bordering foredeeps of platforms. Few are associated with rift zones. The depositional environment consisted of areas of shallow-water marine carbonate with prominent facies controlled by reefs growing on the flanks of paleotopographic basement highs. The deposit type may also be associated with sedimentary-exhalative Pb-Zn (SEDEX) deposits. Examples of this mineral-deposit type are Mayskoye 1 and Sardana, Russia, and Chaihe, Liaoning Province, China.

Sediment-Hosted Cu (Narkelun and others, 1977; Yakovlev, 1977; Eckstrand, 1984; Sotnikov and others, 1985; Cox, D.P., 1986i; Lurie, 1988)

Sediment-hosted Cu deposits consist of stratabound, disseminated Cu sulfides in reduced red-bed sequences with green or gray shale, siltstone, and sandstone, thinly laminated carbonates and evaporates, and local channel conglomerate. Main minerals are chalcocite, bornite, chalcopyrite, pyrite, galena, and sphalerite, and lesser carrollite, Co-pyrite, betekhtinite, native copper, Ag, and Ge minerals. Sulfides are commonly zoned both vertically and laterally in the following sequence upward and outward from the base of the ore body: (1) chalcocite and bornite; (2) bornite-chalcopyrite; (3) chalcopyrite and pyrite; and (4) galena and sphalerite. Sulfides may be weathered to malachite, azurite, chrysocolla, and atacamite. Secondary downdip chalcocite enrichment is common. The genetic model is sedimentary concentration of minerals in red-bed sequences with extraction of Cu from basement rocks or underlying sedimentary rocks by subsurface brines probably derived from evaporates followed by transportation through oxidized beds and precipitation in anoxic sediment. The depositional environment consisted of epicontinental shallow-marine basins or intracontinental rifts along continental margin platforms. Examples of this mineral-deposit type are Pravo-Ingamakitskoye, Sakinskoye, and Udokan (fig. 32), Russia.

Sedimentary-Exhalative Pb-Zn (SEDEX) (Brisky, 1986a; Ponomarev, 1987)

Sedimentary-exhalative Pb-Zn (SEDEX) deposits consist of stratiform massive to disseminated sulfides occurring in sheets or lenses that are conformable with host rocks that consist of carbonates, clastic carbonates, and siliceous carbonates, including limestone and dolomite, and lesser marl, calcareous shale, siltstone, sandstone, and chert. Minerals are mainly galena, sphalerite, pyrrhotite, pyrite, Mg-Fe carbonates, and lesser sulfides and sulfosalts, barite, and fluorite. Minerals typically are finely crystalline. Metamorphosed deposits are coarsely crystalline and massive. Minerals occur in bands, laminae, masses, breccia, streaks, and disseminations. SEDEX silica-siderite and silica-ankerite-sideroplesite is associated with sulfide layers, and diagenetic dolomite is also common. Common depositional sites are interpreted as local synsedimentary depressions, synclines, and paleoslopes. Meager to no association of minerals with volcanism is evident in most areas. Minor volcanic rocks, mainly tuff and breccia, occur in host rocks in some deposits. Extensive hydrothermal alteration may occur near vents, including stockwork and disseminated sulfides, silica, albite, and chlorite. Hydrothermal activity is interpreted to have occurred in association with growth faults between major crustal blocks. The depositional environment consisted of late Proterozoic through late Paleozoic carbonate-rich, fine-grained clastic sedimentary rocks forming in shallow-marine basins undergoing pericratonal platform subsidence along microcontinent margins. Examples of this mineral-deposit type are Gorevskoye (fig 33), Russia; Dongshengmiao, Huogeqi, and Jiashengpan, and Tanyaokou, Inner Mongolia, China.

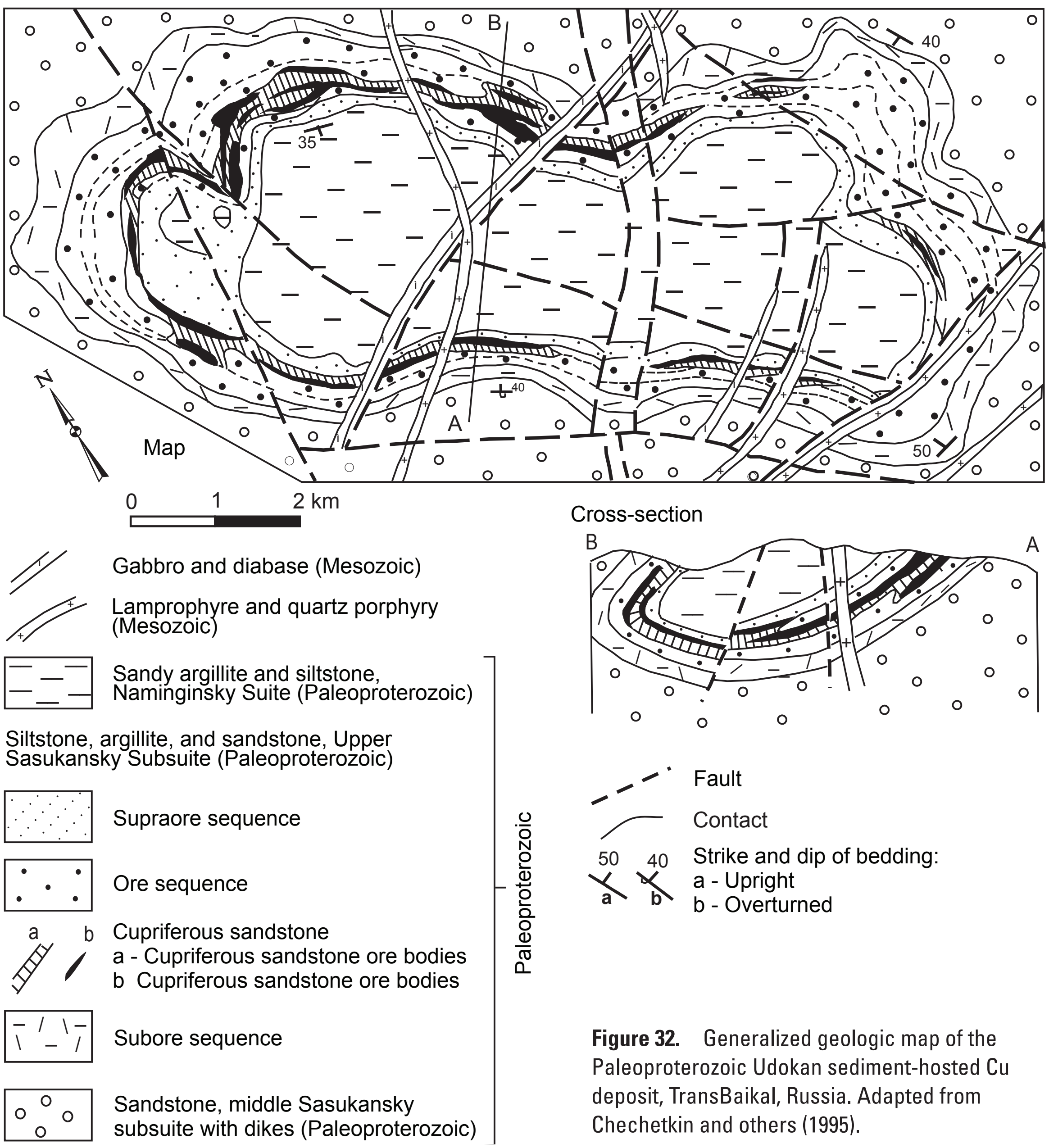


Figure 32. Generalized geologic map of the Paleoproterozoic Udokan sediment-hosted Cu deposit, TransBaikal, Russia. Adapted from Chechetkin and others (1995).

Korean Pb-Zn Massive Sulfide (V.V. Ratkin in Nokleberg and others, 1997)

Korean Pb-Zn massive sulfide deposits consist of Pb- and Zn-sulfides in carbonates, mainly limestone and dolomite, and lesser marl. Minerals are mainly pyrite, galena, sphalerite, fluorite, and magnetite, mainly in lenses and beds conformable to bedding in host rocks; magnetite also forms layers interbedded with sulfides, fluorite, and carbonates. Little to no hydrothermal alteration has occurred; mainly diagenetic alteration in carbonates and associated rocks. This mineral deposit type is intermediate SEDEX and carbonate-hosted Pb-Zn (Mississippi Valley) deposit types. Examples are the Voznesenskoe and Chernyshevskoe mines, Russian Southeast. The depositional environment consisted of typically late Proterozoic through early Paleozoic carbonate-rich sedimentary rocks in basins that overlap folded metamorphic complexes. Examples of this mineral-deposit type are Voznesenka-I, Russia (fig. 34), and Huanggoushan, Jilin Province; and Qingchengzi, Liaoning Province, China.

VII. Sedimentary-Hosted Deposits

Chemical-Sedimentary Fe-Mn (Hwang and Reedman, 1975; Philippova and Vydrin, 1977; Zaitsev and others, 1984; Zhong and Yao, 1987; Ye and others, 1994)

Chemical-sedimentary Fe-Mn deposits consist of sheets and lenses of massive to disseminated Fe and Mn oxides and carbonates that in sedimentary and clastic carbonates, including limestone and dolomite. Minerals are magnetite, hematite, siderite, pyrolusite, hausmannite, braunite, and rhodochrosite (including Ca-rhodochrosite and Fe-rhodochrosite). Ore layers consist of sedimentary chert, quartzite, quartz-sericite-chlorite schist, and clastic carbonates. According to mineralogy and Fe and Mn grade, three subtypes are defined: (1) Fe, (2) Fe-Mn, and (3) Mn. Mn beds commonly occur in the middle to upper part of a progressive sequence within a transitional zone between clastic rocks and chemical precipitations; some Mn

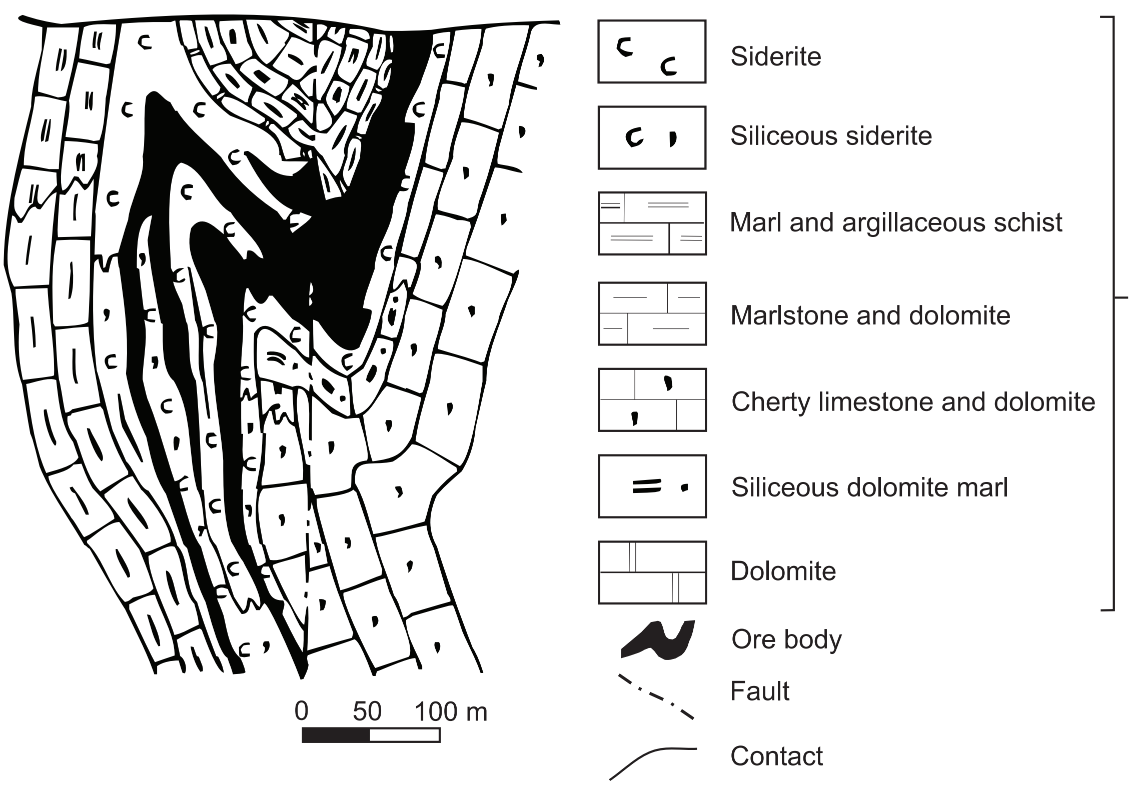


Figure 33. Generalized geologic map of the Early Neoproterozoic Gorevskoye sedimentary exhalative (SEDEX) Pb-Zn deposit, Eastern Siberia. Adapted from Saraev (1999).

beds may occur in the middle to lower parts of a retrogressive sequence. Mn-bearing carbonate commonly occurs in shale or mudstone. However, some Mn carbonate occurs in sandstone and red shale. On the North China platform, a group of B-Mn deposits of to the third Mn subtype is characterized by Mn-boracite; minerals are mainly Mn-boracite, rhodochrosite, Ca-rhodochrosite, and ankerite. In Northeast China, a group of deposits hosted in mudstone, dolostone, and dolomitic limestone that are part of the Mesoproterozoic Jixian System, are named the Jixian type of B-Mn deposit, including: (1) a group of late Paleoproterozoic Fe oxide (Fe siderite) deposits (Xuanlong type of Fe deposit); and (2) a group of late Mesoproterozoic Fe-Mn deposits (Wafanzhi type of Mn deposit) on the North China Platform. Another example is the Khovsgol carbonate basin located in northern Mongolia where Fe, Fe-Mn, and Mn occurrences are associated with sedimentary phosphate, allunite, and V deposits at the same stratigraphic level but without a regular spatial distribution. Associated with

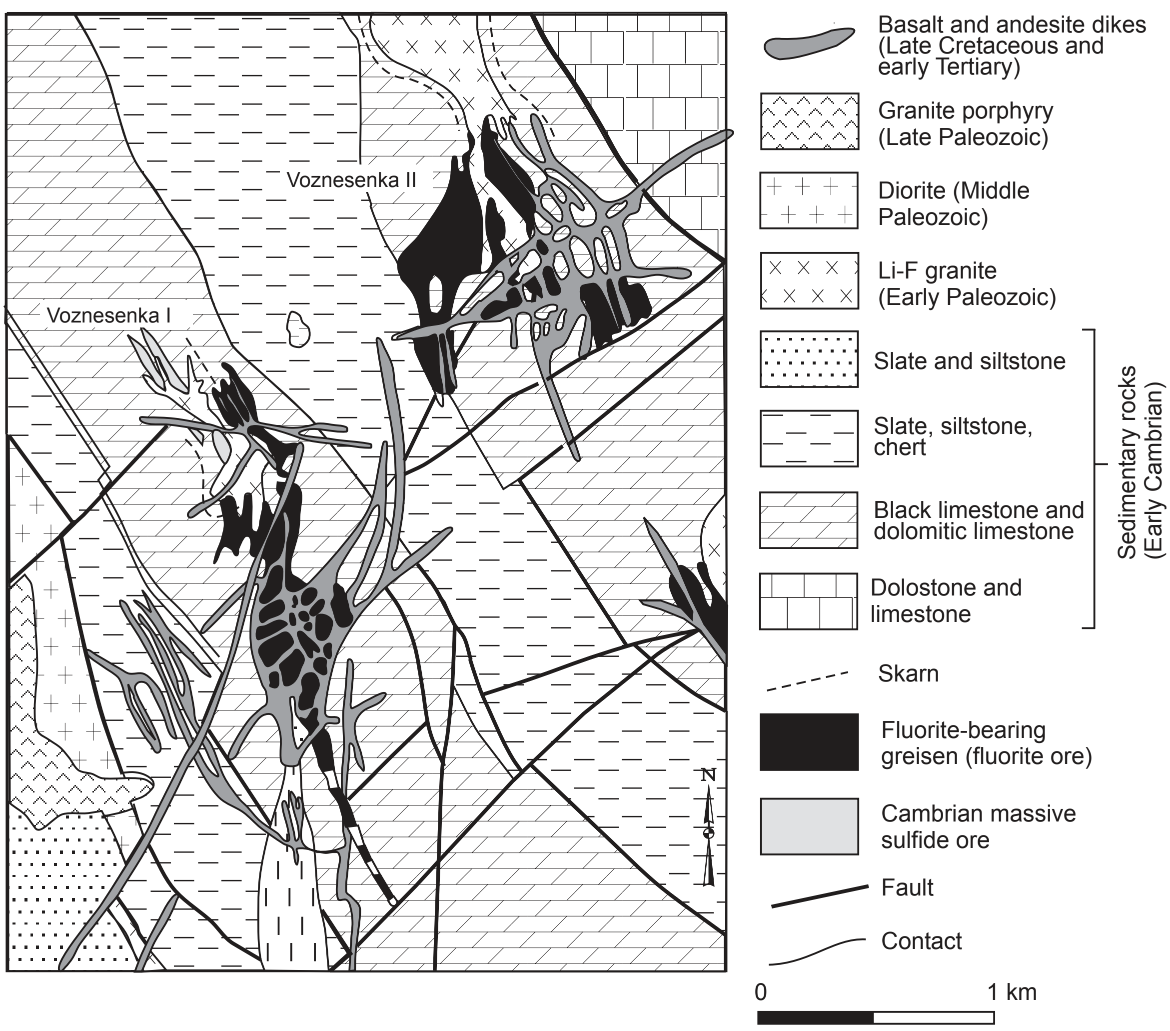


Figure 34. Generalized geologic map of the Cambrian Voznesenka I Korean Pb-Zn massive sulfide deposit, Russian Southeast. Adapted from Ratkin (1995).

extensive phosphate deposits are also low-grade sedimentary Fe, Mn, and Al deposits. The depositional environment consisted of formation of sheets and lenses of massive to disseminated Fe and Mn oxides and carbonates in an epicontinental marine environment. The deposit type may be associated with sedimentary gypsum, and alunite, and rare barite and bauxite deposits. Examples of this mineral-deposit type are Dongshiuchang, Tiejin Province, China; Pangjiapu, Hebei Province, China; and Wafangzi, Liaoning Province, China.

Evaporate Halite (Kleiner and others, 1977)

Evaporate halite deposits consist of halite that occurs mainly in Middle through Late Devonian reef limestone, dolomite, calcareous breccia, arkose, siltstone, diabase, agglomerate, and tuff. Minerals are gypsum, halite, anhydrite, and lesser carbonates, vanthoffite, and sylvinite. The deposits occur in beds that vary from 9 to 50 m thick. Halite is generally smoky, shiny pink, and coarse-grained. Halite bearing beds, which vary from 100 to 600 m, occur mainly in anticlines. Largest known deposits are Shuden-Uul and Davst-Uul in northern part of the Mongolian Altay Range. The depositional environment consisted of formation during continental-margin rifting or along transform-continental-margin boundaries. Examples of this mineral-deposit type are Davst uul and Shuden uul, Mongolia.

Evaporate Sedimentary Gypsum (Kleiner and others, 1977; Yuan others, 1982; Ganbaatar, 1999)

Evaporate sedimentary gypsum deposits occur in evaporite carbonate sequences of supratidal (sabkha) facies in semienclosed sedimentary basins. Two main types of evaporite sequence occur: carbonate and cataclastic. The deposits are multilayered and range in shape from bedded through stratiform to lensoid. The deposits gradually thicken from the margins to the center of a basin. Major minerals are gypsum, anhydrite, and lesser brogniartine, K- and Mg-halite, and native sulfur; gangue minerals are calcite, dolomite, magnesite, native sulfur, clay, and minor halite, authigenic quartz, and chalcedony. Gypsum content is as much as 98 percent. The deposits commonly exhibit idiomorphic, mosaic, and granular textures. The deposit minerals occur in masses, bands, beds, laminae, stockwork, breccia, and bioturbation zones. From the margin to the center of a basin, the common facies are sandstone (conglomerate), mudstone, gypsum, halite, and K- and Mg-halite that occur in circular zones. The deposit-forming materials are derived from weathering the of surrounding rocks, dissolution of ancient halite deposits, or deep brines, volcanic hydrothermal fluids, or marine water. Local later alteration during diagenesis and dissolution may form gypsum veins. The deposit indicators include shallow-water deposition of mudstone and marl with mudcracks. On the North China platform, the deposits are mainly hosted in Cambrian and Late Ordovician epicontinental rocks. The depositional environment consisted of intense evaporation of brine in enclosed or semi-enclosed subsiding basins in a dry climate. Examples of this mineral-deposit type are Baruun Tserd, Mongolia and Taiyuan, Shanxi Province, China.

Sedimentary Bauxite (A.N. Sucharina, in Kuznetsov, 1982)

Sedimentary bauxite deposits consist of bauxite beds hosted in carbonaceous and clastic rocks that form in marine or continental environments. Two subtypes are defined: carbonaceous and clastic. The first subtype, which occurs in neritic marine deposits along passive continental margins, is characterzied by thick, rift-related carbonates with interformational stratigraphic breaks, interlayered with thin (as much as a few meters thick) bauxite horizons. Metamorphosed equivalent consists of diaspore that forms at andalusite-sillimanite facies. The second subtype occurs in clastic sequences as a result of weathering of aluminosilicate rocks and minerals and redeposition in a peneplain environment. Main minerals are gibbsite and gibbsite-kaolinite. The deposits, which range from tens to about 100 m in thickness, are generally flat lying, may be linear or lenticular, and may form in karsts underneath layered deposits. Examples of this mineral-deposit type are Ke'er, Re'er, Shigong, and Xiaoyi, Shanxi Province, China.

Sedimentary Celestite (Yakovlev, 1986)

Sedimentary celestite deposits consist of thin layers and concretions of celestite in sandstone and mudstone. The major mineral is celestite. The depositional environment consisted of formation of continental lacustrine sedimentary rocks in grabens during late-stage continental rifting. Examples of this mineral-deposit type are Dugshih hudag and Horgo uul, Mongolia.

Sedimentary Phosphate (Eckstrand, 1984; Mosier, 1986a,b; V.L. Librovich, in Rundqvist, 1986)

Sedimentary phosphate deposits consist of phosphorite in mainly clastic volcanic silica-carbonates. Phosphate layers may be monomineralic. Major textures and structures are finely laminated (locally aphanitic), oolitic, streaky disseminated, and brecciated; associated rocks are marl, shale, cherty limestone, and dolomite. Volcanic rocks may also occur. The depositional environment consisted of a marine sedimentary basin connected to the open sea, with local upwelling zones over continental-shelf rocks along passive or active continental margins. Examples of this mineral-deposit type are Belkinskoye and Seibinskoye 2, Russia, and Burenhan and Hubsugul, Mongolia.

Sedimentary Fe-V (Oh and Hwang, 1968; Eckstrand, 1984; Sinyakov, 1988; Poznaikin and Shpilikov, 1990)

Sedimentary Fe-V deposits consist of chemical-sedimentary strata containing layered oolitic brown ironstone and (or) V-bearing chert, carbonaceous shale, and chert horizons. Fe deposits occur in mudstone, argillite, black shale, ferruginous sandstone, glauconite sandstone, limestone, and manganiferous and phosphatic shale and sandstone; V deposits occur in cherty-carbonaceous shale with interlayered siliceous shale, carbonaceous and calcareous shale, mudstone, siltstone, chert, and rare limestone. Chert horizons may contain sedimentary quartzite. Massive beds commonly range from 2 to 25 to 30 m in thickness and are interbedded with shale, sandstone, and gritstone. Minerals are mainly hematite, goethite, siderite, and chamosite; associated minerals are calcite, ankerite, various clay minerals, clastic quartz, pyrite, and phosphatic fossil debris. Fe content in ore beds is irregular and ranges from 20 to 45 percent. The deposits are rich in P_2O_5 and V_2O_5. V grade ranges from 0.01 to 1.0 percent. The depositional environment consisted of deposition of ironstone in neritic basins, lagoons, and estuaries under oxygenated to euxinic conditions. Examples of this mineral-deposit type are Kolpashevskoye, Russia, and Hitagiin gol, Mongolia.

Sedimentary Fe Siderite (Rundqvist, 1986)

Sedimentary Fe siderite deposits consist of layers and lenses of siderite in the upper part of a coal series. The deposits are hosted in sandstone and argillite containing siderite oolites and concretions. Siderite content is as much as 80 to 90 percent. Associated matrix minerals are chlorite, hydromica, quartz, and feldspar. Ore layers ranges from 0.1 to 2 m in thickness. This deposit type is of little economic importance. Examples of this mineral-deposit type are Barandatskoye, Ishimbinskoye, Nizhne-Angarskoye, and Parabel-Chuziks-koye, Russia.

Stratiform Zr (Algama Type) (Bagdasarov and others, 1990; Nekrasov and Korzhinskaya, 1991; Zalishchak and others, 1991)

Stratiform Zr deposits consist of hydrozircon and baddeleyite in lenses and veins that occur mainly in a layer of cavernous dolomite marble, as much as 40 m thick. The ore occurs as breccia composed of fragments of metamorphic quartz and dolomite cemented by hydrozircon and baddeleyite aggregate; baddeleyite also occurs as loose aggregates formed by weathering of primary ore. Some caverns in the dolomite contain colloform, sinter-type aggregates of hydrozircon and baddeleyite, but breccia texture predominates. The cavern walls are coated with metamorphic quartz. The host dolomite is not hydrothermally altered. A large deposit occurs in the northern part of the Khabarovsk province, Russia and is hosted mainly in subhorizontal dolomite marble that, along with other miogeoclinal sedimentary rocks, constitutes the Neoproterozoic and early Paleozoic sedimentary cover of the Stanovoy block of the North Asian craton; its origin is speculative. According to B. Zalischak (written commun., 1992), the type Algama deposit in Russia was formed by discharge of hydrothermal solution along a layer of porous dolomite; sudden pressure fall resulted in a blast. A U-Pb isotopic age of about 100 Ma was obtained on hydrozircon (J.N. Aleinikoff, written commun., 1993).

VIII. Polygenetic Carbonate-Hosted Deposits

Polygenic REE-Fe-Nb (Bayan-Obo Type) (Kim and others, 1959; Chao and others, 1992; Cao, 1994; Lin and others, 1994; Ren and others, 1994; Zhang and Tang, 1994; Bai and others, 1996; Pan, 1996; Tu Guangzhi, 1996, 1998)

The major example of a polygenetic REE-Fe-Nb deposit is the Bayan-Obo superlarge REE-Fe-Nb deposit in China (fig. 35), which contains reserves of as much as 70 percent of the world's REE resource. The deposit, which occurs in Mesoproterozoic clastic rocks and Mg-carbonates, consists of layered to lenticular bodies that are generally concordant with the host dolomie. The deposit contains about 170 minerals, including 60 Nb, REE, Ti, Th, Fe minerals, and principal Fe minerals are hematite, magnetite, and siderite. Principal REE minerals are monazite, parisite, huanghoite, and cerapatite; principal Nb-Ta minerals are niobite, aeschynite, fersmite, and pyrochlore. Two subtypes are d Nb-REE-Fe subtype A, and Nb-REE subtype B. Subtype A ore varieties are massive, banded, vein-disseminated (aegirine type), disseminated and laminated (riebeckite type), and massive and disseminated (biotite and dolomite types). Subtype B ore varieties are disseminated muscovite, aegirine, and diopside rich. The deposit consists of several blocks: a northern block with abundant ferrous minerals, blocks with abundant REE minerals with lesser ferrous minerals, and blocks with both ferrous and REE minerals. The deposit type contains well-developed hydrothermal alterations, including riebeckite, aegirine, fluorite, and biotite alterations, especially Mg skarn in the contact zone between dolomite and granite.

Several genetic interpretations exist. Tu (1998) reported Rb-Sr- and Sm-Nd-isotopic compositions and Nb/Ta ratios indicating that REEd and Nb are mantle derived. The current controversy is about the timing and mechanism of ore formation; dome studies suggest a relation to carbonatite magma (Bai, 1996), whereas other studies suggest that the metasomatism formed REE, Nb, Th, and Fe minerals and that the deposit is epigenetic (Chao, 1992). Recent isotopic studies of the country rocks and of ore and gangue minerals (Cao, 1994, Ren, 1994, Zhang, 1994) indicate mainly Mesoproterozoic and Caledonian ages, suggesting formation in the Mesoproterozoic and strong reworking in the early Paleozoic, possibly with partial introduction of new REE minerals (Ren, 1994, Cao, 1994, Pan, 1996). Tu Guangzhi (1996, 1998) interpreted a Mesoproterozoic SEDEX event in which metasomatic activity, diagenesis, and alteration of dolomite were synchronous and mineals were subsequently enriched during Caledonian deformation. The general interpretation is that the deposit formed in a rift zone along the north edge of North China craton.

Another example of a polygenetic REE-Fe-Nb deposit is at Yangyang, Korea, which consists of magnetite in a polymetamorphosed contact deposit hosted in Precambrian biotite gneiss and a younger syenite intrusion. The western part of the syenite contains many lenticular xenoliths of calc-silicate rock, tactite, and amphibolite formed from metasomatized impure limestone. Magnetite occurs in the syenite in close association with tactite or amphibolite and locally in in lenticular masses as xenoliths, or intruded by syenite dikes. The main mineral is magnetite in masses, plates, or brittle zones; gangue minerals include hornblende, epidote, and biotite. This deposit is interpreted as a polymetamorphosed contact deposit in which a primary contact-metasomatic magnetite was intruded by syenite.

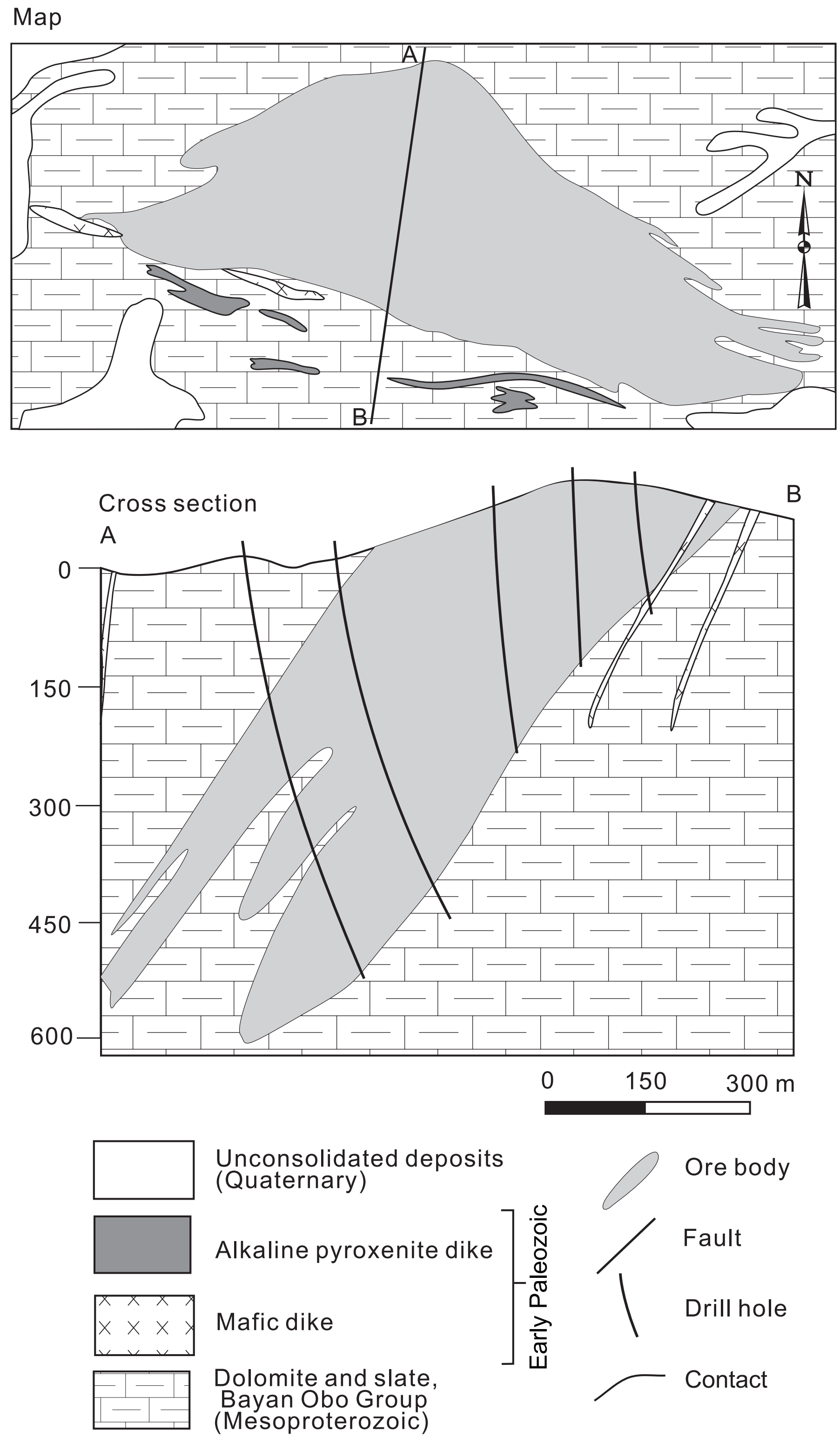


Figure 35. Generalized geologic map of the Mesoproterozoic Baiyan Obo polygenetic REE-Fe-Nb deposit deposit, northern China. Adapted from Li (1993).

Deposits Related to Metamorphic Processes

IX. Sedimentary-Metamorphic Deposits

Banded Iron formation (Algoma type) (Zhang and others, 1984;Yan, 1985; Zhang and others, 1985; Cannon, 1986)

Banded iron formation (Algoma type) deposits consist of Fe minerals hosted mainly in Archean ferrous quartzite beds and Fe-rich mafic to felsic volcanic, volcanoclastic, and clastic rocks. The deposits are typically interlayered on a centimeter scale with quartzite and Fe-rich beds. The deposits may be metamorphosed to varying degrees. At a lower metamorphic grade, main minerals are mainly magnetite, hematite, ilmenite, maghematite, fine-grained quartz, amphibole, and biotite; mineral composition, texture, and structures vary with metamorphic grade. With increasing metamorphism, minerals coarsen and Fe grade increases; at granulite facies minerals are magnetite, quartz, hypersthene, diopside, amphibole, ilmenite, plagioclase, garnet, and biotite. The deposits are widespread in the early Precambrian basement of the Sino-Korean craton and are a major source of iron in North China. Local enrichment associated with regional or contact metamorphism is associated with granitoid intrusion. In comparison with Superior-type deposits, the depositional environment of Algoma-type deposits consisted of tectonically mobile marine volcanic belts in small volcanic-sedimentary basins. Some the deposits are spatially associated with volcanogenic Zn-Cu massive sulfides, Homestake Au, and Au in shear zone and quartz veins deposits. Examples of this mineral-deposit type are Nanfen, Liaoning Province, China; Sijiaying, Hebei Province, China; Gongchangling, Anshan, Liaoning Province, Shanyangping and Yangchaoping, Daixian County, Shanxi Province, China.

Banded Iron Formation (Superior type) (Eckstrand, 1984; Cannon, 1986; Sinyakov, 1988)

Banded iron formation (Superior type) deposits consist of ferrous minerals in quartzite beds of mainly Paleoproterozoic age. The deposits consist mainly of banded, Fe-rich sedimentary rocks, generally of great lateral extent, that typically are interlayered on a centimeter scale with siliceous (chert) and Fe-rich beds. Iron-formation and host rocks commonly exhibit sedimentary textures typical of shallow-water deposition in tectonically stable regions. Main minerals are magnetite, hematite, fine-grained quartz, Fe silicates, and Fe carbonates. Many deposits are isoclinally folded and thrust faulted. The deposits are commonly metamorphosed to varying degrees, or weathered and enriched by supergene processes. Supergene deposits may be localized in irregularities along paleoerosional surfaces. The end product of weathering is Fe hydroxides and high-grade supergene hematite. The depositional environment consisted of stable shallow-water marine basins, commonly on stable continental shelf or intracratonic basin formed on ancient cratons and microcontinents. Examples of this mineral-deposit type are Bakcharskoye, Kostenginskoe, Nelyuki, Olimpiyskoe, Sutarskoye, and Tarynnakh (fig. 36), Russia, and Yuanjiachun, Shanxi Province, China.

Homestake Au (Berger, 1985b)

Homestake Au deposits are mainly hosted in metamorphosed banded iron-formation. The deposits commonly occur in thin laminae, concordant lenses, or veins in Fe-rich, siliceous, and carbonate rocks.

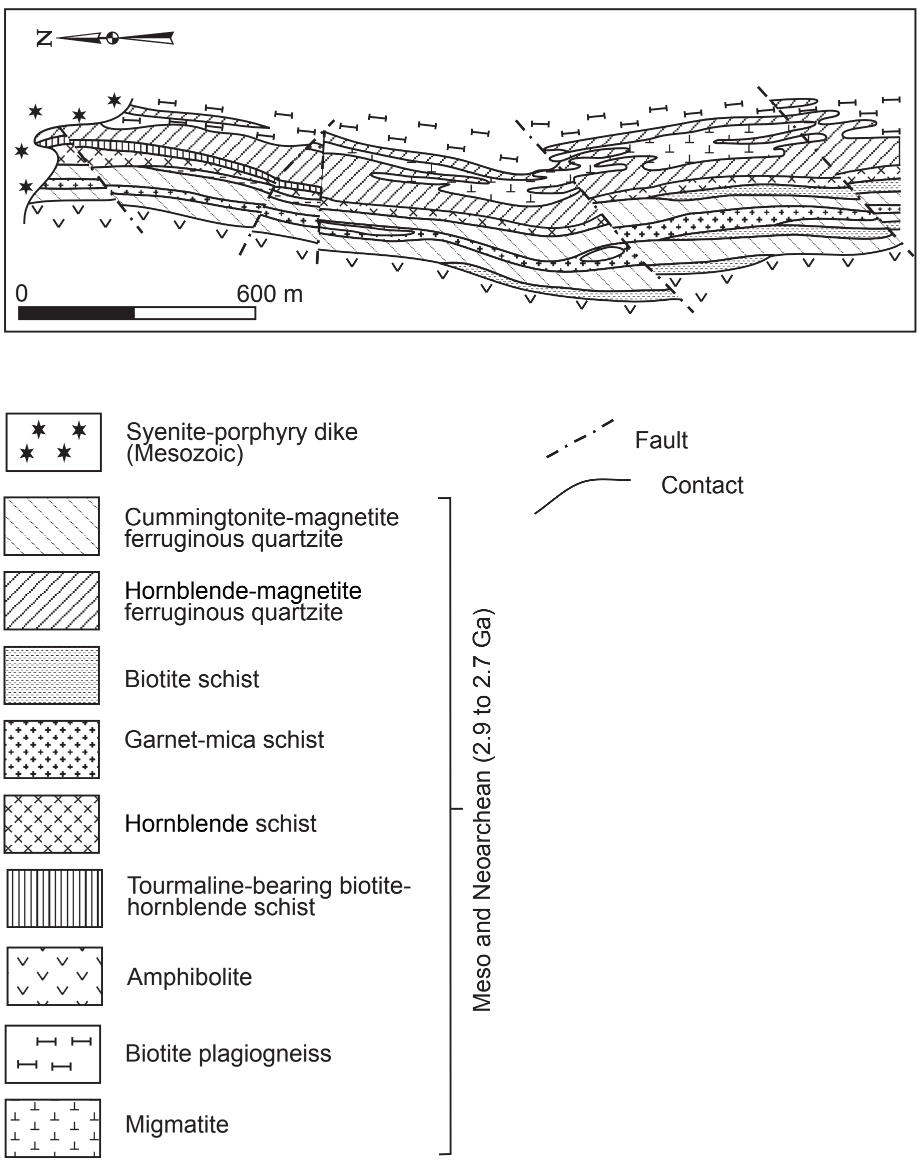


Figure 36. Generalized geologic map of the Archean through Paleoproterozoic Tarynnakh banded-iron formation deposit, Yakutia, Russia. Adapted from Gorelov and others (1984).

Main minerals are native gold, pyrite, pyrrhotite, arsenopyrite, magnetite, sphalerite, and chalcopyrite, with local tetrahedrite, scheelite, wolframite, molybdenite, fluorite, and actinolite. Banded Fe oxides are commonly replaced by pyrite and pyrrhotite. Main alteration minerals are chlorite and tourmaline. Associated deposits are volcanogenic massive sulfice (Kuroko), Algoma banded iron formation, and Au in shear zone and quartz vein deposits. Genesis is debated, but this mineral deposit type is generally interpreted as having formed during marine volcanism or late-stage hydrothermal activity. An example of this mineral-deposit type is at Dongfengshan, Heilongjiang Province, China.

Sedimentary-Metamorphic Borate (Peng and others, 1993)

Sedimentary-metamorphic borate deposits consist of two subtypes: metasedimentary and hydrothermal subtypes. The first subtype is conformably hosted in stratiform Mg carbonates (mainly magnesite), with suanite [$Mg_2(B_2O_5)$] as the main ore mineral, along with magnesite. The second subtype consists of stratiform Mg silicates in breccia or deformed bands, and is the more important of the two subtypes. Breccia fragments contain laminated, fine-grained forsterite and diopside in a matrix of suanile and magnesite. Ludwigite ($(MgFe)_2Fe_3+(BO_3)O_2$) occurs mainly in the second subtype that is Fe rich. Both subtypes, especially the second, may be altered, with replacement of forsterite by serpentinite, phlogopite, and other minerals, and of suanite to szaibelyite [$MgBO_2(OH)$]. Hydrothermal alteration is closely associated with intrusion of granitic rocks and pegmatite. Deposits of the second subtype in eastern Liaoning, northeastern China are hosted in a Paleoproterozoic volcanic-sedimentary sequence, metamorphosed to amphibolite facies, that contains tourmaline, albite, and microcline and exhibits a spatial distribution suggesting an evaporite rift-related genesis. Examples of this mineral-deposit type are Wengquangou (fig. 37) and Zhuanmiao, Liaoning Province, China.

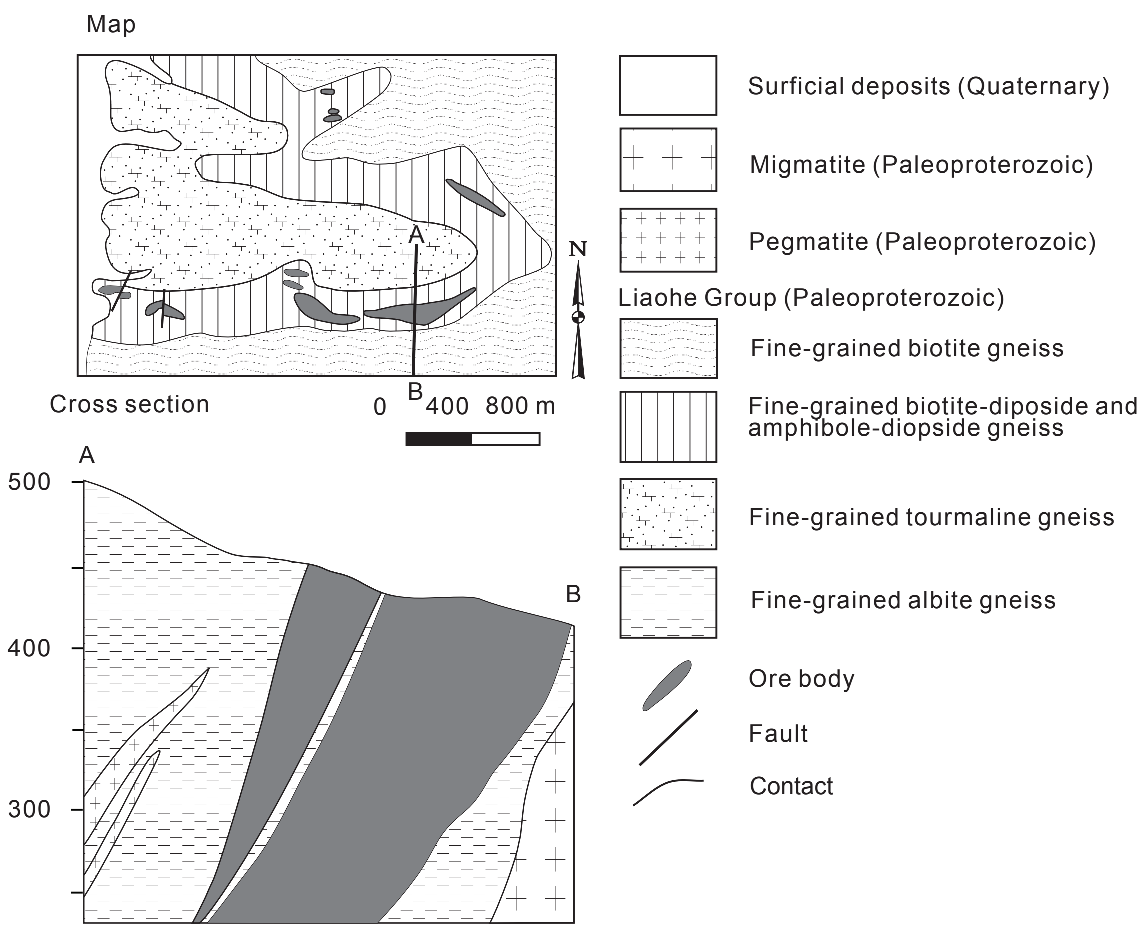


Figure 37. Generalized geologic map of the Late Paleoproterozoic Wengquangou sedimentary-metamorphic borate deposit, northern China. Adapted from Jiang and others (1994).

Sedimentary-Metamorphic Magnesite (Zhang and others, 1984; Li and Zhu, 1992)

Sedimentary-metamorphic magnesite deposits consist of magnesite in beds ranging from 200 to 2,000 m in length and from 30 to 300 m width. The deposits are mainly hosted in Paleoproterozoic carbonates, and generally dolomite marble. The deposits contain sedimentary textures, including ripple marks, and mud cracks, and local metasomatic textures. Minerals are mainly massive with lesser banding. The major mineral is medium- to coarse-grained magnesite, along with lesser talc, tremolite, dolomite, and chlorite and rare calcite, Fe-dolomite, rhodochrosite, Fe-magnesite, siderite, garnet, pyrite, serpentinite, sphalerite, chalcopyrite, magnetite, apatite, and hematite. Maximum MgO content of magnesite is 47 percent. The depositional environment consisted of Paleoproterozoic rifting in a littoral, shallow-marine sedimentary basin. Possible subsequent lower-greenschist- to amphibolite-facies metamorphism and intensive deformation may have resulted in recrystallization of minerals, crystallization of siderite, and formation of lenticular metasomatic deposits. Examples of this mineral-deposit type are Biderin gol, Mongolia, and Xiafangshen and Xiaoshengshuisi, Liaoning Province, China.

X. Deposits Related to Regionally Metamorphosed Rocks

Au in Black Shale (Kazakevich and 1972; Buryak, 1980, Kanovalov, 1985)

Au in black shale deposits consist of stringers, disseminations, and veins that occur in Riphean sequences composed of alternating layers of folded black phyllite or shale, sandstone, limestone, siltstone, and argillite. Microfolds and longitudinal shear zones in anticlines are an important control. Gold occurs in conformable zones as disseminations. Highest Au content is in horizons and lenses of carbonaceous shale. Au-quartz veins occur in upper horizons as relatively thin bodies that pinch out downdip. Minerals constitute a low-sulfide quartz assemblage of mainly pyrite and arsenopyrite with scarce sphalerite, galena, and chalcopyrite. Rare PGE minerals may occur. Peripheral haloes, that are low in gold, contain disseminated pyrite and arsenopyrite. The deposits are polygenic and polychronous. Gold initially accumulated during deposition of the host rocks, and was redistributed and concentrated during dynamic metamorphism and infiltration of ore-bearing fluid. Examples of this mineral-deposit type are Mangazeika 2, Olympiada, and Sukhoy Log (fig. 38), Russia.

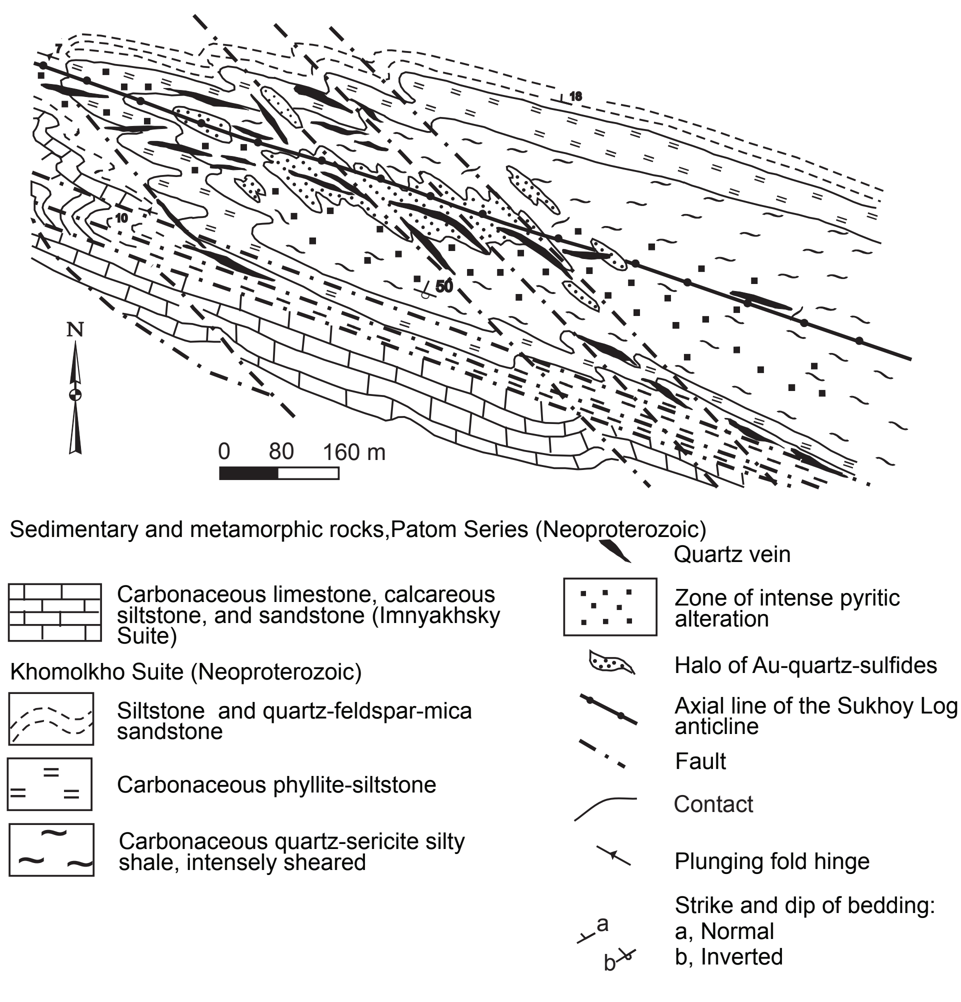


Figure 38. Generalized geologic map of the Devonian through Early Carboniferous Sukhoy Log Au in black shale deposit, TransBaikal, Russia. Adapted from Buryak (1982).

Au in Shear Zone and Quartz Vein (Berger, 1986c)

Au in shear zone and quartz vein deposits includes low-sulfide Au quartz vein, turbidite-hosted, concordant-vein, and shear-zone Au deposits. The deposits consist of gold in massive, persistent quartz veins that are hosted in regionally metamorphosed volcanic rock, and in metamorphosed graywacke, chert, and shale. Veins are generally late synmetamorphic to postmetamorphic and locally cut granitic rocks. Associated minerals are minor pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, pyrrhotite, and sulfosalts; alteration minerals include quartz, siderite, albite, and carbonates. The depositional environment consisted of low-grade metamorphic belts associated with continental margin arcs or collisional (anatectic) zones, or along transform continental margins. Examples of this mineral-deposit type are Nezhdaninka and Zun-Kholba (fig. 39), Russia, and Jiapigou, Jilin Province, China; Jinchangyu, Hebei Province, China; and Paishanlou, and Liaoning Province, China.

Clastic-Sediment-Hosted Sb-Au (Distanov and others, 1977; Berger, 1978, 1993; Indolev and others, 1980)

Clastic-sediment-hosted Sb-Au deposits consist of stibnite and associated minerals that occur in simple, lenticular, and ladder veins and in reticulate veins and veinlets, sometimes with subconformable disseminations. Main minerals are stibnite, berthierite, pyrite, arsenopyrite, and gold, with subordinate sphalerite, galena, chalcopyrite, tetrahedrite, chalcostibite, scheelite, pyrrhotite, marcasite, gudmundite,

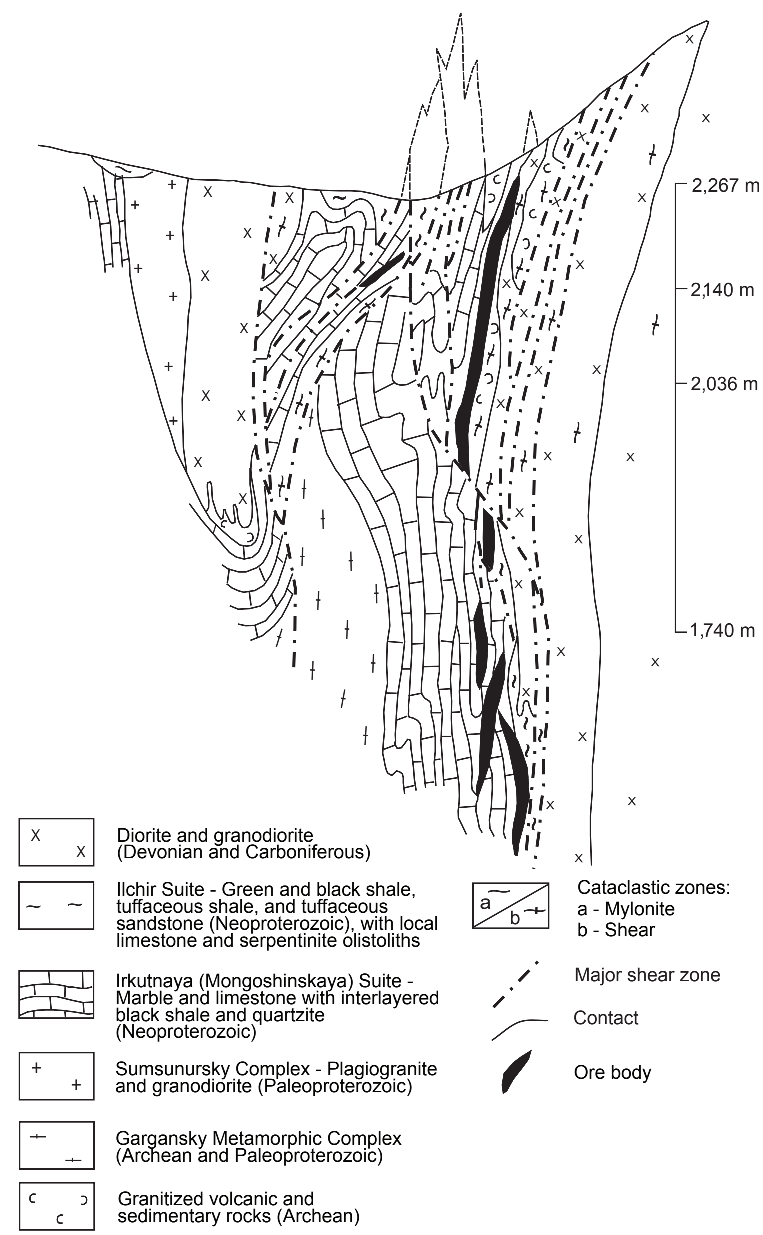


Figure 39. Schematic cross section of the Neoproterozoic through Silurian Zun-Kholba Au in shear zone and quartz vein deposit, TransBaikal, Russia. Adapted from Mironov and others (1995).

gersdorffite, native antimony, and native silver; gangue minerals are mainly quartz and lesser ankerite, calcite, dolomite, siderite, donbassite, sericite, and gypsum. Wallrocks are altered to varying combinations of quartz, carbonates, sericite, and pyrite. The host rocks for these deposits are (1) Proterozoic and Paleozoic greenschist derived from mafic volcanic and volcanic-clastic rocks; (2) interbedded carbonaceous black shale and volcaniclastic rocks; (3) or to a lesser extent, retrogressively-metamorphosed granitic rocks. The depositional environment consisted of strongly deformed fold belts that formed along intracratonic-rift troughs or in reactivated pericratonic-platform subsidences on a passive continental margin. The deposit type is controlled by linear zones of folds and mylonites that are associated with regional strike-slip faults, and are associated with low-grade greenschist facies regional metamorphism, suggesting a hydrothermal-metamorphic origin. The deposit type may also be associated with Au-quartz vein deposits. Examples of this mineral-deposit type are Sentachan, Russia (fig. 40), and Ichinokawa, Japan.

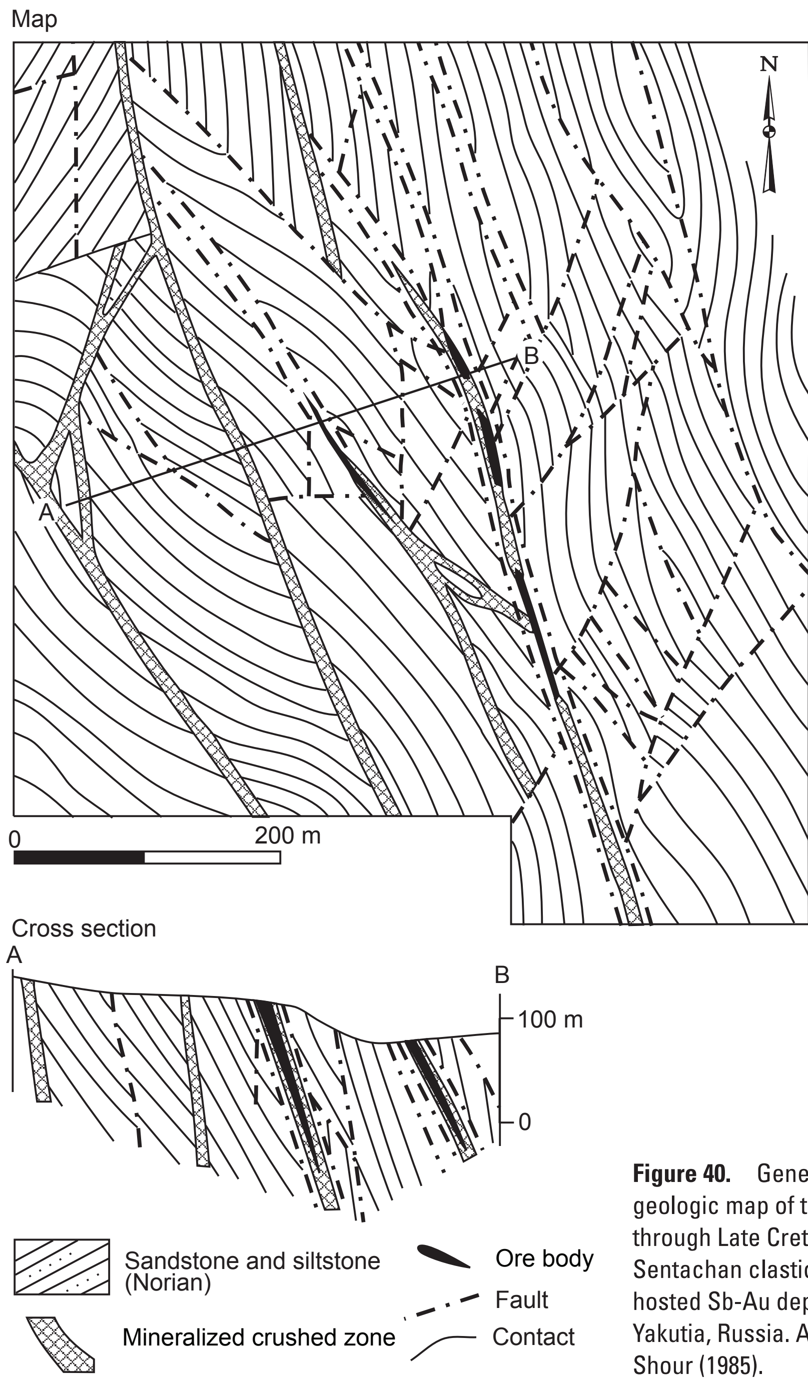


Figure 40. Generalized geologic map of the Aptian through Late Cretaceous Sentachan clastic-sediment-hosted Sb-Au deposit, Yakutia, Russia. Adapted from Shour (1985).

Cu-Ag Vein (Nokleberg and others, 1997)

Cu-Ag Vvein deposits consist mostly of Cu sulfides and accessory Ag minerals in quartz veins and stringers hosted in either weakly, regionally metamorphosed basalt, andesite-basalt, or clastic sedimentary rocks. The deposits may occur in structural slices of ultramafic rocks that occur along regional faults in clastic sedimentary rocks. The occurrences in lower grade, metamorphosed mafic volcanic rocks consist mainly of widespread zones of sulfide-bearing quartz veins; well-formed Cu sulfide quartz stringers and veins may also occur. Minerals are chalcopyrite, bornite, chalcocite, covellite, pyrite, pyrrhotite, malachite, and azurite, and rare native Cu; alteration minerals are epidote, chlorite, actinolite, albite, carbonates, and quartz. Special features are: (1) quartz veins and stringers that occur in extensive linear zones; (2) mineral occurrences in impregnations, stringers, layers, and rare breccia; and (3) locally high grades of Ag, Au, and Zn. In Northeast Asia, many occurrences are in Middle Riphean mafic volcanic rocks, Vendian through Lower Cambrian, and Ordovician through Silurian rocks. The depositional environment consisted of low-grade metamorphic belts containing mafic volcanic or clastic sedimentary rocks in continental margin arcs or collisional (anatectic) zones; veins are generally late-stage metamorphic. Examples of this mineral-deposit type are Goseong and Yanggudong, South Korea.

Piezoquartz (Arkhipov, 1979)

Piezoquartz deposits occur in Precambrian quartzite associated with high-alumina gneiss and mafic schist. The crystalline deposits generally occur at rupture intersections in flexures and periclines of folds, forming single veins (0.5 to 2 m thick and 20 to 30 m long) and vein zones (1 to 30 m thick, average of 5 to 15 m thick, and from a few tens of meters to 400 m long, average of 100 to 200 m). Most deposits occur in pipes, veins, and stockwork, a few tens of meters in diameter. Veins consist of crystalline or smoky quartz, clay filling voids, K-feldspar, and rare crystalline hematite, chlorite, sericite, tourmaline, albite, epidote, and adularia. Crystals occur on the walls of voids or in the lower parts of voids amidst clay; voids occur inside quartz veins, at the contacts of veins and host rocks, or in host rocks adjacent to veins. Host rocks are altered to sericite, chlorite, and epidote. Examples of this mineral-deposit type are Bugarykta and Perekatnoe, Russia.

Rhodusite Asbestos (Andreev, 1962; Romanovich and others, 1982)

Rhodusite asbestos deposits consist of rhodusite-asbestos and nonfibrous rhodusite in mottled layers with salt and gypsum. The mottled rocks consist of rhythmic layers of marl, argillite, siltstone, and sandstone; agillite predominates. The deposits are as much as tens of meters thick. Rhodusite-asbestos and nonfibrous rhodusite also occur in veinlets and disseminations. The depositional environment consisted of formation of epigenetic replacement of red-bed clastic rocks and mottled host rocks during initial metamorphism in intermontane depressions in arid areas with high-salinity water in sedimentary basins. An example of this mineral-deposit type is at Azkizskoye, Russia.

Talc (Magnesite) Replacement (Kim, 1972; Romanovich, 1973; Romanovich and others, 1982)

Talc (magnesite) teplacement deposits consist of metasomatic talc that replaces ultramafic and Mg-bearing sedimentary and magmatic rocks during regional or contact metamorphism.Two subtypes are defined: (1) metasomatic ferrous talc, talc-breunnerite, and talc-chlorite that occur in ultramafic rock, mainly dunite and harzburgite in veins, stocks, and lenses; and (2) low-ferrous talc minerals formed in dolomitic carbonaceous rocks. This second subtype consists of: (1) deposits associated with regional metamorphism with steatite, talc-schist, and talc-carbonates; and (2) deposits of talc, carbonate, and tremolite associated with contact metamorphism and related granitoid intrusions. Wallrocks are dolomite, interlayered dolomitic limestone and aluminosilicates (slate, amphibolite, quartzite). The deposits are bedded and generally large. Surficial processes may form a weathering crust with high-quality, powdery, low-ferrous talc. Associated minerals are magnesite, marshallite, and karst-bauxite. Major deposit control is ultramafic host rocks that are regionally metamorphosed to greenstone facies and intensely intruded by granitoids. The depositional environment consisted of dolomitic and ultramafic rocks in orogenic belts along continental margin arcs and collisional zones, and in pericratonal-platform subsidences. Examples of this mineral-deposit type are Alguiskoye, Savinskoe, Svetlyi Klyuch, and Togulenskoye, Russia, and Fanjiapuzi, Liaoning Province, China.

Metamorphic Graphite (Lee, 1960; Eremin, 1991)

Metamorphic graphite deposits consist of two subtypes: (1) deposits in regional high-grade metamorphosed rocks, including gneiss and schist with coarse-crystalline graphite; and (2) deposits formed during contact metamorphism of coal beds during Trapp intrusion, such as the Tungus graphite province in the North Asian craton, where the deposits formed with thermal metamorphism of coal layers during intrusion of thick Triassic diabase sills. The deposits are compositionally complex and consist of layers of amorphous graphite and numerous fragments and lenses of sedimentary rocks. Major mineral is fine-grained and flake graphite; associated minerals are pyrite, calcite, apatite, zircon, magnetite, rutile, and hydrosilicates. Examples of this mineral-deposit type are Noginskoye, Russia, Itgel Naidvar, Mongolia, and Liumao, Heilongjiang Province, China.

Metamorphic Sillimanite (Zhang, 1984; Jiang, 1994)

Metamorphic sillimanite deposits consist of multiple concordant layers containing 25 to 50 percent sillimanite in graphite-garnet-sillimanite schist, biotite-garnet-sillimanite schist, plagioclase-cordierite-sillimanite schist and gneiss, and lesser garnet schist, and phosphorus marble. Major mineral is sillimanite; accessory minerals are quartz, garnet, biotite, cordierite, K-feldspar, graphite, pyrite, pyrrhotite, tourmaline, and phlogopite. Protolith is high-Al argillaceous sedimentary rocks that formed in nearshore tidal flats and lagoons. Metamorphic grade ranges from amphibolite to granulite facies, with intense folding. The mineral-deposit type is commonly spatially associated with metamorphic graphite deposits. An example of this mineral-deposit type is at Sandaogou, Heilongjiang Province, China.

Phlogopite Skarn (Murzaev, 1974; Arkhipov, 1979)

Phlogopite skarn deposits consist of phlogopite in diopside and phlogopite-diopside schist, marble, and calc granofels that is metasomatized to coarse-grained phlogopite-diopside skarn. Some deposits are controlled by synforms and occur along fold hinges, on axial planes, and in the cores of superposed transverse folds. The deposits range from 0.7 to 2.5 km in length, and from 0.2 to 0.5 km in width; phlogopite skarn ranges from a few meters to several tens of meters in width from 10 to 20 m to several hundreds of meters in length. Minerals are phlogopite, diopside, hornblende, scapolite, apatite, and actinolite. Phlogopite occurs in nests that range from 0.5 to 1.5 to 6 m in width (average of 1 to 2 m); rare phlogopite occurs in thin veins. Phlogopite crystals are irregular, range from brown-green to brown, and vary from 8 to 15 cm across. Most deposits are associated with diopside-magnetite skarn. Local diopside- and diopside-scapolite-plagioclase skarn may contain molybdenite. The depositional environment consisted of the post-collisional stage of Precambrian orogenies. Examples of this mineral-deposit type are Fyodorovsko, Megyuskan, and Nadyozhnoe Russia.

Deposits Related to Surficial Processes

XI. Residual Deposits

Bauxite (Karst Type) (Patterson, 1986)

Bauxite (karst type) deposits consist of sedimentary bauxite that occurs mainly in depressions of karst surfaces in thick carbonate sequences. The deposits are confined to interformational breaks in carbonates. Deformation and metamorphism are typical. Main minerals are diaspore and boehmite; associated minerals are hematite, goethite, kaolinite, and minor quartz. The deposit structures include pisolitic, nodular, massive, and earthy. Examples of this mineral-deposit type are Novogodneye and Oktyabrskoye 4, Russia,

Laterite Ni (Singer, 1986b)

Laterite Ni deposits consist of Ni minerals and silicates in weathering crusts formed from ultramafic rocks, particularly peridotite, dunite, and serpentinized peridotite. Morphological types are areal, linear, and contact karst. The major minerals are complex Fe-Co-Ni silicates or oxides. Major minerals are garnierite, nepuite, and revdenskite; associated minerals are serpentine, nontronite, goethite, Mn oxide, and quartz. Goethite commonly contains abundant Ni. Silicate minerals occur in the lower part of residual weathering crusts and in infiltration deposits. Oxides consist of Ni-bearing Fe hydroxides and asbolan. Zonation from top to bottom is (1) an upper limonite zone with Ni in iron oxides and (2) a lower saprolite and boxwork zone with Ni in hydrous silicates. The depositional environment consisted of convergent margins with obducted ophiolite complexes; uplift was required to expose the ultramafic rocks to weathering. Examples of this mineral-deposit type are Alexandrovskoye 2 and Belininskoye, Russia.

Weathering Crust Mn (±Fe) (Kim and Kim, 1962; Varentsov and Rachmanov, 1978)

Weathering crust Mn (±Fe) deposits consist of extensive Mn-bearing weathering crusts formed as residual deposits on Mn-rich limestone and metamorphic rocks. Mn content results from leaching and removal of carbonates and silica. Mn crust consists of sand and clay masses that contain hypergene concentrations of Mn oxides. Main minerals are pyrolusite, psilomelane, manganite, vernadite, and local Fe hydroxides. Minerals occur in layers, lenses, branches, and sometimes karst cavities. The deposits range are as much as kilometers long and tens of meters thick; thicker deposits exhibit a clear zonation, with Mn minerals in the lower part overlapped by pure Mn bearing and Fe hydroxide minerals. The depositional environment consisted of subaerial exposures of Mn-bearing calcareous rocks in a humid climate. Examples of this mineral-deposit type are Karaulnaya Gorka and Seibinskoye 1, Russia.

Weathering Crust and Karst Phosphate (Rundqvist, 1986)

Weathering crust and karst phosphate deposits consist of phosphorite minerals in weathering crusts and karst in association with phosphatic rocks and phosphorite-bearing carbonates. The deposits formed in linear and karst structures in near-surface exposures. Secondary hypergene enrichment of phosphorite may occur. Dissolution and redeposition of phosphatic matter may form unconsolidated and stony phosphorite with granular and fragmental structures. The deposits occur in extensional regimes containing low-grade phosphates. An example of this mineral-deposit type is at Telekskoye, Russia.

Weathering Crust Carbonatite REE-Zr-Nb-Li (Lapin, 1996)

Weathering crust carbonatite REE-Zr-Nb-Li deposits consist of complex REE minerals in weathering crust formed on nepheline syenite and associated carbonatites. The more productive deposits areis weathering crusts developed on melanocratic feldspar-carbonates containing siderite, dolomite, calcite, pyroxene, amphibole, nepheline, apatite, monazite, fluorite, zircon, torianite, loparite, parisite, eudialyte, lepidomelane, and Cu, Zn, and Pb sulfides. Weathering crust consists of hydromica and ferrihalloysite types. Major REE minerals are bastnaesite, staffelite, rabdofanite, and melanterite, with associated pyrolusite and limonite. The deposits are compositionally complex and contain REE and Nb along with Li and Zr. Some deposits are large. Examples of this mineral-deposit type are Kiiskoye and Tomtor, Russia.

XII. Depositional Deposits

Placer and Paleoplacer Au (Hwang and Choi, 1961; Yeend, 1986)

Placer and paleoplacer Au deposits consist of gold in grains and rare nuggets in gravel, sand, silt, and clay, and their consolidated equivalents in alluvial, beach, eolian, and rarely, glacial deposits. Major minerals are gold, sometimes with attached quartz, magnetite, or ilmenite; rare PGE minerals may also occur. The depositional environment consisted of high-energy alluvial basins where gradients flatten and river velocities lessen, as on the inside of meanders, below rapids and falls, beneath boulders, and in shoreline areas where the winnowing action of surf concentrates gold in modern beaches or in uplifted or submerged beaches; numerous major placer districts occur in Russia, Mongolia, and China.

Placer Diamond (Orlov, 1973; Lampietti and Sutherland, 1978; Cox, 1986f)

Placer diamond deposits consist of diamonds in alluvial and beach sedimentary deposits and in sandstone and conglomerate. The conglomerate beds may contain paleoplacers. The deposits generally range from Tertiary and Quaternary in age, and the tectonic setting is generally stable cratons. An associated deposit type is diamond-bearing kimberlite. Main minerals are diamond (bort or carbonado) and ballas. Diamonds derived from ancient placers in sedimentary rocks commonly retain sand grains cemented to grooves, or to indentations in crystals. The depositional environment consisted of concentration in the low-energy parts of stream systems with other heavy minerals. The diamonds generally decrease in size and increase in quality with distance from the source. An example of this mineral-deposit type is at Huangsongdianzhi, Hunchun City, Jilin Province, China.

Placer PGE (Yeend and Page, 1986)

Placer PGE deposits consist of PGE minerals and alloys in grains in gravel, sand, silt, clay, and their consolidated equivalents in alluvial, beach, eolian, and, rarely, in glacial deposits. In some areas, placer and paleoplacer Au and placer PGE deposits occur together. Major minerals are PGE alloys, Os-Ir alloys, magnetite, chromite, and ilmenite. The depositional environment consisted of high-energy alluvial basins where gradients flatten and river velocities lessen, as on the inside of meanders, below rapids and falls, beneath boulders, and in shoreline areas where the winnowing action of surf concentrates PGE and gold in raised, present, or submerged beaches. An example of this deposit type is at Kondyor, Russia.

Placer Sn (Nokleberg and others, 1997)

Placer Sn deposits consist mainly of cassiterite and elemental gold in grains in gravel, sand, silt, clay, and their consolidated equivalents, mainly in alluvial deposits. The depositional environment was similar to that of placer and paleoplacer Au deposits. Examples of this mineral-deposit type are Verkhnegilyui, Russia, and Janchivlan, Khar Morit, Modot, and Zuuntarts, Mongolia.

Placer Ti-Zr (Yoon and others, 1959; Force, 1986b; Rosliakov and Sviridov, 1998)

Placer Ti-Zr deposits consist of zircon-ilmenite placers concentrated by marine beach processes and in continental surface environments. The host sediment is well-sorted, fine to medium sand with silt. The depositional environment consisted of stable coastal regions receiving sediment from deeply weathered terranes. The deposit morphology consists of lenses and elongate "shoestring" deposits that occur parallel to beaches, sometimes in multilayered packets. Major minerals are low-Fe ilmenite, zircon, leucoxene, anatase, rutile, staurolite, disthene, tourmaline, and monazite. Examples of this mineral-deposit type are Koppi-Nelman and Sash-Yular, Russia.

Exotic Deposits

Impact Diamond (Masaitis and others, 1975, 1998)

Impact diamond deposits occur in the Popigay, Russia, ring structure that is interpreted as an impact structure in a round surficial depression, several tens of kilometers in diameter. Occurring in the depression is a complex variety of impact rocks, volcanic in appearance, with varying amounts of (1) glass of andesite-dacite composition; (2) rocks and mineral fragments; (3) explosive allogenic breccias that were deposited after impact within or beyond the limits of the depression; and (4) authigenic breccia, formed from the bottom of the crater that underwent high-grade shock metamorphism, melting, and formation of pseudotachylite. Impactite also includes massive lavalike tagamite and glassy clastic suevite. Diamond occurs in graphite gneiss and tagamite that underwent shock metamorphism. Diamond crystals range in size from 0.05 to 20 mm in diameter; associated placer deposits contain diamonds as large as 8 to 10 mm in diameter. Most abundant diamonds are yellow; transparent, gray, or black crystals are rare. Diamonds from gneiss retain morphologic and structural features inherited from crystalline graphite. Common are tabular crystals with a characteristic striation of basal planes due to repeated twinning, parallel intergrowths, irregular intergrowths, and aggregates. For the origin of the Popigay ring structure, the prevaling interpretation is impact of a giant meteorite; supporting data consist of numerous indications of shock metamorphism with partial melting of the rocks derived from Early Precambrian crystalline bedrock. An example of this deposit type is at Popigay, Russia.

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