Mineral Deposit Models for Northeast Asia

By Alexander A. Obolenskiy[1], Sergei M. Rodionov[2], Sodov Ariunbileg[3], Gunchin Dejidmaa[4], Elimir G. Distanov[1], Dangindorjiin Dorjgotov[5], Ochir Gerel[6], Duk Hwan Hwang[7], Fengyue Sun[8], Ayurzana Gotovsuren[9], Sergei N. Letunov[10], Xujun Li[8], Warren J Nokleberg[11], Masatsugu Ogasawara[12], Zhan V. Seminsky[13], Akexander P. Smelov[14], Vitaly I. Sotnikov[1], Alexander A. Spiridonov[10], Lydia V. Zorina[10], and Hongquan Yan[8]

[1] Russian Academy of Sciences, Novosibirsk
[2] Russian Academy of Sciences, Khabarovsk
[3] Mongolian Academy of Sciences, Ulaanbaatar
[4] Mineral Resources Authority of Mongolia, Ulaanbaatar
[5] Mongolian National University, Ulaanbaatar
[6] Mongolian University of Science and Technology, Ulaanbaatar
[7] Korea Institute of Geology, Mining, and Materials, Taejon
[8] Jilin University, Changchun, China
[9] Mongolia Ministry of Industry and Commerce, Ulaanbaatar
[10] Russian Academy of Sciences, Irkutsk
[11] U.S. Geological Survey, Menlo Park
[12] Geological Survey of Japan/AIST, Tsukuba
[13] Irkutsk State Technical University, Irkutsk
[14] Russian Academy of Sciences, Yakutsk

Introduction and Companion Studies

Metalliferous and selected non-metalliferous lode and placer deposits for Northeast Asia are classified into various models or types described below. The mineral deposit types used in this report are based on both descriptive and genetic information that is systematically arranged to describe the essential properties of a class of mineral deposits. Some types are descriptive (empirical), in which instance the various attributes are recognized as essential, even though their relationships are unknown. An example of a descriptive mineral deposit type is the basaltic Cu type in which the empirical datum of a geologic association of Cu sulfide minerals with relatively Cu-rich metabasalt or greenstone is the essential attribute. Other types are genetic (theoretical), in which case the attributes are related through some fundamental concept. An example is the W skarn deposit type in which case the genetic process of contact metasomatism is the genetic attribute. For additional information on the methodology of mineral deposit types, the reader is referred to discussions by Eckstrand (1984) and Cox and Singer (1986). For each deposit type, the principal references are listed in parentheses.

This article is prepared by a large group of Russian, Chinese, Mongolian, South Korean, Japanese, and USA geologists who are members of the joint international project on *Major Mineral Deposits, Metallogenesis, and Tectonics of the Northeast Asia*. This project is being conducted by the Russian Academy of Sciences, the Mongolian Academy of Sciences, Mongolian National University, Mongolian Technical University, the Mineral Resources Authority of Mongolia, Geological Research Institute, Jilin University, China Geological Survey, Korea Institute of Geoscience and Mineral Resources, the Geological Survey of Japan, and the U.S. Geological Survey. Information about major goals and pubications for this project is available at the USGS Internet/Web site at http://minerals.usgs.gov/west/projects/minres.html

Several companion studies, that are part of the study of NE Asia, are closely related to this paper. These companion studies are: a detailed geodynamics map of Northeast Asia (Parfenov and others, in press); a database of significant lode mineral deposits and placer districts (Ariunbileg and others, in press); a series of metallogenic belt maps (Obolenskiy and others, 2001).

Classification of Mineral Deposits

The following three main principles are the basis for the following classification of mineral deposits for this study. (1) Ore forming processes are close related to rock forming processes (Obruchev, 1928) and mineral deposits originate as the 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 as more comfortable and understandable for appropriate user as possible. And (3) the classification must be open so that new types of the deposits can be added in the future (Cox and Singer, 1986).

The below classification is constructed as further development of mineral deposit classification of Smirnov (1969), and on the mineral deposit types of Eckstrand (1984), Cox and Singer (1986), Nokleberg and others (1997), cited references for specific models, and available data on the problem. In the classification of Smirnov (1969), the mineral deposits are grouped into six hierarchic levels of metallogenic taxons according to such their stable features as: (a) environment of formation of host and genetically-related rocks, (b) genetic features of the deposit, and (c) mineral and (or) elemental composition of the ore. The six hierarchial levels are as follows.

Group of deposits
  Class of deposits
    Clan of deposits
      Deposit types (models)

Table 1 provides a hierarchial ranking of mineral deposit models according to these levels. For simplicity, the classification in this table does not employ the family and genus levels.

The deposit models are subdivided into the following four large groups according to major geological 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 magmatic-related deposits because they are the most abundant in the project area. In the below classification, lode deposit types models that share a similar origin, such as magnesian and (or) calcic skarns, or porphyry deposits, are grouped together under a single genus with several types (or species) within the genus.

Some of the below deposit models differ from cited descriptions. For example, the Bayan Obo type was described previously as a carbonatite-related deposit. However, modern isotopic, mineralogical, and geological data recently obtained by Chinese geologists have resulted in a new interpretation of the deposit origin. These new data indicate that the deposit consists of deposit minerals that formed during Mesoproterozoic sedimentary-exhalative process, and along with coeval metasomatic activity, sedimentary diagenesis of dolomite, and alteration. The sedimentary-exhalative process consisted of both sedimentation and metasomatism. Later deformation, especially during the Caledonian orogeny, further enriched the ore. Consequently, the Bayan Obo deposit type is herein described as related to sedimentary-exhalative processes, not to magmatic processes. However, 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 are made for carbonate-hosted Hg-Sb and other deposit models.

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)

This deposit type consists of magmatic sulfide Cu-Ni deposits in differentiated layered mafic-ultramafic intrusions. Layered intrusions generally occur in a cratonic setting, in many cases associated with intracontinental rifts and flood basalts. Mafic and ultramafic phases of layered intrusive complexes include peridotite, pyroxenite, gabbro, norite, picrite, troctolite and gabbro-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. Deposit minerals consist of massive sulfide minerals, sulfide-matrix breccias, interstitial sulfide networks, and disseminated sulfide minerals. In well-preserved deposits, the rich areas of deposit minerals occur close to the base, and are overlain by sparse disseminated sulfide minerals. Sulfide veins and dissemination commonly penetrate footwall rocks. The deposit minerals are complex and contain Ni and Cu along with PGE, Co, Se, Te, and Au. Deposit minerals include pentlandite, chalcopyrite, cubanite, millerite, pyrrhotite, various PGE minerals, pyrite, sphalerite, and marcasite. They are associated 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 is 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 the deposit type are at Hongqiling, Jilin Province, China, Kalatongke, Xinjiang, China, Norilsk I and II, Russia, and Talnakh, Russia.

Mafic-Ultramafic Related Ti-Fe (+V) (Lee and others, 1965; G.A. Gross and E.R. Rose, in Eckstrand, 1984; Page, 1986a; Sinyakov, 1988; S.M. Rodionov, this study)

This deposit type consists of layers and lenses, and disseminated titanomagnetite or vanadium-magnetite, with minor amount of ilmenite and chromite, in differentiated gabbroic intrusions. The host rocks are mainly norite, gabbro-norite, dunite, harzburgite, peridotite, pyroxenite, troctolite, anorthosite, gabbro, and diabase. Deposit minerals occur near 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 mineral is titanomagnetite and (or) V-magnetite. Associated minerals are ilmenite, hematite, spinel, and sulfide minerals (pyrite, pyrrhotite, chalcopyrite). Rock-forming minerals are plagioclase, olivine, pyroxene, apatite, and sphene. Also occurring are Fe and Ti-oxide phases that formed during 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 partly solidified gabbro and genetically related host rocks. The depositional environment consists of intrusions of gabbro-anorthosite, dunite-pyroxenite-gabbroic and gabbro-diabasic magmatic associations with magmatic layering of host intrusions. Mafic-ultramafic rocks often intrude into granitic gneiss or into volcanic-sedimentary units. An association exists between the ore-bearing layered plutons and deep-fault zones. Age of the deposits is generally Precambrian, but may be as young as Tertiary. Locally, Precambrian deposits may be highly metamorphosed with occurrence of deposits in hornblende schist as at the Soyonpyong deposit on the Korean Peninsula. The depositional environment consists of stratiform to irregular mafic to ultramafic plutons in continental margins or island arcs. Examples of the deposit type are at Damiao, Hebei Province, China, Kavakta, Russia, and Lysanskoye, Russia.

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

This deposit type consists of zoned ultramafic to mafic plutons with Cr and PGE minerals. The central part of the pluton is generally composed of dunite and the peripheral part consists of pyroxenite, koswite, and rare gabbro. The zoned plutons are often intruded by sills and dikes of gabbro, diorite, monzonite, and various alkaline rocks. The mafic and ultramafic rocks comprising the pluton, as well as host metamorphosed sedimentary-calcareous rocks may be locally altered into feldspar-pyroxene metasomatite and skarn. Deposit minerals in the zoned plutons are chromite, native PGE, various PGE minerals and alloys, and Ti-V magnetite, and accessory local pentlandite, pyrrhotite, bornite, and chalcopyrite. Deposit minerals generally occur in dunite in the top-central part of the pluton. Large (up to 3 kg and more) to small nuggets of platinum may occur in peripheral placer deposits. The depositional environment consists of zoned mafic to ultramafic plutons that form the lower parts of island-arc or continental margin arc systems.

I. Deposits Related to Mafic and Ultramafic Intrusions.

B. Deposits Associated with Ophiolitic Complexes

Podiform Chromite (J.M. Duke in Eckstrand, 1984; Albers, 1986)

This deposit type consists of pods or lenses of chromite in the ultramafic parts of ophiolite complexes (alpine peridotites) that may be locally intensely faulted and dismembered. Host rocks are mainly dunite and harzburgite that are commonly serpentinized, and local troctolite in some few areas. The principal ore mineral is chromite. Associated minerals are olivine, pyroxene, serpentine, magnetite, clinopyroxene, and plagioclase. Deposits generally consists 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 a number of individual pods that tend to occur in linear zones, in some cases, in an echelon fashion. The depositional environment consists of magmatic cumulates in elongate magma pockets along oceanic ridges or the basal parts of island arcs. Associated minerals are magnetite and PGE-minerals and alloys. Examples of the deposit type are at Ganbi, Japan, Hegenshan 3756, Inner Mongolia, China, Khalzan uul, Mongolia, and Sulinheer group, Mongolia.

Serpentinite-Hosted Asbestos (Cho and others, 1970; Zolojev, 1975; J.M. Duke in Eckstrand, 1984; Page, 1986b)

This deposit type consists of chrysotile asbestos developed in stockworks in serpentinized olivine-rich ultramafic rocks that consist mainly of harzburgite, dunite, wehrlite, and pyroxenite. Serpentinized ultramafic rock 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 allochtonous bodies of serpentinized ophiolitic or alpine ultramafic rocks in Phanerozoic orogenic belts. The depositional environment consists of ultramafic rocks that form the basal part of ophiolite sequences that are obducted onto a continental margin, or form part of an accretionary wedge or subduction zone complex. Examples of the deposit type are at Ikh nart, Mongolia, Molodezhnoye, Russia, and Sayanskoye, Russia.

I. Deposits Related to Mafic and Ultramafic Intrusions.

C. Deposits Associated with Anorthosite Complexes

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

This deposit type occurs 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 sometimes mangerite. The plutons generally intrude granulite-facies country rocks. Principal deposit minerals are apatite, titanomagnetite, and ilmenite that occur either as: (1) disseminations near melanocratic gabbro, pyroxenite, and dunite along the margins of the anorthosite plutons; or (2) rich apatite (nelsonite) veins that occur in tectonically weak zones. Associated minerals are lesser ilmenite and magnetite. The depositional environment is intrusion into the basal part of continental crust or craton under hot, dry conditions. Examples of the deposit type are at Gayumskoe, Maimakanskoe, and Dzhaninskoe, Russia.

I. Deposits Related to Mafic and Ultramafic Intrusions.

D. Deposits Associated with Kimberlite.

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

This deposit type consists of pipes and dikes made of kimberlite breccia. The deposits occur mostly near secondary branches of giant, deep, long, extension faults in stable craton (e.g., the Tanlu Fault Belt in eastern North China Platform). The pipes have rounded or elongated shapes with diameters of few hundred meters. In the North Asian Craton in the study area, kimberlite pipes range in age from Devonian through early Tertiary. Within a few hundred meters of the surface, the pipe is usually funnel-shaped, at deeper depths (down to about 1,500 m), is cylindrical, and at greater depths may have the shape of a feeder dike. The kimberlite dikes generally range from 0.3 to 0.7 m to 20 m wide, are 100 to 800 m long and several hundred meters long down dip. Kimberlites usually are concentrated in kimberlite fields generally less than 1 hectare in area, and from several kilometers to 20 kilometers apart. The kimberlite breccia consists of fragments of sedimentary cover rocks, including limestone, sandstone, shale, schist, granulite, and gneiss that from parts of Precambrian cratonal basement, as well as dunite, garnet lherzolite, garnet saxonite, picotite lherzolite, phlogopite, diamond–bearing ultramafic rocks eclogite, spinel and spinel–free ultramafic rock, and pyroxenite. The ultramafic and associated rocks are interpreted as mantle-derived. Inclusions of Phanerozoic sedimentary cover and craton basement rocks are abundant at margins of kimberlite pipes and dikes. Pipes and dikes usually also contain inclusions of mantle-derived minerals that range from 1 to 10 cm, 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 (up to 2 cm) 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, comprise the bulk of the kimberlite in both the upper and deeper parts of the pipe. Rare minerals are Cr diopside, picrotanite, morssanite, rutile, oysanite, and zircon. Kimberlite is intruded in hypabyssal conditions as indicated by typical massive structures and pseudomorph of coarse olivine crystals that are scattered in fine-grained matrix of phlogopite, serpentine, calcite, and perovskite. Only part of kimberlite pipes and dikes contain industrial diamond. Indicator minerals for diamond in kimberlite are Cr diopside and picotite, and associated diamond placer deposits. The depositional environment consists of kimberlite magma 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 craton. Subsequent younger uplift resulted in the erosion of the kimberlite and exposure of root systems, including pipes and dikes. Examples of the deposit type are at Ingashinskoye, Mir, and Yubileinaya, Russia.

II. Deposits Related to Intermediate and Felsic Intrusions. A. Pegmatite.

Muscovite Pegmatite (Sokolov, 1970; Chesnokov, 1975; Vasil'eva, 1983; Hongquan Yan, this study)

This deposit type consists 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 aluminum silicate rocks (e.g., biotite-muscovite granite gneiss, two-mica schist). Groups or fields of pegmatite veins may be hosted in hinge areas of anticlines and flexures in schist that are multiply deformed. The shape of deposits is diverse, and cross-cutting 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 mineral types are dominant. High-grade muscovite is typical in quartz masses that contain corroded feldspar crystals. The depositional environment consists of pegmatite fields in regional metamorphic and granitic belts that occur along the periphery of ancient cratons. A large number of muscovite pegmatite fields, some with REE, occur in some pegmatite belts and may extend for several hundred kilometers. Examples of the deposit type are at Chuyskoye, Lugovka, and Vitimskoye, Russia.

REE-Li Pegmatite (Lee, 1959; Kovalenko and Koval, 1984; Rundqvist, 1986; Kim, and Park, 1986; Zagorskiy and others, 1997; Lin and others, 1994a; S.M. Rodionov, this study; Ochir Gerel, this study; Hongquan Yan, this study)

This deposit type consists of two subtypes.

(1) The first subtype consists of REE spodumene granite pegmatite that is associated mainly with two-mica granite. Pegmatite deposits generally occur exocontact zones of granite intrusions, generally within 1 to 3 km of contacts and intrude metamorphosed carbonaceous and clastic rocks. Pegmatite bodies often clustered in elongated belts that occur along regional faults. Pegmatite veins often occur along feather joints. Two morphological types of pegmatite bodies are distinguished: (a) elongated and persistent veins and vein systems that occur at depth; and (b) 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 sulfide minerals, including pyrite, molybdenite, galena, and others. The principal ore element 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, China) consists of a large cupola-like body that is about 250 m long, 150 m thick, and 250 m high. From an outer graphic pegmatite to a central massive microcline-quartz pegmatite, the temperature of formation gradually decreased.

(2) The second subtype consists of REE pegmatite that is associated mainly with calc-alkaline, Li-F leucocratic granite. Three varieties of REE pegmatite are defined: (a) Li-mica pegmatite; (b) muscovite (muscovite-albite) pegmatite; and (c) muscovite-microcline pegmatite. The first two varieties are Ta-bearing, and the last contains cassiterite and wolframite. Li-mica pegmatite contains Ta-Nb minerals, cassiterite, Li-mica, quartz, albite, microcline, apatite, tourmaline, topaz, beryl, and other minerals. Muscovite-albite pegmatite contains columbite, tantalite, quartz, albite, microcline, and muscovite. Muscovite-microcline pegmatite includes cassiterite, wolframite, quartz, microcline, and muscovite. REE pegmatite deposits form dike-like or lenticular bodies that range from few meters to hundreds of meters long, and from 1 to 10 meters wide. Associated Li-Sn-Be pegmatite contains Li-mica, Ta and Sn-W minerals. The depositional environment is REE-Li pegmatite and associated granitic intrusions in post-accretionary intrusions that postdate the peak of batholith emplacement. Associated granite is mainly calc-alkaline and Li-F leucogranite and related, coeval volcanic and subvolcanic units. Examples of the deposit type are at Kelumute, Xinjiang, China, Keketuohai, Xinjiang, China, and Vishnyakovskoye, Russia.

II. Deposits Related to Intermediate and Felsic Intrusions. B. Greisen and Quartz Vein.

Fluorite Greisen (Govorov, 1977)

This deposit type consists of fine-grained, dark-violet rock composed of fluorite (from 63 to 66%) and micaceous minerals, mainly muscovite (25 to 35%), along with lesser ephesite and phlogopite. Subordinate minerals are (in decreasing order) tourmaline, sellaite, cassiterite, topaz, sulfide minerals, and quartz. Deposits generally occur in veins in gneiss (as on the Korean Peninsular) or in limestone or marble (as in the Khanka area, Russian Southeast). In the latter case, veins occur concordant to limestone layers, and form lenticular and flame-shaped bodies of apocarbonate greisen that occurs in limestone intruded by Li-F, S-type granite. Metasomatic rock replacing limestone occurs at, and above contacts with granitic intrusions. Muscovite-quartz pegmatite veins with molybdenite-cassiterite-diopside, vesuvianite- diopside -andradite, and scapolite skarn also occur near intrusive contacts, and are interpreted as having formed prior to formation of fluorite-mica greisen. Boron isotopic composition of tourmaline indicate 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 absence of paragenetic calcite suggest an extremely high activity of fluorine in silica-poor solutions. The depositional environment is thick clastic limestone sequences or carbonate gneiss in cratonal or continental margin terranes that are intruded by continental margin arc plutonic rocks. Examples of the deposit type are at Preobrazhenovskoye and Voznesenka-II, Russia.

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

This deposit type consists of disseminated cassiterite, cassiterite- and wolframite-bearing veinlets in stockworks, lenses, pipes, and breccia in granite that is altered to greisen. The granite is mainly biotite and (or) muscovite leucogranite emplaced in mesozonal to epizonal environments. Deposits usually associated with cupolas and domes of silicic and ultra-silicic, F-enriched rocks of late-stage, fractionated granitic magmas. Deposits usually consist of simple to complex quartz-cassiterite±wolframite and rare sulfide minerals 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, sheelite, rare molybdenite, beryl, and pyrite. Associated minerals are chalcopyrite, various Bi-minerals, and rare galena, stannite, and sphalerite. Mineralogical and metal zonation may occur on a small scale (within single veins or vein systems) and (or) on a larger scale (within the ore districts). An inner zone of cassiterite±wolframite is usually bordered by Pb, Zn, Cu, and Ag sulfide minerals. The depositional environment generally consists of mesozonal to epizonal (hypabyssal) silicic plutons that contain felsic dike swarms. Typical tectonic environment consists of zones of accreted terranes that are intruded late- to post-orogenic granitoids that ascended from deep-seated magmatic chambers. Examples of the deposit type are at Deputatskoye, Russia, and Mungon-Ondur and Tugalgatain nuruu, Mongolia.

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)

This deposit type consists of veins and stockworks of W, Mo-W and Be-Mo-W deposit minerals that occur within endo- and exocontact zones of multistage granitoid intrusions. Deposits generally occur in cupolas and domes of silicic and ultra-silicic granitic rocks. Deposits consist of elongated quartz veins and vein systems, stockworks, and greisen cupolas. Quartz-sheelite stockworks are common in exocontact zones. Disseminated wolframite and molybdenite occur in greisen, quartz veins, and veinlets. Other deposit 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 deposit type is sometimes associated with Sn-W vein and Sn greisen deposits. The depositional environment consists of tensional fractures in epizonal granitoid plutons that intrude sedimentary or metasedimentary rocks. Typical tectonic setting consists of anatectic granitic plutonic belts related to collisional zones and (or) interplate strike-slip-fault zones. Examples of the deposit type are at Lednikovy-Sarmaka, Ondortsagan, Mongolia, and Okunevskoye, Russia, and Tsunkheg, Mongolia.

II. Deposits related to intermediate and felsic intrusions. C. Alkaline metasomatite.

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

This deposit type consists 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. Deposits are composed of fine- and medium-grained quartz-albite-microcline rock. Ta-Ni minerals (e.g., columbite and pyrochlore), zircon, and thorite are widespread along with REE minerals. Columbite and zircon are of practical significance. REE minerals include gagarinite, yttrofluorite, monazite, bastnasite, and xenotime and are important as accessories. Mineral zonation of metasomatic bodies is characteristic. Complex multistage metasomatic processes, that occur in the apical part of the granite massive and rocks within shear zones, consist of microcline, albite, muscovite, and silica alterations. Relatively rich deposits occur in columns and lens-shaped planar bodies that extend to depths of hundreds of meters. This deposit type is a unique resource containing Ta, Ni, Zr, Hf, and Th along with Li, REE, and U. The depositional environment consists 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 the deposit type are at Katuginskoye, Russia, Khalzanburegtei, Mongolia, and Zashikhinskoe, Russia.

II. Deposits Related to Intermediate and felsic Intrusions. D. Skarn (Contact Metasomatic).

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

This deposit type consists of veinlet-disseminated and bunches of gold-sulfide deposit minerals that are superimposed on hydrothermally-altered calc-silicate and magnesium-silicate skarn. The various skarns replace carbonate rocks and coeval volcanic rocks along intrusive contacts with andesite stocks, diorite, granodiorite, granite, and granite porphyry. Deposits are usually small and irregular, but may persist at the depth. Deposit minerals are garnet, pyroxene, wollastonite, vesuvianite, magnetite, epidote, actinolite, quartz, pyrite, chalcopyrite, bornite, sphalerite, and native gold. Gold forms simultaneously or after deposition of sulfide minerals, sometimes in association with hydrothermal alteration that consists of epidote, chlorite, and silica. The depositional environment consists of contacts of calcareous-volcanic sequences intruded by gabbro-diorite-granitic complexes in continental margin or island-arc systems. Examples of the deposit type are at Boltoro, Mongolia, and Andryushkinskoe and Sinyukhinskoye, Russia.

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

This deposit type consists of danburite and datolite skarn associated with garnet-hedenbergite-wollastonite skarn. The B 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 deposit is 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, boron 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 B solutions was a deep-seated granitoid intrusion. The depositional environment consists of early formation of grossular-wollastonite skarn, followed by formation of thin-banded wollastonite aggregates with datolite, and danburite that occurred simultaneously with eruption of a postaccretionary ignimbrite sequence that overlies an accretionary wedge complex. The complex contains large limestone xenoliths with lateral dimensions of 0.5 by 2.0 km and a highly-deformed siltstone and sandstone matrix. The one example of this deposit type is the large Dalnegorsk boron mine in the Russia Southeast that constitutes the main source of boron in Russia.

Carbonate-Hosted Asbestos (Wrucke and Shride, 1986; Xujun Li, this study)

This deposit type occurs along contacts between mafic dikes and sills that intrude silicified carbonate rocks. The major rock types are serpentinite, diabase, gabbro, chert-bearing dolomite, and marl. The deposits are usually stratiform, lensoid, or irregular in shape and are concordant to host carbonate rocks. The industrial minerals are serpentine asbestos, massive serpentine, calcite, and dolomite. Varied and distinct metasomatic structures occur. Major alteration minerals are serpentinite, talc, tremolite, diopside, and carbonate. Alteration zoning is not apparent. The deposition environment is metasomatism associated with intrusion of mafic intrusions into impure carbonate rocks. The deposits may be of any age, but in the study area, the main deposit age is Mesoproterozoic. The tectonic environment is mafic plutons that form part of continental-margin arcs. The best example of the deposit type is at Chaoyang, Liaoning Province, China.

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

This deposit type forms 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, hedlyite, and bismuthine. Examples of the deposit type are at Karagem and Vladimirovskoye, Russia.

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

This deposit type consists of chalcopyrite, magnetite and pyrrhotite in calc-silicate skarn that replace carbonate rocks along intrusive contacts with plutons ranging in composition from quartz diorite to granite, and from diorite to syenite. Zn-Pb-rich skarn tends to occur farther from the intrusion whereas Cu- and Au-rich skarn tends to occur closer to the intrusion. 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 is mainly calcareous sedimentary sequences intruded by felsic to intermediate granitic plutons that form part of continental-margin arcs.

Examples of the deposit type are at Boltoro, Russia, Kamaishi, Japan, Khokhbulgiin khondii, Mongolia, Kuma, Russia, and Muromets, Russia.

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

This deposit type consists of dispersed magnetite in calc-silicate or magnesium-silicate skarn that replaces carbonate, tuffaceous-carbonate, or calcareous clastic rock near the contact of intrusive rocks that 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 magnesium-silicates, calc-silicates, albite, scapolite, chlorite, and amphibole. The depositional environment is metavolcanic and metasedimentary rock sequences including dolomite, dolostone, and rare limestone that are intruded by gabbro to granite in island arcs, continental marginal arcs, or rifted continental margins. Examples of the deposit type are at Abakanskoye, Beloretskoye, Inskoye, Lavrenovskoye, Tabratskoye, and Timofeevskoe, Russia, and Tomortei, Mongolia.

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

This deposit type consists of sphalerite and associated minerals in calcic skarn that typically occurs along the pre-intrusive tectonic-lithologic contacts between uplifted blocks of metamorphosed calcareous sedimentary rocks that are intruded by granitoids. The intrusive rocks are mainly K-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 intrusives display little or no alteration. Major deposit minerals are sphalerite and magnetite with lesser chalcopyrite, hematite, bismuthinite, molybdenite, pyrite, and galena. Gangue minerals are andradite-grossularite garnet, hedenbergite, magnetite, epidote, and feldspar. Typical and frequently-developed 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. Deposit typically exhibits four stages of mineralization: garnet- pyroxene skarn, andradite-magnetite aposkarn, sulfide, and quartz-carbonate. The depositional environment consists of metamorphosed calcareous rock sequences including dolomite, dolostone, and rare limestone that are intruded by granitoids in island or continental marginal arcs. Examples of the deposit type are at Khol khudag, Mongolia, Jinling, Shandong Province, China, Tumurte, Mongolia, and Tumurtiin-Ovoo, Mongolia.

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

This deposit type consists of Sn-, W-, and Be-minerals in skarn, vein, stockwork, and greisen near intrusive contacts between generally epizonal(?) granitic plutons and limestone. 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 consists of epizonal granitoid plutons that intrude calcareous sedimentary or metasedimentary rocks. Typical tectonic setting is back-arc granitoids forming in continental-margin arcs, or anatectic granitoids forming in collisional zones and (or) interplate strike-slip-fault zones. Examples of the deposit type are at Haobugao and Huanggan, Inner Mongolia, China.

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

This deposit type consists of metasomatic replacement of dolomite by mainly ludwigite and magnetite adjacent to granitoids. Ludwigite forms up to 80 percent of the deposit, and Sn occurs as an isomorphic admixture in ludwigite. Other minerals are magnetite, suanite (Mg_2B_5O), ascharite, kotoite, datolite, harkerite, monticellite, fluroborite, clinohumite, calcite, periclase, forsterite, diopside, vesuvianite, brucite, garnet, axinite, phlogopite, serpentine, spinel, and talc. The deposit consists of limestone that is metasomatically replaced by pyroxene-garnet-calcite skarn that is commonly altered to greisen to form Sn skarn. Magnesium and associated calcic skarn generally form near highly-irregular (convoluted) contacts of granite plutons, and in large xenoliths of carbonate rocks. The depositional environment consists of epizonal granitoid plutons that intrude calcareous sedimentary or metasedimentary rocks. Typical tectonic setting consists of back-arc granitoids forming in continental-margin arcs, or anatectic granitoids forming in collisional zones and (or) interplate strike-slip-fault zones. No noteable examples of this deposit type occur in the region.

W±Mo±Be Skarn (Beus, 1960; Kuznetsov and others, 1966; Cox, 1986j; S.M. Rodionov, this study)

This deposit type consists of scheelite and (or) sheelite-helvite in pure or altered (greisen or silica alteration) calc-silicate skarn that replaces carbonate rocks 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 mineralogical varieties of skarn exist: (1) sheelite skarn containing disseminated W minerals; (2) sheelite-helvite skarn with disseminated W and Be minerals. Skarn typically contains garnet, vesuvianite, pyroxene, epidote, actinolite fluorite, helvite, sheelite, beryl, quartz, muscovite, and rare sulfide minerals. Replacement of wall rocks consists of a wide variety of calc-silicate and related metasomatic minerals. Scheelite also occurs in quartz-topaz and quartz-mica greisen that is formed by replacement of skarn. The depositional environment is contact zones along the margins of granitic intrusions in continental-margin or island arcs, or adjacent to anatectic granitoids intruding into collisional zones. Examples of the deposit type are at Lermontovsky, Russia, Sangdong, South Kora, and Vostok-2, Russia.

Zn-Pb (±Ag, Cu, W) Skarn (Cox, 1986k; K.M. Dawson and D.F. Sangster in Eckstrand, 1984; Nokleberg, and others, 1997)

This deposit type consists of sphalerite and galena in calc-silicate skarn that replaces carbonate rock or impure calcareous sedimentary rock along intrusive contacts with plutons varying in composition from quartz diorite to granite, and from diorite to syenite. Zn-Pb-rich skarns tend to occur farther from the intrusion relative to Cu-, and Au-rich skarns. Deposit may occur at considerable distance from source granitic intrusion. Associated minerals are pyrite, chalcopyrite, hematite, magnetite, bornite, arsenopyrite, and pyrrhotite. 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. Deposits are rather narrow, but may extend downdip to 1 km depth. They may be controlled by ring faults around volcanic-tectonic depressions. The depositional environment is mainly calcareous sedimentary sequences intruded by felsic to intermediate granitic plutons in continental margin arcs. Examples of the deposit type are at Baiyinnuoer, Inner Mongolia, China, Huanren, Liaonig Province, China, Kamioka Tochibora, Japan, and Xiaoyingzi, Inner Mongolia, China.

II. Deposits Related to Intermediate and Felsic Intrusions. E. Porphyry and Granite Pluton-Hosted Deposits.

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

This deposit type consists of linear zones, veins, and stockworks with cassiterite, wolframite, sheelite, and various sulfide minerals in a gangue of quartz with siderophyllite, tourmaline, sericite, and chlorite. Deposit occurs in, or adjacent to hypabyssal multistage intrusive massifs (stocks and laccoliths), subvolcanic bodies that intrude sedimentary, volcanic or metamorphic rocks. Composition of associated intrusive rock varies from gabbro to diorite to granodiorite to granite. Deposit typically contains abundant simple and complicated 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. Deposit often contains stockwork minerals with the same composition as veins and zones. Deposit minerals are cassiterite, arsenopyrite, chalcopyrite, galena, sphalerite, pyrite, pyrrhotite, sheelite, wolframite, fluorite, native bismuth, argentite, native gold, bismuthine, and complex sulfosalt. Gangue minerals are quartz, tourmaline, sericite, and chlorite, and rare muscovite and feldspar. Typical alteration assemblages are quartz-tourmaline, quartz-siderophillite, quartz-sericite, and quartz-chlorite. High-sulfide deposits (cassiterite-sulfide) and low-sulfide (cassiterite-silicate) deposits may occur. Several stages of mineralization may occur along with horizontal zonation. The depositional environment consists of back-arc zones of continental-margin arcs. Examples of the deposit type are at Sherlovogorskoye and Ulakhan-Egelyakh, Russia.

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

This deposit type consists of disseminated uranium minerals, thorium minerals, 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. Deposit minerals include allanite, thorite, uraninite, bastnaesite, monazite, uranothorianite, and xenotime, sometimes with galena and fluorite. The depositional environment is mainly the margins of epizonal to mesozonal granitic plutons in back-arc zones of continental-margin arcs. Examples of the deposit type are at Chergilen, Diturskoe, and Neozhidannoye, Russia.

Granitoid-Related Au Vein (R.I. Thorpe, and J.M. Franklin in Eckstrand, 1984; Firsov, 1985; Cherezov and others, 1992)

This deposit type consists of fissure veins and veinlet-stockwork zones with disseminated gold and and sometimes sulfide minerals that occur generally in small, complex, granitic intrusions. Plutonic rocks consist mainly of calc-alkalic and sub-alkalic diorite, granodiorite, and granite. Deposits may consist of dissemination gold that occurs at apices of plutons, or in contact metamorphic aureoles. Deposit minerals are native gold, Au-bearing telluride and sulfide minerals, and associated quartz, tourmaline, muscovite, sericite, chlorite, feldspar, carbonate minerals, and fluorite. Disseminated sulfide minerals in wall rocks, especially arsenopyrite, are commonly enriched in Au and Ag. Alteration to berizite-listvenite is common with formation of quartz, sericite, tourmaline, and chlorite. The depositional environment is interpreted as epizonal plutons that intrude miogeoclinal sedimentary rocks that in some cases were regionally metamorphosed and deformed before intrusion. The plutons commonly occur in the back arc of a continental-margin arc. Deposits display a similar mineralogy and chemical environment and are often associated with polymetallic vein deposits containing disseminated Au-bearing sulfide minerals. Examples of the deposit type are at Boroo, Mongolia, Linglong, Shandong Province, China, Sanshandao, Shandong Province, China, Xincheng, Shandong Province, China, Tuanjiegou, and 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)

This deposit type consists of quartz-carbonate veins with base metal sulfide minerals and associated Ag-minerals and gold. Deposits are related to hypabyssal bodies that intrude volcanic, sedimentary, and metamorphic rock, including interbedded calcic siltstone, siliceous marble, and rhyolite. Intrusions range in composition from calc-alkaline to alkaline diorite to granodiorite, and 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 vary in form from stratiform or vein to lensoid. Deposits are locally very large and are concordant to the bedding of host rocks (e.g., Au-Ag polymetallic vein deposits in Jilin Province, China). Gold vein deposits are usually sulphide-poor (total sulphide content less than 5%), and generally occur in masses, disseminations, or veinlets. Deposit minerals are native silver, galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, arsenopyrite, argentite, Ag-sulfosalt minerals, native gold, and Cu- and Sn- sulfide minerals. 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 and 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 beresite (pyrite+sericite+carbonate) alterations. Silica alteration usually occurs adjacent to deposit minerals, and successive outward are are sericite and propylite alterations. Width of alteration zones ranges up to several tens to 100 meters. The depositional environment consists of zones of local domal uplift in continental margin arc and island-arc volcanic-plutonic belts. Examples of the deposit type are at Khartolgoi, Mongolia, Kuolanda, Russia, Lianhuashan, Inner Mongolia, China, Meng'entaolegai, Inner Mongolia, China, and Prognoz, Russia.

Porphyry Au (Fogelman, 1964, 1965; R.I. Thorpe and J.M. Franklin in Eckstrand, 1984; Gamyanin and Goryachev, 1990, 1991; Sillitoe, 1993b; Dejidmaa, 1996)

This deposit type consists of stockwork zones and disseminated gold and with local sulfide minerals that generally occur in simple to complex granitic intrusions, or in breccia pipes that are associated with volcanic-plutonic complexes. Related intrusive rocks are calc-alkalic and sub-alkalic granodiorite or granite. Breccia, if present, contains fragments of host rocks (flows, tuffs, granitoids, and sedimentary rocks), igneous breccias, and other hypabyssal and subvolcanic rocks. Deposit minerals are native gold, Au-bearing tellurides, and sulfide minerals. Accessory minerals are quartz, tourmaline, muscovite, sericite, chlorite, feldspar, carbonate minerals, and fluorite. Two mineralogical subtypes exist: (1) a low-sulfide subtype with chalcedony veins; and (2) a high-sulfide subtype with abundant disseminated sulfide minerals. Within breccia pipes, gold generally occurs in the cement (matrix) as disseminations or stringer-disseminations, along with disseminated sulfide minerals (pyrite, sphalerite, galena, arsenopyrite, and chalcopyrite). Disseminated sulfide minerals in wall rocks, especially arsenopyrite, are commonly enriched in Au and Ag. Host rocks exhibit chlorite, argillite, and quartz alteration. Advanced argillic alteration is widespread in shallow parts of deposits. Sericite alteration is typically minor. Stock and associated volcanic rock range in composition from low-K calc-alkalic through high-K calc-alkalic to K-alkalic. The deposit type is often associated with polymetallic vein Au, Au-Ag epithermal vein, and porphyry Cu deposits. The depositional environment consists of subduction-related continental margin or island arc with composite epizonal porphyry stocks that intrude coeval volcanic piles and adjacent passive continental-margin sedimentary rocks that in some cases were regionally metamorphosed and deformed before intrusion. Examples of the deposit type are at Ara-Ilinskoe, Russia, Delmachik, Russia, and Naozhi, Jilin Province, China.

Porphyry Cu (± Au) (Cox, 1986g; Sukhov and Rodionov, 1986; Evstrakhin, 1988; S.M. Rodionov, this study)

This deposit type consists 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. Chalcopyrite and bornite are the main deposit minerals, and associated minerals are magnetite, pyrite, rare native gold, electrum, sylvanite, and hessite. Rare PGE minerals may also occur. 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. Deposit mineral veinlets and mineralized fractures are closely spaced. Deposit generally exhibits a cylindrical or bell-shape that is centered on the volcanic-intrusive center. Highest-grade ore commonly occurs at the level where stock divides into branches. The depositional environment consists of subduction-related continental margin or island arc with porphyry stocks, dikes, and large-scale breccia intruding coeval volcanic rocks nearby volcanic center and adjacent passive continental-margin sedimentary rocks. Granitoids hosting deposit type tend to intrude in waning stage of volcanic cycle. Examples of the deposit type are at Khongoot, Mongolia, Oyu Tolgoi, Mongolia, and Xiaoxinancha, Jilin Province, China.

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

This deposit type consists 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 carbonate minerals. The deposit minerals are chalcopyrite, molybdenite, pyrite, sphalerite, Ag-rich galena, and gold. Alteration minerals are quartz, K-feldspar, sericite, and biotite or chlorite. Anhydrite occurs on deep levels of deposits. Most deposits exhibit varying amounts of hypogene alteration, including sodic, potassic, and phyllic alteration. Alteration zones, from inner to outward, are sodic-calcic, potassic, phyllic, and argillic to propylitic. Widespread, episodic development of abundant joints in intrusions and wall rocks is typical. The depositional environment is shallow, porphyry intrusions that are contemporaneous with abundant dikes, faults, and breccia pipes associated with andesite stratovolcanoes in back-arc regions of subduction-related continental-margin or island arcs. The granitoids are mainly moderately to strongly alkalic plutons. Examples of the deposit type are at Duobaoshan, Heilongjiang Province, China, Erdenetiin Ovoo, Mongolia, Tsagaan Suvarga, Mongolia, 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; S.M. Rodionov, this study)

This deposit type consists of quartz-molybdenite stockwork in felsic porphyries and adjacent country rock. The porphyries range in composition from granite-rhyolite, with >75% SiO_2, to tonalite, granodiorite, and monzogranite. Radial silicic dikes and small breccia pipes are common. Associated deposit minerals are pyrite, scheelite, and chalcopyrite, and rare cassiterite, wolframite, and tetrahedrite. Gangue minerals are quartz, K-feldspar, biotite, calcite, and white mica. Some deposits are high-F and have larger 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. Accordingly deposit mineralogy and tectonic setting, the deposit type is subdivided into two subtypes: (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. High-grade, F-rich deposits are also associated with intraplate alkaline igneous rocks. The depositional environment is shallow, epizonal porphyry intrusions in the back-arc regions of subduction-related, continental-margin arcs that are built on a thick continental crust. Examples of the deposit type are at Birandzha, Russia, Daheishan 2, Jilin Province, china, Melginskoye, Russia, Metrekskoye, Russia, Lanjiagou, Liaoning Province, China, and Zhirekenskoye, Russia.

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

This deposit type consists of mainly cassiterite and associated minerals in stockworks, veinlets, and disseminations that occur in complex, subvolcanic, multiphase granitic plutons, granitic porphyry or quartz porphyry stocks, subvolcanic and volcanic rhyolite breccias, and also in coeval volcanic rocks and surrounding clastic rocks. The composition of the subvolcanic host rocks varies from intermediate to silicic (quartz-latite, dacite, rhyodacite). Cogenetic volcanic rocks consist of calc-alkaline pyroclastic rock 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. The alterations are accompanied by quartz, tourmaline, sulfide minerals, and sericite. Deposit minerals are cassiterite, quartz, pyrrhotite, pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, stannite, wolframite, muscovite, sericite, chlorite, albite, adularia, siderite, rhodochrosite, calcite, topaz, fluorite, and sulfostannates, and Ag- and Bi-minerals. Alteration zones, from interior to periphery, are tourmaline (±adularia), phyllic, propylitic, and argillic. Some deposits exhibit a quartz-tourmaline core with a peripheral zone of sericite. Deposit type is often associated with Sn- and Ag-bearing polymetallic veins. The depositional environment is mainly shallow, subvolcanic stocks emplaced from 1 to 3 km beneath, or within vents of stratovolcanoes in the back-arc region of subduction-related continental-margin arcs. Examples of the deposit type are at 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)

This deposit type consists 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 a mafic complex intruded into crystalline basement. Thickness of the veins varies from a few centimeters to 30-40 m, and the length varies from a few meters to 500 m, rarely up to 1.5 km. Early-stage, apatite carbonatite contains apatite, carbonate (calcite, dolomite), K-feldspar, phlogopite, martite, and serpentine. Apatite occurs as large (up to 20 cm) acicular crystals with coarse cracks filled with breakdown products, including mica, serpentine, and martite. Intergrowths of martite, serpentine, and phlogopite; serpentine and martite that rim apatite grains are common. Apatite may also contain microcrystals of monazite. Late-stage carbonatite occurs as dikes and stocks intruding the early-stage carbonatites, and consist of dolomite, anhydrite, apatite, quartz, chlorite, minor barite and martite, and rare tourmaline, fluorite, sulfate-apatite. Typical are intergrowths of apatite and hematite, visually resembling jaspilite, that are replaced by apatite, martite, and carbonate. Apatite in late-stage carbonatite occurs as subparallel acicular crystals in a carbonate matrix, lacks coarse cracks, and intergrowths of martite, serpentine, phlogopite. Carbonate inclusions are insignificant. The depositional environment is interpreted as generation of alkalic mafic magmas during rifting of craton or cratonal terranes. An example of the deposit type is at Seligdar, Russia.

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

This type of deposit consists of magnetite, calcite, hematite, limonite, chalcopyrite, pyrite, siderite, rhodochrosite, apatite, REE minerals, fluorite, barite, and siderite. The deposit occurs in complicated feather joint 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 (e.g., Hongcheon mine, Korean Peninsula). Deposit minerals are siderite, barite, fluorite, hematite, magnetite, bastnaesite, parisite, REE minerals, and sulfide minerals. 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. Deposit minerals form complex mixtures of magnetite, monazite, apatite, and strontianite that occur in carbonate rock mostly composed of Fe-rich dolomite, ankerite, and siderite that contain anomalous P, Sr, Nb, La, Ce, Nd, Sm, and Ba. 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 carbonate host rock. Magnetite and monazite are often fractured by cataclastic deformation. Pyrite is a common sulfide in alteration zones. Deposit structures vary from breccia to massive to locally banded. High Fe deposit minerals are interpreted as forming during hydrothermal replacement of argillaceous sedimentary rock. The depositional environment is interpreted as generation of alkalic mafic magmas during rifting of craton or cratonal terranes. Examples of the deposit type are at Karasugskoye and Ulatayskoye, Russia.

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

This deposit type consists of ferrous carbonatite that is spatially and genetically related to circular alkali-ultramafic plutons. The plutons tend to occur adjacent to or near deep fault zones. Zoned plutons are characteristic and consist of dunite, pyroxenite, jacupirangite, melteigite, ijolite, urtite, nepheline syenite, and carbonatite. Two types of deposits occur: (1) perovskite-titanomagnetite deposits; and (2) apatite-magnetite deposits. Perovskite-tanomagnetite deposits consist of pyroxenite and dunite with disseminations, branches, lenses, and veinlets of deposit minerals. The main deposit minerals are titanomagnetite, perovskite, olivine, and pyroxene. Apatite-magnetite deposits consists of magnetite, apatite, baddeleite, pyrochlore, forsterite, calcite, dolomite, phlogopite, clinohumite, zircon, and Cu-Ni sulfide minerals. The deposits often occur in linear or ring-shaped veins, pipe-like bodies, and stockworks that are located in both the central and in peripheral parts of plutons. The depositional environment is interpreted as generation of alkalic mafic-ultramafic magmas during rifting of craton or cratonal terranes. Examples of the deposit type are at Esseiy 1, Gulinskoye 1, Iriaas 1, and Kugda 1, Russia.

Phlogopite Carbonatite (K.R. Dawson and K.L. Currie in Eckstrand, 1984; Epstein, 1994)

This deposit type consists of phlogopite bodies and disseminations hosted in alkalic ultramafic plutons. Phlogopite occurs in carbonatite in association with autoreactional skarns. Both endo- and exoskarns occur. Endoskarn consists of metasomatic ijolite and nepheline-pyroxene rock. 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. 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 is a carbonatite-alkali-ultramafic complex that intrudes along major faults during intra-craton rifting. The deposit type is associated with Fe-Ti carbonatite and REE-Ta-Nb carbonatite deposits. Examples of the deposit type are at Gulinskoye 3 and Odikhincha 1, Russia.

REE (±Ta, Nb, Fe) Carbonatite (Smirnov, 1969; Nevskiy and others, 1972; Samoilov and Kovalenko, 1983; K.R. Dawson and K.L. Curie, in Eckstrand, 1984; Sinyakov, 1988; Epstein, 1994; Kovalenko and Yarmolyuk, 1995; S.M. Rodionov, this study)

This deposit type consists of variable-size stockworks, metasomatic veins, breccias, columnar bodies, and lenses containing various REE, Ta-Nb, and Fe minerals in complexley-zoned alkalic ultramafic carbonatite complexes. The igneous complexes occur in: (1) zoned plug-like 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. Igneous complexes tend to cluster near major faults. The zoned carbonatite complexes and stocks generally 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, or syenite. The carbonatites generally consist of various assemblages of augite-diopside-calcite, forsterite-calcite, aegirine-dolomite, aegirine-ankerite, calcite, ankerite, and other minerals. Zonation consists of a central zone of carbonatite, a medial zone of ultramafic rocks, and a peripheral zone of ijolite and nepheline syenite. Zonation sequence may be locally reversed or complex. Igneous and nearby host rocks are usually intensively altered such that the distinction between igneous and country rock is obscure. Alteration assemblages include combination of pyroxene, feldspar, nepheline, alkaline amphibole, ankerite, calcite, siderite, magnetite, apatite, and bastnaesite. Deposit minerals occur in alkaline metasomatic rock and consist of pyrochlore, baddeleyite, perovskite, knopite, dysanalite, synshisite, bastnasite, parisite, zircon, monazite, columbite, apatite, yttrialite, melanocerite, yttrotitanite, hydrothorite, siderite, barite, strontianite, fluorite, hematite, magnetite, celestine, cerrusite, apatite, monazite, and sulfide minerals. REE also occur in siderite, barite, and fluorite. The depositional environment is interpreted as intrusion of alkalic mafic magma during rifting of craton or cratonal terrane. Examples of the deposit type are at Beloziminskoye, Gornoye Ozero, and Gulinskoye 2, Russia, and Mushgai hudag, Mongolia.

III. Deposits Related to Alkaline Intrusions. B. Alkaline-Silicic Intrusions Related Deposits.

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

This deposit type occurs in the alkaline igneous complexes and peripheral country rocks. The deposit type includes three varieties: (1) most common Au-bearing potassium and silica-altered rock; (2) more common Au quartz veins associated with potassium alteration envelope; and (3) less common Au quartz veins. Deposit minerals comprise less than 3 percent of the host rock and are mainly gold and pyrite with lesser magnetite, chalcopyrite, galena, altaite, and others. Gangue minerals are mainly quartz and lesser feldspar, sericite, chlorite, epidote, and others. Gold fineness ranges from 935 to 978. Wallrocks are altered to K-feldspar, silica, pyrite and sericite. The host alkaline igneous complex (e.g., 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 is interpreted as intrusion of alkalic mafic magma during rifting or strike-slip translation of craton or cratonal terrane. Examples of the deposit type are at Akalakhinskoye, Russia, Dongping, Hebei Province, China, and Hougou Chicheng, Hebei Province, China.

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

This deposit type consists of peralkaline granitic rock containing REE-Zr-Nb minerals. Deposit type generally occurs in apical parts of cupolas, and is generally associated 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, gittincite, zircon, pyrochlore, monazite, REE fluorcarbonate, polylitionite, and others. Alteration consists of replacement by epidote, orthoclase, and postmagmatic albite. 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 vein-like zones. Also occurring are fergussonite and zircon with HREE and Y. Accessory minerals are amphibole, magnetite, zircon, epidote, ilmenite, fluorite, beryl, chevkinite, pyrite, and galena. Associated with the deposit type are REE pegmatite and quartz-fluorite veins. The depositional environment is interpreted as intrusion of peralkaline granitic rock into miogeoclinal or island arc assemblages. Examples of the deposit type are at Baerzhe, Inner Mongolia and Ulaantolgoi, Mongolia.

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

This deposit type occurs in: (1) endocontacts of alkaline plutons composed of metasomatically-altered alkaline syenite (nordmarkite); and (2) volcanic peralkaline rock (comendite, pantellerite, peralkaline trachydacite, trachyrhyolite and trachybasalt) intruded by REE-albite nepheline syenite. Deposit minerals are various REE-Zr-Nb minerals. An example of the deposit type is at Maikhan Uul, Mongolia.

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

This deposit type is 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. The main deposit minerals contain Ta with Rb, Nb, Be, Li, and Sn. Plutonic ongonites is rich in Ta (up to 130 ppm, with average concentration of 88 ppm), and Li (average concentration of 2,780 ppm), and Rb (average concentration of 2,380 ppm). Volcanic ongonite (e.g., Teg Uul, Mongolia) contains less REE (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. Average concentrations in igneous rocks are 0.05 to 0.8 Li, 0.5 to 5.0% Zr, and 0.3 to 4.5% REE. High concentrations of Li, Be, Sn and Zn are characteristic. The Teg Uul occurrence, Mongolia, is large, covers over 1 km^2, and is composed of a tuff unit that ranges up to 10 to 20 m thick. Associated rocks are late Mesozoic rhyolite and ongorhyolite that occur in volcanic necks. Examples of the deposit type are at Ongon Khairkhan, Mongolia, and Ulkanskoe, Russia.

III. Deposits Related to Alkaline Intrusions. C. Alkaline-Gabbroic Intrusion-Related Deposits.

Charoite Metasomatite (Konev and others, 1996)

This deposit type consists of breccia-like, vein-like and stratified bodies of charoite that are hosted in the Archean and Proterozoic fenitized gneiss, quartz sandstone, and dolomite. Charoite is interpreted as forming in the final stage of intrusion of ultrapotassic alkaline syenite. However, varying interpretations exist about genesis. One interpretation is a metasomatic origin; the other interpretation is magmatism that resulted in charoite metasomatic replacement of host rock. Mineral composition is diverse and ranges from almost monomineral charoite, to complex mixtures of aegirine, pectolite, K-feldspar, quartz, tinaksite, fedorite, canasite, calcite, and others minerals. Up to 50 minerals are known in the type deposit. The rock morphology varies and consists of dense monoliths with shell-like fractures, pegmatoid, coarse-crystalline, schistose, and gneiss. Charoite color ranges 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 global example of the deposit type is at Murunskoe, Russia.

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

This deposit type consists of two subtypes: (1) magmatic deposits; and (2) metasomatic apatite deposits.

(1) The magmatic apatite deposit subtype occurs in sheeted plutonic or stratiform complexes with alternating, conformable lenses, plates, and dikes that are composed of coarse- and medium-grained alkaline gabbro, melanocratic alkaline gabbro, or alkaline-feldspar syenite. Apatite is concentrated in alkaline gabbro (average concentration of 4% 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 in lenses and nests with hornblende and titanium magnetite. Hornblende-feldspar pegmatite also occurs with numerous apatite inclusions. Host rocks for the intrusions are often gneissic granite and gneiss.

(2) The metasomatic apatite deposit subtype consists of large metasomatite zones in zoned plutons of alkaline nepheline syenite and pseudoleucite syenite with concentrations of up to 19% K_2O and 23% 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. Thickness of melanocratic metasomatite bodies varies from several meters, to dozens to hundreds of meters, and the length varies from dozens to hundreds of kilometers. Melanocratic metasomatite is enriched in Ca, Mg, Fe, P with a high apatite content of 3 to 10%. Apatite is unevenly distributed. Deposits rich in apatite consist of pyroxene, biotite, apatite, orthoclase, nepheline, plagioclase, magnetite (locally up to 10 to 20%), and sphene. Apatite content ranges from 5 to 10 to 80%. Apatite-rich areas with dimensions up to several dozens square meters occur in synnyrite that contains mainly apatite with lesser orthoclase, biotite, pyroxene, and magnetite. The depositional environment of both subtypes is interpreted as intrusion of alkaline syenite magma during rifting or strike-slip translation of craton or cratonal terrane. Examples of the deposit type are at Fanshan, Hebei Province, China, and Murunskoe, Oshurkovskoye, and Synnyrskoye, Russia.

Magmatic Graphite (Lobzova, R.V., 1975; Eremin, N.I., 1991)

This deposit type consists 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 that forms complicated xenoliths in 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 are feldspar, apatite, aegirine, and others. Examples of the deposit type are at Guangyi, Muling, HeilongJiang Province, China, Kureiskoye 2, Russia, and Yangbishan, Heilongiang Province, China.

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

This deposit type consists of high-grade nepheline minerals hosted in alkalic gabbro that intrudes orogenic zones and accreted terranes. Deposits and host intrusives occur along, or adjacent to major fault zones. Host rock for the ore-bearing intrusives is mainly carbonate and carbonaceous pyroclastic rock. Deposit minerals are urtite with up to 90% nepheline that occur in dikes and complicated alkalic gabbro plutons. Associated minerals are titanaugite and lesser apatite, aegirine-augite, titanomagnetite, and pyrrhotite. Examples of the deposit type are at Beltesin gol, Mongolia, Dahu-Nurskoye, Russia, and Kharlinskoye, Russia.

Deposits Related to Extrusive Rocks

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)

This deposit type consists of thin sheets of massive to well-laminated pyrite, pyrrhotite, chalcopyrite and sphalerite, and sulfide minerals. Lesser minerals are magnetite, galena, bornite, and tetrahedrite. Gangue minerals are quartz, carbonates, albite, white mica, and chlorite. Deposit occurs in thick sequences of clastic sedimentary rock and intercalated basalt. Basalt is volumetrically subordinate to sedimentary rock. Thinly laminated chert and black shale occur locally. Wall rocks may include sericite and chlorite schist, coticule, tourmalinite, and albitite lenses that commonly form stratabound bodies or envelopes around massive sulfide minerals, and may extend as much as five to ten 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. Wall rocks exhibit hydrothermal alteration and (or) chemical sedimentation that is coeval with deposition of massive sulfide minerals. Alteration is sometimes difficult to recognize because of subsequent metamorphism. Deposits typically consist of stratiform lenses and sheetlike accumulations of semi-massive to massive sulfide minerals. Footwall feeder zones may occur. Type example is the Besshi deposit in southwest Japan that occurs in the Sambagawa metamorphic terrane. The depositional environment is interpreted as submarine hot springs related to the deeper zones of submarine basaltic volcanism along spreading oceanic ridges or back-arc spreading centers, possibly in areas where a spreading oceanic ridge occurs near a continental margin that is supplying clastic detritus. Examples of the deposit type are at Besshi, Iimori, Kune, Makimine, Minenosawa, and Shimokawa, Japan.

Cyprus Cu-Zn Massive Sulfide (Singer, 1986b; J.W. Lidon, J.M. Franklin, and D.F. Sangster in Eckstrand, 1984)

This deposit type consists of massive sulfide minerals in submarine, predominantly mafic tholeiitic or calc-alkaline volcanic sequences that occur in ophiolite sequences or greenstone belts. Deposit minerals are mainly pyrite, chalcopyrite, sphalerite, and lesser marcasite and pyrrhotite. Sulfide minerals occur in pillow basalt that is 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. Sulfide minerals are sometimes 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 consists of submarine hot springs along an axial graben in oceanic or back-arc spreading ridges, or hot springs related to submarine volcanoes in seamounts. Examples of the deposit type are at Mainskoye, Russia, Nergui, Mongolia, and Okuki, Japan.

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

This deposit type consists of massive to disseminated sulfide Zn-Cu minerals that are hosted in island-arc volcanic belts. The volcanic rocks consist of bimodal rhyolite and basalt, andesite, dacite, and rhyolite with subordinate felsic rock. 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. Apophyses of massive sulfide minerals in lenses in footwall may grade downward into discordant stringers. Multilevel deposits are typical. Deposit minerals are mainly pyrite, chalcopyrite, and sphalerite with minor galena, tennantite, tetrahedrite, and bornite, and various other minerals. Gangue minerals are quartz, sericite, chlorite, and carbonate. Widespread alteration of volcanic and sedimentary host-rocks occurs. 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. Sulfide minerals are zoned with enrichment in Cu and Zn from footwall to hanging-wall and from core to periphery. Most deposit minerals are massive, but locally may be banded or brecciated, or may occur in stringers on the flanks of deposits. Development of thick gossan in weathering zones of deposits is typical. The depositional environment is an ensimatic island-arc constructed on oceanic crust containing differentiated basalt and other volcanic rock. The deposit type is a variant of Cyprus Cu-Zn massive sulfide deposit type. Examples of the deposit type are at Borts Uul, Mongolia, and Khariuzikhinskoye 1, Russia.

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

This deposit type consists of Zn-Pb-Cu massive sulfide minerals hosted in marine felsic to intermediate volcanic, pyroclastic, and bedded volcanic and sedimentary rock. The deposit consists typically of massive stratiform and stockwork parts. The massive stratiform part is typically oval-shaped in a plan view, and is underlain by a stockwork part. The stockwork part is typically funnel-shaped, usually occurs in silicified rhyolite, and is interpreted as a feeder zone for hydrothermal fluid. From stratigraphic bottom to top, the deposit is 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 deposit minerals are pyrite, sphalerite, galena, and 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 is quartz, sericite, and Mg chlorite alteration. Kuroko type deposits occur in the Hokuroku area, northeast Japan and formed in middle Miocene during back-arc rifting. The depositional environment consists of discharge of solutions from high temperature submarine hydrothermal systems onto, or near the sea floor along continental-margin or island arcs or back-arc basins. Discharge sites are fracture-controlled. An examples of the deposit type is at Khotoidokh, Russia.

IV. Deposits Related to Marine Extrusive Rocks. B. Volcanogenic-Sedimentary Deposits.

Volcanogenic-Hydrothermal-Sedimentary Pb-Zn, (±Cu) (Distanov, 1977; Distanov, Kovalev, Tarasova, and others, 1982; I.W. Lydon, and D.F. Sangster in Eckstrand, 1984)

This deposit type consists of massive to stratiform Pb-Zn sulfide deposits of hydrothermal-sedimentary origin that are hosted in basinal assemblages of clastic, volcanic, and carbonate rock that are intruded by shallow basaltic magmas. Sulfide minerals occur in basins in rhythmic, multistage sheets or layers that are hosted in tuffaceous, clastic, carbonate, and black shale. Deposits exhibit lateral and concentric zoning, massive to layered structures, and little or no wall rock hydrothermal alteration. The sulfide mineral aggregates are well laminated and consist of fine-grained quartz and sulfide minerals, or quartz, siderite, and sulfide minerals. Sulfide composition is Pb-Zn-rich with little or no Cu. Main deposit minerals are pyrite, sphalerite, and galena, with minor chalcopyrite arsenopyrite, tetrahedrite, burnonite, pyrrhotite, and others. Gangue minerals are quartz, siderite, calcite, and ankerite. Rhythmic layers are typical, and locally are widespread sedimentary sulfide breccia. Two groups of deposits occur, slightly metamorphosed (Ozernoje type), and highly metamorphosed (Kholodninskoje type). Metamorphism results in recrystallization and partially redistribution of deposit minerals and changes in textures and structures, but has no significant influence on scale of deposit. The depositional environments consist of either continental margin rifting or intra-island-arc basins. Deep-seated faults are interpreted as forming conduits for mafic magmatism and hydrothermal systems. Basinal depressions are a deposit control and also result in burial of deposits. Examples of the deposit type are at Kholodninskoye, Russia, Ozernoye 2, Russia, and Xiaoxilin, Heilongjiang Province, China.

Volcanogenic-Sedimentary Fe (G.A. Gross in Eckstrand, 1984; Sinyakov, 1988)

This deposits type consists of sheeted magnetite-hematite accumulations in volcanogenic and sedimentary sequences. Deposits are stratiform, and beds of iron formation are interlayered with volcanic rock, greywacke, and shale. Deposits occur from near to far from extrusive centers in submarine volcanic belts associated with deep fault systems and rift zones. The volcanic rock is mainly siliceous with lesser mafic rock, including rhyolite, siliceous porphyry, trachyrhyolite, trachyandesite, and basalt that are interlayered with pyroclastic, sedimentary, and siliceous exhalative rock and metamorphic analogs. The main deposit 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. Deposit minerals 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, and are interbedded with clastic sedimentary and volcanic strata. Two groups of deposits are distinguished: (1) unmetamorphosed hematite-magnetite; and (2) metamorphosed actinolite-magnetite. Metamorphic mineral assemblages reflect the mineralogy of primary sedimentary facies. Some studies of Fe skarn deposits in Altai-Sayan, Russia, and other regions suggest metamorphic derivation from volcanogenic-sedimentary Fe deposits. The depositional environment consists of eruption of siliceous with lesser mafic volcanic rock in fault-controlled marine basins associated with island arcs, back arcs, or rifts. Examples of the deposit type are at Belokitatskoye, Russia, Eloguiskoye, Russia, Gar, Russia, Kholzunskoye, Russia, Turukhanskoye, Russia, and Udorongovskoye, Russia.

Volcanogenic-Sedimentary Mn (Watanabe and others, 1970; Varentsov and Rakhmanov, 1978; Koski, 1986; M. Ogasawara, this study)

This deposit type consists of sheets and lenses of braunite, hausmannite, and rhodochrosite, and oxidized braunite that is intercalated with shale, chert, jasper, limestone, marine basalt flows, mafic tuff, spilite, and siliceous keratophyre. Host mafic volcanic rock differs from normal tholeiitic basalt in relatively higher content of K, Na, and Ti. Deposits generally occur in sequences with abundant chert and sedimentary rock, rather than in sequences dominated by volcanic rock. Deposits are often associated with volcanogenic Fe deposits, and sometimes contain complex oxidized ferromanganese minerals. Strong development of secondary Mn oxides (todorokite, psilomelane, amorphous MnO_2) is typical at the surface and along fractures. Japanese Mn deposits are mainly hosted in chert in a Jurassic accretionary-wedge complex and do not contain volcanic rock. However, a volcanogenic-sedimentary origin is interpreted (Watanabe and others, 1970). The depositional environment is interpreted as related to marginal basins associated with island arcs or young intraplate rift basins. Examples of the deposit type are at Bidzhanskoe (Kabalinskoe), Russia, Mazulskoye, Russia, Saihangol, Mongolia, and Usinskoye, Russia.

V. Deposits Related to Subaerial Extrusive Rocks.

A. Deposits Associated with Mafic Extrusive Rocks and Dike Complexes.

Ag-Sb Vein (Borisenko and others, 1992)

This deposit type consists of siderite and quartz-siderite veins and vein-systems with Ag-sulfosalt minerals that are hosted in carbonaceous clastic black-shale sequences that are often contact metamorphosed. The principal deposit minerals are Sb-, Cu-, Pb-, and Ag-sulfosalt minerals, including tetrahedrite, freibergite, schwatzite, chalcostibite, zinkenite, jamesonite, boulangerite; Bi-sulfosalt minerals, chalcopyrite, antimony, arsenopyrite, and pyrite. Main gangue minerals are siderite, quartz, calcite, ankerite, barite, and fluorite. Associated carbonate and argillic alteration may occur. The depositional environment is accumulation of black shale near fault-controlled basins and back-arc basins in interplate rift zones. The deposit type is commonly associated with Sb-Hg and Ni-Co-As epithermal deposits. Examples of the deposit type are at Asgat, Mongolia and Kyuchyus, Russia.

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

This deposit type consists of stratabound disseminated Cu minerals in basalt lava erupted into shallow coastal marine basins, and less onto subaerial oceanic volcanic islands. Volcanic rocks are generally interbedded with red sandstone, conglomerate, and siltstone. Basalt is generally potassic or alkalic, and may include shoshonite and trachybasalt. Major deposit minerals are native copper, chalcocite, bornite, chalcopyrite, and native silver. These minerals occur both in the matrix of, and as amygdules in the porous roofs of basalt flows, and in veinlets within the basalts. Deposit minerals occur as disseminations, stringers, lenses, and irregular patchy accumulations. Wallrocks are altered mainly to epidote, calcite, chlorite, and zeolite. The largest deposits tend to be concordant or peneconcordant, and occur along specific lithologies 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 fault breccias. The depositional environment consists of continental, rift-related, flood-basalt sequences, and continental-margin and island arcs. The deposit type is often associated with sediment-hosted Cu deposit type. Examples of the deposit type are at Arylakhskoye, Russia, and Zuunturuu gol, Mongolia.

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

This deposit type consists of small veins and stockworks of low-temperature, hydrothermal chalcedony-like quartz, and ferberite-scheelite, stibnite, and cinnabar. The deposit type occurs in Neoproterozoic and Paleozoic metamorphic rock (shale and quartzite) along major fractures or cross-cutting faults in schist. Commonly the deposits occur in platy stockwork with pseudostratification. Deposits occur far from intrusive bodies and are associated with deep faults that occur along edges of late Mesozoic intermountaine basins, or are associated with Late Cretaceous explosive extrusive siliceous volcanism.

Deposit minerals are ferberite and local stibnite, cinnabar, scheelite; pyrite, chalcopyrite, sphalerite, siderite, fluorite, and native sulfur, and lesser pyroluzite. Gangue minerals are chalcedony-like quartz, fine-grained quartz, and hydromica. The deposit types can be divided into subgroups of ferberite, stibnite, and cinnabar; and scheelite; and stibnite and ferberite mineral. Deposit textures are breccia, kidney-shaped, colloform, and banded. Scarce hydromica wall rock alteration may occur. Examples of the deposit type are at Ryushoden and Yamatosuigin, Japan.

Hydrothermal Iceland Spar (Kievlenko, 1974)

This deposit type consists of low temperature hydrothermal island spar that occurs in crystalline masses in traps in pillow basalt, amygdaloidal basalt, tuffaceous rock and subvolcanic dolerite. Iceland spar occurs in cavities; fractures, and fissures in basalt, dolerites, and in fractures in tuff. Associated minerals are zeolite, analcite, chalcedony, chlorite, montmorillonite, and hydromica. Alteration to chlorite and montmorillonite may occur. Examples of the deposit types are at Khrustalnoye and Skala Suslova, Russia.

Ni-Co Arsenide Vein (Borisenko and others, 1984; Krutov, 1978; R.J. Thorpe in Eckstrand, 1984)

This deposit type consists of carbonate and quartz-carbonate-chlorite veins containing Ni-Co arsenides and Cu, Bi, Ag sulfosalt minerals. Another name is five-metal arsenide (Ag-Co-Ni-Bi-U) ore association. The deposits occur along steeply-dipping vein and vein systems that occur along deep-seated faults and conjugate fractures, and are associated with basalt and alkalic basalt dikes. Host rocks are mainly siltstone, shale, schist, mafic and felsic volcanic rocks, and contact metamorphic rocks, and relatively older mafic and ultramafic granitoids. Deposit minerals are Ni-Co-Cu-Ag-Bi arsenides, sulfoarsenides, and sulfosalt minerals including skutterudite, smaltite, chloantite, safflorite, rammelsbergite, nickeline, gersdorfite, argentite, native silver, and others. Gangue minerals are dolomite, calcite, ankerite, quartz, barite, fluorite, and chlorite. The deposit type contains two subgroups: (1) Ni-Co arsenide; and (2) Cu-Co sulfoarsenide-sulfosalt. The first subgroup exhibits colloform and incrustate structures, and the second group exhibits disseminated and streaky-disseminated structures. Minor zones of talc-carbonate-chlorite alteration, and quartz-carbonate-hydromica metasomatic alteration occur in wall rock. The depositional environment consists hydrothermal fluids ascending deep faults and fractures in intraplate areas undergoing tectonic and magmatic reactivation. Examples of the deposit type are at Hovu-Aksinskoye, Russia, and Teht, Mongolia.

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

This deposit type consists of cinnabar and associated minerals along contacts of serpentinite and siltstone-graywacke, and limestone that occur in major thrust zones. Deposit mineral is mainly cinnabar, along with stibnite, pyrite, realgar, orpiment, arsenopyrite, sometimes 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 consists of zones of thrust faults containing lenses of serpentinite, ultramafic rock, and graywacke. Deposits generally occur in accretionary-wedge and subduction zone terranes in association with subduction-related thrust faults, and are often reactivated by younger interplate movement. Examples of the deposit type are at Chagan-Uzunskoye and Krasnogorskoye 1, Russia.

Trap-Related Fe skarn (Angara-Ilim type) (Mazurov and Bondarenko, 1997)

This deposit type consists of magnesian magnetite skarn formed during mafic trap magmatism. The deposit type occurs mainly in the North Asia (Siberian) Craton in connection with late Paleozoic and early Mesozoic tectonism and magmatism. Spatial distribution of deposits is controlled by deep basement faults, magmatic trap centers, and occurrence of dolomite and evaporate sequences in lower parts of the crust. The occurrence of evaporite and Ca-Na salt brines are important. Four types of deposits occur: (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. Main deposits occur in explosion pipes that extend to depths of 1,000 to 1,200 m. Calc-silicate and magnesium-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. Deposits contain halite, anhydrite, typical oolitic hematite, and magnetite that form lenses in massive and banded ore. The depositional environment consists of intrusion of trap-related mafic magma into evaporate horizons with brine. Examples of the deposit type are at Kapaevskoye, Korshunovskoe, Nerjundinskoye, and Rudnogorskoe, Russia.

V. Deposits Related to Subaerial Extrusive Rocks.

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; Rodionov and Khanchuk, 1997; Nokleberg and others, 1997; Yan and others, 2000; S.M. Rodionov, this study; M. Ogasawara, this study; Hongquan Yan, this study)

This deposit type consists of gently to steeply dipping quartz veins, stockworks, and disseminations that are hosted mainly in volcanic rocks. Associated igneous rock is commonly subaerial, calc-alkaline, volcanic rocks (andesite, dacite, and rhyolite). Also associated may be porphyritic shoshonite dikes or alkalic igneous rock in continental crustal sequences (thickness > 20 km) and in island arcs. Two main types of deposits occur - low sulfidation Au-Ag epithermal vein, and high sulfidation Au epithermal vein.

(1) Low sulfidation Au-Ag epithermal vein. This deposit type includes the Comstock Au, Creede, and Sado epithermal vein deposit types that 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 that grades into chalcedony, occurs in laminated and thin-banded colloform textures. Deposits are typically open-space filling veins. Hydrothermal alteration adjacent to veins consists of illite and smectite. Deposits formed from low sulfidation hydrothermal solutions with neutral pH.

(2) High sulfidation Au epithermal vein. This type 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 sulfosalt minerals, such as enargite and luzonite, and relatively high sulfidation tennantite characterizes this type. Replacements are also common. Gangue minerals are mainly quartz, alunite, kaolinite, pyrophyllite, diaspore, illite, and barite that also occur in peripheral alteration zones. Deposit is interpreted as forming from acidic and oxidized hydrothermal fluids. Closely-related deposit types are epithermal quartz-alunite Au, acid-sulfate gold, and enargite gold.

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

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

This deposit type consists of quartz-sulfide veins and mineralized zones in various rock types intruded by mafic dikes. Deposits extend along strike for several hundreds meters, and extend downdip to 300 m. Thickness of deposits ranges up to several tens of meters. Deposits consist of quartz-carbonate-sulfide and carbonate-sulfide types. Major deposit minerals are galena, arsenopyrite, stibnite, and Ag minerals, and subordinate chalcopyrite, sphalerite, cinnabar, and pyrite. Gangue minerals are quartz, siderite, chalcedony, kaolin, calcite, barite, and fluorite. Main wall rock alterations are quartz, chalcedony, kaolinite and chlorite. The deposit type exhibits three major stages: quartz-galena, quartz-fluorite, and quartz-carbonate. The depositional environment consists of intrusion of mafic dikes along active, deep-seated faults in areas of rifting of continental-margin arcs. Examples of the deposit type are at Boorch and Dulaan khar uul, Mongolia.

Au Potassium Metasomatite (Kuranakh type) (Kazarinov, 1967; M.B. Boradoevskaya and I.S. Rozhkov in Smirnov, 1974; Fredericksen, 1998; Fredericksen, Rodionov, and Berdnikov, 1999; S.M. Rodionov, this study)

This deposit type occurs along contacts between lamprophyre dikes with calcareous rock and sandstone adjacent to high-angle faults. Host rocks may be underlain by Precambrian metamorphic rock. Hydrothermal activity formed metasomatite and is 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. Deposits consist of several subhorizontal, blanket- or ribbon-like bodies up to several dozen meters thick. Bodies occur mainly along, and (or) locally above or below contacts between calcareous footwall rocks and overlying clastic rocks along narrow, long fault zones. Two types of metasomatite occur - 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 sulfide minerals constitute only a few percent of the total rock mass. Deposits are intensely oxidized and only traces of arsenopyrite and pyrite occur. Gold occurs primarily as grains less than 5 microns, usually in friable grains of porous goethite. Fluid inclusions studies indicate homogenization temperatures of 80° to 220°C and averaging from 110° to 160°C. Mineralization controlled by interplate rifting structures. In many cases, deposits are complicated by karst formation that resulted in formation of secondary rubble ore and surficial weathering of ore and gold. The depositional environment consists of intrusion of lamprophyre into passive continental margins during rifting. Examples of the deposit type are at Hadamengou, Inner Mongolia, China, Kuranakh, Russia, and Wulashan, Baotou City, Inner Mongolia, China.

Be Tuff (Kovalenko and Koval, 1984)

This deposit type consists of bedded and graded-bedded tuff with fragments of ongorhyolite, rhyolite, quartz, feldspar, fluorite, and Be-bearing bertrandite. Average Be content is about 0.05%. The main examples are at Durvent, Dorit Uu,l and Teg Uul, Mongolia. The depositional environment consists of extrusive centers rhyolite and ongorhyolite. Examples of the deposit type are at Dorvon Dert and Teg uul, Mongolia.

Barite Vein (Marinov, Khasin, and Khurts, 1977; Sodov Ariunbileg, this study)

This deposit type consists of quartz-barite and barite veins and veinlet in stockwork in quartz porphyry, diabase, porphyry, tuff, and biotite granite. The deposits often occur along contacts of volcanic and sedimentary rocks. This deposit type is commonly associated with fluorite deposits. Examples of the deposit type are at Bayan Khoshuu, Mongolia, Chapsordag, Russia, and Taptan-Turazy, Russia.

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

This deposit type consists 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 deposit minerals are arsenopyrite and pyrite with less abundant galena, sphalerite, marcasite, and chalcopyrite, and local gold. Main gangue minerals are quartz, calcite, and dolomite. Wall rock alteration consists of quartz, dolomite, ankerite, serpentine, chlorite, sericite, talc, and kaolinite. Deposits generally contain galena, and sphalerite. The depositional environment consists of intrusion of granite porphyry or lamprophyre into miogeoclinal sequences during continental collision. Examples of the deposit type are at Gurulevskoe and Oktjabrskoye, Russia.

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

This deposit type consists of co-crystallized quartz and fluorite metasomatite that occurs in sheets, mineralized fracture zones, or veins in layers in sequences of shale, limestone, and dolomite that form small xenoliths in granitoid plutons. 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 rock. Deposit layering is concordant with layering in host rock. Margin 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. Deposit is associated with hydrothermal veins that intrude a variety of aluminosilicate rock. The depositional environment consists of intrusion of granite into shale, limestone, and dolomite in continental-margin arcs. Examples of the deposit type are at Egitinskoye, Russia, and Urgen 2, Russia.

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

This deposit type consists of stratabound, lenses, and nests in dolomite-limestone breccia, and in layers in siliceous carbonate rock and jasperoid (silicified, dolomitized carbonate breccia) that are intercalated with clay and coal-clay shale. Sedimentary rocks are cut by dikes quartz porphyry, diabase, and lamprophyre. The calcareous host rock is subsequently altered to dolomite and brecciated during diagenesis and karst-formation. Other wall-rock alteration consists of jasperoid, and quartz and calcite veinlets. Mineralization is usually confined to thrust zones and is localized under impermeable clay layers. Clear boundaries do not ocir. Major ore minerals are cinnabar and stibnite, and lesser pyrite, marcasite, sphalerite, stibnite, realgar, and orpiment, and rare chalcopyrite, cassiterite, arsenopyrite, chalcostibite, kermezite, servantite, gold, schwatzite, aktaschite, galkhaite, and fluorite. The depositional environment is an epithermal system in deep-fault zones in passive continental shelf margins, and interplate rifts. Examples of the deposit type are at Aktashskoye and Kelyanskoye, Russia.

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

This deposit type consists of simple and complex ladder, and concordant carbonate-quartz and quartz veins and veinlets, and mineralized breccia. Host rocks are terrigenous and volcanic-terrigenous units in accretionary-wedge terranes, including flysch composed of siltstone, shale, sandstone, and conglomerate. Wall rocks are altered to quartz, carbonate, and pyrite, and rare argillite and sericite. Deposit minerals are cinnabar, pyrite, stibnite, arsenopyrite, and 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. 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 sometimes in thrust fault zones. In thrust fault zones, extensive alteration occurs, and zones generally contain vertical quartz-carbonate veins with high-grade Sb and moderate-grade Au. Deposit type may occur in linear fold belts with ladder and concordant carbonate-quartz veins with Au grade higher than Sb. Deposits are structurally controlled by fracture sets and feathering major faults, anticlines, and domes. Deposits usually contain several ore horizons that occur in saddle-shaped veins, and bodies. Associated igneous rocks are mainly rare alkalic basalt dikes. The depositional environment is interpreted as low-temperature hydrothermal fluids that originated in deep magmatic chambers. Examples of the deposit type are at Zagadka and Zvyozdochka, Russia.

Epithermal Quartz-Alunite (S.M. Rodionov, this study)

This deposit type occurs in volcanic cones, caldera ring fractures, and areas of igneous activity underlain by sedimentary evaporite. 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 rock. Early-stage, high temperature 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 propylitic alteration. Ammonium-bearing clay may occur. Deposit type is closely related to epithermal Au, porphyry Cu, and polymetallic volcanic-hosted metasomatite. An example of the deposit type is at Iskinskoe (Askum), Russia.

Fluorspar Vein (Ivanova, 1974; Bulnaev, 1976)

This deposit type consists of fluorspar in steeply-dipping veins and brecciated zones and less frequently of metasomatite in carbonate rock, granite, and volcanic, and volcanic-sedimentary sequences. Main mineral assemblages are quartz-fluorite, quartz-calcite-fluorite, barite-quartz-calcite-fluorite, and pyrite-marcasite-fluorite. Main deposit minerals are fluorspar and quartz. Varying associated minerals are barite, calcite, pyrite, marcasite, and clay. Argillic hydrothermal alteration is common in aluminosilicate host-rocks; silicification alteration is common in limestone. The depositional environment is flanks or inner parts of volcanic rift depressions. Deposit type is 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. Examples of the deposit type are at Anas, Berkh 1, Bujgar, Bilkh-Uul, and Chuluut tsagaan del, Mongolia, and Naranskoye, Russia.

Hydrothermal-Sedimentary Fluorite (Cheng, Gao, and Cao, 1994)

This deposit type consists of multi-layered fluorite and associate minerals that occur conformably in layered volcanic and sedimentary rock, including limestone, slate, rhyolite, and dacite. Deposit minerals occur in layers, bands, and breccia. Major deposit mineral is fluorite with minor clay and carbonate minerals. 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 is related to volcanism. The depositional environment consists of late Paleozoic volcanic island arcs. Examples of the deposit type are at Aobaotu and Sumochaganaobao, Inner Mongolia, China.

Limonite from Spring Water (Shiikawa, 1970; M. Ogasawara, this study)

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

Mn Vein (Mosier, 1986a)

This deposit type occurs as manganese minerals in epithermal veins that occur along faults and fractures in subaerial volcanic rock. Host rock is rhyolite, dacite, andesite, and basalt flows, tuffs, breccia, and agglomerate. Deposit minerals are rhodochrosite, manganocaloite, calcite, quartz, chalcedony, barite, and zeolite that occur in veins, masses, stringers, and disseminations. Kaolinite alteration is most common. Depositional environment is interpreted as penetrative fracture systems in volcanic centers in continental-margin arcs. Examples of the deposit type are at Inakuraishi, Jokoku, and Yakumo, Japan.

Polymetallic (Pb, Zn ± Cu, Ba, Ag, Au) Volcanic-Hosted Metasomatite (Distanov, 1977; Morris, 1986)

This deposit type consists of hydrothermal-metasomatic polymetallic sulfide minerals that occur in volcanic and sedimentary rock. Intensely-deformed and sheared rock forms most favorable replacement site. Deposits are complicated lenses and stockworks that contain massive, vein, and disseminated minerals. Host rocks are commonly felsic to mafic extrusive rock, tuff, and volcanic rock, 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, as well as silica and barite alterations. Aluminosilicate lithologies are more extensively altered. Deposit type is divided into barite-polymetallic, pyrite-polymetallic, and Cu-sulfide epigenetic subtypes. Early-stage pyrite and barite-sulfide-polymetallic, and late-stage quartz-carbonate-sulfide minerals are typical. Deposit minerals are mainly pyrite, sphalerite, galena, tennantite, tetrahedrite, and 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 fault zones in basement. Steep-fault zones locally are important. Deposit type is associated with small porphyry intrusions and mafic dikes. The depositional environment is active continental-margin arcs built on zones of accreted terranes. Examples of the deposit type are at Jiawula, Inner Mongolia, China, Sanmen, Jilin Province, China, Salairskoye, Russia, and Urskoye district, Russia.

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

This deposit type consists of hydrothermal-metasomatic polymetallic Pb-Zn minerals hosted mainly in limestone and dolomite. Deposits and districts are controlled by folds and fracture with major faults, companion fractures, and shear zones. Deposits are complicated and vary from layered, lenticular, and often vein, stock, or pipe-like bodies. Major assemblages are galena and sphalerite; boulangerite, galena, and arsenopyrite; and sphalerite and pyrite. Abundant pyrite and Pb-Sb sulfide minerals are typical. 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 consists of active continental-margin arcs built on carbonate sequences overlying continental crust. Examples of the deposit type are at Leiba, Lugovoye, and Vozdvizhenskoye, Russia.

Rhyolite-Hosted Sn (Reed and others, 1986)

This deposit type consists of cassiterite and wood tin that occur in discontinuous veinlets and stockworks, and in disseminations in rhyolite flow-dome complexes. Other deposit minerals are hematite, cristobalite, fluorite, tridymite, opal, chalcedony, adularia, and zeolite. Accessory minerals are topaz, fluorite, bixbyite, pseudobrookite, and beryl. Associated wall rock alteration minerals are mainly cristobalite, fluorite, smectite, kaolinite, and alunite. Host rhyolite commonly contains greater than 75% SiO_2 and is K-enriched. Controlling fracture and breccia zones occur in the most permeable, upper portions of flow-dome complexes. The depositional environment is felsic volcanism erupted onto continental crust. An example of the deposit type is at Dzhalinda, Russia.

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

This deposit type consists of three subtypes: (1) sublimation subtype consisting of surficial sulfur deposited from gas and solution; (2) sedimentary subtype consisting of lacustrine deposits formed in volcanic craters; and (3) replacement subtype, the most valuable subtype, consisting of replacement metasomatic sheets and irregular bodies in porous and fractured rock. All three subtypes are genetically and spatially associated with andesite. Deposit 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 are generally hydrothermally altered to opal, pyrite, alunite, and kaolinite. An example of the deposit type is at Kusatsu-Shirane district, Matsuo, and Shojingawa, Japan.

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

This deposit type consists of metasomatic listvenite-beresite zones with sulfide minerals. The zones occur in propylitically-altered trachyandesite and latite that are intruded by small stockworks and dikes of diorite porphyry, granodiorite porphyry, and granite porphyry. Zones extend up to several kilometers along strike with thicknesses up to several hundred meters. Zones exhibit gradational boundaries with host volcanic rock. Deposits occur in pipes, nests, lenses, veins, and echelon-like fractures. Both continuous veins and disseminations occur. Massive deposits are not abundant, but contain between 60 to 80% pyrite, galena, and sphalerite along with sulfosalt minerals, quartz, and dolomite. Textures range from massive, layered, densely disseminated, spotted, to colloform. Veinlets and disseminations form haloes around the massive deposit minerals, but generally form independent bodies with an irregular distribution of sulfide. The following assemblages are recognized: (1) tourmaline and pyrite, and local arsenopyrite, chalcopyrite, and gold; (2) pyrite, galena, and sphalerite with gold, quartz, and carbonates; (3) sulfosalt minerals (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 sulfide minerals. The depositional environment is intrusion of intermediate to siliceous granitoids into hypabyssal parts of collisional zones and extrusion of associated andesite and latite. Examples of the deposit type are at Bupyoung, South Korea, and Yixingzai, Fanshi, Shanxi Province, China.

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

This deposit type consists of disseminated and locaol masses of cinnabar in veinlets and breccia in layers, lenses, and irregular bodies. Deposit type is hosted in felsic, and lesser intermediate and mafic volcanic rocks, or along contacts between subvolcanic intrusive and volcanic rock. Other common deposit minerals are stibnite, pyrite, and marcasite, with subordinate or rare arsenopyrite, hematite, lead, Zn- and Cu-sulfide minerals, tetrahedrite, schwatzite, Ag sulfosalt minerals, gold, realgar, and native mercury. Gangue minerals are mainly quartz, chalcedony, hydromica, kaolinite, dickite, alunite, carbonate, chlorite, and solid bitumen. Deposit minerals may occur in multiple layers. Wallrocks may be altered to propylite and argillite with various combinations of quartz, sericite, kaolinite, and epidote. Mercury is deposited mainly during intense metasomatic replacement, and, to lesser extent, in open fissures and voids. The depositional environment is generally 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 of the deposit type are at Dogdo and Terligkhaiskoye, Russia, and Itomuka, Japan.

Volcanic-Hosted U (Bagby, 1986)

This deposit type consists of U minerals in pervasive fractures and breccias that occur along margins of shallow intrusives. Common deposit 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, potash trachyte, and peralkaline and peraluminous rhyolite. Host rocks are altered to kaolinite, montmorillonite, and alunite. Wall rocks are altered to silica and adularia. Deposits occur in subaerial to subaqueous, near-surface volcanic complexes that are associated with shallow intrusive rocks. The depositional environment consists of continental rifts and associated calderas. Examples of the deposit type are at Dornod and Gurvanbulag, Mongolia.

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

This deposit type consists of concordant beds and lenses of zeolite-altered tuff in epicontinental basins and lacusterine volcanic and sedimentary rock sequences. Deposits are formed by replacement of siliceous tuff, volcanic breccia composed of trachyrhyolite and trachydacite. Deposit minerals are clinoptilolite, and 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 are formed by isochemical alteration of porous vitric tuff permeated by low-temperature water with normal salinity and alkalinity. Zeolite beds are homogenous and zoned as a function of temperature gradient. The depositional environment consists of volcanic depressions in epicontinental volcanic belts or continental margin arcs. Examples of the deposit type are at Pezasskoye, Russia, and Tsagaantsav, Mongolia.

Deposits Related to Hydrothermal-Sedimentary Processes

VI. Stratiform and Stratabound Deposits.

Bedded Barite (Orris, 1986)

This deposit type consists of stratiform, massive, and nodular barite interbedded with marine chert and calcareous sedimentary rock, mainly dark chert, shale, mudstone, and dolomite. Deposit type often associated with sedimentary exhalative Zn-Pb massive sulfide deposits. Alteration consists of secondary barite veining and local, weak to moderate sericite replacement. Associated minerals are minor witherite, pyrite, galena, and sphalerite, quartz, and carbonate. The depositional environment consists of epicratonal marine basins or embayments, often with smaller local restricted basins. Examples of the deposit type are at Martyuhinskoye, Sorminskoye, and Tolcheinskoye, Russia.

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

This deposit type consists of stratabound, carbonate-hosted deposits of Pb- and Zn-sulfide minerals hosted in carbonate rock with both primary and secondary porosity that commonly formed on reefs on paleotopographic highs. Deposits are hosted mainly in dolomite and limestone, but are locally hosted in sandstone, conglomerate, and calcareous shale. Deposit minerals are mainly galena, sphalerite, pyrite, marcasite, dolomite, calcite, and barite, with minor chalcopyrite, siegenite, bornite, tennantite, bravoite, digenite, covellite, arsenopyrite, and other sulfide minerals. Alteration consists of regional dolomite alteration. Also common is disseminated secondary carbonate gangue that is occasionally massive and occurs in coarsely crystalline aggregates. Deposits are highly irregular in shape, stratiform or often discordant on deposit-scale, but stratabound on a district-scale. Deposit minerals occur mainly in open-space fillings in highly brecciated dolomite. Sphalerite commonly exhibits a colloform texture. Deposits commonly occur at the margins of clastic basins, generally in 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 consists of areas of shallow-water marine carbonate with prominent facies controlled by reefs growing on flanks of paleotopographic basement highs. Deposit type may be also associated with sedimentary-exhalative Pb-Zn deposits. Examples of the deposit type are at Chaihe, Liaoning Province, China, and Mayskoye 1 and Sardana, Russia.

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

This deposit type consists of stratabound, disseminated Cu sulfide minerals that occur in reduced red-bed sequences with green or gray shale, siltstone, and sandstone, thinly-laminated carbonate and evaporate beds, and local channel conglomerate. Main deposit minerals are chalcocite, bornite, chalcopyrite, pyrite, galena, and sphalerite, and lesser carrollite, Co-pyrite, betekhtinite, native Cu, Ag, and Ge minerals. Sulfide minerals are commonly zoned both vertically and laterally with the following type 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. Sulfide minerals may be weathered to malachite, azurite, chrysocolla, and atacamite. Secondary down-dip chalcocite enrichment is common. The genetic model is sedimentary concentration of deposit minerals in red-bed sequences with extraction of Cu from basement rocks or underlying sedimentary rocks by subsurface brines that are probably derived from evaporates, with transportation through oxidized-beds and precipitation in anoxic sediments. The depositional environment is epicontinental shallow-marine basins or intracontinental rifts along continental margin platforms. Examples of the deposit type are at Pravo-Ingamakitskoye, Sakinskoye, and Unkurskoye, Russia.

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

This deposit type consists of stratiform massive to disseminated sulfide minerals occurring in sheets or lenses that are conformable with host rock that consists of carbonate, clastic-carbonate, and siliceous-carbonate rock, including limestone and dolomite, and lesser marl, calcareous shale, siltstone, sandstone, and chert. Deposit minerals are mainly galena, sphalerite, pyrrhotite, pyrite, and Mg-Fe carbonate. Lesser minerals are various sulfide and sulfosalt minerals, barite, and fluorite. Deposit minerals are typically finely crystalline. Metamorphosed deposits are coarsely crystalline and massive. Deposit minerals occur in bands, laminae, masses, breccia, streaks, and disseminations. Sedimentary-exhalative silica-siderite and silica-ankerite-sideroplesite rock is associated with deposit layers, and diagenetic dolomite is also common. Common sites for deposition are interpreted as local synsedimentary depressions, synclines, and paleoslopes. Meager to no association of deposit minerals with volcanism exists in most areas. Minor volcanic rock, mainly tuff and breccia, occurs in host rock in some deposits. Extensive hydrothermal alteration may occur near vents, including stockwork and disseminated sulfide minerals, silica, albite, and chlorite. Hydrothermal activity is interpreted as associated with growth faults between major crustal blocks. The depositional environment is typically late Proterozoic to late Paleozoic carbonate-rich and fine-grained clastic sedimentary rock forming in shallow-water marine basins that are undergoing pericratonal platform subsidence along microcontinent margins. Examples of the deposit type are at Dongshengmiao, Inner Mongolia, China, Gorevskoye, Russia, Huogeqi, Inner Mongolia, China, Jiashengpan, Inner Mongolia, China, and Tanyaokou, Inner Mongolia, China.

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

This deposit type consists of Pb- and Zn-sulfide minerals in carbonate rock, mainly limestone and dolomite, and lesser marl. Deposit minerals are mainly pyrite, galena, sphalerite, fluorite, and magnetite. Deposit minerals occur mainly as lenses and beds conformable to bedding in host rocks. Magnetite also forms layers that are interbedded with sulfide minerals, fluorite, and carbonate minerals. Little to no hydrothermal alteration occurs; mainly diagenetic alteration occurs in carbonates and associated rocks. The deposit type is intermediate between the sedimentary exhalative Pb-Zn and carbonate-hosted Pb-Zn (Mississippi Valley) deposit types. Examples in the Russian Southeast are the Voznesenskoe and Chernyshevskoe mines. The depositional environment is typically Late Proterozoic to Early Paleozoic carbonate-rich sedimentary rocks in basins that overlap folded metamorphic complexes. Examples of the deposit type are at Huanggoushan, Jilin Province, China, Qingchengzi, Liaoning Province, China, and Voznesenka-I, Russia.

VII. Sedimentary Rock-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; Hongquan Yan, this study)

This deposit type consists of sheets and lenses of massive to disseminated Fe and Mn oxide and carbonate minerals that are hosted in sedimentary and clastic carbonate rock, including limestone and dolomite. Deposit minerals are magnetite, hematite, siderite, pyrolusite, hausmannite, braunite, and rhodochrosite (Ca-rhodochrosite, Fe-rhodochrosite, and others). Ore layers consist of sedimentary chert, quartzite, quartz-sericite-chlorite schist, and clastic carbonate rocks. According to mineralogy and Fe and Mn grade, the deposit type is divided into Fe, Fe-Mn, and Mn subtypes. Mn beds usually occur in the middle to upper parts of a progressive sequence that occurs in a transitional zone between clastic rocks and chemical precipitations. Some Mn beds may occur in the middle to lower parts of a retrogressive sequence. Mn-bearing carbonate usually occurs in shale or mudstone. However, some Mn carbonate occurs in sandstone and red shale. In the North China Platform, a group of B-Mn deposits belongs to the Mn subtype and is characterized by Mn-boracite. Deposit minerals are mainly Mn-boracite, rhodochrosite, Ca-rhodochrosite, and ankerite. In northeast China, a group of deposits is hosted in mudstone, dolostone, and dolomitic limestone that are part of the Mesoproterozoic Jixian System, and are named the Jixian type of B-Mn deposit. Also occurring are: (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) in 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 vanadium deposits that occur in the same stratigraphic level but without a regular spatial distribution. Associated with extensive phosphate deposits are also low-grade sedimentary Fe, Mn, and Al deposits. The depositional environment is interpreted formation of sheets and lenses of massive to disseminated Fe and Mn oxide and carbonate minerals in a shallow, epicontinental marine environment. Deposit type may be associated with sedimentary gypsum, and alunite, and rare barite and bauxite deposits. Examples of the deposit type are at Dongshiuchang, Tiejin Province, China, Pangjiapu, Hebei Province, China, and Wafangzi, Liaoning Province, China.

Evaporate Halite (Kleiner and others, 1977; Sodov Ariunbileg, this study)

This deposit type consists of halite that occurs mainly in Middle to Late Devonian reef limestone, dolomite, calcareous breccia, arkose, siltstone, diabase, agglomerate, and tuff. Deposit minerals are gypsum, halite, and anhydrite, with lesser carbonate, vanthoffite, and sylvinite. Deposits occur in beds and vary in thicknesses from 9 to 50 m. Halite is generally smoky, shiny pink, and coarse-grained. Thicknessof halite bearing units varies from 100 to 600 m, and they occur mainly in anticlines. Largest known deposits in the study area are Shuden-Uul and Davst-Uul in northern part of Mongolian Altay range. The deposit type is interpreted as forming during rifting of continental margin or along transform continental-margin boundaries. Examples of the deposit type are at Davst uul and Shuden uul, Mongolia.

Evaporate Sedimentary Gypsum (Kleiner and others, 1977; Yuan, Cao, and others, 1982; Ganbaatar, 1999; Sodov Ariunbileg, this study)

The deposit type occurs in evaporite carbonate sequences of supratidal (Sabkha) faces in enclosed to semi-enclosed sedimentary cover basins. Two main types of evaporite sequence occur, a carbonate sequence and a cataclastic sequence. Deposits are multiply-layered, and their shape varies from bedded to stratiform to lensoid. From the margins to the centers of a basin, thickness of deposits increases gradually. Major minerals are gypsum and anhydrite with lesser brongniartine, K- and Mg-halite, and native sulfur. Gangue minerals are calcite, dolomite, magnesite, native sulphur, clay, and minor halite, authigenic quartz, and chalcedony. Gypsum content ranges up to 98%. Deposits often exhibit idiomorphic, mosaic, and granular textures. Deposit minerals occur in masses, bands, beds, laminae, stockwork, breccia, and bioturbation zones. From margin to the center of a gypsum basin, usual facies are sandstone (conglomerate), mudstone, gypsum, halite, and K- and Mg-halite that occur in circular zones. Deposit-forming materials are derived from the weathering of surrounding rocks, dissolution of the ancient halite deposits, or from deep brines, volcanic hydrothermal fluids, or marine water. Local later alteration during diagenesis and dissolution may form gypsum veins. Deposit indicators include shallow-water deposition of mudstone and marl with mud cracks. On North China Platform, deposits are mainly hosted in a Cambrian and Late Ordovician epicontinental units. The depositional environment consists of intense evaporation of brine in enclosed or semi-enclosed subsiding basins in a dry climate. Examples of the deposit type are at Baruun Tserd, Mongolia andTaiyuan, Shanxi Province, China.

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

This deposit type consists of layered sedimentary bauxite hosted in carbonaceous and clastic rocks that form in marine or continental environments. Two subtypes exist. (1) A carbonaceous bauxite subtype occurs in neritic marine deposits along passive continental margins. Thick, rift-related carbonate rock with interformational stratigraphic breaks, and interlayered with thin (up to a few meters) bauxite horizons are characteristic. Metamorphosed equivalent consists of diaspore that forms at andalusite-sillimanite facies. And (2) a clastic bauxite 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. Thickness of deposits varies from tens to about 100 m. Deposits are generally flat-lying. Deposits may be linear or lens-shape, and may form in karsts underneath layered deposits. Examples of the deposit type are at Ke'er, Re'er, Shigong, and Xiaoyi, Shanxi Province, China.

Sedimentary Celestite (Yakovlev, 1986; Gunchin Dejidmaa, this study)

This deposit type consists of thin layers and concretions of celestite in sandstone and mudstone. Major ore mineral is celestite. The depositional environment is continental lacustrine sedimentary rock that forms in grabens in a late stage of continental rifting. Examples of the deposit type are at Dugshih hudag and Horgo uul, Mongolia.

Sedimentary Phosphate (V.L. Librovich, and L.M. Miznikova in Rundqvist, D.V., 1978; Mosier, 1986a, b; R.L. Christie in Eckstrand, 1984)

This deposit type consists of phosphorite in mainly clastic silica-carbonate and volcanic-silica-carbonate rock. Phosphate layers may be monomineralic. Major textures and structures are fine-grained laminations (locally aphanitic), oolitic, streaky-disseminated, and brecciated. Associated rocks are marl, shale, cherty limestone, and dolomite. Volcanic rocks may occur. The depositional environment is a marine sedimentary basin connected to open sea, and local upwelling zones that occur over continental shelf rock along passive or active continental margins. Examples of the deposit type are at Belkinskoye, Russia, Burenhan, Mongolia, Seibinskoye 2, Russia, and Hubsugul, Mongolia.

Sedimentary Fe-V (Oh and Hwang, 1968; Gross, in Eckstrand, O.R. (ed.), 1984; Sinyakov, 1988; Poznaikin and Shpilikov, 1990; Gunchin Dejidmaa, this study)

This deposit type consists 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 chert-carbonaceous shale with interlayered siliceous shale, carbonaceous and calcareous shale, mudstone, siltstone, and chert, and rare limestone. Chert horizons may contain sedimentary quartzite. Massive deposit beds commonly range from 2 to 25 to 30 m thick and are interbedded with shale, sandstone, and gritstone. Deposit minerals are mainly hematite, goethite, siderite, and chamosite. Associated minerals are calcite, ankerite, various clay minerals, clastic quartz, pyrite, and phosphatic fossil debris. Distribution of Fe in ore beds is irregular and varies from 20 to 45%. Deposits are high in P_2O_5 and V_2O_5. V grade ranges from 0.01% to 1.0%. Depositional environment consists of deposition of ironstone is neritic basins, lagoons, and estuaries in oxygenated to euxinic conditions. Examples of the deposit type are at Kolpashevskoye, Russia, and Hitagiin gol, Mongolia.

Sedimentary Siderite Fe (V.E. Popov and J.G. Staritskiy in Rundqvist, 1986)

This deposit type consists of layers and lenses of siderite in upper part of a coal series. Deposit is hosted in sandstone and argillite with siderite oolites and concretions. Siderite content ranges up to 80 to 90%. Associated minerals in matrix are chlorite, hydromica, quartz, and feldspar. Thickness of ore layers ranges from 0.1 to 2 m. Deposit type is of little economic importance. Examples of the deposit type are at Barandatskoye, Ishimbinskoye, Nizhne-Angarskoye, and Parabel-Chuzikskoye, Russia.

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

This deposit type consists of hydrozircon and baddeleyite in lenses and veins that occur mainly in a layer of cavernous dolomite marble up to 40 m thick. The ore occurs as breccia composed of fragments of metamorphic quartz and dolomite cemented by an aggregate of hydrozircon and baddeleyite. 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 of this type occurs in the northern part of the Khabarovsk province and is hosted mainly in subhorizontal dolomite marble that, along with other miogeoclinal sedimentary rock, constitute the Neoproterozoic and early Paleozoic sedimentary cover of the Stanovoy block of the North Asian Craton. The origin of the deposit is speculative. According to B. Zalischak (written commun., 1992) the deposit formed by discharge of hydrothermal solution along a layer of porous dolomite. A sudden pressure fall resulted in a blast. An U-Pb isotopic age of about 100 Ma was obtained for hydrozircon (J.N. Aleinikoff, written commun., 1993). An example of the deposit type is at Algama, Russia.

VIII. Polygenic Carbonate-Hosted Deposits.

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

The only typical example of this deposit model is the Bayan-Obo superlarge REE-Fe-Nb deposit in China that contains reserves of up 70 percent of the world's REE resource. Deposit occurs in the Mesoproterozoic clastic and Mg-carbonate rock. Deposit consists of layered to lenticular bodies that are generally concordant with host dolomite marble. Deposit contains about 170 minerals, including 60 Nb-, REE-, Ti-, Th-, Fe-minerals. Principal Fe minerals are hematite, magnetite, and siderite. Principal Nb-Ta minerals are niobite, aeschynite, fersmite, and pyrochlore. Principal REE minerals are monazite, parisite, huangheite, cerapatite, and others. Deposit is subdivided into Nb-REE-Fe subtype A, and Nb-REE subtype B. Subtype A is divided into massive ore, banded ore, vein-disseminated ore (aegirine type), disseminated and laminated ore (riebeckite type), massive and disseminated ore (biotite and dolomite types). Subtype B is divided into disseminated muscovite, aegirine, and diopside rich areas. Deposit consists of several blocks. A northern block contains abundant ferrous minerals. Others blocks contain abundant REE minerals with lesser ferrous minerals. Other blocks contain both ferrous and REE minerals. 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) describes Rb-Sr and Sm-Nd isotopic composition and Nb/Ta ratios that indicate that REE and Nb are mantle derived. The current controversy is about the timing and the mechanism of ore formation. Some studies suggest a relation to carbonatite magma (Bai, 1996). 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 rock, and deposit 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) interprets a Mesoproterozoic sedimentary-exhalative event in which metasomatic activity, diagenesis, and alteration of dolomite were synchronous, and were subsequently enriched during Caledonian deformation. The general interpretation is that the deposit formed in a rift zone along north edge of North China Craton.

Another example of this deposit type is at Yangyang, Korea that consists of magnetite in a polymetamorphosed contact deposit. The deposit is hosted in Precambrian biotite gneiss and a younger syenite intrusion. The west part of the syenite contains many lenticular xenoliths of calc-silicate rock, tactite, and amphibolite formed from metasomatized impure limestone. Magnetite occurs in syenite and is closely associated with tactite or amphibolite and occurs in lenticular masses locally in syenite as xenoliths, or is intruded by the syenite dikes. Deposit mineral is mainly magnetite that occurs in masses, plates, or brittle zones, and gangue minerals, including hornblende, epidote, and biotite. This deposit is interpreted as a polymetamorphosed contact deposit in which a primary contact-metasomatic magnetite was intruded by syenite.

Deposits Related to Metamorphic Processes

IX. Sedimentary-Metamorphic Deposits.

Banded Iron Formation (BIF, Algoma Fe) (Cannon, 1986; Zhang and others, 1984;Yan, 1985; Zhang and others, 1985, Hongquan Yan, this study)

This deposit type consists of Fe minerals hosted mainly in Archean ferrous quartzite beds and Fe-rich mafic to felsic volcanic, volcanoclastic, and clastic rock. Deposit type is typically layered on a centimeter scale with quartzite interlayered with Fe-rich beds. Deposit may be metamorphosed to varying degrees. At lower metamorphic grade, the 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, deposit minerals coarsen, and Fe grade increases. At granulite facies the deposit consists of magnetite, quartz, hypersthene, diopside, amphibole, ilmenite, plagioclase, garnet, and biotite. Deposit type is widespread in Early Precambrian basement of the Sino-Korean Craton and is a major source of iron in North China. Local enrichment associated with regional metamorphism or contact metamorphism associated with granitoid intrusion. Compared with the Superior deposit type, this deposit type is interpreted as forming in tectonically mobile marine volcanic belts that occur in small volcanic-sedimentary basins. Some Fe deposits are spatially associated with Zn-Cu volcanogenic massive sulphide, Homestake gold, and Au in shear zone and quartz veins deposits. Examples of the deposit type are at Nanfen, Liaoning Province, Sijiaying, Hebei Province, Gongchangling, Anshan, Liaoning Province, Shanyangping, Daixian County, Shanxi Province, and Yangchaoping, Daixian County, Shanxi Province, China.

Banded Iron Formation (BIF, Superior Fe) (Cannon, 1986; G.A. Gross in Eckstrand, 1984; Sinyakov, 1988)

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

Homestake Au (Berger, 1985b; Xujun Li, this study)

This deposit type is hosted mainly in metamorphosed banded iron formation. Deposit usually occurs in thin laminations, concordant lenses, or veins in Fe-rich, siliceous, and carbonate rock. Main deposit minerals are native gold, pyrite, pyrrhotite, arsenopyrite, magnetite, sphalerite, and chalcopyrite, along with local tetrahedrite, scheelite, wolframite, molybdenite, fluorite, and actinolite. Banded iron oxides are frequently replaced by pyrite and pyrrhotite. Main alterations are chlorite and tourmaline. Associated deposits are Kuroko type massive sulphide, Algoma type Fe and low sulphide Au quartz vein deposits. Genesis is debated, but deposit type is frequently interpreted as forming during marine volcanism or during late-stage hydrothermal activity. An example of the deposit type is at Dongfengshan, Heilongjiang Province, China.

Sedimentary-Metamorphic Borate (Peng and others, 1993)

Deposit type is divided into metasedimentary and hydrothermal subtypes. Metasedimentary subtype A is conformably hosted in the stratiform Mg carbonates (mainly magnesite) with suanite ($Mg_2[B_2O_5]$) as the main ore mineral, along with magnesite. Hydrothermal subtype B 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 subtype B that is Fe rich. Both subtypes A and B, especially the latter, may be altered with replacement of forsterite by serpentinite, phlogopite, and other minerals, and alteration of suanite to szaibelyite ($Mg_2[B_2O_4](OH)OH$). Hydrothermal alteration is closely associated with the intrusion of granitic rock and pegmatite. B deposits in eastern Liaoning, northeastern China are hosted in amphibolite facies Paleoproterozoic volcanic-sedimentary sequences that contain tourmaline, albite, and microcline and exhibit a spatial distribution suggesting an evaporite rift-related genesis. Examples of the deposit type are at Wengquangou, Liaoning Province, China, and Zhuanmiao, Liaoning Province, China.

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

This deposit type consists of magnesite that occurs in beds ranging from 200 to 2,000 m long and 30 to 300 m wide. Deposit type is hosted mainly in Paleoproterozoic carbonate rock, and generally in dolomite marble. Deposit contains sedimentary textures, including ripple marks, and mud cracks, and local metasomatic textures. Deposit minerals are mainly massive with lesser banding. The major mineral is medium- to coarse-grained magnesite, and minor talc, tremolite, dolomite, and chlorite, and rare calcite, Fe-dolomite, rhodochrosite, Fe-magnesite, siderite, garnet, pyrite, serpentinite, sphalerite, chalcopyrite, magnetite, apatite, and hematite. MgO content of magnesite ranges up to 47%. The depositional environment is Paleoproterozoic rift in a littoral, shallow sea sedimentary environment. Subsequent lower greenschist to amphibolite facies metamorphism and intensive deformation may occur, resulting in recrystallization of deposit minerals, crystallization of siderite, and formation of lenticular metasomatic deposits. Examples of the deposit type are at Xiafangshen and Xiaoshengshuisi, Liaoning Province, China, and Biderin gol, Mongolia.

X. Deposits Related to Regionally Metamorphosed Rocks.

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

This type of deposit consists 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 gold content is in horizons and lenses of carbonaceous shale. Quartz-gold veins occur in upper horizons as relatively thin bodies that pinch out downdip. Deposit minerals constitute a low-sulfide quartz assemblage and are mainly pyrite and arsenopyrite, and scarce sphalerite, galena, and chalcopyrite. Rare PGE minerals may occur. Peripheral haloes, that are low in gold, contain disseminated pyrite and arsenopyrite. Deposits are polygenic and polychronous. Gold initially accumulated during deposition of host rock, and was redistributed and concentrated during dynamic metamorphism and infiltration of ore-bearing fluid. Examples of the deposit type are at Mangazeika 2, Olympiada, and Sukhoy Log, Russia.

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

This deposit type includes low-sulfide Au quartz vein, turbidite-hosted, concordant vein, and shear zone Au deposits. The deposit type consists 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 sulfosalt minerals. Alteration minerals include quartz, siderite, albite, and carbonate minerals. The depositional environment consists of low-grade metamorphic belts associated with continental margin arcs or collisional (anatectic) zones, or along transform continental margins. Examples of the deposit type are at Jiapigou, Jilin Province, China, Jinchangyu, Hebei Province, China, Nezhdaninka, Russia, Paishanlou, and Liaoning Province, China.

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

This deposit type consists of stibnite and associated minerals that occur in simple, lenticular, and ladder veins, and in reticulate veins and veinlets, sometimes with subconformable disseminations. Main deposit minerals are stibnite, berthierite, pyrite, arsenopyrite, and gold, with subordinate sphalerite, galena, chalcopyrite, tetrahedrite, chalcostibite, scheelite, pyrrhotite, marcasite, gudmundite, gersdorffite, native antimony, and native silver. Gangue minerals are mainly quartz and lesser ankerite, calcite, dolomite, siderite, donbassite, sericite, and gypsum. Wall rocks are altered to varying combinations of quartz, carbonate, sericite, and pyrite. The host rocks for these deposits are: (1) Proterozoic and Paleozoic greenschist derived from mafic volcanic and volcanic-clastic rock; (2) interbedded carbonaceous black shale and volcaniclastic rock; (3) or to a lesser extent, retrogressively-metamorphosed granitic rock. The depositional environment is strongly deformed fold belts developed along intracratonic rift troughs or reactivated pericratonic platform subsidence in a passive continental margin. Deposit type is controlled by linear zones of folds and mylonites that are associated with regional strike-slip faults. Deposits 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 the deposit type are at Sentachan, Russia, and Ichinokawa, Japan.

Cu-Ag Vein (Nokleberg and others, 1997; Gunchin Dejidmaa, this study)

This deposit type consists mostly of Cu-sulfide minerals and accessory Ag minerals in quartz vein and stringers hosted in either weakly, regionally metamorphosed basalt, andesite-basalt, or clastic sedimentary rock. The deposit type may also occur in structural slices of ultramafic rock that occur along regional faults in clastic sedimentary rocks. The occurrences are found in lower grade, metamorphosed mafic volcanic rock, and consist mainly of widespread zones of sulfide-bearing quartz veins. Cu-Ag quartz vein occurrences occur widely in the western part of Mongolia (Obolenskiy and others, 1989). Well-developed Cu-sulfide quartz stringers and veins may occur. Deposit 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) occurrence of deposit minerals in impregnations, stringers, layers, and rare breccia; and (3) local high grades of Ag, Au, and Zn. In the study area, many occurrences are in Middle Riphean mafic volcanic rock, Vendian to Lower Cambrian, and Ordovician-Silurian Biji units. The depositional environment consists of low-grade metamorphic belts containing mafic volcanic or clastic sedimentary rock in continental margin arcs or collisional (anatectic) zones. Veins are generally late-stage metamorphic. Examples of the deposit type are at Goseong and Yanggudong, South Korea.

Piezoquartz (Arkhipov, 1979)

This deposit type occurs in Precambrian quartzite associated with high-alumina gneiss and mafic schist. The rock crystal deposits tend to occur at rupture intersections in flexures and periclines of folds, and form single veins (from 0.5 to 2 m thick and 20 to 30 m long) and vein zones (from 1 to 30 m thick with an average of 5 to 15 m thick, from a few tens of meters to 400 m long with an average of 100 to 200 m). Most deposits occur in pipes, veins, and stockworks with diameters of a few tens of meters. Veins consist of rock crystal or smoky quartz, clay filling voids, K-feldspar, and rare crystals of hematite, chlorite, sericite, tourmaline, albite, epidote, and adularia. Rock crystals occur on the walls of the voids or in the lower parts of voids amidst clay. Voids occur inside quartz veins, at the contacts of veins and host rock, or in host rock adjacent to veins. Host rock is altered to sericite, chlorite, and epidote. Examples of the deposit type are at Bugarykta and Perekatnoe, Russia.

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

This deposit type consists of rhodusite-asbestos and nonfibrous rhodusite in layers of mottled rock sequences with salt and gypsum. The mottled rocks consist of rhythmic layers of marl, argillite, siltstone, and sandstone. Argillite predominates. Thickness of deposits ranges up to tens of meters. Rhodusite-asbestos and nonfibrous rhodusite also occur in veinlets and disseminations. The deposit is interpreted as forming during epigenetic replacement of red-bed clastic rock and mottled host rock during initial metamorphism. The depositional environment is intermountain depressions in arid areas with high salinity water in sedimentary basins. An example of the deposit type is at Azkizskoye, Russia.

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

This deposit type consists of metasomatic talc that replaces ultramafic and Mg-bearing sedimentary and magmatic rock during regional or contact metamorphism. One group of deposits consists of ultramafic rock, mainly dunite and harzburgite, that contain ferrous-talc and talc-chlorite. Deposits occur in veins, stocks, and lenses, and consist of metasomatic ferrous talc, talc-breunnerite, and talc-chlorite. Another group of deposits consists of low-ferrous talc minerals formed in dolomitic carbonaceous rock. This group consists of: (1) deposits associated with regional metamorphism with steatite, talc-schist, and talc-carbonate rock; and (2) deposits of talc, carbonate, and tremolite that are associated with contact metamorphism and related granitoid intrusions. Wall rocks are dolomite, interlayered dolomitic limestone and aluminosilicate rock (slate, amphibolite, quartzite). Deposits are bedded and generally large. Surficial processes result in formation of weathering crust with high-quality, powdery, low-ferrous talc. This deposit type is commonly associated with magnesite, marshallite and karst-bauxite deposits. Major deposit control is ultramafic host rock that is regionally metamorphosed to greenstone facies and intensely intruded by granitoids. The depositional environment consists of dolomitic rock and ultramafic rock in orogenic belts along continental margin arcs and collisional zones, and pericratonal subsidences. Examples of the deposit type are at Alguiskoye, Russia, Fanjiapuzi, Liaoning Province, China, Savinskoe, Russia, Svetlyi Klyuch, Russia, and Togulenskoye, Russia.

Metamorphic Graphite (Lee, 1960; Eremin, 1991)

This deposit type consists of two subtypes: (1) deposits in regional high-grade metamorphosed rock, including gneiss and schist with coarse-crystalline graphite; and (2) deposits formed during contact metamorphism of coal beds during trap intrusion, such as the Tungus graphite province in the North Asian Craton. In this area, deposits formed during thermal metamorphism of coal layers during intrusion of thick Triassic diabase sills. Deposits display a complicated composition and consist of layers of amorphous graphite and numerous fragments and lenses of sedimentary rock. Major mineral is fine-grained and flake graphite. Associated minerals are pyrite, calcite, apatite, zircon, magnetite, rutile, and hydrosilicates. Examples of the deposit type are at Itgel Naidvar, Mongolia, Liumao, Heilongjiang Province, China, and Noginskoye, Russia.

Metamorphic Sillimanite (Zhang, 1984; Jiang, 1994)

This deposit type consists of multiple concordant layers that contain 25 to 50% sillimanite in graphite-garnet-sillimanite schist, biotite-garnet-sillimanite schist and plagioclase-cordierite-sillimanite schist and gneiss, and lesser garnet schist, phosphorus marble, and other lithologies. Major ore mineral is sillimanite, and accessory minerals are quartz, garnet, biotite, cordierite, K-feldspar, graphite, pyrite, pyrrhotite, tourmaline, phlogopite, and others. Protolith is high-aluminum argillaceous sedimentary rock that formed in near-shore tidal flats and lagoons. Metamorphic grade ranges from amphibolite to granulite facies metamorphism with intense folding. Deposit type usually spatially associated with metamorphic graphite deposits. An example of the deposit type is at Sandaogou, Heilongjiang Province, China.

Phlogopite Skarn (Murzaev, 1974; Arkhipov, 1979)

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

Deposits Related to Surficial Processes

XI. Residual Deposits.

Bauxite (Karst Type) (Patterson, 1986)

This deposit type consists of sedimentary bauxite that occurs mainly in depressions of karst surfaces in thick carbonate sequences. Deposits are confined to interformational breaks in carbonate rock. Deformation and metamorphism are typical. Main deposit minerals are diaspore and boehmite. Associated minerals are hematite, goethite, and kaolinite, and minor quartz. Deposit structures include pisolitic, nodular, massive, and earthy. Examples of the deposit type are at Novogodneye and Oktyabrskoye 4, Russia,

Laterite Ni (Singer, 1986b)

This deposit type consists of Ni and silicate minerals in weathering crust developed from ultramafic rock, particularly peridotite, dunite and serpentinized peridotite. Three morphological types of deposits occur - areal, linear, and contact karst. The major minerals are complex Fe-Co-Ni silicates or oxides. Silicate minerals occur in lower part of residual weathering crust and in infiltration deposits. Major deposit minerals are garnierite, nepuite, and revdenskite. Associated minerals are serpentine, nontronite, goethite, Mn-oxide, and quartz. Goethite commonly contains abundant Ni. Oxide deposit minerals consist of Ni-bearing Fe-hydroxide 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 is convergent margins with obducted ophiolite complexes. Uplift is required to expose ultramafic rock to weathering. Examples of the deposit type are at Alexandrovskoye 2 and Belininskoye, Russia.

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

This deposit type consists of extensive Mn-bearing weathering crust formed as a residual deposit on Mn-rich limestone and metamorphic rocks. Mn concentration is a result of leaching and removing of carbonates and silica. Mn crust consists of sand and clay masses that contain hypergene concentrations of Mn oxides. Main deposit minerals are pyrolusite, psilomelane, manganite, and vernadite, and local Fe-hydroxides. Deposit minerals occur in layers, lenses, and branches, and sometimes in karst cavities. Deposits ranges up to kilometers long and tens of meters thick. Thick deposits exhibit a clear zonation with Mn-minerals in a lower part that is overlapped by pure Mn-bearing and Fe-hydroxide minerals. The depositional environment consists of subaerial exposures of Mn-bearing calcareous rock in a humid climate. Examples of the deposit type are at Karaulnaya Gorka and Seibinskoye 1, Russia.

Weathering Crust and Karst Phosphate (V.L. Librovich and L.M. Miznikova in Rundqvist, 1986)

This deposit type consists of phosphorite minerals forming in weathering crust and karst in association with phosphatic rock and phosphorite-bearing carbonate rock. Deposit forms 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. Deposits occur in extension regimes containing low-grade phosphate rock. An example of the deposit type is at Telekskoye, Russia.

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

This deposit type consists of complex REE minerals in weathering crust developed on nepheline syenite and associated carbonatites. The more productive is weathering crust developed on melanocratic feldspar-carbonate rock that contains feldspar, siderite, dolomite, calcite, pyroxene, amphibole, nepheline, apatite, monazite, fluorite, zircon, torianite, loparite, parisite, eudialyte, and lepidomelane, and Cu-, Zn-, and Pb-sulfide minerals. This type of weathering crust is divided into hydromica and ferrihalloysite types. The major REE-deposit minerals are bastnaesite, staffelite, rabdofanite, and melanterite, and associated pyrolusite and limonite. The deposits are complex and contain REE and Nb along with Li and Zr. Some deposits are large. Examples of the deposit type are at Kiiskoye and Tomtor, Russia.

XII. Depositional deposits.

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

This deposit type consists of gold in grains and rare nuggets in gravel, sand, silt, and clay, and their consolidated equivalents in alluvial, beach, eolian, and rare glacial deposits. Major deposit minerals are gold, sometimes with attached quartz, magnetite, or ilmenite. Rare PGE mineral may also occur. The depositional environment is high-energy alluvial where gradients flatten and river velocities lessen as at the inside of meanders, below rapids and falls, beneath boulders, and in shoreline areas where the winnowing action of surf causes gold concentrations in modern beaches, or in uplifted or submerged beaches. Numerous major placer districts with placer and paleoplacer Au deposits occur in Russia, Mongolia, and China.

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

This deposit type consists of diamonds in alluvial and beach sediments and in sandstone and conglomerate. The conglomerate beds may contain paleoplacers. The age range is generally Tertiary and Quaternary, and the tectonic setting is generally stable cratons. The associated deposit type is diamond-bearing kimberlite. The main deposit 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 is concentration in 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 the deposit type is at Huangsongdianzhi, Hunchun City, Jilin Province, China.

Placer PGE (Yeend and Page, 1986)

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

Placer Sn (Nokleberg, W.J. and others, 1997)

This deposit type consists of mainly cassiterite and elemental gold in grains in gravel, sand, silt, and clay, and their consolidated equivalents, mainly in alluvial deposits. The depositional environment is similar to that of placer Au deposits. Examples of the deposit type are at Janchivlan, Mongolia, Khar Morit, Mongolia, Modot , Mongolia, Verkhnegilyui, Russia, and Zuuntarts, Mongolia.

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

This deposit type consists of zircon-ilmenite placers concentrated by marine beach processes and in continental surface environments. The host sediments are well-sorted, medium- to fine-grained sand with silt. The depositional environment is stable coastal regions receiving sediments from deeply weathered terranes. Deposit morphology consists of lenses and elongate "shoe-string" deposits that occur parallel to beaches, sometimes in multilayerd packets. Major deposit minerals are low-Fe ilmenite, zircon, leucoxene, anatase, rutile, staurolite, disthene, tourmaline, and monazite. Examples of the deposit type are at Koppi-Nelman and Sash-Yular, Russia.

REE and Fe Oolite (Arkhipov, 1979)

This deposit type is hosted in thick quartz and arkose sandstone with gravelstone. REE minerals occur in gravelstone and conglomerate horizons that are 15 to 30 km long, and vary from a few to 150 m thick. Principal heavy minerals are monazite and zircon (up to 95%) containing Ce, La, Y, Hf, Ta, and Nb. Siltstone in middle part of section may include concordant hematite beds that vary from 0.3 to 3 m thick and extend up to 40 km. Deposits exhibit oolitic, pisolitic, and colloform textures. Principal deposit mineral is hematite. Grade ranges from 29.6 to 70.7% Fe, 0.01 to 0.05 % S, and 0.1 to 0.2 % P_2O_5. The depositional environment consists of sedimentation in rifts in Paleoproterozoic grabens formed in intracratonic basins. No deposits of this type occur in the region.

Exotic deposits

Impact diamond (Masaitis and others, 1975, 1998)

This deposit type occurs in the Popigay, Russia ring structure that is interpreted as an impact structure in a round surficial depression with diameter of several tens of kilometers. Occurring in the depression is a complex variety of impact rocks that appear like volcanic rocks with varying amounts of: (1) glass of andesite-dacite composition; (2) rock and mineral fragments; (3) explosive allogenic breccias that were deposited after impact within, or beyond the limits of the depression; and (4) authigenic breccia that formed from the bottom of the crater that underwent high-grade shock metamorphism, melting, and formation of pseudotachylite. Impactite also includes massive lava-like tagamite and glassy clastic suevite. Diamond occurs in graphite gneiss and tagamite that underwent shock metamorphism. Diamond crystals range from 0.05 to 20 mm diameter. Associated placer deposits contain diamonds ranging up to 8 to 10 mm. Most abundant diamonds are yellow - transparent, gray, and black crystals are rare. Diamonds from gneiss retain morphological 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 origin of the Popigay ring structure, the prevaling interpretation is impact of a giant meteorite. Supporting data consists of numerous indications of shock metamorphism with partial melting of the rock derived from Early Precambrian crystalline bedrock.

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Table 1. Hierarchial 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 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 apatite-Ti-Fe-P
      - D. Deposits associated with kimberlite
        - Diamond-bearing kimberlite
    - II. Deposits related to intermediate 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
        - Boron (datolite) skarn
        - Carbonate-hosted asbestos
        - Co skarn
        - Cu (±Fe, Au, Ag, Mo) skarn
        - Fe skarn
        - Fe-Zn skarn
        - Sn skarn
        - Sn-B (Fe) skarn (ludwigite)
        - W±Mo±Be skarn
        - Zn-Pb (±Ag, Cu) skarn
      - 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
    - III. Deposits related to alkaline intrusions
      - A. Carbonatite-related deposits
        - Apatite carbonatite
        - Fe-REE carbonatite
        - Fe-Ti (±Ta, Nb, Fe,Cu, apatite) carbonatite
        - Phlogopite carbonatite
        - REE (±Ta, Nb, Fe) carbonatite
      - B. Alkaline-silicic intrusions 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 massive sulfide Pb-Zn (±Cu)
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 (listvenite) Hg
Trap related Fe skarn (Angara-Ilim type)

B. Deposits associated with felsic to intermediate extrusive rocks

Au-Ag epithermal vein
Ag-Pb epithermal vein
Au potassium metasomatite (Kuranakh type)
Barite vein
Be tuff
Carbonate-hosted As-Au metasomatite
Carbonate-hosted fluorspar
Carbonate-hosted Hg-Sb
Clastic sediment-hosted Hg±Sb
Epithermal quartz-alunite
Fluorspar vein
Hydrothermal-sedimentary fluorite
Limonite from spring water
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 sedimentary processes

VI. Stratiform and stratabound deposits

Bedded barite
Carbonate-hosted Pb-Zn (Mississippi valley type)
Sediment-hosted Cu
Sedimentary exhalative Pb-Zn (SEDEX)
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 siderite Fe
Stratiform Zr (Algama Type)

VIII. Polygenic carbonate-hosted deposits

Polygenic REE-Fe-Nb deposits (Bayan-Obo type)

Deposits related to metamorphic processes

IX. Sedimentary-metamorphic deposits
- Banded iron formation (BIF, Algoma Fe)
- Banded iron formation (BIF, Superior Fe)
- 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 carbonatite REE-Zr-Nb-Li

XII. Depositional deposits
- Placer and paleoplacer Au
- Placer diamond
- Placer PGE
- Placer Sn
- Placer Ti-Zr
- REE and Fe oolite

Exotic deposits

Impact diamond
