Geology and Nonfuel Mineral Deposits of the United States

By Michael L. Zientek and Greta J. Orris

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Geology and Nonfuel Mineral Deposits of the United States

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Abstract

This report, which is one of a series of reports summarizing the World's endowment of nonfuel mineral resources, describes the location and general geologic setting of deposits of major mineral commodities in the United States. The discussion in this report focuses on those commodities produced in the United States that constituted at least 5 percent of global production or global reserve base in 2003 or had at least $100 million production value in 2001. The discussion for each commodity begins with a brief description of the chemical and physical properties of the material and how it is used. The importance of the commodity in the United States relative to the world is also presented. However, most of the discussion emphasizes the geology of mineral commodities – the important mineral deposit types, their geologic setting, and the processes that led to their formation. A compilation of almost 400 major mineral deposits in the United States is included as an appendix.

Introduction

This report is one of a series that summarize information about the World's endowment of nonfuel mineral resources. These area reports are designed to inform the non-earth scientist about the location and general geologic setting of deposits of major mineral commodities. The reports are organized by the five areas shown in Figure 1; this report covers the United States. Additional information, such as production statistics, economic factors that affect the mineral industries of the region, and historical information, is available in USGS publications such as the Minerals Yearbook (available on the web) and through the detailed references provided at the end of this report. A brief overview of the potential for undiscovered mineral resources is included in this report.

The data in this report will be incorporated into the ongoing USGS international quantitative mineral resource assessment of the nonfuel mineral resources of the continental regions of the world. This assessment, led by the USGS, is designed to assess the global endowment of both discovered and undiscovered nonfuel mineral resources at a scale of 1:1,000,000 (Briskey and others, 2001, 2002). The results will delineate areas of the world that are geologically permissive for the occurrence of selected undiscovered nonfuel mineral resources, together with estimates of the quantity and quality of those resources. The global assessment will result in information that will assist in efforts to maintain a world supply of essential mineral resources while minimizing the global environmental and societal impacts of mining.

Currently, more than 5 percent of the world's production of barite, beryllium, boron, bromine, copper, garnet, gypsum, gold, salt (halite), iron, lead, zinc, molybdenum, palladium, phosphate rock, soda ash, silver, and titanium come from mining operations in the United States. These materials are derived from mineral deposits – a concentration of a mineral commodity of sufficient size and grade that might be mined or developed given favorable socio-economic conditions. A variety of mineral deposits types have been recognized that occur in distinctive geologic settings. Knowledge about the geologic context of mineral deposits can be applied to predict where undiscovered resources may be found.

The information in this report is organized by commodity; table 1 lists those materials that are described. Each section begins with a brief description of the chemical and physical properties of the material and how it is used. The relative importance of the commodity in the United States relative to the world is also presented. However, most of the discussion emphasizes the geology of mineral commodities – the important mineral deposit types, their geologic setting, and the processes that led to their formation.

Table 1. Value of selected mineral commodities produced in the United States.

[Value can be measured either in dollars (annual production value) or in the relative contribution to the global output of a commodity (percent of world production). Commodities highlighted with bold type are discussed in this report. Annual production value from National Mining Association (undated); percent of world production from USGS (2004)]

Commodity	Annual production value in 2001	Percent of world production in 2003
Stone, crushed	$8,920,000,000	
Cement: portland and masonry	$6,827,000,000	
Sand and gravel - construction and industrial	$6,246,000,000	
Gold	$2,930,000,000	10
Copper	$2,270,000,000	8
Clays (includes ball**, bentonite,** common, fire, fuller's earth, and **kaolin**)	$1,467,170,000	40[1], 18[2]
Iron ore (usable)	$1,210,000,000	5
Lime	$1,160,000,000	
Salt	$1,110,000,000	20
Phosphate rock	$856,000,000	24
Zinc	$774,000,000	9
Soda ash	$773,000,000	95[3]
Boron minerals (B_2O_3)	$506,000,000	24
Lead	$437,000,000	16
Potash (K_2O)	$260,000,000	4
Silver	$245,000,000	7
Palladium	$237,000,000	8
Diatomite	$174,000,000	27
Bromine	$159,000,000	38
Gypsum (crude)	$119,000,000	16
Platinum	$61,900,000	2
Feldspar	$44,100,000	
Rare-earth metal concentrates	$27,600,000	

Table 2. Value of selected mineral commodities produced in the United States - continued.

Peat	$24,800,000	
Perlite, crude	$21,300,000	
Iodine	$18,400,000	
Pumice and pumicite	$18,000,000	
Gemstones	$15,100,000	
Tripoli	$15,100,000	
Kyanite	$13,400,000	
Barite	$11,000,000	7
Mica, crude	$7,990,000	
Garnet, industrial	$6,430,000	14
Silica stone	$4,040,000	
Iron Oxide pigments (crude)	$3,460,000	
Beryllium Concentrates	$3,000	62
Molybdenum	Data withheld	27
Talc	No data	9
Titanium	No data	7

[1] bentonite; [2] kaolin; [3] natural soda ash

In addition, this report contains a compilation of major mineral deposits in the United States (appendix 1). In the United States, hundreds of thousands of mineral occurrences (a concentration of a mineral commodity that is or has been considered valuable) have been found, and well over a thousand of these are thought to be significant (Long and others, 1998). However, most of the mineral resources and mine production in the United States are associated with a small number of large deposits. For example, the largest 10 percent of the known gold deposits in the world contain 86 percent of the gold that has ever been discovered (Singer, 1995). Only large deposits are included in appendix 1. For some commodities (appendix 2), specific criteria were used to select the mineral deposits to include in appendix 1; for other commodities, qualitative measures, such as the relative proportion of material contained in the deposit compared to deposits outside the United States, were used to identify major deposits.

This report is not intended as a comprehensive overview of the geology or mineral resources of the United States. Interested readers are referred to other available literature on the geologic evolution and mineral resources of the United States. Compendiums include Bally and Palmer (1989); Brobst and Pratt (1973); Gluskoter and others (1991); Harben and Kužvart (1996); Long and others (1998); and U.S. Geological Survey National Mineral Resource Assessment Team (2000).

Some basic terms and concepts

The surface of the Earth is constantly being modified by the action of wind, water, ice, and the movement of large masses of rock and magma (naturally-occurring molten material from which igneous rocks are formed). The distribution of many mineral deposits is intimately related to processes that operate at the scale of the planet. The discussion of mineral commodities in this report emphasizes how the geologic evolution of North America has determined the mineral resource endowment of the United States. This section introduces some basic geologic concepts that are essential to understanding the genesis and spatial distribution of mineral deposits.

The Earth consists of 3 main layers, or shells, like an onion (fig. 2; Kious and Tilling, 1996). The **crust**, the outermost layer, is rigid and relatively thin, ranging in thickness from 5 to 100 kilometers. Below the crust is the **mantle**, a dense, hot layer of semi-solid rock approximately 2,900 kilometers thick. At the center of the Earth lies the **core**, which is composed of solid and liquid iron-nickel alloy.

The **theory of plate tectonics** states that the Earth's outer layers are fragmented into a dozen or more slabs that are moving relative to one another (figs. 1 and 3; Kious and Tilling, 1996). These **tectonic plates** are massive, irregularly shaped slabs of solid rock, generally composed of continental and oceanic crust and part of the underlying upper mantle, that together comprise the lithosphere. Plate size can vary greatly, from a few hundred to thousands of kilometers across. Plate thickness also varies greatly, ranging from less than 15 kilometers for young oceanic lithosphere to about 200 kilometers or more for ancient continental lithosphere (for example, the interior parts of North America).

The relative motion between tectonic plates generally is on the order of several millimeters per year. Geologic features of the Earth's crust record the movement and interaction of tectonic plates; features include linear belts of mountains; long narrow valleys bounded by faults; volcanoes; and earthquakes along the margins of tectonic plates. Geologists distinguish three types of plate margins depending on their relative motion. Plates can move toward each other, move away from each other, or slide past each other. When two lithospheric plates come together, a plate covered by oceanic crust will sink into the mantle, forming a subduction zone. On continental crust, mountain belts (orogens) form where plates collide. Most volcanoes on land occur parallel to and inland from subduction zones. Rift zones form where plates move apart. Strike-slip or transform faults form where plates slide past each other.

Scientists also believe that masses of relatively hot, low-density mantle rise from the upper boundary of the core (fig. 4). On reaching the base of the upper mantle, these **mantle plumes** can spread laterally and cause rock to melt, forming magma (Condie, 2001). Geological features linked to mantle plumes include broad doming of the crust, modification of continental-scale drainage patterns, rifting of continental crust and the breakup of continental tectonic plates, and the rapid eruption of large volumes of magma enriched in iron and magnesium (fig. 5; Buchan and Ernst, 2001).

Many mineral deposits are found in areas where the movements of magmas and water-rich fluids have been focused. Heat generated by the radioactive decay of elements deep within the Earth can melt rocks to form magma; causes rocks, magmas, and fluids to move by making them less dense and more buoyant; and provides the energy needed to drive chemical reactions. The interaction of tectonic plates that make up the upper 200 kilometers of the Earth and ascent of plumes of hot rock toward the surface from deep within the mantle generates the magmas and fluids, fractures and faults, mountain ranges and sedimentary basins that are critically important to localizing **magmatic, hydrothermal, and metamorphic mineral deposits**.

Magmatic mineral deposits form during the cooling and crystallization of magma. These deposits are typical of igneous rocks that form from magmas enriched in magnesium, nickel, and chromium. Some deposits, such as those enriched in chromium, simply are made up of crystals that grew from the magma. In other cases, deposits form from sulfur- or iron-rich liquids that segregate from a silicate magma and crystallize separately. These sulfur- or iron-rich liquids are denser than the original magma. Once formed, these separated sulfur- or iron-rich liquids do not mix or blend with the silicate-rich magma (the separation of oil and vinegar in a salad dressing is an example of a similar process). The sulfur-or iron-rich liquids accumulate in zones or layers and solidify. Sulfide-rich liquids can be enriched in nickel, copper, and platinum-group elements. In addition, the resulting sulfide mineralization potentially contains important by-products such as cobalt, gold, silver, selenium, and tellurium; the ores also are used to produce sulfuric acid and liquid sulfur dioxide. Iron-rich liquids are enriched in titanium, vanadium, and phosphorus. Large magmatic mineral deposits enriched in nickel, chromium, and platinum-group elements are associated with plume-related igneous activity. Other magmatic mineral deposits are associated with igneous rocks that formed from magmas enriched in silicon, potassium, and sodium. When these magmas cool, the last material to crystallize may be enriched in water and elements such as lithium, tantalum, and niobium. These igneous rocks, called pegmatites, are characterized by crystals that can be quite large, ranging from centimeters to meters in diameter. Gem minerals such as tourmaline and topaz may also form in these rocks. Figure 6 shows the distribution of magmatic ore deposits in the United States.

Hydrothermal mineral deposits form by the interaction of hot water and rock. Water is a good solvent and hot water, called hydrothermal fluid, can efficiently move and deposit materials that occur in some mineral deposits. Plate interactions (collisions and rifts) are characterized by the large-scale movement of magmas and hydrothermal fluids that can form hydrothermal mineral deposits (fig. 7). Faults formed at plate margins form discontinuities in the crust that focus the movement of fluids and magmas. Cooling igneous magmas can produce hydrothermal fluids that form a variety of deposit types enriched in a broad suite of metals (Thompson and Newberry, 2000).

Not all hydrothermal fluids are directly related to magmatic activity. Some hydrothermal fluids are generated in sedimentary basins - regions of the crust where relatively great thicknesses of sediment have accumulated. Sedimentary basins commonly form where the interaction of tectonic plates locally cause the Earth’s crust to subside (Busby and Ingersoll, 1995). The decay of naturally-occurring radioactive elements within the Earth causes rock temperatures to rise with increasing depth. As sediments are buried, hydrothermal fluids form by the heating of pore water trapped in the sediment and the break-down of water-rich minerals that are only stable at low temperatures. As these hydrothermal fluids move through the crust, they interact with other fluids, rocks, and, ultimately, the atmosphere, locally forming mineral deposits. Most hydrothermal deposits are located in the western part of the United States (fig. 8).

Metamorphic deposits. Rocks are changed (metamorphosed) as they are subjected to higher temperature and/or pressure. New minerals can form, and the size and shape of existing minerals are modified. Mountain building processes or burial of sediment or rocks can cause metamorphism. Emplacement of magma can also cause metamorphism by heating rocks around the intrusion. In some cases, the new metamorphic minerals have useful properties. Examples include garnet (silicate minerals containing variable proportions of iron, aluminum, magnesium, and calcium that are used for abrasives, water filtration, and semi-precious gems), wollastonite (a calcium silicate used for asbestos substitutes, ceramics, friction products, metallurgy, paint, plastics), and kyanite (aluminum silicate used for brake linings and clutch facings, ceramics, grinding and cutting wheels, refractories). Figure 6 shows the distribution of metamorphic ore deposits in the United States.

Rocks disintegrate when exposed to water, air, and microbes at the Earth’s surface. The movement of water and air, in part driven by solar radiation, redistributes rock and soil particles. These processes can also cause the transportation, concentration, and localization of materials that form some types of mineral deposits. **Sedimentary mineral deposits** are economic concentrations of minerals in sedimentary rocks that formed directly from water in oceans, lakes, or in underground reservoirs. The precipitation of minerals can be caused by evaporation of water or by mixing of waters with different compositions. The resources associated with these deposits can be quite large because minerals can be deposited uniformly over large areas. The uniformity of these deposits and their lateral extent also can make them easier to mine. **Evaporite and brine deposits** are sedimentary mineral deposits that form by the evaporation of lake water or seawater. These deposits are sedimentary layers that are enriched in a variety of salts. These deposits form from bodies of water that have restricted circulation and high evaporation rates. Major deposits of evaporites are commonly found in sedimentary basins that formed when continental crust is pulled apart to form a rift and in sedimentary basins that form on continental crust well away from tectonic plate boundaries. The composition of water constrains the mineralogy and composition of evaporite deposits (Guilbert and Park, 1986). Salts that form from seawater include halite (sodium chloride), gypsum (hydrated calcium sulfate), sylvite (potassium chloride), and carnalite (hydrated calcium-magnesium chloride). The variable composition of lake water results in a variety of evaporation-concentrated mineral deposits. Large deposits of nitrates, sodium carbonates, and borates have formed by the evaporation of lakes. Sedimentary mineral deposits also include large bedded deposits of iron minerals that formed from ancient oceans. Organic activity plays an important role in the formation of other sedimentary mineral deposits, such as phosphate rock and diatomite. Figure 9 shows the distribution of sedimentary mineral deposits in the United States.

Erosion and weathering of rocks can form **surficial mineral deposits**. **Placer deposits** form as heavy particles of rocks or minerals are physically concentrated by the action of moving water. Placer deposits can form in active stream deposits or along the shoreline of oceans or lakes. Minerals typically concentrated in placer deposits include gold, platinum, titanium-minerals, and garnet (silicate minerals containing variable proportions of iron, aluminum, magnesium, and calcium). Placer deposits are relatively easy to find and simple to mine. **Residual deposits** are formed by the intense weathering of rocks under hot, humid conditions. The mineralogy and composition of the weathered rock determines which elements will be concentrated by weathering. Aluminum, nickel, manganese, iron, and clay deposits can form by this process. Weathering of near-surface exposures of mineral deposits can also form minerals that are easier to treat and extract during mining. In other situations, the metals leached from near surface exposures can be re-deposited near the groundwater table, forming **secondary enrichment zones**. Figure 10 shows the distribution of surficial deposits in the United States.

Overview of geologic and tectonic history

The movement of material in the mantle and of tectonic plates is responsible for the development of cratons, orogens, large provinces of igneous rocks, and rifts that are characteristic of continental crust. In general, the interiors of continents consist of ancient continental crust that is surrounded by younger belts of deformed rocks. The ancient parts of a continent, that have been structurally stable for a prolonged period of time, are called cratons (Condie, 1997). The younger, curvilinear belts of deformed rocks, often accompanied by metamorphic and igneous rocks, are called orogens. The linear belts of igneous rocks associated with orogens are called igneous arcs. Orogens form on continental crust in response to the convergence of tectonic plates. Young orogens are expressed on the Earth's surface as mountain ranges. Orogens are important in the formation of mineral deposits; the collisional process provides heat to generate magmas and hydrothermal fluids and fractures and faults that focus their flow. Many types of mineral deposits are spatially and temporally associated with orogenic belts.

Parts of some continents are characterized by large tracts of igneous rocks enriched in magnesium and iron (basalt) that are not associated with orogens. These igneous rocks, along with sedimentary rocks, found in long, linear fault-bounded valleys may have formed as mantle plumes reached the base of the crust or as tectonic plates moved away from each other. As with orogens, heat related to magmatism and faulting can give rise to a variety of mineral deposits in this geologic setting.

Throughout this report, events related to the physical formation and development of the Earth are described using either absolute (chronometric) or relative (chronostratigraphic) time scales. Absolute time is reported as numerical ages in billions of years (Ga) or millions of years (Ma) that are measured using radiometric dating methods. Relative time is based relations of rock units and fossils that can be recognized globally. These relative subdivisions of geologic time have been given names and are grouped hierarchically; the boundaries between these units can be calibrated using the absolute time scale (fig. 11).

The geologic architecture of the United States uniquely reflects the sequence of geologic events that culminated in the distribution of rocks (fig. 12) and mineral deposits (figs. 6, 8, 9, and 10) we see today. The more we know about the geologic fabric of each continent and the processes that control the regional and local distribution of mineral deposits, the better we can predict where new deposits will be found and what they may contain.

Today, most of the United States land mass lies on one tectonic plate, the North American plate (fig. 1). The western margin of this plate is the site of an orogen that started to develop 100s of millions of years ago and is still active today. The mountain ranges, active volcanoes, and earthquakes that are characteristic features of the landscape of the western conterminous United States and Alaska are a result of on-going subduction and transform motion between tectonic plates. Magmatic activity at Hawaii and Yellowstone is thought to be the result of mantle plumes. However, the plates and continents have not always been dispersed around the globe as they are today.

The geology of the United States records a long history of tectonic plate and mantle plume interactions (figs. 13 and 14). The rocks that make up the interior of the North American continent were assembled by the merger of smaller continental masses during the Early Proterozoic followed by the accretion of younger continental crust during the Middle Proterozoic (Hoffman, 1989). The oldest continental crust is exposed in Archean cratons. Most of the Archean cratons that make up the interior of the conterminous United States are now covered by younger sedimentary rocks. Part of the largest Archean craton in North America, the Superior province, is exposed in Minnesota. Archean rocks of the Wyoming province are exposed in some mountain ranges in Wyoming and Montana. Although older rocks are present, these cratonic provinces experienced strong compression, magmatism, and metamorphism between 2.8 and 2.6 Ga. During the Archean, these cratons appear to have been separate continental masses. About 1.9-1.7 Ga, convergence of tectonic plates welded the Superior and Wyoming cratons together; the convergent boundary is delineated by the Trans-Hudson orogen.

Subduction of tectonic plates along the southern margin of the combined Superior and Wyoming provinces created several orogens that added new continental crust to the North American continent. The oldest is the Penokean orogen, south of Lake Superior. Younger orogens (Yavapai, Mazatzal, Central Plains) developed between 1.8 and 1.6 Ga and accreted additional crust to the southern margin of the North American continent. Following these events, the North American continent experienced no orogenic activity for about 350 million years.

Many, if not all, of the major continents were joined together during the Middle Proterozoic (about 1.3 to 1.0 Ga) and the Paleozoic (between about 543 and 248 Ma (millions of years before the present) forming super continents, called Rodinia and Pangea, respectively (Condie, 1997). The Middle Proterozoic Grenville orogen exposed from eastern Canada to Mexico formed during the series of plate collisions that formed Rodinia (fig. 13). This supercontinent broke apart between 750 to 550 Ma. The Paleozoic Appalachian orogen in the eastern United States and the Ouachita orogen in Arkansas and Texas formed during the assembly of Pangea (figs. 12 and 13). Pangea began to break up about 160 Ma. In the Middle and Late Jurassic, the North American continent split from Africa and Europe to form the North Atlantic Ocean. The breakup of the continents was accompanied by igneous activity and the formation of rift-related sedimentary basins.

The Cordilleran orogen lies on the western part of the North American continent. The orogen developed along a continental margin that formed about 600 Ma during the breakup of the super continent Rodinia. This orogen reflects intermittent convergent margin tectonic activity between oceanic and continental plates starting in middle Paleozoic time and continuing to present (Bally and Palmer, 1989; Burchfiel and others, 1992). The Cordilleran orogen is one of the longest-lived orogenic belts in the world. The long history of magmatic and tectonic activity and its young age has resulted in the formation and preservation of a large number of major mineral deposits.

About 20 igneous events in the United States are linked to mantle plumes (fig. 14; Ernst and Buchan, 2001). Many of these events are also associated with the development of continental rifts. The igneous rocks associated with these events range in age from a few million years to 2.9 billion years. Examples of geologic provinces related to plume events are the Tertiary Columbia River flood basalt province in Washington, Oregon and Idaho, the Triassic Wrangellia rocks of Alaska, and the Late Proterozoic Keewenawan flood basalt province that extends from Kansas to Minnesota and Michigan (fig. 12). These provinces are characterized by the rapid eruption of large volumes of sheet-like lava flows that are enriched magnesium and iron. Major mineral deposits are associated with the Keewenawan event and the older Stillwater event in Montana. Plume-related magmatic activity also appears to be associated with the tectonic events that resulted in the breakup of the Rodinian and Pangean supercontinents.

Principal commodities and deposit types

For this report, information is organized following usage in USGS Minerals Yearbooks. Metallic and industrial commodities are distinguished, with each commodity listed alphabetically and discussed under one of these categories. Some mineral deposits produce more than one commodity. The discussion for these polymetallic deposits is repeated for each commodity that is present. This creates some redundancy in the report;

however, it allows each commodity section to stand alone if the reader wants to relate this discussion to information in the USGS Minerals Yearbooks.

Appendix 1 is a compilation of the major mineral deposits in the United States. The importance and diversity of mineral deposits as sources of commodities in our modern society is evident from almost 400 major mineral deposits summarized in appendix 1. This table gives the deposit name, the commodities produced, deposit-type categories, and a reference. At some level of understanding, every mineral deposit is unique. However, shared characteristics of some deposits allow them to be considered as a group. Studies of these groups provide the insight needed to recognize the fundamental processes and controls that lead to the formation of mineral deposits. These insights can be formalized as models that give geologists the ability to understand the known distribution of mineral deposits and to predict the location, quantity, and quality of undiscovered resources. Therefore, if possible, the mineral deposit model (Cox and Singer, 1986; Stoeser and Heran, 2000) that applies to each deposit is also given.

Although the table is comprehensive, our discussion focuses on those commodities produced in the United States that constituted at least 5 percent of global production or global reserve base in 2003 (Appendix 3) or had at least $100 million production value in 2001 (table 1). For each commodity, the use of the commodity, the United States contribution to world production and reserves, and the geology of the deposits that account for the majority of the commodity production in the United States are briefly described. The geologic discussion focuses on the combination of geologic factors that concentrated the commodity into a deposit. A broad genetic classification of mineral deposits is used as the primary framework for discussion. Our simple classification includes magmatic, hydrothermal, metamorphic, sedimentary, and surficial mineral deposits.

Metals

Beryllium

Beryllium is a hard, silvery-white, and very light metal with a very high melting point. The combination of its light weight and high melting point make it valuable for making metal alloys, which are used in electronic and electrical components and aerospace and defense applications (Mineral Information Institute, USGS, and American Coal Foundation, undated).

Table 2. Beryllium - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003	Rank of world production
United States	62.1	1

Known world resources of beryllium have been estimated to be more than 80,000 metric tons. In 2003, the apparent consumption of beryllium in the United States was 190 metric tons (USGS, 2004). About 65 percent of the global beryllium resource is in the United States, for the most part concentrated in the Spor Mountain and Gold Hill areas in Utah and the Seward Peninsula area in Alaska. The United States produced over 60 percent of the total world output of beryllium in 2003.

The deposits in the Spor Mountain region of Utah (fig. 15) are the only developed source of beryllium in the United States and North America (Brush Engineered Materials Inc., 2003). Proven bertrandite (hydrous beryllium silicate) reserves in Utah total about 16,000 metric tons of beryllium. These proven ore reserves—the largest in the world—are sufficient to fill the requirements of the world's beryllium industry for at least the next sixty years, based on present production rates.

The hydrothermal mineralization at Spor Mountain is associated with a volcano that was active about 20 million years ago. The volcanic activity formed a caldera (a large basin-shaped volcanic depression), deposited layers of volcanic fragmental rock or tuff, and erupted silica-rich lavas. Beryllium mineralization, along with fluorite (calcium fluoride) and uranium, is found in the volcanic tuff unit (Lindsey, 1998). The volcanic complex is part of an east-west trending belt of igneous activity that developed late in the evolution of the Cordilleran orogen and extends from the Sierra Nevada to the Wasatch Range in Utah (Christiansen and Yeats, 1992).

Cobalt

Cobalt is a bluish-gray, shiny, brittle metallic element. Some applications of cobalt include: catalysts, cemented carbides for cutting tools and drill bits, drying agents for paints, magnets, and superalloys for jet engine components (Mineral Information Institute, USGS, and American Coal Foundation, undated). Identified world cobalt resources are about 15 million metric tons (USGS, 2004). The apparent consumption of cobalt in the United States in 2003 was 10,000 metric tons (USGS, 2004).

Table 3. Cobalt - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	--	--	--	7.2

Cobalt can be recovered from mineral deposits developed primarily for their cobalt content or as a by-product of mining nickel. Mines in the United States currently are not producing significant quantities of cobalt. However, primary cobalt reserves have been identified and are associated with metamorphosed hydrothermal deposits in Idaho (fig. 15). By-product cobalt resources also could be recovered if the copper-nickel-PGE deposits associated with the Duluth Complex, Minnesota are developed (see discussion under copper, nickel, or platinum-group elements).

The primary cobalt deposits in Idaho formed when hydrothermal solutions moving along fractures towards the Earth’s surface vented into the ocean and formed hot springs (fig. 16). The hydrothermal solutions mixed with ocean water and formed layered deposits of sulfide minerals enriched in iron, cobalt, copper, and gold on the seafloor. Geologists refer to this type of mineralization as sedimentary exhalative (sedex) deposits. The ore minerals were deposited in sedimentary rocks from hydrothermal solutions that may have been generated as water-rich sediments were deeply buried in sedimentary basins within the crust. Thin layers of volcanic rock in the sedimentary basins suggest igneous processes also may have had some role in generating the hydrothermal fluids. Deposits may have been localized near faults that were active during sedimentation and provided channel ways for the fluids to escape to the surface.

Sedimentary-exhalative cobalt deposits occur in a linear trend in east-central Idaho. The belt extends for about 55 kilometers and contains at least eleven sediment-hosted copper-cobalt deposits and occurrences (Box and others, 1995). Recently, Formation Capital has established a cobalt-copper-gold reserve/resource on two zones, the Sunshine and Ram deposits (Formation Capital, undated). The diluted proven and probable reserves and inferred resources for their Idaho Cobalt Project are estimated to be 2.86 million metric tons grading 0.602 percent cobalt, 0.45 percent copper, and 0.5 grams per ton gold (Shedd, 2002). Nearby, the Blackbird deposit has resources estimated to be 4.89 million metric tons grading 0.71 percent cobalt and 1.24 percent copper (Spanski, 2004).

The cobalt deposits are hosted in a Proterozoic sedimentary basin (the **Belt basin**) that is made up of about 16 kilometers of layered sedimentary rocks, covers 200,000 square kilometers, and extends from Idaho, Montana, and Washington north into Canada (fig. 17; Chandler, 2000). This basin formed about 1.5 Ga when a rift developed on a supercontinent that was made up of most of North America, along with Siberia, Australia, or Antarctica filled with sediment (Chandler, 2000; Lydon, 2000). The high heat flows associated with basins that form as continents are pulled apart or rifted generate hydrothermal fluids that can form sedex deposits (Lydon, 1988; Lydon, 1996). Sedex deposits with lead and zinc are relatively common and found world-wide (Lydon, 1996); those enriched in cobalt and copper have only been described from Idaho.

Copper

Copper is a mineral and an element (Mineral Information Institute, USGS, and American Coal Foundation, undated). Copper has become a major industrial metal because of its high ductility, malleability, thermal and electrical conductivity, and resistance to corrosion; it ranks third after iron and aluminum in terms of quantities consumed. About one-half of the copper and copper alloys are used in building construction, and about one-half of the remainder is used in electric and electronic products. Known land-based resources are estimated to be 1.6 billion metric tons of copper (USGS, 2004). In 2003, the apparent unmanufactured consumption of copper in the United States was 2,370,000 metric tons (USGS, 2004). The United States supplied about 8 percent of the world's production of copper in 2003. United States copper production largely comes from deposits in Arizona, New Mexico, and Utah. The location of major copper deposits in the United States is shown in figure 18.

Table 4. Copper - proportion of world mine production, reserves, reserve base, and resource base for the United States.

[USGS, 2004; Singer, 1995; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base	Percent of world discovered resources
United States	8.1	3	7.4	7.5	19.2

Currently, most of the copper production in the United States is derived from large, relatively low grade hydrothermal mineral deposits that formed beneath composite volcanoes. Important, undeveloped hydrothermal copper deposits are hosted by sedimentary rocks in Montana; these deposits are also enriched in silver. Historically, considerable copper production came from hydrothermal deposits associated with plume-related volcanic lava flows in Michigan. In the future, significant copper production can be expected from magmatic copper-nickel deposits in the Duluth Complex in Minnesota.

Porphyry copper deposits Hydrothermal copper mineral deposits associated with composite volcanoes are called porphyry-type deposits by geologists (figs. 19 and 20). The name is derived from the close association of mineralization with igneous rock called porphyry. Most of the minerals that make up porphyry are too small to discriminate by eye; however, they also contain conspicuous larger crystals scattered throughout the rock. This texture is indicative of crystallization and cooling of magma near the surface of the Earth.

Porphyry intrusions and associated hydrothermal copper mineralization form deep beneath composite volcanoes. Some magmas that erupt to the Earth's surface create steep-sided, symmetrical, cone-shaped, composite volcanoes comprised of alternating layers of lava flows, volcanic ash, cinders, blocks, and bombs (Kious and Tilling, 1996). A composite volcano, such as Mount Rainier in Washington, can rise as much as 2500 meters above the surrounding landscape. Magma that crystallizes deep within the volcano forms porphyry intrusions.

Magma that forms composite volcanoes is typically rich in gases like water and carbon dioxide. The release of these gases as the magmas reach the surface can result in explosive eruptions; they are also a component of the hydrothermal fluids that are typically associated with these magmas. Porphyry copper deposits are derived from hydrothermal fluids released from and driven by the cooling magma. As the fluids cool and react with rocks, copper is deposited both in the igneous porphyry intrusions as well as adjacent rocks (fig. 19). As the hydrothermal fluids move away from the porphyry intrusions, mineral deposits rich in lead, zinc, gold, and silver are also formed (figs. 19 and 20). An average porphyry copper deposit can contain 140 million metric tons of mineralization with 0.5 percent copper (Singer and others, 2002). Most porphyry copper deposits are found in rocks younger than 300 million years.

Composite volcanoes and associated porphyry copper deposits are not randomly distributed over the Earth's surface. Most are concentrated on the edges of continents or along island chains in the oceans. In North and South America, more than 270 composite volcanoes have been active in the last 10,000 years; almost of them occur in linear belts along the western margins of these continents (Siebert and Simkin, 2002). The linear belts of modern volcanic activity are clearly associated with the convergence and subduction of tectonic plates. Today, off the coast of Washington, Oregon, and northern California, the Juan de Fuca tectonic oceanic plate is pushing into and is sinking (being subducted) under the continental part of the North American Plate (fig. 1). This convergence of oceanic and continental plates generates the magma that is erupted to form the active composite volcanoes such as Mount Rainier and Mount St. Helens in the Cascades Range.

For at least the last 300 million years, the western margin of the North American continent has been a convergent plate boundary where the Earth’s tectonic plates are moving toward each other. Subduction and destruction of oceanic crust has created linear belts of igneous rocks on the continental crust that makes up the western side of the North American continent. The position, duration, and intensity of these igneous belts have shifted with time. Variable uplift and erosion have cut through the volcanic rocks to expose underlying igneous intrusions that may host copper deposits. Subduction may have caused many thousands (millions?) of igneous intrusions to be emplaced in the Cordillera orogen of North America; so far, exploration geologists have found over 200 porphyry copper deposits along the western margin of the North American continent (Singer and others, 2002). Approximately 100 porphyry copper deposits occur in the United States and almost half of these are found in southeastern Arizona and southwestern New Mexico.

The largest copper-producing operations in the United States are all porphyry copper deposits. Eight of the 9 top producers are in southeast Arizona and southwestern New Mexico (National Mining Association, 2003a). The remaining deposit is in Utah. The largest deposits in the United States are Continental/Butte in Montana and Morenci-Metcalf and Safford in Arizona; all three deposits each contained over 32 million metric tons of copper. Safford contains over 7 billion metric tons of ore averaging 0.44 percent copper (Singer and others, 2002). These ore bodies also are an important source of molybdenum, gold, and silver.

Revett copper deposits Revett copper deposits are lens-shaped bodies of disseminated copper sulfides with silver that occur in a narrow interval of sedimentary layers in a large sedimentary basin (Hayes and Einaudi, 1986; Hayes and others, 1989; Hayes, 1990; Cox and others, 2003). However, mineralization does not necessarily conform to sedimentary bedding. These deposits form after the host sediment is deposited, but in most cases, before the sediment is converted into solid rock. The ore minerals appear to have been deposited from waters that filled pores between the sediment particles. These copper deposits are formed where waters of different composition and temperature mix in the subsurface in porous sediments. The distribution of minerals in the rocks that host the deposit indicate that the sulfide minerals were deposited as warm, salty, metal-bearing water (brine) moved through the porous beds and mixed with cool, pre-existing pore water.

Revett-type copper deposits occur in quartzite beds (quartz-rich metamorphosed sedimentary rocks) of the Revett Formation in the **Belt basin**, a middle Proterozoic sedimentary basin (fig. 21; Harrison, 1972). The Belt basin covers 200,000 square kilometers and extends from Idaho, Montana, and Washington north into Canada (fig. 17; Chandler, 2000). This basin formed about 1.5 Ga when a rift developed on a supercontinent that was made up of most of North America, along with Siberia, Australia, or Antarctica filled with sediment (Chandler, 2000; Lydon, 2000). Over 16 kilometers of layered sedimentary rocks were deposited in this basin. The sediment layers were originally deposited on the bottom of a lake or an embayment open to the ocean. As layers were buried by younger sediments, their pore waters become warmer and contained more dissolved components. Copper can be one of these dissolved components if ferromagnesian minerals (dark-colored minerals enriched in magnesium and/or iron) or mafic rock fragments (rock chiefly composed of ferromagnesian minerals) are present in the sediments. The pressure of the overlying sediments and the high geothermal gradients associated with basins that form as continents are pulled apart can ultimately drive these warm brines upwards along faults that were active during deposition of the basin. Fluid mixing responsible for mineral deposition occurred as these brines moved vertically through the section and laterally into the porous sediment layers that ultimately were converted into quartzite.

Long and others (1998) described 9 significant Revett-type copper deposits; 2 deposits are large enough to include in this compilation. The median size of a Revett-type sediment-hosted copper deposit is 14 million metric tons with 0.79 percent copper and 31 grams per ton silver (Cox and others, 2003). The largest deposit, Rock Lake-Rock Creek, contains approximately 300 million metric tons of ore containing 0.81 percent copper and 71 grams per ton silver.

Native copper deposits associated with basalt flows Approximately 1.1 Ga, a mantle plume is thought to have developed under what is now the area around Lake Superior. This plume event was associated with the eruption of lavas and emplacement of igneous intrusions between 1,109 and 1,087 Ma along a linear belt where the earth’s crust subsided forming a rift valley. The rift extends for more than 2,500 kilometers from Kansas northward beneath Lake Superior and then southeast through Michigan (fig. 8); however, exposures of rocks related to the rift are only found in the Lake Superior region (Schulz and Cannon, 1997). Part of the igneous activity involved the voluminous eruption of sheet-like lava flows now consisting of a rock called basalt (an igneous rock enriched in iron and magnesium). Taken together, these basalt flows exceed 10 kilometers in thickness. Some of these lavas, the Portage Lake Volcanics, are well-exposed on the Keweenaw Peninsula of upper Michigan (fig. 22). Relative to other types of volcanic rocks, basalts, like those that form the flows in Michigan, are enriched in copper. Hydrothermal solutions generated deeper in the rift basin leached copper from the basalt flows and deposited copper minerals principally as native copper in thin layers of sediments between lava flows or in the rubble that occurs along the base or top of lava flows. Prehistoric Native Americans found and mined native copper from these deposits. Before large-scale mining of porphyry copper deposits began early in the 20th century, these deposits in basalt flows in Michigan were an important source of copper in the United States. Long and others (1998) described 13 significant native copper deposits associated with basalt flows in Michigan; 3 are large enough to include in this compilation. There are no active mines on these deposits.

Magmatic copper-nickel deposits in the Duluth Complex. Igneous intrusions formed during the 1.1 billion Ga mantle plume event in the Lake Superior area also contain copper mineralization. The largest of the intrusions occurs in Minnesota and is known as the Duluth Complex (fig. 22; Miller, Green, and others, 2002). When this intrusion was emplaced, it reacted with the surrounding rocks resulting in the formation and segregation of immiscible liquids containing sulfur, iron, copper, nickel, platinum-group elements and cobalt. As a result, large volumes of rock with a few percent sulfide minerals occur along the western margin the Duluth Complex; locally, the rocks are made up almost entirely of sulfide minerals. Exploration activity has delineated several low-grade copper-nickel deposits in these rocks that have local zones enriched in platinum-group elements. At this time, no mines are developing these resources. Listerud and Meineke (1977) estimate the resources along the western margin of the complex to be 4,400 million short tons of rock containing 0.66 percent copper and 0.20 percent nickel. Subsequent exploration has focused on three deposits – Dunka Road (the Northmet project), Babbitt (the Mesaba project), and Maturi. An open pit minable resource of 808 million metric tons containing 0.432 percent copper, 0.109 percent nickel, 0.166 grams per ton platinum, 0.437 grams per ton palladium, 0.061 grams per ton gold, and 1.5 grams per ton silver has been defined at the Northmet project (Polymet Mining Corporation, 2003). Copper, along with platinum-group elements and nickel, will be recovered when these deposits are developed. Worldwide, this type of large tonnage, low grade copper-nickel-PGE mineralization is relatively uncommon. Similar deposits are known in South Africa, Finland, Australia, Canada, and Russia.

Gold

Gold is a metallic element that is beautiful, durable, easily worked, and rare (Mineral Information Institute, USGS, and American Coal Foundation, undated). It has been used throughout human history for jewelry and as currency. It is also chemically stable and, as a result, seldom combines with other elements. It does not corrode or rust and conducts heat and electricity very well. Gold is very malleable and ductile. Today, gold is primarily used in coins and jewelry and is stored by many countries to support their currencies. It is also used in dentistry and electrical and electronic applications.

About 190,000 metric tons of gold has been discovered in the world (Singer, 1995). About 10 percent of total gold discovered is in the United States. Total world gold resources are currently estimated to be about 100,000 metric tons (USGS, 2004). The reported consumption of gold in the United States in 2003 was 150 metric tons (USGS, 2004). The location of major deposits of gold in the United States is shown in figure 23.

Table 5. Gold - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	10.2	3	13.0	6.8

Major gold deposits are either hydrothermal or surficial. Over 80 percent of the 295 metric tons of gold produced in the United States in 2002 came from mines in Nevada (Price and Meeuwig, 2002). These mines also produced 422 metric tons of silver, approximately 30 percent of United States output. The gold and silver in Nevada are mined from three types of hydrothermal deposits – Carlin-type gold deposits, distal disseminated gold deposits, and epithermal gold deposits.

Sedimentary rock-hosted or Carlin-type gold deposits contain most of discovered gold resources in Nevada. The gold in these deposits is associated with small amounts (about 5 percent) of pyrite (iron sulfide) that is dispersed through altered sedimentary rocks that contain more than 50 percent carbonate minerals (Hofstra and Cline, 2000). The gold grains form particles that are usually less than a millionth of a meter in diameter. The hydrothermal fluids that formed these deposits moved upwards along major structures until they encountered units that restricted fluid flow. At that point, the fluids migrated laterally into sedimentary units that easily allowed the movement of fluids. As the fluids reacted with the rock, they dissolved carbonate minerals and deposited clay minerals, silica, and gold-bearing pyrite (iron sulfide). Gold ore is concentrated in areas where faults and fractures intersect rocks that easily react with hydrothermal fluids. Most deposits formed at depths of greater than 2 kilometers. The vertical extent of gold mineralization in a deposit rarely exceeds 1,000 meters; more commonly, mineralization extends over vertical intervals of 100 to 500 meters. The largest example of a Carlin-type deposit, Betze-Post, contains 1,250 metric tons of gold (fig. 24; Bettles, 2002).

These deposits are associated with the processes that formed the Cordilleran orogen, specifically when tectonic plate motions changed directions about 43 Ma (Hofstra and Cline, 2000). This change in plate motion was associated with the development of an east-west trending, subduction related igneous belt that formed at the same time that the Earth's crust was slowly being pulled apart. However, the gold deposits are not spatially associated with igneous centers; instead they are located along old (Late Proterozoic) faults that penetrate deep into the crust (fig. 25). Different types of hydrothermal fluids can be generated in this type of setting; research on these deposits has not definitively identified the process that generated the ore-forming fluid. More than 100 Carlin-like gold deposits and occurrences are now recognized in northern Nevada and northwest Utah with a pre-mining resource of more than 4,800 metric tons of gold. About 20 percent of this resource had been recovered by the end of the twentieth century (Kerrich and others, 2000). Eleven deposits are included in this compilation.

Distal disseminated gold deposits are found sedimentary in rocks that may be over a kilometer from igneous intrusions that cooled and crystallized to form porphyry copper deposits (fig. 19; see discussion on copper for a description of porphyry copper deposits). These deposits share many of the characteristics of Carlin-type gold deposits except that the hydrothermal fluids are clearly related, spatially and genetically, to the cooling and crystallization of subduction-related magmas that formed nearby porphyry copper deposits and related replacement and vein deposits (Cox, 1992). Gold and silver mineralization is associated with the dissolution of carbonate minerals and the deposition of silica in sedimentary units. Silver and gold minerals may be dispersed throughout altered sedimentary rock or be concentrated in narrow veinlets and fractures (Peters and others, 2004). Fractures are the most important feature that controlled the flow of hydrothermal fluids and the concentration of gold and silver. These deposits have significantly higher silver grades than Carlin-type deposits. Long and others (1998) described 25 significant deposits in the United States; 1 deposit in Arizona and 4 in Nevada are large enough to include in this compilation. Distal disseminated deposits currently being mined in Nevada include McCoy-Cove and Rochester. Silver is the dominant commodity in these deposits. However, they produce significant by-product gold.

Epithermal gold deposits form less than a kilometer below the surface of the Earth and typically are found with volcanic rocks that are related to igneous arcs formed at convergent tectonic plate margins (Cooke and Simmons, 2000; Hedenquist and others, 2000). Typically, the volcanic rocks were erupted on the land surface rather than beneath the ocean. These deposits commonly are found in young orogens where rocks formed near the surface of the earth are more likely to be preserved. These epithermal deposits can be enriched in gold and silver and also can contain minor amounts of zinc, lead, and/or copper.

The most common type of deposit forms from hydrothermal fluids that are similar to waters tapped by drilling beneath modern geothermal hot springs. In most cases, geothermal systems are driven by intrusions located as much as 5 to 6 kilometers below the surface. Epithermal gold deposits formed from geothermal systems usually occur several kilometers above the site of the igneous intrusion. Gold deposition is initiated as the hydrothermal fluids start to boil when they approach the surface. Gold is commonly associated with quartz (silicon oxide) and adularia (potassium aluminum silicate). Gold is concentrated in places where the hydrothermal solutions could easily flow – fractures, faults, and porous volcanic and sedimentary units (fig. 26). Ore bodies can extend laterally hundreds or thousands of meters but rarely extend more than 600 meters vertically. Clusters of epithermal deposits cover areas that range from a few to several tens of square kilometers. If the hydrothermal fluids discharge to the land surface, they form boiling hot springs that deposit silica, similar to those found today in Yellowstone National Park. Long and others (1998) described 129 significant epithermal and hot-spring gold deposits in the United States; 11 deposits are large enough to include in this compilation. Over 40 percent of the significant and major deposits are in Nevada; significant deposits also occur in Alaska, Arizona, California, Colorado, Idaho, Montana, North Carolina, New Mexico, Oregon, South Carolina, Utah, and Washington. Examples of epithermal deposits recently being mined include Round Mountain, Mesquite, and McLaughlin.

Outside of Nevada, several other types of major gold deposits are found in the United States. Some, gold placer deposits and hydrothermal orogenic gold veins, were the principle sources of gold production in the 19th and early 20th centuries. A belt of hydrothermal porphyry gold deposits is currently being developed in northwestern Canada and south-central Alaska.

Orogenic gold veins are associated with major fault zones that occur in orogens formed by convergence of tectonic plates (Hageman and Brown, 2000). These fault zones cut regionally metamorphosed rocks of all ages, are up to several kilometers wide, can be over 100 kilometers long, and are nearly vertical. These fault zones were the pathways for hydrothermal fluids generated by subduction-related thermal events. Scientific studies have not conclusively determined if the hydrothermal fluids have an igneous or metamorphic origin. Gold deposition occurred in and near fault zones at depths ranging from 3 to 20 kilometers. Gold mineralization is primarily associated with hydrothermal veins that occur near the major fault zones in metamorphic rocks. Mineralization in the veins can be traced over 2 kilometers in depth. The metamorphic rocks that most commonly host the gold deposits are sedimentary and volcanic rocks that formed at the margins of the converging tectonic plates. World-wide, quartz-carbonate-gold veins have been found in metamorphic rocks of all ages. However, most of the mineralized veins in the United States have been found in the Cordilleran orogen in California.

The veins are mainly composed of quartz (silicon oxide), with less abundant carbonate minerals. Pyrite (iron sulfide) and arsenopyrite (iron arsenic sulfide) constitute less than 5 percent of the veins. The main ore mineral in most deposits is native gold. The gold in these veins can be abundant, coarse-grained, and easy to extract. However, gold is commonly concentrated in rocks next to the veins that are iron-rich and difficult to deform, such as banded iron formation (sedimentary rock consisting of alternating iron-rich and silica-rich layers). Examples of quartz-carbonate-gold veins associated with banded iron formation include the Homestake mine in South Dakota.

These deposits have been a significant source of historic (and prehistoric) gold production. Long and others (1998) described 150 significant orogenic gold deposits, primarily in the western United States and Alaska; 6 deposits in Alaska, California, and South Dakota are large enough to include in this compilation. Over 70 percent of the significant deposits occur in the western foothills of the Sierra Nevada. This belt of quartz-carbonate-gold veins is known as the Mother Lode; the discovery of placer gold deposits derived from these veins caused the 1849 gold rush to California.

Intrusion-related gold – Tintina gold belt Gold exploration has recently focused on igneous intrusions formed at convergent plate margins. Upon cooling, the magmas generated by subduction at convergent tectonic plate margins can generate hydrothermal fluids that can form porphyry copper deposits (see discussion under copper) or replacement deposits (such as the distal disseminated gold deposits discussed earlier in this section). The association of gold with these particular hydrothermal systems has been known for decades.

Recently, a new type of gold deposit associated with igneous rocks has been defined (Thompson and Newberry, 2000). Like porphyry copper deposits, these gold deposits are related to hydrothermal systems formed during the cooling of magmas generated by the convergence and subduction of tectonic plates. However, the composition of the magma is different from the magmas that are associated with porphyry copper deposits; mineralization associated with the hydrothermal systems is characterized by economically significant gold; high concentrations of bismuth, arsenic, antimony, and tellurium; and low concentrations of copper, molybdenum, tungsten, and tin. The best examples of this style of mineralization are associated with a Cretaceous igneous arc in the Cordilleran orogen that extends from the Yukon Territory in Canada to interior Alaska (also known as the Tintina gold belt). However, similar gold deposits have been described in subduction-related igneous arcs in Europe, central Asia, northeast China, eastern Australia, and Bolivia (Thompson and Newberry, 2000). Long and others (1998) described 6 significant intrusion-related gold deposits in the United States (5 in Alaska and 1 in Nevada); 2 deposits, Donlin Creek and Fort Knox, are large enough to include in this compilation.

Placer gold deposits Heavy minerals, like gold, can be concentrated in sediments by moving water. These gold-rich sediments, or placers, are derived by weathering and erosion of hydrothermal deposits with relatively coarse-grained particles of gold. Placer gold deposits can be high grade, easy to locate, and relatively simple to mine. Most of these deposits have been found with little difficulty by prospectors with little or no formal training in geology. These deposits usually were the first metal deposits to be discovered and developed in the eastern and western areas of the United States.

Placer gold deposits in the United States have produced over 2,500 metric tons of gold (Long and others, 1998). This represents about 20 percent of the gold production in the United States through 1998. 154 significant placer gold deposits have been described in the western conterminous United States and Alaska. Most of these deposits are related to the development of the Cordilleran orogen. Ten placer deposits in Alaska, Arizona, California, and Wyoming are large enough to include in this compilation (fig. 23).

Most placer gold production in the United States came from deposits in California (1,170 metric tons) and Alaska (750 metric tons) (Long and others, 1998). The largest concentration of gold placer deposits in the United States is along the western side of the Sierra Nevada in California. The 1849 gold rush initiated the development of these deposits; ultimately producing more than 1,000 metric tons of gold. These placer deposits, as well as some of the larger deposits in Alaska, were derived from orogenic gold deposits. Most placer gold mining in the United States took place in the 19th and early 20th century. Although identified gold resources still remain in placer gold deposits, they are unlikely to be developed on a large scale because of the impact to aquatic and riparian environments. Small-scale and recreational placer mining will continue to be a minor source of gold production in the United States.

Other deposit types Significant quantities of gold are recovered from the porphyry copper deposits in the Cordilleran orogen (see copper discussion) and from volcanogenic massive sulfide deposits in Alaska (see lead-zinc discussion).

Iron ore

Iron is one of the most abundant elements on Earth, but it does not occur in nature in useful metallic form (Mineral Information Institute, USGS, and American Coal Foundation, undated). "Iron ore" is the term applied to a natural iron-bearing mineral or rock in which the content of iron is sufficient to be commercially usable. Metallic iron, from which steel is derived, must be extracted from iron ore. Iron ore is the source of primary iron for the world's iron and steel industries. Identified world resources are estimated to exceed 800 billion metric tons of crude ore containing more than 230 billion metric tons of iron. The United States is ranked seventh in the world in iron ore production and has about 5 percent of the world reserve base (USGS, 2004). In 2003, the apparent consumption of useable iron ore in the United States was 56,100,000 metric tons (USGS, 2004). The locations of major iron deposits in the United States are shown in figure 27.

Table 6. Iron ore - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	4.5	7	4.7	4.6

Most of the iron mined in the United States comes from iron-rich sedimentary deposits (called banded iron formation or BIF) that occur in Minnesota, Michigan, and Wisconsin (fig. 22). These deposits originally formed flat-lying sedimentary layers, but have been tilted and deformed in later orogenic events. The most important occurrences are in the Mesabi, Marquette, and Menominee Ranges (Kuck, 1998). Most of the iron production has been from deposits in the Mesabi Range in Minnesota. Leading iron producers in 2001 include Hibbing Taconite Co., Minntac, National Steel Pellet Co., and Thunderbird in Minnesota and Empire Iron Mining Partnership and Tilden Mining Co. in Michigan (National Mining Association, 2003a).

BIF is not unique to this region. More than 95 percent of iron resources of the world occur in banded iron formation (Gross, 1996a). Banded iron formation is sedimentary rock characterized by alternating iron-rich and silica-rich layers. The thickness of individual layers varies from less than a millimeter to meters; overall, a succession of rock layers may be 100s of meters thick. The principal iron minerals are the iron oxides hematite and magnetite. Banded iron formation has been found on all continents except Antarctica.

Although they are widespread geographically, sedimentary iron deposits mostly formed during two periods in the development of the Earth. These deposits occur in rocks ranging in age from 3.8 to about 1.8 Ga and from 0.8 to 0.6 Ga. The oldest deposits tend to be smaller and are associated with volcanic rocks. The mot extensive deposits of banded iron formation are associated with sedimentary units that formed from oceans during the Late Archean to Early Proterozoic (2.7 to 1.9 Ga). Sedimentary iron deposits formed from 0.8 to 0.6 Ga are smaller and less widely distributed than the older banded iron formations.

The iron resources in BIF's are large because the deposits are laterally extensive. The iron minerals formed from ocean water and were deposited uniformly over large areas. At the time they were deposited, some iron formations and associated sedimentary rocks may have covered over 100,000 square kilometers. Individual layers in some sequences can be traced for over 100 kilometers. The iron-rich deposits may have formed on submerged continental shelves surrounding Archean cratons. Younger (Paleozoic) iron-rich sedimentary units, ironstones, do not show the lamination characteristic of the older banded-iron formations.

The origin of banded iron formation is still controversial. These deposits are studied because they provide insights into the early evolution of the Earth's atmosphere and oceans (Konhauser and others, 2002). They also provide insights on biological processes early in the Earth's history because of the close association of iron and oxygen. The iron minerals present today are not those that were chemically precipitated from seawater. The present minerals reflect the burial of these rocks in sedimentary basins, where the rocks interacted with hydrothermal fluids and grew new minerals as temperature and pressure increased. In addition, weathering in tropical climates leached silica from some deposits, enriching the iron content in these rocks, and changing the iron minerals.

Iron formation typically contains about 30 percent iron. However, leaching of silica during weathering can produce iron ores with as much as 66 percent iron. From the 1800s until about 1955, most of the iron produced from Minnesota, Michigan, and Wisconsin was from these naturally-enriched iron ores. Since then, lower grade iron-formation has been mined and treated to produce taconite pellets. The iron formation in Minnesota, Michigan, and Wisconsin has been metamorphosed. In the process, grain size of minerals increased and new minerals, such as magnetite (iron oxide), formed from pre-existing iron silicate or iron carbonate minerals without significantly changing the amount of iron in the rock. Metamorphosed iron formation is called taconite. Powerful magnets can concentrate magnetite from pulverized taconite into a rich concentrate containing about 60 percent iron. This powder is mixed with clay and water, balled, and fired in a kiln to make hard pellets. The taconite pellets are the product shipped to the foundry to make iron or steel (Schaetzl, undated).

Even though iron mining has been important in the upper Great Lakes region for the last 100 years, iron-rich resources have not been entirely depleted. For example, an immense oxidized taconite resource remains undeveloped in the western Mesabi Range (Zanko and others, 2003). Economics and advances in non-magnetic iron ore processing technology will help determine if any portion of this resource will be further developed.

Lead and zinc

Lead is a very corrosion-resistant, dense, ductile, malleable blue-gray metal (Mineral Information Institute, USGS, and American Coal Foundation, undated). The majority of the lead consumed annually is used by the transportation industry, mainly for lead-acid batteries. Remaining uses include ammunition, electrical, electronic, and communication applications, and radiation shields. Zinc is also a blue-gray metallic element. Because of its anticorrosion properties, more than one-half of zinc metal consumed annually is used for galvanizing followed by the production of zinc-based alloys - brass and bronze.

About 350 million metric tons of lead has been discovered in the world (Singer, 1995). About 20 percent of total lead discovered is in the United States. The apparent consumption of lead in the United States in 2003 was 14,600,000 metric tons (USGS, 2004).

Table 7. Lead - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	15.8	3	12.2	14.4

About 710 million metric tons of zinc has been discovered (Singer, 1995). About 18 percent of total zinc discovered is the United States. The apparent consumption of zinc in the United States in 2003 was 1,370,000 metric tons (USGS, 2004).

Table 8. Zinc - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	9.1	5	13.6	19.6

Lead and zinc minerals commonly occur together in polymetallic mineral deposits that form from low-temperature hydrothermal fluids. Several types of deposits can be recognized based on the how the hydrothermal fluids were generated and where they moved, the distribution of ore minerals in the mineral deposit, and the geologic setting. The location of major lead and zinc deposits in the United States is shown in figure 28.

Two deposit types can form when hydrothermal fluids vent into the ocean. For the type geologists call **volcanogenic massive sulfide (VMS) deposits,** cooling of magma, either from volcanic rocks erupted on the ocean floor or emplaced in shallow intrusions, supplies the heat needed to generate hydrothermal solutions (fig. 29). For the type called **sedimentary exhalative (sedex) deposits**, hydrothermal solutions are generated as water-rich sediments are deeply buried in sedimentary basins within the crust (fig. 16). For both deposit types, hydrothermal solutions move towards the surface along fractures and form hot springs where they vent into the ocean. The hydrothermal solutions mix with ocean water and can deposit large quantities of iron, zinc, lead, and copper minerals as mounds and layers on the seafloor.

Like porphyry copper deposits, VMS deposits are associated with magma that is generated at convergent plate boundaries. However, these deposits are associated with the eruption of volcanic rocks under water. Unlike porphyry copper deposits, they are found in rocks of all ages. The oldest deposits, in Archean rocks, have less lead than younger deposits. Deposits of all ages also can contain copper, gold, and silver.

VMS deposits are a common deposit type and are widely distributed in orogenic belts around the world. Long and others (1998) identifies over 77 significant VMS deposits in the United States. They are associated with igneous arcs developed in the Cordilleran orogen (including deposits in the Brooks Range in Alaska; in southeast Alaska, and the Sierra foothills in California) and the Paleozoic igneous arcs of the Appalachian orogen. Proterozoic VMS deposits are associated with orogenic igneous arcs developed in what is now Wisconsin and Arizona. However, only three deposits, Arctic Camp, Greens Creek, and Crandon, were large enough to include in this compilation. The deposit at Greens Creek is currently being mined. Arctic Camp and Crandon have not been developed.

Sedex deposits are found in sedimentary basins characterized by high geothermal gradients (Lydon, 1988; Lydon, 1996). These basins commonly form as continents are pulled apart or rifted. Sedex deposits typically occur in large basins sometimes filled with more than 10 kilometers of sediments. Copper is rarely present in sedex deposits but silver may be present in economic amounts. Globally, sedex deposits are younger than 1,800 million years. No sedex deposits older than 1,300 million years are known from the United States. Sedex deposits occur less frequently than VMS deposits. Long and others (1998) lists 6 significant sedex deposits in the United States; 3 are large enough to include in this report (Red Dog, Su-Lik, and Pierrepont-Balmat-Edwards). The Red Dog lead-zinc deposit in the Brooks Range of Alaska is the single largest zinc deposit in the world and presently supplies 10 percent of the world's zinc (Leach, undated).

Mississippi Valley-type deposits Another type of lead-zinc deposit also forms from hydrothermal fluids generated in a sedimentary basin. However, in these deposits, the hydrothermal fluids move through underground formations that can store or transmit water until they mix with other fluids and deposit minerals in open cavities in carbonate sedimentary rocks. Geologists refer to these mineral bodies as **Mississippi Valley-type** (MVT) deposits (Sangster, 1996). The movement of hydrothermal fluids in the sedimentary basins is driven by plate boundary interactions. These deposits form in the relatively undeformed sedimentary rocks that occur inland from orogenic belts formed at convergent plate margins. Long and others (1998) described 22 MVT deposits in the United States; 6 deposits in Missouri, Oklahoma, Kansas, Tennessee, and Kentucky are large enough to include in this compilation. Historically, MVT deposits accounted for 57 percent of lead and 45 percent of zinc production in the United States.

The genesis of MVT lead-zinc ores is directly related to enormous hydrothermal systems generated by the uplift of sedimentary basins that developed as orogens form at convergent tectonic plate boundaries (Leach and others, 2001; Leach and Rowan, 1986). As orogens develop, the crust may subside between the main orogenic belt and the relatively undeformed continental craton (Moores and Twiss, 1995; Busby and Ingersoll, 1995). This zone of subsidence forms on the side of the orogenic belt away from the zone of active subduction. Sediments derived by erosion of the mountains formed during the orogenic process are deposited in this area of crustal subsidence, forming sedimentary basins. Sedimentary rocks in the basin can reach a thickness of about 10 kilometers near the mountain front. Away from the orogen, these sedimentary rocks are only slightly deformed. However, near the mountain front, these sedimentary rocks are commonly uplifted and deformed by folds and faults late in the development of the orogen.

Uplift of the sedimentary basin allows gravity to drive hydrothermal fluids out of the basin and on to the adjacent platform (fig. 30; Leach and others, 2001). MVT deposits generally form in carbonate-rich sedimentary rocks that overlie the relatively undeformed continental craton and had some hydrologic connection to the sedimentary basins developed adjacent to the orogenic belts. Hydrothermal fluids that formed most MVT mineral deposits have migrated considerable distances into relatively undisturbed rocks. The deposits occur where local geological and hydrological features focused the migrating hydrothermal fluids into areas where they could mix with other fluids or react with rocks and precipitate ore minerals.

MVT deposits are found world-wide but the largest deposits occur in North America (Leach and others, 2001). Most deposits formed in response to hydrothermal systems developed during two large subduction-related tectonic events during the Devonian to Late Permian and again during the Cretaceous and Tertiary. The Devonian to Late Permian event is the most important and corresponds to the assembly of the supercontinent known as Pangea. During the assembly of Pangea, convergence of tectonic plates towards the North American craton formed both the Ouchita and Appalachian orogens. In the United States, the world-class Viburnum Trend, Old Lead Belt, and Tri-State MVT deposits are found in the Ozark region north of the Ouachita orogen (fig. 31). The Ouchita orogen formed as the result of closure of a Paleozoic ocean basin and the late Paleozoic collision of the Llanorian and North American plates (Leach and Rowan, 1986). Sedimentary basins, like the Arkoma basin, formed on the northern flank of the Ouchita orogen in response to crustal down warping and rapid sedimentation accompanying the orogeny. At least 12 kilometers of sediments were deposited on the southern edge of the Arkoma basin. Deformation of the Arkoma basin and uplift of the Ouachita Mountains caused hot, subsurface brines (water containing at least 100,000 parts per million dissolved salts; Harben and Kužvart, 1996) to migrate onto the southern flank of the North American craton and formed MVT lead-zinc deposits in the Ozark region of Missouri, Arkansas, Kansas, and Oklahoma. Other MVT deposits occur intermittently along the west side of the Appalachian orogen and probably formed from hydrothermal systems generated from this orogenic system.

Molybdenum

Molybdenum is a metallic element used principally as an alloying agent in cast iron, steel, and super alloys to enhance hardness, strength, toughness, and wear and corrosion resistance (Mineral Information Institute, USGS, and American Coal Foundation, undated). Identified molybdenum resources of the world are about 18 million metric tons (USGS, 2004). The apparent consumption of molybdenum in the United States in 2003 was 13,900 metric tons. The location of major molybdenum deposits in the United States is shown in figure 32.

Table 9. Molybdenum - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	26.8	1	31.4	26.8

The United States ranks first in world production of molybdenum and has a large proportion of the world reserve base. Generally, molybdenum is produced as a byproduct of mining copper, in particular, porphyry copper deposits.

Porphyry copper deposits Hydrothermal copper mineral deposits associated with composite volcanoes are called porphyry-type deposits by geologists (figs. 19 and 20). This type of hydrothermal copper mineralization forms deep beneath steep-sided volcanoes that form as magma rises to the surface along subduction zones. Porphyry copper deposits are derived from hydrothermal fluids released from and driven by the cooling magma deep within the volcano. As the fluids cool and react with rocks, copper and other metals, such as molybdenum, is deposited both in the igneous porphyry intrusions as well as adjacent rocks (fig. 19).

Molybdenum is recovered as a by-product of mining copper from porphyry copper deposits. Eight of the 9 top producing mines developed on porphyry copper deposits are in southeast Arizona and southwestern New Mexico (National Mining Association, 2003a). The remaining deposit is in Utah. These ore bodies also are an important source of gold and silver.

Porphyry molybdenum deposits Some hydrothermal deposits are mined principally for their molybdenum contents. Carten and others (1993) identified 25 molybdenum or molybdenum-copper deposits in the United States that are related to felsic rocks (composed primarily of feldspar (sodium and potassium aluminosilicate) and quartz (silicon oxide)). Thirteen are large enough to include in this compilation. Four of these deposits are associated with continental igneous arcs that formed as a result of subduction of tectonic plates, analogous to the geologic setting previously described for porphyry copper deposits. A complete continuum exists between subduction-related porphyry copper deposits (that contain some molybdenum) and porphyry molybdenum deposits (with some copper). Subduction-related molybdenum-copper deposits tend to be low grade and have low fluorine contents.

However, nine of the hydrothermal molybdenum deposits included in the compilation are associated with magmas that are generated when continental crust is pulled apart. These **Climax-type molybdenum deposits** formed from hydrothermal fluids derived from shallowly-emplaced, silica- and fluorine-rich magmas in continental rifts (Carten and others, 1993). Magmas associated with the continental rift-associated deposits in the United States do not appear to be related to mantle plumes. Instead, the magmas are generated as hot mantle rises and melts in areas where continental tectonic plates are being pulled apart following a period of subduction-related magmatism. The molybdenum deposits tend to be found far from continental margins in areas of thick continental crust (Ludington, 1986). Many of the deposits in this compilation are associated with a Tertiary continental rift Colorado and New Mexico; today the Rio Grande River follows this partially-filled rift valley. Climax-type molybdenum deposits tend to have higher molybdenum grades than the subduction-related deposits.

Like porphyry copper deposits, economic porphyry molybdenum deposits (both subduction-related and rift-related) are primarily Cretaceous and Tertiary in age (Carten and others, 1993).

Platinum-group elements and nickel

The platinum-group elements (PGE) are platinum, palladium, rhodium, iridium, ruthenium, and osmium. In general, platinum-group elements exhibit high density, high electrical conductivity, high melting points, and low reactivity (Mineral Information Institute, USGS, and American Coal Foundation, undated). Platinum is used in automobile pollution abatement systems, jewelry, and catalysts to produce industrial chemicals. Palladium is used in automobile pollution abatement systems, electronic components, process catalysts, and dental alloys. Identified world resources of platinum-group elements in mineral concentrations that can be mined economically are estimated to total more than 100 million kilograms (USGS, 2004). In 2003, the United States imported 111,000 kilograms platinum and 73,000 kilograms palladium for consumption (USGS, 2004). For the same year, mine production in the United States was 4,100 kilograms platinum and 14,600 kilograms palladium.

Table 10. Platinum-group elements - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Platinum, percent of world production, 2003	Palladium, percent of world production, 2003	Palladium, Rank of world production	PGE, Percent of world reserves	PGE, Percent of world reserve base
United States	2.2	8.5	3	1.3	2.5

Nickel is a silvery metallic element (Mineral Information Institute, USGS, and American Coal Foundation, undated; International Nickel Study Group, undated). About 65 per cent of nickel is used to manufacture stainless steels and 20 per cent in other steel and non-ferrous (including "super") alloys, often for highly specialized industrial, aerospace and military applications. About 9 per cent is used in plating and 6 per cent in other uses including coins and a variety of nickel chemicals. Globally, identified land-based resources averaging 1 percent nickel or greater contain at least 130 million metric tons of nickel (USGS, 2004). In 2003, the apparent primary consumption of nickel in the United States was 218,000 metric tons (USGS, 2004). No mine projection, reserves, or reserve base of nickel have been reported in the United States (USGS, 2004). However, magmatic mineral deposits that PGE commonly contain nickel and copper. Nickel is recovered from the magmatic PGE deposit in the Stillwater Complex, Montana; a large resource of nickel is associated with copper and PGE-bearing rocks of the Duluth Complex, in Minnesota (figure 15).

Magmatic PGE deposit in the Stillwater Complex, Montana A major palladium-platinum deposit in south-central Montana, the J-M Reef, is currently the sole source of primary PGE production and reserves in the United States. This deposit is associated with igneous activity that probably resulted from an Archean mantle plume event (Ernst and Buchan, 2001). The only geologic feature that is attributed to this event is an igneous intrusion, the Stillwater Complex. Layers of igneous rock, characterized by different proportions, sizes, and shapes of igneous minerals, formed when this intrusion cooled and crystallized. In the Stillwater Complex, over 5,500 meters of layered rocks are exposed. Igneous layering is an uncommon phenomenon; the minerals in most igneous intrusions are homogeneously distributed.

Layered igneous intrusions, like the Stillwater Complex, are economically important because they can host magmatic mineral deposits containing economic concentrations of chromium, nickel, copper, titanium, and platinum-group elements (Zientek and others, 2002). The mineralization can also occur as layers within the intrusion that also may be enriched in chromium or titanium and vanadium; sulfide mineralization variably enriched in PGE can also occur in the rocks that crystallized near the margin of the intrusion (fig. 33). The palladium-platinum deposit at Stillwater, the J-M Reef, is a 1- to 3 m-thick layer that contains 0.5 to 3 volume percent PGE-enriched sulfide minerals. The sulfide minerals represent the crystallization products of an immiscible sulfide liquid that formed by the mixing of two magmas in the intrusion. The J-M Reef sulfide mineralization has been traced for 42 kilometers along the extent of the intrusion and at least a kilometer down the dip of layering. The average grade is 19 grams per ton palladium and platinum with a palladium- to platinum ratio of 3.4 to 1. Geologic resource estimates range from 116 to 421 million metric tons of ore containing 18.8 grams per ton palladium plus platinum. Two mines, the Stillwater mine and the East Boulder mine, are developing this deposit.

Mineral deposits similar to the J-M Reef in the Stillwater Complex are the major source of platinum in the world (Sutphin and Page, 1986; Cawthorn, 1999). The largest deposit, the Merensky Reef, is in South Africa. An analogous deposit also is being mined in Zimbabwe. Although the J-M Reef is smaller than these deposits in Africa, it has the highest overall concentration of platinum-group elements.

Magmatic copper-nickel-PGE deposits in the Duluth Complex_Approximately 1.1 Ga, a mantle plume is thought to have developed under what is now the area around Lake Superior. This plume event was associated with the eruption of lavas and emplacement of igneous intrusions between 1,109 and 1,087 Ma along a linear belt where the earth’s crust subsided forming a rift valley. The rift extends for more than 2,500 kilometers from Kansas northward beneath Lake Superior and then southeast through Michigan (fig. 13); however, exposures of rocks related to the rift are only found in the Lake Superior region (Schulz and Cannon, 1997). Igneous rocks associated with this event cover more than 160,000 square kilometers (Ernst and Buchan, 2001). The largest of the intrusions is known as the Duluth Complex (fig. 22; Miller, Green, and others, 2002). When this intrusion was emplaced, it reacted with the surrounding rocks resulting in the formation and segregation of immiscible liquids containing copper, nickel, platinum-group elements and cobalt. As a result, large volumes of rock with a few percent sulfide minerals occur along the western margin the Duluth Complex; locally, the rocks are made up almost entirely of sulfide minerals. Exploration activity has delineated several low-grade nickel-copper deposits in these rocks that have local zones enriched in platinum-group elements. At this time, no mines are developing these resources. Listerud and Meineke (1977) estimate the resources along the western margin of the complex to be 4,400 million short tons of rock containing 0.66 percent copper and 0.20 percent nickel. This represents the largest known nickel resource in the United States and is one of the largest in the world. Subsequent exploration has focused on three deposits – Dunka Road (the Northmet project), Babbitt (the Mesaba project), and Maturi. An open pit minable resource of 808 million metric tons containing 0.432 percent copper, 0.109 percent nickel, 0.166 grams per ton platinum, 0.437 grams per ton palladium, 0.061

grams per ton gold, and 1.5 grams per ton silver has been defined at the Northmet project (Polymet Mining Corporation, 2003). PGE, along with copper and nickel, will be recovered when these deposits are developed. Worldwide, this type of large tonnage, low grade copper-nickel-PGE mineralization is relatively uncommon. Similar deposits are known in South Africa, Finland, Australia, Canada, and Russia.

Rare-earth elements

The rare-earth elements (REE) are a group of 17 elements that include scandium, yttrium, and the lanthanides. The lanthanides, a group of 15 elements with atomic numbers 57 through 71, are lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium. (Mineral Information Institute, USGS, and American Coal Foundation, undated). The REE are a chemically coherent group of elements with diverse nuclear, metallurgical, chemical, catalytic, electrical, magnetic, and optical properties. Uses of REE range from the ordinary, such as glass polishing and lighter flints, to high-tech, such as liquid crystal displays, fiber-optic cables, and, potentially, magnetic refrigeration. In 2002, the approximate distribution by end use was: petroleum refining catalysts, 27 percent; glass polishing and ceramics, 23 percent; automotive catalytic converters, 21 percent; metallurgical additives and alloys, 15 percent; permanent magnets, 5 percent; rare-earth phosphors for lighting, televisions, computer monitors, radar, and X-ray intensifying film, 4 percent; and other uses, 5 percent (USGS, 2004).

REE are relatively abundant in the Earth's crust, but minable concentrations are uncommon. United States and world resources are contained primarily in the minerals bastnäsite, a rare-earth fluorocarbonate mineral, and monazite, a rare-earth phosphate mineral (USGS, 2004). Bastnäsite deposits in China and the United States make up the largest proportion of the world's identified economic resources of REE; ion-absorption clays are also a significant source of REE in China. The remaining resources are monazite deposits located in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand, and the United States (USGS, 2004). In the United States, production is from a single deposit, Mountain Pass, in California (fig. 27). Until the mid-1960s, almost all REE production was derived from monazite-bearing placer deposits (Haxel and others, 2002). In 1965, bastnäsite production began at the Mountain Pass deposit; this single deposit dominated world REE supply until the mid-1980s. The United States was once largely self-sufficient in REE, but has become a net importer in the last decade, with more than 90 percent of US industry needs now supplied by deposits mined in China (Haxel and others, 2002).

Table 11. Rare-earth elements - proportion of world mine production in 2002 and 2003, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2002	Percent of world production, 2003	Rank of world production, 2002	Percent of world reserves	Percent of world reserve base
United States	5.1	none	2	14.8	9.1

REE in the United States are associated with uncommon and unusual igneous rocks (carbonatites) and with surficial (placer) deposits.

Carbonatites. The world's largest REE deposits are associated with igneous rocks called carbonatites. Carbonatites contain more than 50 percent by volume carbonate minerals, with calcite (calcium carbonate) and dolomite (calcium magnesium carbonate) most common. These carbonate-rich rocks commonly are part of larger complexes of alkaline intrusive and volcanic igneous rocks containing relatively high concentrations of potassium and sodium. Magmas that can crystallize large amounts of carbonate minerals are unusual; only about 330 carbonatites are known worldwide (Woolley, 1989). Igneous intrusions with carbonatite occur mainly on continents; they rarely are in an oceanic setting. The intrusions generally are found near large fractures in continental crust that formed as plate tectonic activity was stretching or extending the continental crust. Weathering of these deposits can generate REE-enriched soils.

The most important REE deposit in the United States, Mountain Pass in California, is associated with carbonatite. The REE mineralization is dominated by bastnäsite (rare-earth fluorocarbonate) with lesser parasite (a calcium rare-earth fluorocarbonate), monazite (rare-earth phosphate), allanite (rare-earth silicate) and other REE-bearing minerals. The economic potential of the Hicks Dome carbonatite in Illinois also has been evaluated. At least seven other carbonatites with REE mineralization are known to occur in the US, but are not considered to be economically viable sources of REE at the present time.

Alkaline deposits other than carbonatites. REE occur in a wide variety of alkaline igneous (enriched in sodium and potassium) and hydrothermally-altered rocks other than carbonatite. The REE ore minerals in these deposits include eudialyte (hydrated zirconium silicate with sodium, calcium, rare-earth elements, and iron), loparite (titanium-niobium oxide with cerium, sodium and calcium), allanite (rare-earth silicate), and REE-bearing zircon (zirconium silicate). These deposits are significant producers of byproduct REE in Russia and byproduct production has occurred from deposits in China and Brazil. The United States has resources in this type of deposit at Bokan Mountain and Mt. Prindle in Alaska, and at Wind Mountain (Cornudas Mountains) and Pajarito Mountain in New Mexico (Woolley, 1987).

Placer deposits. In placer deposits, the action of water tends to concentrate minerals of higher density that are resistant to abrasion through transport and to breakdown by chemical and mechanical action. Because many of these minerals are dense and (or) dark colored, these placer deposits are referred to as heavy mineral sands or as black sand placers. Minerals concentrated in this process include gold, ilmenite (iron titanium oxide), cassiterite (tin oxide), rutile (titanium oxide), zircon (zirconium silicate), monazite (rare-earth phosphate), xenotime (yttrium phosphate), and many others. Although monazite and xenotime contents of these placers are typically fairly low, these minerals have been extracted as byproducts of titanium, tin, and gold placer mining operations in the past. Recovery of byproduct monazite has been discontinued in recent years due to concerns related to the thorium content of most monazite. While thorium is not radioactive, thorium has radioactive daughter products. Historically, the United States has produced monazite from Idaho and the southeast United States, and significant reserves are still present.

Silver

Silver is a metal that has been used for thousands of years in jewelry, ornaments, and utensils; and as the basis of many monetary systems (Mineral Information Institute, USGS, and American Coal Foundation, undated). Industrial applications of silver include: electrical and electronic products, mirrors, and photography, which is the largest single end use of silver. Silver's catalytic properties make it ideal for use as a catalyst in oxidation reactions. Over 1.7 million metric tons of silver has been discovered in the world (Singer, 1995). In 2003, the apparent consumption of silver in the United States was 5,430 metric tons (USGS, 2004). About 21 percent of total silver discovered is in the United States. The location of major silver deposits in the United States is shown in figure 34.

Table 12. Silver - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	6.8	5	9.2	14.1

More than two-thirds of the world's silver resources are associated with copper, lead, and zinc deposits. The remainder is associated with hydrothermal gold deposits. Historically, the largest proportion of silver production in the United States has come from polymetallic replacement deposits, Coeur d'Alene polymetallic veins, and polymetallic veins (Long and others, 1998). Remaining resources associated with these deposit types are relatively small and mining has ceased except for two mines on Coeur d'Alene polymetallic veins.

Currently, the largest silver-producing mines in the United States are developed on VMS deposits, sedex deposits, distal disseminated gold-silver deposits, Coeur d'Alene polymetallic veins, and porphyry copper deposits (Hilliard, 2002). The majority of the identified remaining silver resources in the United States are associated with porphyry copper deposits; Revett copper deposits, and VMS deposits (Long and others, 1998). Silver production from epithermal deposits has been and will continue to be important. In the following sections VMS and sedex deposits are discussed first, followed by sections on Coeur d'Alene veins and Revett copper deposits. Deposits related to the igneous activity in subduction zones (porphyry copper deposits, polymetallic replacement deposits, and epithermal deposits) are discussed last.

VMS and sedex deposits Lead, zinc, and silver commonly occur together in mineral deposits that form from low-temperature hydrothermal fluids. In particular, two different-types of lead, zinc, and silver deposit types can form when hydrothermal fluids vent into the ocean. For the type geologists call **volcanogenic massive sulfide (VMS) deposits**, cooling of magma, either from volcanic rocks erupted on the ocean floor or emplaced in shallow intrusions, supplies the heat needed to generate hydrothermal solutions (fig. 29). For the type called **sedimentary exhalative (sedex) deposits**, hydrothermal solutions are generated as water-rich sediments are deeply buried in sedimentary basins within the crust (fig. 16). For both deposit types, hydrothermal solutions move towards the surface along fractures and form hot springs where they vent into the ocean. The hydrothermal solutions mix with ocean water and can deposit large quantities of iron, zinc, lead, silver, and copper minerals as mounds and layers on the seafloor.

VMS deposits are associated with magma that is generated at convergent plate boundaries. VMS deposits are a common deposit type and are widely distributed in orogenic belts around the world. Long and others (1998) identifies over 77 significant VMS deposits in the United States. They are associated with igneous arcs developed in the Cordilleran orogen (including deposits in the Brooks Range in Alaska; in southeast Alaska, and the Sierra foothills in California) and the Paleozoic igneous arcs of the Appalachian orogen. Proterozoic VMS deposits are associated with orogenic igneous arcs developed in what is now Wisconsin and Arizona. However, only three deposits, Arctic Camp, Greens Creek, and Crandon, were large enough to include in this compilation. The deposit at Greens Creek is currently being mined. Arctic Camp and Crandon have not been developed.

Sedex deposits are found in sedimentary basins characterized by high geothermal gradients (Lydon, 1988; Lydon, 1996). These basins commonly form as continents are pulled apart or rifted. Sedex deposits typically occur in large basins sometimes filled with more than 10 kilometers of sediments. Sedex deposits occur less frequently than VMS deposits. Long and others (1998) lists 6 significant sedex deposits in the United States; 3 are large enough to include in this report; silver is reported in two of these deposits (Red Dog and Su-Lik).

Coeur d'Alene-type polymetallic vein deposits - Since the 1880s, the Coeur d'Alene mining district has produced more than 30,000 metric tons of silver, more than any silver mining district in the world with the exception of Cerro Rico de Potosi in Bolivia (Long, 1998). Total production from the Coeur d'Alene district accounts for more than 28 percent of historic production of silver in the United States. In addition to silver, veins in this district have also produced significant amounts of lead and zinc with lesser amounts of copper, gold, cadmium, and cobalt. This style of silver-lead-zinc mineralization is unique to this mining district. Long and others (1998) described 26 significant deposits in the Coeur d'Alene district in northern Idaho; 5 deposits are large enough to include in this compilation. Two mines, the Galena and the Lucky Friday, are still active and ranked 4th and 7th in United States silver production in 2002 (Hilliard, 2002). Resources measured for the Lucky Friday mine and the Galena mine are 6.55 million metric tons containing 538 grams per ton silver, 10.2 percent lead, and 1.6 percent zinc and 6.3 million metric tons containing 777 grams per ton silver, 0.8 percent copper, 0.15 percent lead, and 0.03 percent antimony, respectively (Long, 1998).

Coeur d'Alene (CDA)-type polymetallic vein deposits are clustered near large faults that cut metamorphosed sedimentary rocks of the **Belt basin** (Hobbs and Fryklung, 1968). The middle Proterozoic **Belt basin** covers 200,000 square kilometers and extends from Idaho, Montana, and Washington north into Canada (fig. 17; Chandler, 2000). These faults are the western end of a complex system of faults that extend from northern Idaho to south-central Montana (Smith, 1965). These near vertical faults have a long and complex history of movement. The zone affected by faulting is up to several kilometers wide. The veins occur in fractures that develop near the large faults in any metamorphosed sedimentary rock derived from fragments of older rocks. However, silver-lead-zinc ore bodies are commonly found in rocks that are relatively more difficult to deform, such as quartzite (quartz (silicon oxide)-rich metamorphosed sedimentary rock).

There are literally hundreds of veins, both mineralized and barren, that belong to the main period of lead-zinc-silver mineralization of the Coeur d'Alene district (Hobbs and Fryklung, 1968). Most of the veins range in width from a few millimeters up to 3 meters. Unmineralized veins are composed mainly of quartz (silicon oxide) and carbonate minerals. Mineralized veins also contain various proportions of galena (lead sulfide), sphalerite (zinc-iron sulfide), and tetrahedrite (copper-iron-zinc-silver-antimony sulfide). Some veins are mined mostly for lead and zinc, whereas others are mined mostly for silver (Box and others, 1995; Long, 1998). The mineralized portions of veins are called ore shoots. The vertical dimensions of ore shoots are several times longer than their horizontal dimensions. Measured horizontally, individual ore shoots range in length from several meters to over 1 kilometer. The vertical dimension of ore shoots can exceed 2 kilometers.

The faults and the veins formed late in the sequence of events that deformed and metamorphosed the sedimentary rocks (Hobbs and Frykland, 1968). These veins are deposited from hydrothermal fluids generated by metamorphism of the sedimentary rocks (Fleck and others, 2002). Subduction-related magmatism that formed a Cretaceous batholith (large mass of igneous intrusions) in Idaho may have been the thermal event that initiated the metamorphism of the rocks and caused long-distance migration of hydrothermal fluid. The fault zones were the pathways that controlled the migration of the hydrothermal fluids.

Revett copper deposits Revett copper deposits are lens-shaped bodies of disseminated copper sulfides with silver that occur in a narrow interval of sedimentary layers in a large sedimentary basin (Hayes and Einaudi, 1986; Hayes and others, 1989; Hayes, 1990; Cox and others, 2003). However, mineralization does not necessarily conform to sedimentary bedding. These deposits form after the host sediment is deposited, but in most cases, before the sediment is converted into solid rock. The ore minerals appear to have been deposited from waters that filled pores between the sediment particles. These copper deposits are formed where waters of different composition and temperature mix in the subsurface in porous sedimentary rocks. The distribution of minerals in the rocks that host the deposit indicate that the sulfide minerals were deposited as warm, salty, metal-bearing water (brine) moved through the porous beds and mixed with cool, pre-existing pore water.

Revett-type copper deposits occur in quartzite beds (quartz-rich metamorphosed sedimentary rocks) of the Revett Formation in the **Belt basin**, a middle Proterozoic sedimentary basin (figs. 17 and 21; Harrison, 1972). This basin formed about 1.5 Ga when a rift developed on a supercontinent that was made up of most of North America, along with Siberia, Australia, or Antarctica filled with sediment (Chandler, 2000; Lydon, 2000). The sediment layers were originally deposited on the bottom of a lake or an embayment open to the ocean. As layers were buried by younger sediments, their pore waters become warmer and contained more dissolved components. The pressure of the overlying sediments and the high geothermal gradients associated with basins that form as continents are pulled apart can ultimately drive these warm brines upwards along faults that were active during deposition of the basin. Fluid mixing responsible for mineral deposition occurred as these brines moved vertically through the section and laterally into the porous sediment layers that ultimately were converted into quartzite.

Long and others (1998) described 9 significant Revett-type copper deposits; 2 deposits are large enough to include in this compilation. The median size of a Revett-type sediment-hosted copper deposit is 14 million metric tons with 0.79 percent copper and 31 grams per ton silver (Cox and others, 2003). The largest deposit, Rock Lake-Rock Creek, contains approximately 300 million metric tons of ore containing 0.81 percent copper and 71 grams per ton silver.

Porphyry copper deposits Hydrothermal copper mineral deposits associated with composite volcanoes are called porphyry-type deposits by geologists (figs. 19 and 20). This type of hydrothermal copper mineralization forms deep beneath steep-sided volcanoes that form as magma rises to the surface along subduction zones. Porphyry copper deposits are derived from hydrothermal fluids released from and driven by the cooling magma deep within the volcano. As the fluids cool and react with rocks, copper and other metals, such as silver, is deposited both in the igneous porphyry intrusions as well as adjacent rocks (fig. 19). Silver, along with gold and molybdenum, is recovered as a by-product of mining copper from porphyry copper deposits. Eight of the 9 top producing mines developed on porphyry copper deposits are in southeast Arizona and southwestern New Mexico (National Mining Association, 2003a). The remaining deposit is in Utah.

Polymetallic replacement deposits form when hydrothermal solutions generated and driven by the cooling of volcanic rock and shallow igneous intrusions flow into nearby carbonate sedimentary rocks (Nelson, 1996). The igneous activity is related to igneous arcs developed by subduction of oceanic crust beneath the western margin of the United States. Polymetallic replacement deposits are typically associated with, but distal from, porphyry copper mineralization (figs. 19 and 20). Ore minerals, typically galena (lead sulfide), sphalerite (zinc-iron sulfide), tetrahedrite (copper-iron-zinc-silver-antimony sulfide), and other silver sulfosalts (minerals that contain silver, a semi-metal such as antimony or arsenic, and sulfur), can be deposited along bedding, related to dissolution of carbonate sedimentary rocks, and fracture zones to form irregularly shaped orebodies that can form horizontal sheets (mantos) parallel to sedimentary bedding or veins or pipes discordant to bedding. These deposits are variably enriched in silver, lead, and zinc. Long and others (1998) described 45 significant polymetallic replacement deposits in the United States; 8 deposits in Arizona, Colorado, Nevada, and Utah are large enough to include in this compilation. The mines on these major deposits are now closed.

Distal disseminated gold deposits are found sedimentary rocks that may be over 1 kilometer from igneous intrusions that cooled and crystallized to form porphyry copper deposits (fig. 19). Gold and silver mineralization is associated with the dissolution of carbonate minerals and the deposition of silica in sedimentary units. Silver and gold minerals may be dispersed throughout altered sedimentary rock or be concentrated in narrow veinlets and fractures (Peters and others, 2004). Fractures are the most important feature that controlled the flow of hydrothermal fluids and the concentration of gold and silver. Long and others (1998) described 25 significant deposits in the United States; 1 deposit in Arizona and 4 in Nevada are large enough to include in this compilation. Examples of distal disseminated deposits currently being mined in Nevada include McCoy-Cove and Rochester.

Epithermal gold deposits form less than a kilometer below the surface of the Earth and typically are found with volcanic rocks that are related to igneous arcs formed at convergent tectonic plate margins (Cooke and Simmons, 2000; Hedenquist and others, 2000). Typically, the volcanic rocks were erupted on the land surface rather than beneath the ocean. These deposits commonly are found in young orogens where rocks formed near the surface of the earth are more likely to be preserved. These epithermal deposits can be enriched in gold and silver and also can contain minor amounts of zinc, lead, and/or copper.

The most common type of deposit forms from hydrothermal fluids that are similar to waters tapped by drilling beneath modern geothermal hot springs. In most cases, geothermal systems are driven by intrusions located as much as 5 to 6 kilometers below the surface. Epithermal gold deposits formed from geothermal systems usually occur several kilometers above the site of the igneous intrusion. Gold and silver deposition is initiated as the hydrothermal fluids start to boil when they approach the surface. Gold and silver are commonly associated with quartz (silicon oxide) and adularia (potassium aluminum silicate). Gold and silver are concentrated in places where the hydrothermal solutions could easily flow – fractures, faults, and porous volcanic and sedimentary units (fig. 26). If the hydrothermal fluids discharge to the land surface, they form boiling hot springs that deposit silica, similar to those found today in Yellowstone National Park. Long and others (1998) described 129 significant epithermal and hot-spring gold deposits in the United States; 11 deposits are large enough to include in this compilation. Over 40 percent of the significant and major deposits are in Nevada; significant deposits also occur in Alaska, Arizona, California, Colorado, Idaho, Montana, North Carolina, New Mexico, Oregon, South Carolina, Utah, and Washington. Examples of epithermal deposits recently being mined include Round Mountain, Mesquite, and McLaughlin.

Titanium

Titanium is a hard silvery-white metallic element found in the minerals ilmenite, leucoxene, and rutile (Mineral Information Institute, USGS, and American Coal Foundation, undated; Rio Tinto, 2001). Titanium dioxide (TiO_2) is world's premier white pigment in the coatings and plastics industry, which accounts for nearly all of its industrial applications. Titanium dioxide is non-toxic and biologically inert, so is used for coloring in foodstuffs like flour, icing sugar, sweets, cosmetics and toothpaste. Titanium metal is strong yet lightweight. About 65 percent of the titanium metal is used in aerospace applications; the remaining 35 percent is used in medical, sporting goods, and other applications. Ilmenite supplies about 90 percent of the world's demand for titanium minerals. Identified world ilmenite resources total about 1 billion metric tons of titanium dioxide (USGS, 2004). Identified world resources of rutile (including anatase) total about 230 million metric tons of contained TiO_2. The location of major titanium deposits in the United States is shown in figure 27.

Table 13. Titanium concentrate (ilmenite) - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	7.0	5	1.4	8.0

Economic titanium mineralization occurs as primary deposits, formed by igneous processes, or secondary (surficial) deposits, formed by weathering and sedimentary processes. In primary deposits, concentrations of titanium-enriched minerals form during the crystallization of igneous rocks (Gross, 1996b). Production of titanium from primary deposits in the United States is largely of historical interest (Harben and Kužvart, 1996). Large reserves of primary titanium minerals occur in an igneous rock called anorthosite in the Adirondack Mountains of New York State. However, production from these deposits ended in the 1970s. Secondary deposits form as titanium-rich minerals are weathered from rocks. Titanium-enriched minerals are heavier than many other minerals; flowing water will concentrate these heavy minerals in sediments (Harben and Kužvart, 1996). Most production and known reserves of titanium in the United States occur in heavy-mineral sand deposits. These deposits are known to occur on the United States Atlantic and Gulf coastal plains, from New Jersey to Florida (Harben and Kužvart, 1996). The deposits formed on the shoreline of the ocean; however, they are not restricted to the present-day coast. Sea-level has risen or lowered many times due to expansion or contraction of the polar ice caps in the last 1.6 million years. As a result, heavy-mineral sand deposits can now be found inland, 10s of meters above current sea-level, or off-shore on the continental shelf.

The largest secondary deposit in the United States is Trail Ridge in Florida (fig. 35). Trail Ridge is the largest of several long, low north-trending heavy-mineral enriched sand ridges in Florida (Force, 1991; http://tapestry.usgs.gov/features/43trailridge.html accessed May 6, 2004). The Trail Ridge deposit is part of a 200-km long sand ridge that extends from north-central Florida to southeastern Georgia (Harben and Kužvart, 1996). The commercial section of Trail Ridge is 27 kilometers long and 1.5 to 3 kilometers wide. It has an average thickness of 12 meters and contains on average 3.5 percent heavy minerals. About half of these heavy minerals contain titanium. Other heavy-mineral bearing sand ridges in northern Florida and southern Georgia include Green Cove Springs, Folkston, Boulogne, Jacksonville, and Mineral City (Ponte Vedra) (fig. 35; Harben and Kužvart, 1996). These ridges are complexes of sand dunes formed near the shoreline during different stands of sea-level during the Pleistocene. The titanium minerals were ultimately derived from rocks in the southern Appalachian Mountains. DuPont has extracted heavy minerals from Trail Ridge sands since 1949 (http://www.titanium.dupont.com/NASApp/TTPORTAL/Mediator?action=230 accessed May 6, 2004). Major shoreline deposits of heavy-mineral sands are also mined in Australia and have been discovered in Africa; smaller shoreline deposits have been developed in India and Sri Lanka.

Industrial materials

Barite

Barite is a mineral comprised of barium sulfate. Barite is relatively soft but is unusually heavy for a nonmetallic mineral (Mineral Information Institute, USGS, and American Coal Foundation, undated). The high density is responsible for its value in many applications. Barite is chemically inert and insoluble. Nearly 98 percent of the barite used in the United States is as a weighting agent in oil- and gas-well drilling fluids. Because it looks opaque on X-ray film, barium is used in medicine to diagnose gastrointestinal problems. The world's identified barite resources are about 2 billion metric tons, but only about 740 million metric tons are in identified reserves (USGS, 2004). The apparent consumption of crude barite was 2,470,000 metric tons in 2003 (USGS, 2004). The location of major barite deposits in the United States is shown in figure 36.

Table 14. Barite - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	7.2	3	13.1	8.1

Most barite mined in the United States comes from bedded barite deposits in Nevada (Harben and Kužvart, 1996). These deposits occur in a northeast-trending zone up to 100 kilometers wide that stretches about 480 kilometers across the central part of the state. This zone coincides with the extent of the Antler orogenic belt. This orogenic event was caused by the convergence of tectonic plates beginning in the Late Devonian; it is an early phase of the Cordilleran orogen.

Barite deposits occur as layers with organic-rich and silica-rich sedimentary rocks that commonly formed in deep water in ocean basins (Paradis and others, 1999). These barite-rich layers may be meters thick and may extend laterally over several square kilometers. The bedded barite deposit at the Greystone mine, Nevada is about 17 meters thick (Harben and Kužvart, 1996).

The bedded barite deposits in Nevada formed around springs where solutions moving through the sediments vented into the ocean. These solutions mixed with ocean water and formed layers of barite on the seafloor. This process is similar to the formation of sedex deposits (see discussion on cobalt or lead-zinc); however, no iron-lead-zinc sulfide minerals are formed. Some geologists believe the barite deposits formed from hydrothermal solutions that vented to the seafloor to form sedex lead-zinc deposits (Paradis and others, 1999). In this view, the iron-lead-zinc sulfide minerals are deposited close to the vent while barite-rich layers are formed at some distance from the vent. However, others believe the deposits like those in Nevada formed where cold, methane- and barium-rich fluids seeped into the oceans (Torres and others, 2003) and have no relationship to higher-temperature sedex-forming vent systems. Modern barite deposits that are found forming around active methane seeps on the ocean floor support their hypothesis. Modern cold seeps are often associated with faults located along continental margins.

Bentonite

Bentonite is a rock consisting of clay minerals (Mineral Information Institute, USGS, and American Coal Foundation, undated). The most common clay minerals in bentonite are one or more members of the smectite mineral group (most commonly the mineral montmorillonite, a hydrous aluminum silicate with some calcium, sodium, potassium, or magnesium). The properties of bentonite are dictated by the properties of the dominant clay minerals. For the most part, bentonites are divided into sodium bentonite (swelling bentonite) and calcium bentonite (non-swelling bentonite); other varieties of bentonite include palygorskite and hectorite (discussed below; Harben and Kužvart, 1996). Most bentonites can swell to over 10 times their dry volume with the addition of liquid; have the ability to increase the viscosity of a liquid; and have good bonding characteristics and high adsorption. These properties lead to diverse end uses such as drilling mud, pet litter, chemical carrier, thickeners, and fillers. Almost half of the world production of bentonites is from the United States. The location of major bentonite deposits in the United States is shown in figure 37.

Table 15. Bentonite - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003	Rank of world production
United States	39.2	1

Bentonite deposits can form through a variety of processes that alter volcanic rocks (commonly tuffs) and, on rare occasions, other rocks. The most extensive deposits are derived the alteration of volcanic ash beds deposited in water. Volcanic ash is dust-sized particles of rock ejected from a volcano. The dust is transported through the air and ultimately settles as layers on land or is deposited as beds underwater. The ash beds that are altered to form bentonite are made up of particles of volcanic rocks derived from magmas that are enriched in silicon and aluminum and would crystallize feldspars and quartz. The ash beds deposited in oceans alter to form bentonite only if the water composition is alkaline (contains various soluble salts sufficient to raise the pH value above 7.0). Bentonite is stable near the surface of the Earth. The abundance of this mineral decreases with depth in the crust; bentonite is not found at greater than 4 kilometers (Hosterman and Orris, 1998a,b; Weaver, 1959). Most deposits are Cretaceous or younger in age.

Sedimentary bentonite. Sedimentary bentonite forms through the chemical alteration of volcanic ash deposited in, or washed into, an alkaline ocean environment. Calcium bentonite forms where calcium-ions are available. Sodium bentonite only forms where calcium-ion concentrations are low and sodium ions are relatively abundant (Hosterman and Orris, 1998a,b). Deposits range in age from Cretaceous to mid-Tertiary. Major sodium bentonite deposits are found in two districts in the western United States: the Hardin district (Montana and Wyoming) and the Black Hills district (Montana, Wyoming, and South Dakota). As much as 90 percent of sodium-bentonite production has come from these two areas. In the United States, the most significant Ca-bentonite resources are in the Aberdeen-Tipley district in Mississippi.

Hectorite. Hectorite is a lithium-bearing variety of smectite, a clay mineral. Hectorite deposits occur in a variety of geologic settings. Hectorite deposits form by: 1) alteration of volcanic glass to lithium-rich smectite; 2) precipitation from lake waters; and/or 3) incorporation of lithium into existing smectites (Asher-Bolinder, 1991). All deposits form in arid environments and are associated with alkaline waters enriched in magnesium and lithium, volcanic rocks, hot-spring travertine deposits, and very fine-grained masses of silica (Odom, 1992; Asher-Bolinder, 1991).

Palygorskite. Palygorskite is a clay mineral that can contain up to 50 percent water. Palygorskite commonly forms through alteration of smectite clays in sediments in an ocean environment or as a primary precipitate through a reaction between sea water and magnesium-rich sea water (Hosterman, 1998). Known deposits in the United States are Tertiary in age.

Boron

Boron is a semi-metallic element that is a dark, amorphous (noncrystalline), nonreactive solid (Mineral Information Institute, USGS, and American Coal Foundation, undated). Borates, which are usually boric acid and anhydrous borax, are processed from boron minerals. Borates have a wide variety of uses, such as in ceramic glazes, fertilizers, fire retardants, and soaps and detergents. Sales of boron for glass consumption represented 78 percent of domestic demand in 2002 (Lyday, 2002). The location of major boron deposits in the United States is shown in figure 38.

Table 16. Boron - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	24.4	2	23.3	19.6

Four minerals comprise almost 90 percent of the borates used by industry worldwide; they are the hydrated sodium borates, borax and kernite, the hydrated calcium borate, colemanite, and the hydrated sodium-calcium borate, ulexite. These minerals are extracted primarily in California and Turkey and to a lesser extent in Argentina, Bolivia, Chile, China, and Peru. The majority of boron production in California is from Kern County, California, with the balance from San Bernardino and Inyo Counties, California (Lyday, 2002). Large domestic reserves of boron materials occur in California, chiefly in sediments and their contained brines. Extensive resources also occur in Turkey. At current levels of consumption, world resources are adequate for the foreseeable future (USGS, 2004). In 2003, the apparent consumption of boric oxide in the United States was 488,000 metric tons (USGS, 2004).

Most of the world’s significant commercial borate deposits were created by the evaporation of shallow lakes that were fed by boron-bearing springs (Harben and Kužvart, 1996; Smith, 2002). Boron-bearing springs are spatially associated with volcanic activity. Boron is leached from hot rock associated with tectonic plate subduction zones and is concentrated in water that moves through geologic formations on its way to the surface where it forms geothermal springs (Smith, 2002). If the springs feed into lakes in closed basins characterized by high-evaporation rates, boron salts will crystallize and form layers in sediments that accumulate in the lake. The boron-bearing salt layers are surrounded by layers of clay minerals that prevent the salt layers from being re-dissolved. Almost all important sedimentary borate deposits are less than 20 million years old.

The Boron deposit (Kramer district) in California has been the world’s leading source of borates since it opened in 1926 (Harben and Kužvart, 1996). The deposit is a sodium-borate bed that occurs in lake deposits near the edge of a large Tertiary sedimentary basin. The sodium-borate deposit is more than 3 kilometers long, 1.5

kilometers wide, and ranges from a meter to 10 meters thick. Only the Bigadic, Emet, and Kirka deposits in Turkey are larger than the Boron deposit (Deeby, 2002).

Bromine

Bromine is a reddish-brown fuming liquid at room temperature; it has a very strong irritating odor and is chemically reactive and rather poisonous (Mineral Information Institute, USGS, and American Coal Foundation, undated). The natural form of bromine is a solution of sodium bromide in natural brines, oceans, salt lakes, and seas. Bromine is used in agriculture, fire retardants, petroleum additives, and other applications. Resources of bromine are virtually unlimited. In 2003, the apparent consumption of bromine in the United States was 211,000 metric tons (USGS, 2004). The location of the major bromine deposit in the United States is shown in figure 38.

Table 17. Bromine - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003	Rank of world production
United States	38	1

The major commercial sources of bromine are seawater (containing an average of 65 parts per million bromine) and surface and subsurface brines (Harben and Kužvart, 1996). Subsurface brines in Arkansas contain about 5,000 parts per million bromine; the brines that make up the Dead Sea contain between 5,000 and 10,000 parts per million bromine.

Brines produced from wells in Arkansas and Michigan are the main source of United States bromine production (Harben and Kužvart, 1996). The brines occur in sedimentary layers in the Gulf Coast and Michigan sedimentary basins. Both basins contain thick layers of evaporite minerals such as salt (sodium chloride). The brines may represent a mixture of trapped seawater, fluids expelled from the salt layers, or ground waters that dissolved beds of salt, gypsum, and carbonate minerals.

Diatomite

Diatomite is a sedimentary rock consisting chiefly of the fossilized, silica-rich skeletons of single celled aquatic plants called diatoms. Diatomite is chemically inert and stable. This characteristic, combined with the varying shapes and sizes of the diatom fossils, makes diatomite a popular filter aid. Diatomite's brightness, low bulk density, high adsorptive capacity, and its high surface area combined with its chemical stability lead to its use as a filler, as a carrier (such as for pesticides and herbicides), and as an abrasive. Estimated end uses of diatomite in the United States were filter aids (68 percent); absorbents (14 percent); fillers (12 percent); and other (mostly cement manufacture - 6 percent; USGS, 2004). The location of major diatomite deposits in the United States is shown in figure 37.

Table 18. Diatomite - proportion of world mine production and reserves for the United States.

[USGS, 2004; reserve is defined in Appendix 3]

Country	**Percent of world production, 2003**	**Rank of world production**	**Percent of world reserves**
United States	36.3	1	27.3

Economic diatomite deposits can be found in sedimentary rocks deposited in lakes and the ocean. Diatoms first became numerous in the Late Cretaceous (Harben and Kužvart, 1996) and most commercial deposits are Tertiary in age. Formation of high grade deposits requires a large continuous supply of silica, clear water, and adequate light and nutrients (phosphate and nitrogen). In ocean environments, these conditions typically occur in submerged coastal basins and shelves where nutrients and silica are supplied by upwelling ocean waters and limited sediment is derived from surrounding land masses. The largest production of high-purity diatomite comes from the extensive deposits near Lompoc, California (Harben and Kužvart, 1996). These deposits in the Miocene Sisquoc Formation formed from ocean waters and extend in a belt for more than 160 kilometers. About 25 minable units occur with in the upper part of the Sisquoc Formation, ranging in thickness from 1 to 10 meters. A notable example of a diatomite deposit that formed in a fresh water lake in a closed basin occurs near Lovelock, Nevada. Numerous other deposits occur throughout the United States, although most productive deposits are found in the west.

Garnet

Garnet refers to a group of chemically-complex and physically-similar minerals. They are silicate minerals that also contain variable proportions of iron, aluminum, magnesium, and calcium. Garnets are all quite hard – harder than most common rock-forming minerals, including quartz (silicon oxide), but less hard than corundum (aluminum oxide) or diamond (carbon). When broken, they fracture into sharp, irregular pieces. The hardness and irregular fracture of garnet make it a valuable abrasive material. The color of garnet is typically deep red but can occur as green or yellow crystals. Large, clear crystals with few flaws are used in jewelry. The vast majority of garnet is used as an abrasive blasting material, for water filtration, in a process called water jet cutting, and to make abrasive powders (Mineral Information Institute, USGS, and American Coal Foundation, undated). The location of major garnet deposits in the United States is shown in figure 36.

Table 19. Garnet - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003	Rank of world production
United States	13.8	3

Garnets are most commonly formed by metamorphism of other rocks. Garnets will form in igneous or sedimentary rocks (containing the appropriate proportions of silicon, aluminum, iron, magnesium, and calcium) when temperatures exceed 500˚C and the depth of burial ranges from 6 to 30 kilometers (Bucher and Frey, 2002). Large domestic resources of industrial garnet are associated with unique metamorphic rocks found near North Creek, New York (USGS, 2004). At this locality, a metamorphosed igneous rock contains 5 to 20 percent garnet that forms crystals measuring 5 centimeters to nearly a meter in diameter (Harben and Kužvart, 1996). When crushed, these garnets break into sharp, chisel-like fragments. It has been estimated that this deposit contributes about 95 percent of the world's production of high-quality abrasive-grade garnet.

Due to its high density, garnet can be concentrated into surficial deposits by running water. In Idaho and Montana, the concentration of garnet is great enough to form a placer garnet deposit than can be economically developed. The Emerald Creek placer garnet deposits are currently being mined from modern and ancient stream deposits in Benewah County, Idaho (Harben and Kužvart, 1996). Garnet in these deposits is derived from metamorphosed sedimentary rocks.

Gypsum

Gypsum (hydrated calcium sulfate) is the most common of the approximately 150 sulfate minerals. More than two-thirds of the produced gypsum is used for plaster and wallboard in houses and other buildings (Mineral Information Institute, USGS, and American Coal Foundation, undated). Gypsum is produced from 50 mines located in 19 states (Olson, 2002). The location of major gypsum deposits in the United States is shown in figure 38.

Table 20. Gypsum - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003	Rank of world production
United States	15.7	1

Bedded deposits of gypsum in sedimentary rocks are the primary source of gypsum mined in the United States. These gypsum layers are found in sedimentary basins with restricted circulation where brines formed as the result of the evaporation ocean or lake water. The first minerals to crystallize from evaporated water are gypsum and carbonates (Guilbert and Park, 1986). If evaporation continues, salt (halite or sodium-chloride) and potash (sylvite or potassium chloride) will precipitate, followed by a variety of salts of potassium, sodium, magnesium, chlorine, and bromine late in the evaporation process. The actual proportions of minerals that precipitate are determined by the unique conditions that developed for each basin.

Several sedimentary basins host major bedded gypsum deposits in the United States (fig. 38; Harben and Kužvart, 1996). Silurian rocks host gypsum deposits at two localities on the northwest margin of the Appalachian Basin in New York and Ohio. In the Michigan basin, Mississippian rocks with gypsum deposits are found in Michigan and Indiana. Gypsum deposits in the Permian Basin are mined in Oklahoma, Texas, and Kansas. In California, gypsum deposits occur in the Miocene Salton (or Guaymas) basin. The thickness of the gypsum beds mined in these deposits range from 1 to 35 meters.

Kaolin

Kaolin is a term for a group of clays that might best be described as kaolinite-bearing clays. This group of clays includes commercial varieties (or subgroups) such as ball clay, halloysite, kaolin, and fire, or refractory, clay. Although best known as the main component in porcelain and other ceramics, kaolin has diverse uses in the production of paper, refractories, cosmetics, and other products. Many of its uses are determined by its whiteness and composition (Mineral Information Institute, USGS, and American Coal Foundation, undated; USGS, 2004). The location of major kaolin deposits in the United States is shown in figure 37.

Table 21. Kaolin - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003	Rank of world production
United States	17.8	1

Sedimentary kaolin. Sedimentary hi-alumina kaolins, such as those found in Georgia, formed in temperate climates when atmospheric-derived water containing weak acids percolated through feldspar (calcium-potassium-sodium aluminosilicate)-rich rocks and converted the feldspar to kaolinite (hydous aluminosilicate) or halloysite (hydrous aluminosilicate forming tubular or spherical particles). The clays were then eroded and deposited in tidal flats or estuaries. Some deposits also may have formed in-place by weathering of older, clay-rich sediments (Hosterman and Orris, 1998c). In the eastern United States, a belt of kaolin-bearing rocks extends almost 400 kilometers from Aiken, South Carolina to Eufaula, Alabama and contains 7 to 10 billion metric tons of sedimentary kaolin (Harben and Kužvart, 1996). Ninety percent of United States kaolin production is concentrated in a 240 kilometers long segment of this belt that extends from Macon, Georgia to Aiken, South Carolina. The kaolin deposits occur as lenses in quartz (silicon oxide) sands and may be up to 13 meters thick and 2 kilometers long (Harben and Kužvart, 1996).

Ball clay contains abundant organic matter and has high plasticity and dry strength; it is the dominant type of kaolin in Tennessee. Ball clay originates in rivers and is deposited in shallow lakes with abundant organics and particles of sand (Hosterman and Orris, 1998d). Fire clay, used in refractories, is hard, nonplastic, and homogeneous kaolin that fractures with long smooth surfaces, like broken glass. These kaolins form when clay minerals undergo severe leaching of potassium and silica in acidic swamps (Hosterman and Orris, 1998e). Fire clay is produced in Missouri and Pennsylvania.

Hydrothermal kaolin. Hydrothermal kaolin (including halloysite) is formed from the alteration of feldspar-rich rocks by acidic hydrothermal solutions that leach the alkalies from the host rock (Hosterman and Orris, 1998f). This type of kaolin is typically used for ceramics and filler.

Phosphate rock

Phosphorus is an essential element for plant and animal nutrition. It is mined in the form of phosphate rock. Most production is converted to phosphate fertilizers. The location of major phosphate rock deposits in the United States is shown in figure 37.

Table 22. Phosphate rock - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	24.2	1	5.6	8.0

About 80 percent of the world's phosphate production comes from bedded sedimentary deposits called phosphorites that formed from ocean water. These phosphate-rich deposits form extensive layers that can cover thousands of square kilometers. These rocks formed near middle to low latitude margins of continents where organic productivity was high and the flux of other sediments was low (Harben, 2002; Harben and Kužvart, 1996). The phosphorus-bearing mineral, carbonate fluorapatite, occurs in very thin layers, pellets, or nodules and as fragments of shell or bone.

Weathered rocks are the ultimate source of most of the phosphorus in the ocean; phosphorus derived from the weathering of rocks on the continents enters the oceans through rivers (Benitez-Nelson, 2000). However, the primary source of phosphorus in phosphorites is plankton and other fauna found in the oceans (Hein and others, 2004). Phosphorus is an essential nutrient for the growth and development of all organisms and is concentrated in their tissues and skeletons relative to seawater (Rusch and others, 1996).

Where enough light is available to support photosynthesis, biological activity depletes the phosphorus content of near-surface ocean water. Below this zone of depletion and up to a depth of approximately 1,000 m, phosphorus concentrations go up with increasing depth of the water. Below 1,000 m, phosphorus concentrations are relatively constant and are about 10 times higher than surface water (Benitez-Nelson, 2000).

Biological productivity is stimulated when upwelling currents carry phosphorus-rich cold waters from deeper ocean levels (Kesler, 1994). Most phosphorite deposits are found where these nutrient-rich cold waters mix with shallow ocean water with a limited influx of sediment derived from nearby landmasses. Upwelling, and the resultant high biological activity, occurs at certain coastal locations determined by the interplay of major winds, ocean currents, and the distribution of continents (Chandler and Christie, 1996). Upon death of the organisms, their remains sink to the ocean floor. Phosphate is leached from some of the remains and concentrated in the pore waters of sediments. The subsequent growth of carbonate fluorapatite from pore waters of organic-rich sediment is the predominant mechanism for formation of phosphorite (Hein and others, 2004). Ocean currents that move material along the sea floor and chemical changes that take place as the sediments change into rocks have important roles in concentrating these phosphate mineral precipitates into deposits (Rusch and others, 1996). Weathering can further concentrate the phosphorus contents of the rocks (Kesler, 1994).

Major phosphorite deposits in the United States are related to zones of oceanic upwelling that took place along the western coast of North America in the Permian (forming the western phosphate field in Wyoming, Idaho, Montana, and Utah) and off the southeast North American coast in the Miocene (forming the phosphate deposits in Florida and Carolina; fig. 39).

Potash

"Potash" refers to a group of water-soluble salts that contain the element potassium (Mineral Information Institute, USGS, and American Coal Foundation, undated). Potassium, like phosphorus, is an essential element for animal and plant nutrition. Potassium is present in every living cell and is an essential nutrient for plant growth; for that reason, over 95 percent of potash production is used for fertilizers. Potash is also used in medicine; in the chemical industry; and to produce decorative color effects on brass, bronze, and nickel. Estimated world resources total about 250 billion metric tons (USGS, 2004). In 2003, apparent consumption in the United States was 5,300,000 metric tons K_2O equivalent. The location of major potash deposits in the United States is shown in figure 38.

Table 23. Potassium - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
United States	4.0	7	1.1	1.8

Sedimentary potash deposits form by the evaporation of seawater. As evaporation proceeds and carbonate minerals and gypsum (hydrated calcium sulfate) have crystallized, salt (halite or sodium-chloride) and potash (sylvite or potassium chloride) will form. The actual proportions of minerals that precipitate are determined by the unique conditions that developed for each basin.

Five sedimentary basins host major potash deposits in the United States (fig. 40; Harben and Kužvart, 1996). They are the Silurian **Salina Basin** (also called the Michigan-Appalachian basin) that covers part of Michigan, New York, Ohio, Pennsylvania, and West Virginia; the Permian-Jurassic **Gulf Coast Basin** that covers parts of Alabama, Arkansas, Florida, Mississippi, eastern Texas, Louisiana, and extends into Mexico; the Permian **Permian Basin** that covers parts of Colorado, Kansas, New Mexico, Oklahoma, and western Texas; the Middle Pennsylvanian-Permian **Paradox Basin** that covers parts of Utah and Colorado, and the Ordovician-Permian **Williston Basin** that covers part of North and South Dakota and extends into Canada.

Most domestic production is from evaporite deposits in the **Permian Basin** near Carlsbad, New Mexico. The estimated potash reserves in this district amount to more than 502 million metric tons (USGS, 2002). Beds mined for potash range in thickness from 1.4 meters to more than 3 meters. Estimated domestic potash resources total about 6 billion metric tons (USGS, 2004). Most of this resource lies at depths between 1,800 and 3,100 meters in a 3,110-square-kilometer area of Montana and North Dakota. These potash deposits occur in the **Williston Basin** and are extensions of the potash deposits in Saskatchewan, Canada. The **Paradox Basin** in Utah contains approximately 2 billion metric tons, mostly at depths of more than 1,200 meters. A large potash resource lies about 2,100 meters under central Michigan in the **Michigan Basin**.

Salt (halite)

Salt (sodium chloride) is necessary to support life. As a mineral, salt is called halite. The chemical industry uses about 40 percent of salt produced (chlorine is a major product), and highway de-icing for about 35 percent (Mineral Information Institute, USGS, and American Coal Foundation, undated). World continental resources of salt are practically unlimited, and the salt content in the oceans is virtually inexhaustible (USGS, 2004). The location of major salt deposits and the sedimentary basins hosting the deposits in the United States are shown in figure 38.

Table 24. Salt - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003	Rank of world production
United States	19.6	1

The United States is the world's largest salt producer, producing 45 million metric tons a year, nearly half of that in the form of brines produced by solution mines located at the site of chemical plants. The remaining is "dry salt" produced using three basic technologies: solar evaporation of seawater or saline lake water; solution mining and vacuum pan evaporation; and underground mining. Currently, the United States salt industry operates 48 salt production plants with major production sites in Louisiana, Ohio, New York, Kansas, Michigan, Utah, Texas and California (Salt Institute, undated).

Sedimentary salt deposits form by the evaporation of seawater. As evaporation proceeds and carbonate minerals and gypsum (hydrated calcium sulfate) have crystallized, salt (halite or sodium-chloride) and potash (sylvite or potassium chloride) will form. The actual proportions of minerals that precipitate are determined by the unique conditions that developed for each basin.

Four sedimentary basins host major rock salt deposits in the United States and are some of the largest accumulations of salt in the world (fig. 40; Harben and Kužvart, 1996). They are the Silurian **Salina Basin** (also called the **Michigan-Appalachian basin**) that covers part of Michigan, New York, Ohio, Pennsylvania, and West Virginia; the Permian-Jurassic **Gulf Coast Basin** that covers parts of Alabama, Arkansas, Florida, Mississippi, eastern Texas, Louisiana, and extends into Mexico; the Permian **Permian Basin** that covers parts of Colorado, Kansas, New Mexico, Oklahoma, and western Texas; and the Ordovician-Permian **Williston Basin** that covers part of North and South Dakota and extends into Canada.

The salt can occur as relatively flay-lying layers with other sedimentary rocks - typically carbonates, shales, or other evaporite layers. Individual rock salt layers in the Gulf Coast basin are 2 to 3 meters thick and cover 460,000 square kilometers. The aggregate thickness of salt layers exceeds 600 meters for the Salina group in the Michigan basin and is over 1,000 meters in part of the Permian Basin (Johnson, 2002).

Salt is less dense than the surrounding sedimentary rocks. When buried deeply, salt layers will deform and flow, forming salt domes that rise up towards the surface. Louisiana and Texas are the leading salt producing states (Harben and Kužvart, 1996). In these states, most production comes from salt domes, either by underground or solution mining.

Soda ash (sodium carbonate)

"Soda ash" is the trade name for sodium carbonate (Mineral Information Institute, USGS, and American Coal Foundation, undated). "Natural soda ash" is refined from the mineral trona (hydrated sodium carbonate) or sodium-carbonate-bearing brines. "Synthetic soda ash" is manufactured from one of several chemical processes. Worldwide, synthetic production of about 22 million metric tons is about twice that of natural production. Most soda ash in the United States is used in the manufacture of glass. It is also used to make a variety of chemicals, soap and powdered detergents, in medicine, as a food additive, in cleaning compounds, in paper and paper pulp production, and water treatment. At least 62 natural sodium carbonate deposits have been identified worldwide. Although soda ash can be manufactured from salt and limestone, both of which are practically inexhaustible, synthetic soda ash is more costly to produce and generates environmentally harmful wastes.

Table 25. Soda ash - proportion of world mine production, reserves, and reserve base for the United States.

[USGS, 2004; reserves and reserve base are defined in Appendix 3]

Country	Percent of world production, 2003 (natural)	Percent of world production, 2003 (natural and synthetic)	Rank of world production (natural)	Percent of world reserves (natural)	Percent of world reserve base (natural)
United States	95	28	1	95	98

All United States soda ash production (unlike Europe) is "natural" and comes from sodium carbonate mines in Wyoming and Colorado and from brine in California; the United States produces more than 95 percent of the world's natural soda ash (USGS, 2004). The largest known trona deposit in the world is in the Green River Basin of Wyoming. This deposit alone could produce as much as 47 billion metric tons of soda ash. In California, Searles Lake and Owens Lake are soda brine lakes that are estimated to contain 815 million metric tons of soda ash. The location of major sodium carbonate deposits in the United States is shown in figure 38.

The deposits in the Green River Basin of Wyoming are part of the Eocene Green River Formation. The sediments that make up the Green River Formation were deposited in two large lakes that occupied several structural basins in Colorado, Wyoming, and Utah (fig. 41). Lake Gosiute occupied the Green River, Washakie, and Sand Wash Basins. Lake Uinta occupied the Uinta and Piceance Creek Basins in Utah and Colorado. Much of the time, the lakes were closed with no outlets. During arid periods, evaporation of lake water caused large quantities of sodium salts to form, either directly from the lake waters or from waters within the sediments.

The Green River Formation contains world-class resources of oil shale and sodium-carbonate minerals (Dyni, 1996). The formation contains the world's largest known resource of natural sodium carbonate as bedded trona in southwest Wyoming. As many as 42 beds of trona have been described in Green River Formation in the Green

River Basin in Sweetwater County, southwest Wyoming (Dyni, 1996). The thickest and economically most important of these beds are numbered from 1 to 25 in ascending order. Twenty-two of the 25 numbered beds are estimated to contain a total of 115 billion metric tons of trona ore. Trona bed 17 is one of the most important in the district. The bed, where it is more than 4 feet (1.2 m) thick, underlies about 775 square miles (2,007 square kilometers) and ranges from 4 to 17 feet (1.2 to 5.2 m) in thickness (fig. 42). The second largest known resource of sodium carbonate occurs as bedded and nodular nahcolite (sodium bicarbonate) in northwest Colorado. Four companies currently mine beds of trona in Wyoming and one company mines a bed of nahcolite in Colorado. The Wyoming trona district currently produces about 15 million metric tons per year (8.3 million metric tons of refined soda ash; Kostick, 2004).

Talc

Talc is an extremely soft hydrous magnesium silicate mineral. Soapstone and steatite are rocks composed primarily of the mineral talc. Talc is used commercially because of its fragrance retention, luster, purity, softness, and whiteness. Other commercially important properties of talc are its chemical inertness, high dielectric strength, high thermal conductivity, low electrical conductivity, and oil and grease adsorption. Ground talc is used as an ingredient in ceramics, paper, paint, roofing, plastics, and cosmetics (such as talcum and baby powders) (Mineral Information Institute, USGS, and American Coal Foundation, undated). The location of major talc deposits in the United States is shown in figure 36.

Table 26. Talc - proportion of world mine production for the United States.

[USGS, 2004]

Country	Percent of world production, 2003
United States	9

Nine mines in five States produced talc in 2003. Most domestic production came from mines in Montana, New York, Texas, and Vermont (USGS, 2004). Montana has been the leading talc-producing state for more than 20 years, supplying more than a third of the United States talc production in recent years. The largest producing mine in Montana, and in the United States, is the Yellowstone mine near Ennis (Virta and others, 2000).

Talc deposits form when hydrothermal solutions react with rocks enriched in magnesium at relatively high temperatures (Harben and Kužvart, 1996). Magnesium-enriched rocks include dolomite (a sedimentary rock rich in carbonate minerals) and ultramafic igneous rocks (very enriched in magnesium and iron minerals and low in silica) that represent fragments of oceanic crust that have been faulted into continental crust near plate tectonic boundaries. The deposits may be adjacent to major fault zones, which provide a pathway for the introduction of hydrothermal fluids, or near contacts between magnesium-enriched and silica-enriched rocks (Simandl and Ogden, 1999; Simandl and Paradis, 1999). For deposits hosted in carbonate rocks, the hydrothermal fluids provided silica; for ultramafic-rock hosted deposits, the hydrothermal fluids supplied carbon dioxide. In the United States, most of the talc deposits, except those in Vermont, are associated with carbonate rocks (Harben and Kužvart, 1996). The deposits in Vermont are associated with ultramafic igneous rocks. The hydrothermal fluids may be generated by the emplacement and cooling of magma or by regional metamorphism. The deposits in Montana appear to be related to the continental rifting that formed the **Belt Basin** (fig. 17; Brady and others, 1998; also see discussion on cobalt, copper, and silver). Continental rifting and associated emplacement of magma into dikes elevated the temperature of the sequence of rocks containing the carbonate units. The talc deposits formed when seawater circulated into these rocks along fault zones.

Regional exploration history and significant recent discoveries

Information needed to directly monitor and assess all mineral exploration activities in the United States is not readily available in the public domain. Some information is available for Federally-managed land, but exploration activity elsewhere is not systematically recorded. However, trends in minerals exploration activities can be ascertained by reviewing information in trade literature, the number of active mining claims on Federal lands, and the number of operating mines. When plotted by year for a given area, this type of information can reveal cyclic as well as systematic patterns of activity. Some of these cycles and trends appear to be in response to global economic, social, and political events; others are only regional.

Exploration sites Minerals-related exploration activity reported in trade journals and other literature can be used to discuss regional trends in exploration and variations with time. Because states are not the same size, the density of exploration sites in a state (number of sites divided by the area of the state) is used to discuss trends. The density of exploration sites is illustrated in figure 43 is based on information compiled from 1995 to 2003 (David Wilburn, written communication, 2003). These values are estimates – not all exploration sites are described in literature and not all commodities may be represented. However, if the same information sources and compilation criteria are used, the estimates provided here should reveal trends in exploration activity. The states with the highest density of exploration sites are those covering the Cordilleran orogen and Precambrian rocks near Lake Superior. Nevada, by far, has the highest density of exploration sites reported. Western states in the conterminous United States show a similar pattern of activity – a peak around 1997/1998, a low in 2000/2001, and higher numbers in 2002/2003. Other states show different patterns. The density of sites in Alaska peaked in 1999/2000; activity in Minnesota has been steadily increasing from 1997 to 2003.

Mining claims The number of active mining claims held on Federally-owned lands from 1976 to 2003 is illustrated in figure 44. This information is summarized from information available from the Bureau of Land Management Land and Mineral Records – LR2000 system (http://www.blm.gov/lr2000/ accessed June 23, 2004; D.C. Causey, written communication, 2004). The number of claims peaked around 1980 and again around 1988 before dropping dramatically in 1993. A minor peak in 1997 is followed by decreasing number of claims through to 2003.

Number of active mines The number of active mines is illustrated in figure 45. These data are summarized from information collected by the Mine Safety and Health Administration (National Mining Association, 2003b). With the exception of sand and gravel and stone operations, the number of active mines has systematically decreased in the United States from 1979 to 2001. The number of stone and sand and gravel mining operations has increased during the same time period. This increase largely reflects construction needs in the United States, especially in coastal urban areas.

To understand these patterns, we need to briefly discuss the factors that control exploration activity. Minerals exploration activity can be divided into two components (Singer and Kouda, 1999). Lower risk minerals exploration focuses on finding extensions to existing deposits or new ore bodies near previously discovered large deposits. This type of exploration activity is often driven by the depletion of reserves at known deposits. Exploration has added additional resources to known gold deposits in Nevada, zinc-lead-silver deposits in Alaska, palladium-platinum deposits in Montana, and silver deposits in

Idaho. In the 1990s, a new porphyry copper deposit, Resolution, was found in a well explored area in southeastern Arizona known for its major porphyry copper deposits (Manske and Paul, 2002). The last discovery of a major copper deposit in this area occurred over 20 years ago. This high-grade porphyry copper deposit is covered by younger rocks and lies at depths between 1500 and 2100 meters; rock pressures at that depth are high and temperatures are approximately 77°C (Ducote, 2004). Higher-risk exploration looks for mineral deposits where none have been previously discovered. Some discoveries are made as the result of model-driven exploration programs. Others are found serendipitously. However, low versus high risk exploration does not explain the cyclic patterns of mineral activity.

Cyclic patterns of exploration activity and resource development have been described around the world (Dummett, 2000). A cycle of exploration is followed by a wave of discovery which is succeeded by a period of production. Cycles of exploration are driven by events. A new period of exploration activity can be initiated by innovation (new use of a commodity, new information, new technology, new concepts); change in commodity metal price; a change in market conditions, or a changes in public policy. Some examples relevant to the United States are discussed below.

Changes in monetary policy and technology innovations in the 1970s and 1980s and the emergence of new geologic concepts lead to the discovery and development of one of the world's major gold provinces in northern Nevada. In the early 1970s, the United States government removed restrictions on the price of gold and allowed its citizens to buy and hold gold (Amey, 1998). In an eight year period, the price of gold rose from $38 per ounce to approximately $850 per ounce. About the same time, cyanide leaching technology, developed by the U.S. Bureau of Mines in the 1950s, was refined to allow the processing of lower-grade gold ore at low costs (http://www.mme.state.va.us/DMR/DOCS/MinRes/GOLD/extract.html accessed May 20, 2004). Cyanide heap leaching technology involves spraying a cyanide-bearing leach solution over a pile of crushed or pulverized rock that contains minute particles of native gold. The solution moves through the pile and dissolves the gold and silver. The solution, collected at the base of the pile is stripped of precious metals with activated carbon or other electrochemical exchange processes. Large mobile conveyors have been developed that can produce heap leach piles 900 meters in diameter and 18 meters high.

Fine-grained gold mineralization was discovered in northern Nevada in the 1930s (Bettles, 2002). However, the style of mineralization was not economic to develop until the price of gold increased and a low-cost method of extraction was developed. Effective exploration techniques were then developed and dozens of previously unknown gold deposits were discovered. Gold production started soon thereafter. Exploration continues in Nevada, focusing on extensions to known deposits and targets at depth. As these deposits were developed and studied, new deposit models and exploration concepts were developed that have guided successful exploration programs in other places (Hofstra and Cline, 2000). Northern Nevada is now recognized as containing one of the largest concentrations of gold in the world. Annual gold production in Nevada around 1970 was less than 500,000 oz (15,550 kg) per year; since 2000, over 8 million ounces (250,000 kg) of gold are produced annually.

A cycle of mineral exploration can result in the discovery of a previously unknown style of mineralization. The successful discovery and development of the gold deposits in Nevada initiated a world-wide search for gold deposits that could be mined using cyanide heap leach technology. Geologists took their experience and exploration technologies to new areas. The peak in mining claim activity in the late 1980s largely reflects this phase of gold exploration programs being conducted around the United States. In Alaska, the gold deposits at Fort Knox, Donlin Creek, and Pogo were discovered in the 1990s. Geologists realized that these gold deposits were unlike those in Nevada. They appeared to be associated with subduction-related igneous activity, but were unlike porphyry copper-gold deposits found elsewhere. Geologists defined a new type of gold deposit and were able to relate this style of mineralization to an igneous arc that extended from the Yukon Territory to interior Alaska during the Cretaceous. This then stimulated a phase of new exploration throughout the geologic terrane for this type of gold deposit. This activity may be the cause of increase in the number of exploration sites in Alaska up to 2000.

Exploration activity for nickel-copper-platinum-group element (PGE) mineralization has been driven by metal price, new exploration concepts, and a new process to extract minerals from ore. Between 1997 and 2000, the price of palladium increased from less than $200 per ounce to over $1,000 per ounce (Johnson Matthey, 2004). Throughout the 1990s, geologists were able to develop new exploration models for magmatic mineral deposits. Important events included the discovery in 1994 of the Voisey's Bay nickel deposit in Labrador and research projects that allowed western geologists to study the major Noril'sk-Talnakh nickel-copper-PGE deposits in Siberia. In addition, a new process, called PLATSOL™, was developed to dissolve copper, nickel, gold and the PGE's from low-grade sulfide concentrates (Fleming, undated). Taken together, these events lead to a surge in exploration activity in areas where platinum-group element enriched deposits could be found. In United States, this activity was principally focused in Montana, Minnesota, and Wisconsin. Although palladium prices have subsequently dropped, platinum prices have recently increased along with demand and this probably will sustain interest in exploration for the platinum-group elements.

Changes in technology have been especially important for some industrial minerals that occur in natural brines or that can be mined by solution methods. Improved brine processing technology has allowed the development of some previously sub-economic deposits and led to the closure of other, more traditional mining operations. Within the last decade, lower cost production of lithium from brines associated with desert lakes has displaced much of the traditional production of lithium from igneous rocks. The Fort Cady borate deposit lies at a depth of more than 400 m; development was possible through the use of an in-situ leaching technique. Other industrial mineral commodities for which brine mining (including sea water) and (or) in-situ leaching are or might in the future be significant include rock salt, magnesium, sodium carbonate, sodium sulfate, potash, borates, lithium, iodine, and bromine.

New information that could stimulate exploration activity also includes systematic collection of new data in an area with mineral potential. Work supported by government, industry, and universities is generating the scientific infrastructure needed by the mining industry to find new deposits. For example, the airborne geophysical/geological mineral inventory sponsored by the Alaska Division of Geological and Geophysical Surveys is a multi-year project to expand the knowledge base of Alaska's mineral resources as a catalyst to private sector investment (Burns, undated). This effort focuses on Alaska state lands; the BLM in Alaska funds similar work focused on Federal lands in Alaska.

Finally, government policies and programs can have a significant impact on minerals exploration and development. As previously discussed, governments can create scientific information useful to the minerals exploration industry. However, laws on mineral rights, ownership, taxation, and environmental protection have the strongest affect on stimulating or discouraging minerals exploration. Global events in the early 1990s also had a significant impact on exploration activities in the United States. In 1992, Chile, Mexico, and Peru initiated comprehensive mining law reforms. Starting with the collapse of communist regimes throughout Eastern Europe in 1989 and culminating with the end of the USSR in 1991, the Cold War was brought to an end. In 1994, free multiracial elections were held in South Africa. These and other events profoundly changed the global minerals economy by removing restrictions on where exploration activity, investment, and development could take place. At the same time, tougher environmental laws and permitting requirements were put in place in the United States. In 1993, regulations for hard-rock mining claims on Federal lands were changed. Prior to 1993, exploration expenditures could be used to maintain rights to mining claims. After 1993, a fee of $100 per mining claim was required to paid to the government in order to hold a mining claim. Even though the geology of an area may be favorable for the discovery of new mineral deposits, exploration companies generally are unwilling to invest if laws and regulations make it difficult or expensive to develop mineral resources. The global change in the minerals economy, the changing attitude towards mineral development in the United States, and the change in mining regulation is reflected in the precipitous drop of the number of active mining claims in the United States in 1993.

The declining number of mining operations in the United States may be an early reflection of the decreased exploration activity in the United States starting in the 1990s. The deposits being mined today were mostly discovered decades ago. Decreased exploration will mean fewer discoveries which will lead to fewer mines in the United States in the years to come.

Potential for undiscovered mineral resources

Despite the high level of exploration activity that has occurred in parts of the United States, undiscovered mineral resources remain to be found. Mineral resources are currently being produced from world class mineral deposits. The mere presence of a mineral deposit suggests that others are likely to exist because the processes that result in mineralization commonly form clusters and linear belts of mineral deposits. In this section, the following discussion will address where new deposits will be found, the commodities that will be present, and the difficulty in finding them.

From our discussion of mineral commodities, we hope the reader has come away with these points. 1) **Mineral deposits are associated with large scale geologic processes that reoccur in time and place.** The decay of radioactive elements deep within the Earth provides the heat needed to drive the movement of materials in the Earth's mantle and tectonic plates. This movement of materials generates the magmas and hydrothermal fluids, fractures and faults, mountain ranges and sedimentary basins that are locally and critically important to localizing mineral deposits. 2) **Mineral deposits do not occur randomly; their distribution is intimately related to the geologic history of each continent.** The movement of material in the mantle and tectonic plates is responsible for the development of cratons, orogens, and rifts that are characteristic of continental crust. The geologic architecture of each continent uniquely reflects the sequence of events that culminated in the distribution of rocks and mineral deposits we see today. The more we know about the geologic fabric of each continent and the processes that control the regional and local distribution of mineral deposits, the better we can address where new deposits may be found and what they may contain.

Our ability to find undiscovered mineral deposits is affected by many factors. For example, how well has the geology of the continent been mapped? There are still parts of the world where the geologic framework of the continents is poorly mapped or largely unknown. Terrain and access can limit field investigations; in other regions, thick vegetation, soils, and younger deposits conceal the underlying geology. In other cases, the policies of governments have restricted access to information about geology and mineral resources. The less that is known about an area, the more likely mineral deposits are left to be discovered. Alaska remains an exploration frontier; the basic geologic framework has been established but the remoteness of the area and the prevalence of overlying deposits obscure much detail. Geochemical surveys routinely used to explore for mineral deposits are more difficult to interpret because unconsolidated material transported by glaciers is harder to trace to a bedrock source.

How well do we understand the type of mineral deposit for which we are searching? Robust exploration models can be developed from the shared characteristics and associations of many deposits. If geologists understand the ore forming process, a variety of geologic, geochemical, and geophysical tools can be developed to identify areas where undiscovered mineral deposits may occur. Porphyry copper deposits and volcanogenic massive sulfide deposits are well understood styles of mineralization in part because many deposits of these types have been discovered and studied in detail. Effective deposit models are hard to create for styles of mineralization only known from one or two deposits (such as the hydrothermal beryllium mineralization at Spor Mountain). The search for more mineral deposits represented by these rare occurrences will be more complicated and less certain.

How difficult will it be to find them? The approach that involves the least risk to the exploration geologist is to search in ‘mature’ areas with known mineral deposits, well characterized geology, and an experience base that has identified which exploration techniques have been successful. However, the expected returns may be lower because the remaining concealed deposits will be harder to find and may not be as large as those found first. The most exciting discoveries, and some of the largest, are in areas where no mineral deposits have been found previously. The opportunities for these “grass-roots” discoveries are usually in those areas for which the least amount of information is available.

However, ultimately it still comes back to the geology. The basic requirements to form a mineral deposit involve source and process. There must be a source area of the material, a mechanism to transport it, and a means to concentrate it. If any part of this is missing, a mineral deposit will not be formed. Certain types of mineral deposits only are found in specific geologic settings. If that setting is not present, the associated mineral deposit will not be found. The geologic evolution of each continent has developed with characteristic environments in which mineral deposits may be found. Some of the major geologic areas in the United States that constrain the types and distribution of mineral deposits that could be expected include:

- The geologically-young Cordilleran orogen has considerable potential for undiscovered hydrothermal deposits of copper, molybdenum, gold, lead, zinc, and silver related to emplacement and cooling of igneous rocks.

- The Appalachian orogen has potential for undiscovered volcanogenic massive sulfide deposits and pluton-associated gold deposits.
- Carbonate sedimentary rocks adjacent to the Ouchita and Appalachian orogens and throughout Alaska may host undiscovered Mississippi Valley Type zinc-lead deposits.
- Hydrothermal fluids generated in sedimentary basins formed during the extension of continental crust can vent to the seafloor to form sedex zinc-lead deposits. Undiscovered deposits of this type may occur in the Belt basin in Montana and Idaho and the northern Brooks Range in Alaska.
- Sedimentary basins also contain large deposits of minerals formed by the evaporation of lake or seawater. These deposits are commonly covered by younger layers of sediment and many basins have not been drilled to great depths. These deposits are easily developed by solution mining.
- Large provinces of magnesium- and iron-rich igneous rocks emplaced on the continent during mantle upwelling events have resulted in the rapid emplacement of large volumes of volcanic flows and igneous intrusions over large parts of North America. These igneous rocks are not directly related to the development of continental orogens. Undiscovered nickel, copper, and platinum-group element deposits may be associated with these igneous rocks. One event formed a belt of Mesozoic rocks extending from British Columbia through the Yukon Territory to Alaska. Another belt of Proterozoic igneous rocks extends from Kansas through Minnesota, Michigan, and Wisconsin.

In 1998, the USGS estimated the gold, silver, copper, lead, and zinc in undiscovered deposits in the United States (U.S. Geological Survey National Mineral Resource Assessment Team, 2000). The identified resources and past production of these five metals were also estimated. Assessment results include the following:

- 18,000 metric tons of gold, 460,000 metric tons of silver, 290,000,000 metric tons of copper, 85,000,000 metric tons of lead, and 210,000,000 metric tons of zinc are estimated to be present in undiscovered deposits minable with existing technology.
- 15,000 metric tons of gold, 160,000 metric tons of silver, 260,000,000 metric tons of copper, 51,000,000 metric tons of lead, and 55,000,000 metric tons of zinc remain in identified resources.
- Past production from the largest identified resources of gold, silver, copper, lead, and zinc is estimated to be 12,000 metric tons of gold, 170,000 metric tons of silver, 91,000,000 metric tons of copper, 41,000,000 metric tons of lead, and 44,000,000 metric tons of zinc. These deposits account for about 99 percent of cumulative domestic production in the United States.

From this assessment, about as much gold, silver, copper, lead, or zinc is left to be discovered in the United States as has already been found. However, finding new, minable mineral deposits will be challenging, given that undiscovered deposits are not exposed, access is more difficult, environmental regulations impose constraints on the techniques used to find and develop mineral deposits, landownership is more fragmented than in the past, and the constant competition from low-cost foreign producers.

References cited

Amey, E.B., 1998, Annual average gold price: U.S. Geological Survey Metal prices in the United States through 1998, p. 49-53. ONLINE. Available: *http://minerals.er.usgs.gov/minerals/pubs/commodity/gold/300798.pdf* [Accessed May 20, 2004].

Anstett, T.F., Krauss, U.H., Ober, J.A., and Schmidt, H.W., 1990, International strategic mineral inventory summary report – lithium: U.S. Geological Survey Circular 930-I, 28 p.

Asher-Bolinder, Sigrid, 1991, Descriptive model of lithium in smectites of closed basins, *in* Orris, G.J., and Bliss, J.D., eds., Some industrial mineral deposit models: Descriptive deposit models: U.S. Geological Survey Open-File Report 91-11A, p. 9-10.

Atkinson, Jr., W.W., and Einaudi, M.T., 1978, Skarn formation and mineralization in the contact aureole at Carr Fork, Bingham Utah: Economic Geology v. 73, p. 1326-1365.

Austin, G. S., Kottlowski, F.E., Siemers, W.T., 1982, Industrial minerals of New Mexico in 1981, *in* Austin, G.S., comp., Industrial rocks and minerals of the Southwest: New Mexico Bureau of Mines and Mineral Resources Circular 182, p. 9-16.

Bally, A.W., and Palmer, A.R., 1989, The Geology of North America; An overview: Geological Society of America, The Geology of North America, volume A, 619 p.

Bally, A.W., Scotese, C.R., and Ross, M.I., 1989, North America; Plate tectonic setting and tectonic elements, *in* Bally, A.W., and Palmer, A.R., The Geology of North America; An overview: Geological Society of America, The Geology of North America, volume A, p. 1-16.

Bauer, R.R., Copeland, J.R., and Santini, Ken, 1994, Wollastonite, *in* Carr, D.D., ed., Industrial minerals and rocks: Littleton, Colorado, Society for Mining, Metallurgy, and Exploration, p. 1119-1128.

Benitez-Nelson, Claudia, 2000, The biogeochemical cycling of phosphorus in marine systems: Earth-Science Reviews v. 51, p. 109-135.

Bettles, Keith, 2002, Exploration and geology, 1962 to 2002, at the Goldstrike property, Carlin Trend, Nevada, *in* Goldfarb, R.J., and Nielsen, R.L., eds., Integrated methods for discovery: global exploration in the twenty-first century: Society of Economic Geologists Special Publication 9, p. 275-298.

Box, S. E., Bookstrom, A. A., Zientek, M. L., Derkey, P. D., Ashley, R. P., Elliott, J. E., and Peters, S. G., 1995, Assessment of undiscovered mineral resources in the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-682, 415 p.

Brady, J.B., Cheney, J.T., Rhodes, A.L., Vasquez, Angela, Green, Chris, Duvall, Mathieu, Kogut, Ari, Kaufman, Lewis, and Kovaric, Dana, 1998, Isotope geochemistry of Proterozoic talc occurrences in Archean marbles of the Ruby Mountains, southwest Montana, U.S.A.: Geological Materials Research vol. 1, p. 1-41.

Briskey, J.A., Schulz, K.J., Mosesso, J.P., Horwitz, L.R., and Cunningham, C.G., 2001, It's time to know the planet's mineral resources: Geotimes, v. 46, no. 3, (March), p. 14-19.

Briskey, J.A., Schulz, K.J., Mosesso, J.P., Horwitz, L.R., and Cunningham, C.G., 2002, Environmental planning issues and a conceptual global assessment of undiscovered nonfuel mineral resources, *in* Briskey, J.A., and Schulz, K.J., eds., Agenda, extended abstracts and bibliographies for a Workshop on Deposit Modeling, Mineral Resources

Assessment, and Their Role in Sustainable Development - 31st International Geological Congress, Rio de Janeiro, Brazil [extended abstract]: U. S. Geological Survey Open-File Report 02-423, p. 7-10.

British Sulphur Corporation Limited, 1964, A world survey of phosphate deposits: London, The British Sulphur Corporation Limited, 206 p.

British Sulphur Corporation Limited, 1979, World survey of potash resources: London, The British Sulphur Corporation Limited, 138 p.

British Sulphur Corporation Limited, 1985, World survey of potash resources: London, The British Sulphur Corporation Limited, 144 p.

British Sulphur Corporation Limited, 1987, A world survey of phosphate deposits: London, The British Sulphur Corporation Limited, 274 p.

Brobst, D.A., and Pratt, W.P., eds., 1973, United States mineral resources: U.S. Geological Survey Professional Paper 820, 722 p.

Brush Engineered Materials Inc., 2003, Brush Resources, a Brush Engineered Materials Inc.Company. ONLINE. Available: *http://www.brushresources.com/* [Accessed February 14, 2004].

Buchan, K.L., and Ernst, R.E., 2001, Introduction, *in* Ernst, R.E., and Buchan, K.L., eds., Mantle plumes: their identification through time and space: Geological Society of America Special Paper 352, p. 1-4.

Bucher, Kurt, and Frey, Martin, 2002, Petrogenesis of metamorphic rocks, 7th edition: Berlin, Springer, 341 p.

Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., 1992, Introduction, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran orogen: Geological Society of America, The Geology of North America, v. G-3, p. 1-7.

Burns, Laurel, undated, Airborne geophysical/geological inventory: Alaska Division of Geological and Geophysical Surveys, 1 p. ONLINE. Available: *http://wwwdggs.dnr.state.ak.us/Briefing03/M_FY03_CouncilGeophys.pdf* [Accessed May 21, 2004].

Busby, C.J., and Ingersoll, R.V., eds., 1995, Tectonics of sedimentary basins: Cambridge, Massachusetts, Blackwell Science, 579 p.

Cannon, W.F., Kress, T.H., Sutphin, D.M., Morey, G.B., Meints, Joyce, and Barber-Delach, R.D., 1997, Digital Geologic Map and Mineral Deposits of Minnesota, Wisconsin, and Michigan (Version 3.0): U.S. Geological Survey Open-File Report 97-455.

Carr, D.D., Rooney, L.F., and Freas, R.C., 1994, Limestone and dolomite, *in* Carr, D.D., ed., Industrial minerals and rocks, 6th edition: Littleton, Colorado, Society for Mining, Metallurgy and Exploration, Inc., p. 605-629.

Carten, R.B., White, W.H., and Stein, H.J., 1993, High-grade granite-related molybdenum systems: classification and origin, *in* Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds., Mineral deposit modeling: Geological Association of Canada Special Paper 40, p. 521-554.

Cathcart, J.B., Sheldon, R.P., and Gulbransen, R.A., 1984, Phosphate-rock resources of the United States: U.S. Geological Survey Circular 888, 48 p.

Cawthorn, R.G., 1999, The platinum and palladium resources of the Bushveld Complex: South African Journal of Science v. 95, p. 481-489.

Chandler, F.W, 2000, The Belt-Purcell Basin as a low-latitude passive rift—Implications for the geological environment of Sullivan-type deposits, *in* Lydon, J.W. and others, eds., The Geological Environment of the Sullivan Deposit British Columbia:

Geological Association of Canada Mineral Deposits Division, Special Publication No. 1, p. 82-112.

Chandler, F.W., and Christie, R.L., 1996, Stratiform phosphate, *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 33-40.

Chernoff, C.B., and Orris, G.J., 2002, Data set of world phosphate mines, deposits, and occurrences; Part A, Geologic data: U.S. Geological Survey Open-File Report 02-0156A, 352 p.

Christiansen, R.L., and Yeats, R.S., 1992, Post-Laramide geology of the U.S. Cordilleran region, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran orogen: Conterminous U.S.: Geological Society of America, The Geology of North America, volume G-3, p. 261-406.

Coffin, M.F., and Eldholm, Olav, 1993, Large igneous provinces: Scientific American, October 1993, p. 42- 49.

Condie, K.C., 1997, Plate Tectonics and Crustal Evolution, *Fourth Edition*: Butterworth-Heinemann, Oxford, UK, 282 p.

Condie, K.C., 2001, Mantle plumes and their record in Earth history: Cambridge University Press, Cambridge, 306 p.

Cooke, D.R., and Simmons, S.F., 2000, Characteristics and genesis of epithermal gold deposits, *in* Hageman, S.G., and Brown, P.E., eds., Gold in 2000: Society of Economic Geologists Review in Economic Geology v. 13. p. 221-244.

Courtillot, Vincent, Davaille, Anne, Besse, Jean, and Stock, Joann, 2002, Three distinct types of hotspots in the Earth's mantle: Earth and Planetary Science Letters v. 205, p. 295-308.

Cox, D.P., 1992, Descriptive model of distal disseminated Ag-Au, *in* Bliss, J.D., editor, Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004, p. 19.

Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.

Cox, D.P., Lindsay, D.A., Singer, D.A., and Diggles, M.F., 2003, Sediment-hosted copper deposits of the world: Deposit models and database: U.S. Geological Survey Open-File Report 03-107, 1 CD-ROM.

Crockett, R.N., and Sutphin, D.M., 1993, International strategic mineral inventory summary report – niobium (columbium) and tantalum: U.S. Geological Survey Circular 930-M, 36 p.

Dawson, K.M., 1996, Skarn zinc-lead-silver; *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I.,eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 448-459.

Deeby, D.J., 2002, Borate deposits of California: past, present, and future, *in* Scott, P.W., and Bristow, C.M., eds., Industrial minerals and extractive industry geology: Geological Society of London, London, p. 87-92.

Ducote, Richard, 2004, Copper find at Superior enormous: Arizona Daily Star, published May 2, 2004. ONLINE. Available: *http://www.dailystar.com/dailystar/printDS/20375.php* [Accessed May 19, 2004].

Dummett, H.T., 2000, Mineral resource development – our new challenges: Mining Engineering v. 52, p. 37-42.

Dyni, J.R., 1996, Sodium carbonate resources of the Green River Formation: U.S. Geological Survey Open-File Report 96-729, 39 p.

Edwards, A.F., and others, 1992, The geology of Main Pass sulphur and oil deposit: Society of Mining Engineers Preprint 92-254, 14 p.

Ernst, R.E., and Buchan, K.L., 2001, Large mafic magmatic events through time and links to mantle-plume heads, *in* Ernst, R.E., and Buchan, K.L., eds., Mantle plumes: their identification through time: Geological Society of America Special Paper 352, p. 483-575.

Evans, J.R., Taylor, G.C., and Rapp, J.S., 1976, Mines and mineral deposits in Death Valley National Monument, California: California Division of Mines and Geology Special Report 125, 61 p.

Eyde, T.H., and Eyde, D.T., 1987, The Bowie chabazite deposit, *in* Pierce, H.W., ed., Proceedings of the 21st Forum on the Geology of Industrial Minerals: Arizona Bureau of Geology and Mineral Technology Geological Survey Branch Special Paper 4, p. 133.

Fleck, R.J., Criss, R.E., Eaton, G.F., Cleland, R.W., Wavra, C.S., and Bond, W.D., 2002, Age and origin of base and precious metal veins of the Coeur d'Alene mining district, Idaho: Economic Geology v. 97, p. 23-42.

Fleming, Chris, undated, Platsol™ process provides a viable alternative to smelting: reprinted from African Mining, 4 p. ONLINE. Available: *http://www.lakefield.com/pdf/metservices/Paper%202002-1%20AM%20Jan-Feb%202%20Platsol.pdf* [Accessed May 20, 2004].

Foose, M.P., 1993, Digital metallogenic data set for North America and South America: U.S. Geological Survey Open-File Report 93-328.

Force, E.R., 1991, Geology of titanium-mineral deposits: Geological Society of America Special Paper 259, 112 p.

Formation Capital, undated, U.S. Projects. ONLINE. Available: *http://www.formcap.com/frus1.htm* [Accessed April 7, 2004].

Foster, H.L., 1969, Asbestos occurrence in the Eagle C-4 quadrangle, Alaska: U.S. Geological Survey Circular 611, 7 p.

Garrett, D.E., 1992, Natural soda ash: occurrences, processing, and use: New York, Van Nostrand Reinhold Publishing Company, 636 p.

Garrett, D.E., 1996, Potash: deposits, processing , properties, and uses: New York, Kluwer Academic Publishers, 752 p.

Garrett, D.E., 2001, Sodium sulfate: handbook of deposits, processing, and use: San Diego, Academic Press, 365 p.

Geological Survey of Canada, 1995, Generalized geological map of the World and linked databases: Geological Survey of Canada Open File 2715d. CD-ROM.

Gluskoter, H.J., Rice, D.D., and Taylor, R.B., eds., 1991, Economic geology, U.S.: Geological Society of America, The Geology of North America, volume P-2, 622 p.

Griffiths, J.B., 1995, Industrial Minerals Directory, A world guide to producers and processors: London, Industrial Minerals Information Ltd., 553 p.

Gross, G.A., 1996a, Lake Superior-type iron-formations, *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p.54-66.

Gross, G.A., 1996b, Mafic intrusion-hosted titanium-iron, *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p.573-582.

Guilbert, J.M., and Park, Jr., C.F., 1986, The geology of ore deposits: New York, W.H. Freeman and Company, 985 p.

Hageman, S.G., and Brown, P.E., 2000, Gold in 2000 – An introduction, *in* Hageman, S.G., and Brown, P.E., eds., Gold in 2000: Society of Economic Geologists Review in Economic Geology v. 13. p. 1-7.

Ham, W.E., and Curtis, N.M., Jr., 1958, Gypsum in the Weatherford-Clinton district, Oklahoma: Oklahoma Geological Survey Mineral Report 5, 32 p.

Hansen, W.R., 1991, Suggestions to authors of the reports of the United States Geological Survey, seventh edition: U.S. Government Printing Office, 289 p.

Haq, B.U., and Van Eysinga, F.W.B., 1998, Geological Time Table, Fifth revised enlarged and updated edition: Amsterdam, The Netherlands, Elsevier Science B.V.

Harben, P.W., 2002, The industrial minerals handybook - 4th Edition: A guide to markets, specifications & prices: Surrey, U.K., Industrial Minerals Information, 412 p.

Harben, P.W., and Bates, R.L., 1984, Geology of the nonmetallics: New York, Metal Bulletin Inc., 392 p.

Harben, P.W., and Bates, R.L., 1990, Industrial minerals: geology and world deposits, Metal Bulletin, Inc., 312 p.

Harben, P.W., and Kužvart, Milǒs, 1996, Industrial minerals: A global geology: London, Industrial Minerals Information Ltd., 462 p.

Harrison, J.E., 1972, Precambrian Belt basin of northwestern United States: Its geometry, sedimentation, and copper occurrences: Geological Society of America Bulletin, v. 83, p. 1215-1240.

Haxel, G.B., Hedrick, J.B., and Orris, G.J., 2002, Rare earth elements—Critical resources for high technology: U.S. Geological Survey Fact Sheet 087-02, 4 p.

Hayes, T.S, 1990, A preliminary study of thermometry and metal sources of the Spar Lake stratabound copper-silver deposit, Belt Supergroup, Montana: U.S. Geological Survey Open File Report 90-0484, 30 p.

Hayes, T.S., and Einaudi, M.T., 1986, Genesis of the Spar Lake strata-bound copper-silver deposit, Montana: Part 1. Controls inherited from sedimentation and preore diagenesis: Economic Geology, v. 81, p. 1899-1931.

Hayes, T.S., Rye, R.O., Whelan, J.F., and Landis, G.P.,1989, Geology and sulfur isotope geothermometry of the Spar Lake stratabound copper-Ag deposit in the Belt Supergroup, Montana *in* Boyle, R.W., Brown, A.C., Jefferson, C.W., Jowett, E.C., and Kirkham, R.V., eds., Sediment-hosted Stratiform Copper Deposits: Geological Association of Canada Special Paper 36, p. 319-338.

Hedenquist, J.W., Arribas R., Antonio, Gonzalez-Urien, Eliseo, 2000, Exploration for epithermal gold deposits, *in* Hageman, S.G., and Brown, P.E., eds., Gold in 2000: Society of Economic Geologists Review in Economic Geology v. 13. p. 245-277.

Hein, J.R., Perkins, R.B., and McIntyre, B.R., 2004, Evolution of thought concerning the origin of the Phosphoria Formation, western US phosphate field, *in* Hein, J.R., Life cycle of the Phosphoria Formation: From deposition to post-mining environment: Handbook of Exploration and Environmental Geochemistry v. 8, Elsevier, B.V., Amstersdam, p. 19-42.

Hilliard, H.E., 2002, Silver - 2002: U.S. Geological Survey Minerals Yearbook - 2002, 13 p. ONLINE. Available: *http://minerals.usgs.gov/minerals/pubs/commodity/silver/silvemyb02.pdf* [Accessed April 7, 2004].

Hite, R. J., 1964, Salines, *in* Mineral and water resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 206-215.

Hite, R.J., 1967, Distribution and geologic habitat of marine halite and associated potash deposits: U.S. Geological Survey Open-File Report 67-113, 52 p.

Hobbs, S.W., and Fryklund, Jr., V.C., 1968, The Coeur d'Alene mining district, Idaho, *in* Ridge, J.D., ed., Ore deposits of the United States, 1933-1967 (Graton-Sales volume): New York, American Institute of Mining, Metallurgical and Petroleum Engineers, v. 2, p. 1417-1435.

Hoffman, P.F., 1989, Precambrian geology and tectonic history of North America, *in* Bally, A.W., and Palmer, A.R., eds., The Geology of North America; An overview: Geological Society of America, The Geology of North America, volume A, p. 447-512.

Hofstra, A.H., and Cline, J.S., 2000, Characteristics and models for Carlin-type gold deposits, *in* Hageman, S.G., and Brown, P.E., eds., Gold in 2000: Society of Economic Geologists Reviews in Economic Geology v. 13. p. 163-220.

Holmes, D.A., 1994, Zeolites, *in* Carr, D.D., ed., Industrial minerals and rocks: Littleton, Colorado, Society for Mining, Metallurgy, and Exploration, p. 1129-1158.

Hosterman, J.W., 1998, Preliminary descriptive model for palygorskite, *in* Orris, G.J., ed., Additional descriptive models of industrial mineral deposits: U.S. Geological Survey Open-File Report 98-505, p. 39-40.

Hosterman, J.W., and Orris, G.J., 1998a, Preliminary descriptive model of sedimentary bentonite; Deposit subtype: Sodium Bentonite, *in* Orris, G.J., ed., Additional descriptive models of industrial mineral deposits: U.S. Geological Survey Open-File Report 98-505, p. 24-26.

Hosterman, J.W., and Orris, G.J., 1998b, Preliminary descriptive model of sedimentary bentonite; Deposit subtype: Calcium Bentonite, *in* Orris, G.J., ed., Additional descriptive models of industrial mineral deposits: U.S. Geological Survey Open-File Report 98-505, p. 27-29.

Hosterman, J.W., and Orris, G.J., 1998c, Preliminary descriptive model of sedimentary kaolin—deposit subtype: kaolin, *in* Orris, G.J., ed., Additional descriptive models of industrial mineral deposits: U.S. Geological Survey Open-File Report 98-505, p. 36-38.

Hosterman, J.W., and Orris, G.J., 1998d, Preliminary descriptive model of sedimentary kaolin—deposit subtype: Ball Clay, *in* Orris, G.J., ed., Additional descriptive models of industrial mineral deposits: U.S. Geological Survey Open-File Report 98-505, p. 30-32.

Hosterman, J.W., and Orris, G.J., 1998e, Preliminary descriptive model of sedimentary kaolin—deposit subtype: Fire Clay, *in* Orris, G.J., ed., Additional descriptive models of industrial mineral deposits: U.S. Geological Survey Open-File Report 98-505, p. 33-35.

Hosterman, J.W., and Orris, G.J., 1998f, Preliminary descriptive model of hydrothermal kaolin, *in* Orris, G.J., ed., Additional descriptive models of industrial mineral deposits: U.S. Geological Survey Open-File Report 98-505, p. 21-23.

Hosterman, J.W., and Patterson, S.H., 1992, Bentonite and fuller's earth resources of the United States: U. S. Geological Survey Professional Paper 1522, 45 p.

Industrial Minerals, 1987, Merlin's rare earths venture, in Company News: Industrial Minerals no. 243, p. 92.

Industrial Minerals, 1992, Baroid to reopen Rossi barytes operation: Industrial Minerals no. 301, p. 16.

Industrial Minerals, 1995, Newcomer to nepheline syenite: Industrial Minerals no. 332, p. 17.

Industrial Minerals, 1999a, Montana vermiculite production planned: Industrial Minerals no. 376, p. 8.

Industrial Minerals, 1999b, American Soda plans soda ash production from nahcolite: Industrial Minerals no. 378, p. 19.

Industrial Minerals, 1999c, AZCO invests in Arizona muscovite mica project: Industrial Minerals no. 380, p. 15-16.

Industrial Minerals, 2002, AZCO secures $8m for 10,000 tpa mica project: Industrial Minerals no. 412, p. 15.

Industrial Minerals, 2003, Minsand update: Industrial Minerals no. 431, p. 12-13.

Industrial Minerals, 2004a, April start for Atlas halloysite mine: Industrial Minerals no. 439, p. 31

Industrial Minerals, 2004b, Bear River Zeolite sales up: Industrial Minerals no. 439, p. 33.

International Nickel Study Group, undated, The world of nickel. ONLINE. Available: *http://www.insg.org/nickel.htm* [January 25, 2004].

Jackson, W.D., and Christiansen, Grey, 1993, International strategic mineral inventory summary report – rare-earth oxides: U.S. Geological Survey Circular 930-N, 68 p.

Jasinski, S.M., 1998, Phosphate rock- 1998: U.S. Geological Survey Minerals Yearbook 1998, p 57.1-57.13.

Jasinski, S.M., 2000, Phosphate rock - 2000: U.S. Geological Survey Minerals Yearbook 2000, pp.58.1-58.12.

Johnson Matthey, 2004, Platinum Today. Price Charts. ONLINE. Available: *http://www.platinum.matthey.com/prices/price_charts.html* [January 31, 2004].

Johnson, K.S., 2002, Salt resources and production in the United States, *in* Scott, P.W., and Bristow, C.M., eds., Industrial minerals and extractive industry geology: Geological Society of London, London, p. 83-86.

Kerrich, Robert, Goldfarb, Richard, Groves, David, and Garwin, Steven, 2000, The geodynamics of world-class gold deposits: characteristics, space-time distribution, and origins, *in* Hageman, S.G., and Brown, P.E., eds., Gold in 2000: Society of Economic Geologists Review in Economic Geology v. 13. p. 501-551.

Kesler, S.E., 1994, Mineral resources, economics, and the environment: New York, Macmillan College Publishing Company, Inc., 391 p.

Kious, W.J and Tilling, R.I., 1996, This dynamic Earth: The story of plate tectonics, version 1.0. ONLINE. Available: *http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449* [January 30, 2004].

Kirkham R.V., and Sinclair W. D., 1996a, Porphyry copper, gold, molybdenum, tungsten, tin, silver; *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 421-446.

Kirkham, R.V., 1996, Volcanic redbed copper; *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 241-252.

Kirkham, R.V., and Sinclair, W.D., 1996b, Vein copper; *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 399-408.

Konhauser, K.O., Hamade, Tristan, Raiswell, Rob, Morris, R.C., Ferris, F.G., Southam, Graham, and Canfield, D.E., 2002, Could bacteria have formed the Precambrian banded iron formations?: Geology, v. 30, p. 1079-1082.

Kostick, D.S., 2004, Soda ash: U.S. Geological Survey, Mineral Commodity Summaries, January 2004, p. 152-153. ONLINE. Available: *http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/sodaamcs04.pdf* [Accessed April 9, 2004].

Krauss, U.H., Saam, H.G., and Schmidt, H.W., 1984, International strategic mineral inventory summary report – phosphate: U.S. Geological Survey Circular 930-C, 41 p.

Kuck, Peter, 1998, Iron ore: U.S. Geological Survey Statistical Compendium. ONLINE. Available: *http://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/stat/* [Accessed February 28, 2004].

Laznicka, Peter, 1999, Quantitative relationships among giant deposits of metals: Economic Geology, v. 94, p. 455-473.

Leach, D.L., and Rowan, E.L., 1986, Genetic link between Ouchita foldbelt tectonism and the Mississippi Valley-type lead-zinc deposits of the Ozarks: Geology v. 14, p. 931-935.

Leach, D.L., and Sangster, D.F., 1993, Mississippi Valley-type lead-zinc deposits, *in* Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds., Mineral deposit modeling: Geological Association of Canada Special Paper 40, p. 289-314.

Leach, D.L., Bradley, Dwight, Lewchuck, M.T., Symons, D.T.A., de Marsily, Ghislain, and Brannon, Joyce, 2001, Mississippi Valley-type lead-zinc deposits through geologic time: implications from recent age-dating research: Mineralium Deposita, v. 36, p. 711-740.

Leach, David, undated, The giant Red Dog massive sulfide deposit, Brooks Range, Alaska: Discovery, geology, geochemistry and genesis. ONLINE. Available: *http://www.cpgg.ufba.br/metalogenese/Leach1.htm* [Accessed May 21, 2004].

Lindsey, D.A., 1998, Slides of the fluorspar, beryllium, and uranium deposits at Spor Mountain, Utah: U.S. Geological Survey Open-File Report 98-524. ONLINE. Available: *http://pubs.usgs.gov/of/1998/ofr-98-0524/HOME.HTM* [Accessed April 7, 2004].

Listerud, W.H., and Meineke, D.G., 1977, Mineral resources of a portion of the Duluth Complex and adjacent rocks in St. Louis and Lake Counties, northeastern Minnesota: Minnesota Department of Natural Resources, Division of Minerals Report 93, 49 p.

Long, K.C., DeYoung, J.H., Jr., and Ludington, S.D., 1998, Database of significant deposits of gold, silver, copper, lead, and zinc in the United States: U.S. Geological Survey Open-File Report 98-206, Part A: Database description and analysis, 60 p. and Part B: Excel spreadsheet and references.

Long, K.L., 1998, Grade-tonnage models for Coeur d'Alene-type polymetallic veins: U.S. Geological Survey Open-File Report 98-583, 28 p.

Ludington, S.D., 1986, Descriptive model of Climax Mo deposits, *in* Cox, D.P., and Singer, D.A., eds., Ore deposit models: U.S. Geological Survey Bulletin 1693, p. 73.

Lyday, P.A., 2002, Boron - 2002: U.S. Geological Survey Minerals Yearbook - 2002, 14 p. ONLINE. Available: *http://minerals.usgs.gov/minerals/pubs/commodity/boron/boromyb02.pdf* [Accessed April 7, 2004].

Lydon, J.W., 1988, Volcanogenic massive sulphide deposits part 1: A descriptive model, *in* Roberts, R.G., and Sheahan, P.A., eds., Ore Deposit Models: Geoscience Canada Reprint Series 3, p. 145-153.

Lydon, J.W., 1996, Sedimentary exhalative sulphides (sedex), *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 130-152.

Lydon, J.W., 2000, A synopsis of the current understanding of the geological environment of the Sullivan deposit, Chapter 3, *in* Lydon, J.W. and others, eds., The Geological Environment of the Sullivan Deposit British Columbia: Geological Association of Canada Mineral Deposits Division, Special Publication No. 1, p. 12-31.

Manske, S.L.and Paul, A.H., 2002, Geology of a major new porphyry copper center in the Superior (Pioneer) district, Arizona: Economic Geology, v. 97, p. 197-220.

McFaul, E.J., Mason, G.T., Jr., Ferguson, W.B., and Lipin, B.R., 2000, U. S. Geological Survey mineral databases; MRDS and MAS/MILS: U.S. Geological Survey Digital Data Series DDS 52. CD-ROM.

Miller, J.D, Jr., Severson, M.J., and Hauck, S.A., 2002, History of geologic mapping and mineral exploration in the Duluth Complex, *in* Miller, J.D., Jr., Green, J.C., Severson, M.J., Chandler, V.W., Hauck, S.A., Peterson, D.M., and Wahl, T.E., eds., Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, p. 21- 51.

Miller, J.D., Jr., Green, J.C., Severson, M.J., Chandler, V.W., Hauck, S.A., Peterson, D.M., and Wahl, T.E., 2002, Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, 207 p.

Mineral Information Institute, USGS, and American Coal Foundation, undated, Minerals in your world: Mineral Information Institute, Golden, Colorado. CD ROM.

Moores, E.M., and Twiss, R.J., 1995, Tectonics: New York, W.H. Freeman and Company, 415 p.

Mutschler, F.E., Ludington, Steve, and Bookstrom, A.A., 1999, Giant porphyry-related metal camps of the world – a database: U.S. Geological Survey Open-File Report 99-556, Online Version 1.0. Available: *http://geopubs.wr.usgs.gov/open-file/of99-556/* [Accessed July 15, 2004].

National Mining Association, 2003a, Leading nonfuel mining operations in the United States by crude ore output in 2001: National Mining Association, 1 p. ONLINE. Available: *http://www.nma.org/pdf/m_mining_operations.pdf* [Accessed April 8, 2004].

National Mining Association, 2003b, Mine Safety and Health Administration's number of coal and nonfuel mineral operations in the United States, 1979-2002, 2p. ONLINE. Available: *http://www.nma.org/pdf/m_number_operations.pdf* [Accessed April 8, 2004].

National Mining Association, undated, Mining in the United States: National Mining Association, 2 p. ONLINE. Available: *http://www.nma.org/pdf/states_01/us2001.pdf* [Accessed May 18, 2004}.

Neary, C.R., and Highley, D.E., 1984, The economic importance of the rare earth elements, *in* Henderson, P., ed., Rare earth element geochemistry: New York, Elsevier, Developments in Geochemistry 2, p. 423-466.

Nelson, J.L., 1996, Polymetallic mantos Ag-Pb-Zn, *in* Lefebure, D.V., and Hoy, T., eds., Selected British Columbia mineral deposit profiles, Volume 2 – Metallic deposits: British Columbia Ministry of Employment and Investment Open-File 1996-13, p. 101-104.

New York State Department of Environmental Conservation, undated, Mining data. ONLINE. Available: http://www.dec.state.ny.us/website/dmn/minedata.htm [Accessed June 23, 2004].

Newmont, 2003, Information handbook 2003: Newmont Mining Corporation. ONLINE. Available: *www.newmont.com/en/pdf/infohandbook/HB2003-Complete.pdf* [February 16, 2004].

Odom, I.E., 1992, Hectorite: deposits, properties and use, *in* Griffiths, J.B., ed., Proceedings, 10th Industrial Minerals International Congress: San Francisco, Metal Bulletin plc, p. 105-111.

O'Driscoll, Mike, 1990, Minerals in the US South-West; breaking rocks in the hot sun: Industrial Minerals, no. 272, p. 52-83.

O'Driscoll, Mike, 1993, Garnet--Set for blast off?: Industrial Minerals, no. 304, p. 19-33.

Olson, D.W., 2002, Gypsum - 2002: U.S. Geological Survey Minerals Yearbook - 2002, 14 p. ONLINE. Available: *http://minerals.usgs.gov/minerals/pubs/commodity/gypsum/gypsumyb02.pdf* [Accessed April 7, 2004].

Orris, G.J., 1985, Bedded/stratiform barite deposits: Geologic and grade-tonnage data, including a partial bibliography: U.S. Geological Survey Open-File Report 85-447, 32 p.

Orris, G.J., and Bliss, J.D., 1985, Geologic and grade-volume data on 330 gold placer deposits: U.S. Geological Survey Open-File Report 85-213, 167 p.

Orris, G.J., and Chernoff, C.B., 2002, Data set of world phosphate mines, deposits, and occurrences; Part B, Location and mineral economic data: U.S. Geological Survey, Open-File Report 02-0156B, 328 p.

Orris, G.J., and Chernoff, C.B., 2004, Review of world sedimentary phosphate deposits and occurrences, in Hein, J.R., Life cycle of the Phosphoria Formation: From deposition to post-mining environment: Handbook of Exploration and Environmental Geochemistry v. 8, Elsevier, B.V., Amsterdam, p. 559-573.

Papke, K.G., 1984, Barite in Nevada: Nevada Bureau of Mines and Geology Bulletin 98, 125 p.

Papke, K.G., 1987, Gypsum deposits in Nevada: Nevada Bureau of Mines and Geology Bulletin 103, 26 p.

Paradis, S., Simandl, G.J., MacIntyre, D., and Orris, G.J., 1999, Sedimentary-hosted, stratiform barite, *in* Simandl, G.J., Zdenek, D.H., and Lefebure, D.V., Selected British Columbia mineral deposit profiles. Volume 3 – Industrial minerals and gemstones: British Columbia Ministry of Energy and Mines, Mineral Resources Division, Geological Geological Survey Branch Open File 1999-10, p. 43-46.

Pearson, Karine, 1999, A TiO_2 feedstock review: Industrial Minerals, no. 378, p. 42-53.

Peters, S.G., Mihalasky, M.J., and Theodore, T.G., 2004, Assessment for sedimentary rock-hosted Au-Ag deposits, *in* Wallace, A.R., Ludington, S., Mihalasky, M.J., Peters, S.G., Theodore, T.G., Ponce, D.A., John, D.A., and Berger, B.R., Assessment of metallic mineral resources in the Humboldt River Basin, northern Nevada, with a section on PGE potential of the Humboldt mafic complex by M.L. Zientek, G.B. Sidder, and R.A. Zierenberg: U.S. Geological Survey Bulletin 2218, p. 189-239.

Pirkle, F.L., Pirkle, E.C., Reynolds, J.G., Pirkle, W.A, Henry, J.A., and Rice, W.J., 1993, The Folkston West and Amelia heavy mineral deposits of Trail Ridge, southeastern Georgia: Economic Geology, v. 88, p. 961-971.

Placer Dome, Inc., 2002a, PDG Placer Dome Operations: Cortez mine. Placer Dome Gold, Inc. ONLINE. Available: *http://www.placerdome.com/operations/cortez/cortez.html* [March 1, 2004].

Placer Dome, Inc., 2002b, PDG Placer Dome Operations: Turquoise Ridge mine. Placer Dome Gold, Inc. ONLINE. Available: *http://www.placerdome.com/operations/getchell/getchell.html* [March 1, 2004].

Polymet Mining Corporation, 2003, The Northmet project: ONLINE. Available: *http://www.polymetmining.com/northmet.pdf* [Accessed April 6, 2004].

Price, J.G., and Meeuwig, R.O., 2002, Overview, in the Mineral Industry of Nevada: Nevada Bureau of Mines and Geology Special Publication MI-2002, p. 3-11.

Price, R.A., and Sears, J.W., 2000, Preliminary palinspasthic map of the Belt-Purcell Supergroup: Implications for tectonic setting and structural evolution, *in* Lydon, J.W. and others, eds., The Geological Environment of the Sullivan Deposit British Columbia: Geological Association of Canada Mineral Deposits Division, Special Publication No. 1, p. 61-81.

Riggs, S.R., 1979, Phosphate sedimentation in Florida – a model phosphogenic system: Economic Geology, v. 74, p. 285-314.

Riggs, S.R., 1989, Phosphate deposits of the North Carolina coastal plan, continental shelf, and adjacent Blake Plateau, USA, *in* Notholt, A.J.G., Sheldon, R.P., and Davidson, D.R, eds., Phosphate deposits of the world, volume 2, phosphate rock resources: Cambridge, Cambridge University Press, 42-52 p.

Rio Tinto, 2001, Fact sheet series: Industrial Minerals. ONLINE. Available: *http://www.riotinto.com/library/reports/PDFs/corpPub_FactSheet_IndustMin.pdf* [January 26, 2004].

Robert, Francois, 1996, Quartz-carbonate vein gold, *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 350-366.

Roberts, R.G., 1988, Archean lode gold deposits, *in* Roberts, R.G, and Sheahan, P.A. eds., Ore deposit models: Geoscience Canada Reprint Series 3, p. 1-20.

Roskill Information Services, 1983, The economics of salt, 4th ed.: London, Roskill Information Services Ltd., 183 p. plus appendices.

Roskill Information Services, 1988, The economics of rare earths & yttrium, seventh edition: London, Roskill Information Services, 359 p. plus appendices.

Roskill Information Services, 1989, The economics of potash: London, Roskill Information Services, variously paginated.

Roskill Information Services, 1992, The economics of gypsum and anhydrite 1992, 6th ed.: London, Roskill Information Services Ltd., 168 p. plus appendices.

Roskill Information Services, 1993, The economics of boron, 7th ed.: London, Roskill Information Services Ltd., 156 p.

Roskill Information Services, 1994, The economics of iodine 1994, 6th ed.: London, Roskill Information Services Ltd., 98 p. plus appendices.

Rusch, T.L., Sankar, R., Scharf, J.E., Follmi, K.B, 1996, The phosphorus cycle, phosphogenesis and marine phosphate-rich deposits: Earth-Science Reviews, v. 40, p. 55-124.

Russell, Alison, 1988, Potash- Long haul recovery under way: Industrial Minerals, no. 244, p. 16-34.

Salt Institute, undated, About the salt industry: ONLINE. Available: *http://www.saltinstitute.org/3.html* [accessed May 10, 2004].

Sangster, D. F., 1996, Mississippi Valley-type lead-zinc; *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian Mineral Deposit Types: Geological Survey of Canada, Geology of Canada, no. 8, p. 253-261.

Sawkins, F.J., 1984, Metal deposits in relation to plate tectonics: Berlin, Springer-Verlag, 325 p.

Schaetzl, R.J., undated, Iron mining today: GEO 333 Geography of Michigan and Great Lakes region – a course at the Michigan State University. ONLINE. Available: *http://www.geo.msu.edu/geo333/iron_iii.html* [Accessed February 28, 2004].

Schulz and Cannon, 1997, Potential for new nickel-copper sulfide deposits in the Lake Superior region. Available ONLINE. *http://pubs.usgs.gov/info/mwni_cu/* [Accessed April 6, 2004].

Shedd, K.B., 2002, Cobalt - 2002: U.S. Geological Survey Minerals Yearbook - 2002, 21 p. ONLINE. Available: *http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/cobalmyb02.pdf* [Accessed April 7, 2004].

Siebert, L., and Simkin, T., 2002, Volcanoes of the World: an illustrated catalog of Holocene volcanoes and their eruptions: Smithsonian Institution, Global Volcanism Program Digital Information Series, GVP-3. ONLINE. Available: *http://www.volcano.si.edu/gvp/world/* [January 16, 2004].

Simandl, G.J., and Ogden, D., 1999, Ultramafic-hosted talc-magnesite, *in* Simandl, G.J., Zdenek, D.H., and Lefebure, D.V., Selected British Columbia mineral deposit profiles. Volume 3 – Industrial minerals and gemstones: British Columbia Ministry of Energy and Mines, Mineral Resources Division, Geological Geological Survey Branch Open File 1999-10, p. 65-68.

Simandl, G.J., and Paradis, S., 1999, Carbonate-hosted talc, *in* Simandl, G.J., Zdenek, D.H., and Lefebure, D.V., Selected British Columbia mineral deposit profiles. Volume 3 – Industrial minerals and gemstones: British Columbia Ministry of Energy and Mines, Mineral Resources Division, Geological Geological Survey Branch Open File 1999-10, p. 35-38.

Singer, D.A., 1995, World class base and precious metal deposits – a quantitative analysis: Economic Geology, v. 90, p. 88-104.

Singer, D.A., and Kouda, Ryoichi, 1999, Examining risk in mineral exploration: Natural Resources Research, v. 8, p. 111-122.

Singer, D.A., Berger, V.I., and Moring, B.C., 2002, Porphyry copper deposits of the World: database, maps, and preliminary analysis: U.S. Geological Survey Open-File Report 02-268. ONLINE. Available: *http://geopubs.wr.usgs.gov/open-file/of02-268/* [Accessed July 15, 2004].

Singer, D.A., Mosier, D.L., and Menzie, D.W., 1993, Digital grade and tonnage data for 50 types of mineral deposits: U.S. Geological Survey Open-File Report 93-280. ONLINE. Available: *http://pubs.usgs.gov/of/1993/ofr-93-0280/* [Accessed July 15, 2004].

Smith, J.G., 1965, Fundamental transcurrent faulting in the northern Rocky Mountains: Bulletin of the American Association of Petroleum Geologists v. 49, p. 1398-1409.

Smith, R.A., 2002, Basic geology and chemistry of borate: American Ceramic Society Bulletin, v. 81, no. 8, 6 p.

Spanski, G.T., 2004, Inventory of significant mineral deposit occurrences in the Headwaters project area in Idaho, western Montana, and extreme eastern Oregon and Washington: U.S. Geological Survey Open-File Report 2004-1038, 13 p.

St. John, B., 2000, Sedimentary provinces of the World (BG), including GIS layer for giant oil & gas fields: AAPG Datapages Digital Product, Digital Map, Product Code 52. CD-ROM.

Stoeser, D.B., and Heran, W.D., 2000, USGS deposit models: U.S. Geological Survey Digital Data Series DDS-064, version 1.0. CD-ROM.

Sutphin, D.M., and Page, N.J, 1986, International Strategic Minerals Inventory Summary Report - Platinum-group metals: U.S. Geological Survey Circular 930-E, 34 p.

Taylor, Lindsey, 2004, Clear winners: Industrial Minerals, no. 436, p. 45-49.

Thompson, J.F.H and Newberry, R.J., 2000, Gold deposits related to reduced granitic intrusions, *in* Hagemann, S.G., and Brown, P.E., eds., Gold in 2000: Society of Economic Geologists Reviews in Economic Geology, v. 13, p. 377-400.

Tingley, J.V., 2002, Major precious-metal deposits, in the Mineral Industry of Nevada: Nevada Bureau of Mines and Geology Special Publication MI-2002, p. 26-41.

Torres, M.E., Bohrman, Gerhard, Dube, T.E., and Poole, F.G., 2003, Formation of modern and Paleozoic stratiform barite at cold methane seeps on continental margins: Geology, v. 31, p. 897-400.

Towner, R.R., 1992 International strategic mineral inventory summary report – zirconium U.S. Geological Survey Circular 930-L, 47 p.

Towner, R.R., Gray, J. M., and Porter, L.M., 1988, International strategic mineral inventory summary report – titanium: U.S. Geological Survey Circular 930-G, 58 p.

U.S. Geological Survey National Mineral Resource Assessment Team, 2000, 1998 assessment of undiscovered deposits of gold, silver, copper, lead, and zinc in the United States: U.S. Geological Survey Circular 1178, 21 p. and CD-ROM.

USGS, 1997, Active mines and mineral plants in the US. ONLINE. Available: http://tin.er.usgs.gov/mineplant/ [Accessed July 1, 2004].

USGS, 2002, The mineral industry of New Mexico: U.S. Geological Survey Minerals Yearbook, 10 p. ONLINE. Available: *http://minerals.usgs.gov/minerals/pubs/state/2002/nmstmyb02.pdf* [Accessed May 17, 2004].

USGS, 2004, Mineral Commodity Summaries 2004: U.S. Government Printing Office, Washington, D.C., 197 p. Available: *http://minerals.usgs.gov/minerals/pubs/mcs/2004/mcs2004.pdf* [January 30, 2004].

Van Kauwenbergh, S.J., and McClellan, G.H., 1990, Comparative geology and mineralogy of the southeastern United States and Togo phosphorites: Geological Society Special Publication 52, p. 139-155.

Van Kauwenbergh, S.J., Cathcart, J.B., and McClellan, G.H., 1990, Mineralogy and alteration of the phosphate deposits of Florida: U.S. Geological Survey Bulletin 1914, 46 p.

Virta, R.L., van Gosen, B.S., and Berg, R.B., 2000, Industrial minerals of the United States, U.S. talc – baby powder and much more: U.S. Geological Survey Fact Sheet FS-065-00, 2 p. ONLINE. Available: *http://pubs.usgs.gov/fs/fs-0065-00/fs-0065-00.pdf* [Accessed May 13, 2004].

Warren, John, 1999, Evaporites-- their evolution and economics: Malden, Massachussetts, Blackwell Science, 438 p.

Weaver, C.E., 1959, The clay petrology of sediments: Clays and Clay Minerals, v. 6, p. 154-187.

Williams-Stroud, S.C., Searls, J.P., and Hite, R.J., 1994, Potash resources, *in* Carr, D.D., ed., Industrial minerals and rocks: Littleton, Colorado, Society for Mining, Metallurgy, and Exploration, p. 783-802.

Woolley, A.R., 1987, Alkaline rocks and carbonatites of the world. Part 1: North and South America: University of Texas Press, Austin, Texas, 216 p.

Woolley, A.R., 1989, The spatial and temporal distribution of carbonatites, *in* Bell, Keith, ed., Carbonatites: genesis and evolution: Unwin Hyman, Boston, p. 15-37.

Yeats, C.J., and Vanderhor, Fop, 1998, Archaean lode-gold deposits: AGSO Journal of Australian Geology and Geophysics v. 17, no. 4, p. 253-258.

Zanko, L.M, Severson, M.J., Oreskovich, J.A., Heine, J.J., Hauck, S.A., 2003, Oxidized taconite geological resources for a portion of the western Mesabi Range (west half of the Arcturus mine to the east half of the Canisteo mine), Itasca County, Minnesota – a GIS-based resource analysis for land-use planning: University of Minnesota Duluth Natural Resources Research Institute NRRI/TR-2001-40, 86 p.

Zientek, M.L., Cooper, R.W., Corson, S.R., and Geraghty, E.P., 2002, Platinum-group element mineralization in the Stillwater Complex, Montana, *in* Cabri, L.J., The geology, geochemistry, mineralogy, and mineral beneficiation of platinum-group elements: Canadian Institute of Mining, Metallurgy, and Petroleum Special Volume 54, p. 459-481.

Figures

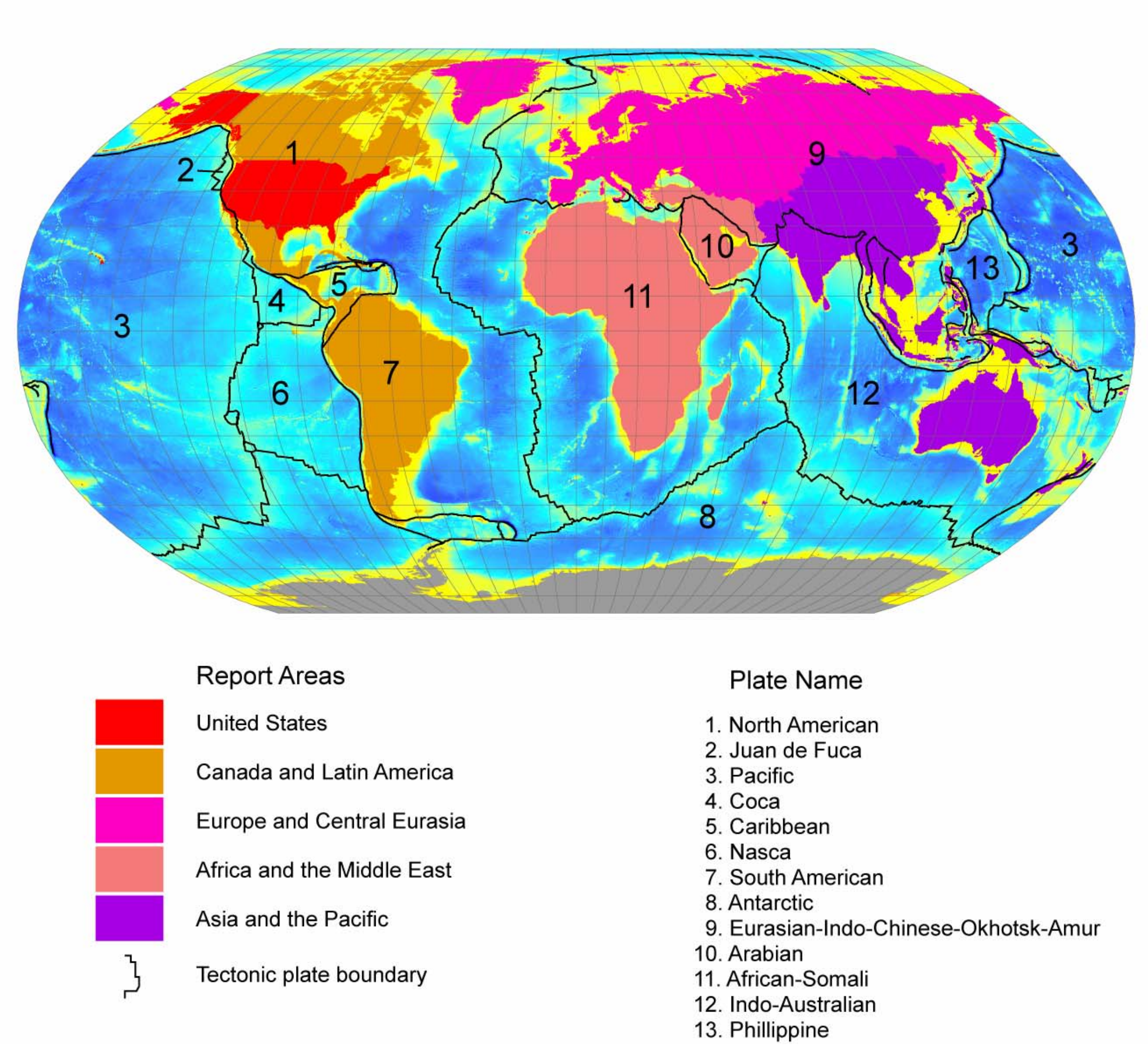


Figure 1. Map of the World showing the areas covered by this series of regional reports, tectonic plate boundaries, and ocean bathymetry. Continental shelves are shown in yellow; in oceans, increasing water depth is indicated by darker shades of blue. Tectonic plate boundaries (black lines) from *http://map.ngdc.noaa.gov/website/seg/hazards/viewer.htm* [Accessed May 23, 2005]. Plate names from *http://www.ig.utexas.edu/research/projects/plates/plates.htm* [Accessed May 23, 2005]. Ocean bathymetry from derived from ETOPO2 (*http://www.ngdc.noaa.gov/mgg/image/2minrelief.html* [Accessed May 23, 2005]).

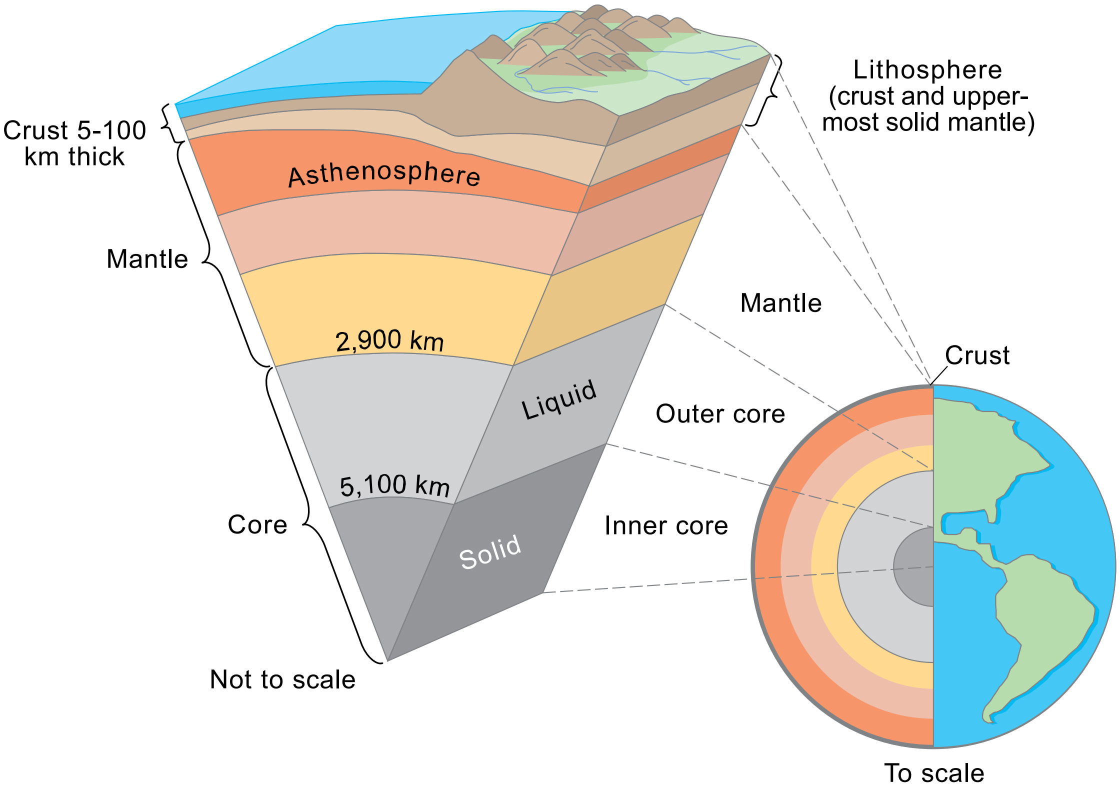


Figure 2. Sketches showing the layered internal structure of the Earth. The three major layers (crust, mantle, and core) comprising the Earth are schematically portrayed in the sectional wedge (not to scale). The cutaway view in the lower right shows the layers drawn to scale. Modified from Kious and Tilling (1996).

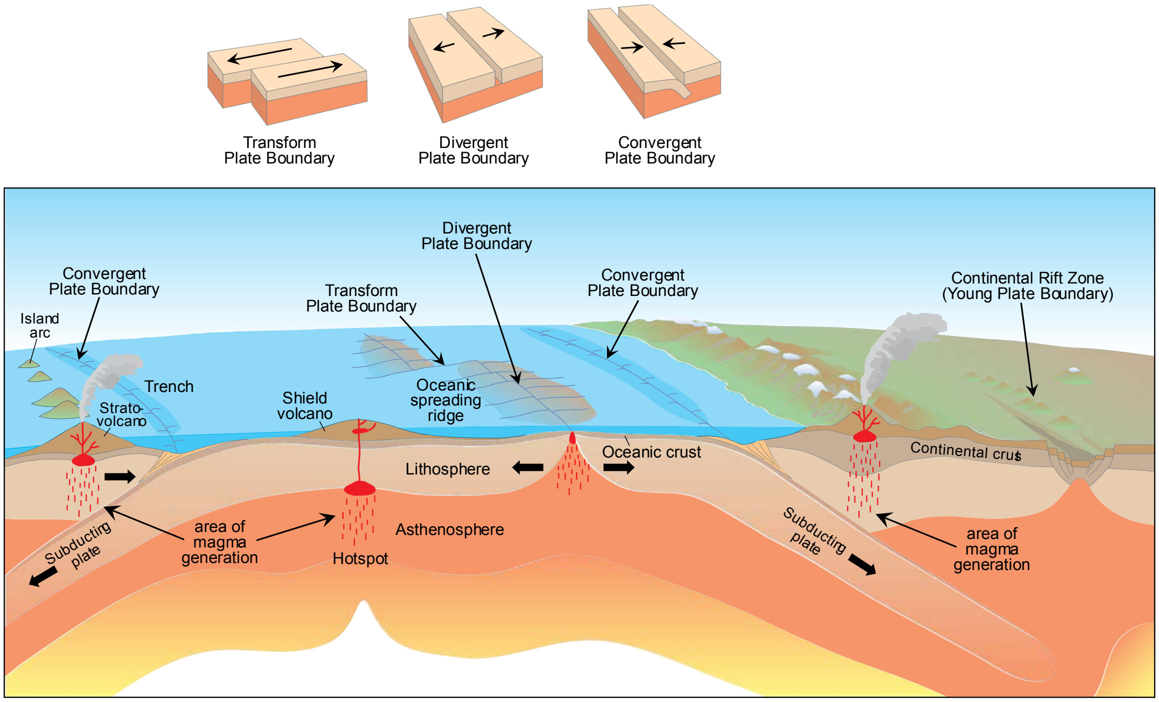


Figure 3. Perspective diagram and cross section of the uppermost layers of the Earth illustrating the main types of tectonic plate boundaries. Modified from Kious and Tilling (1996).

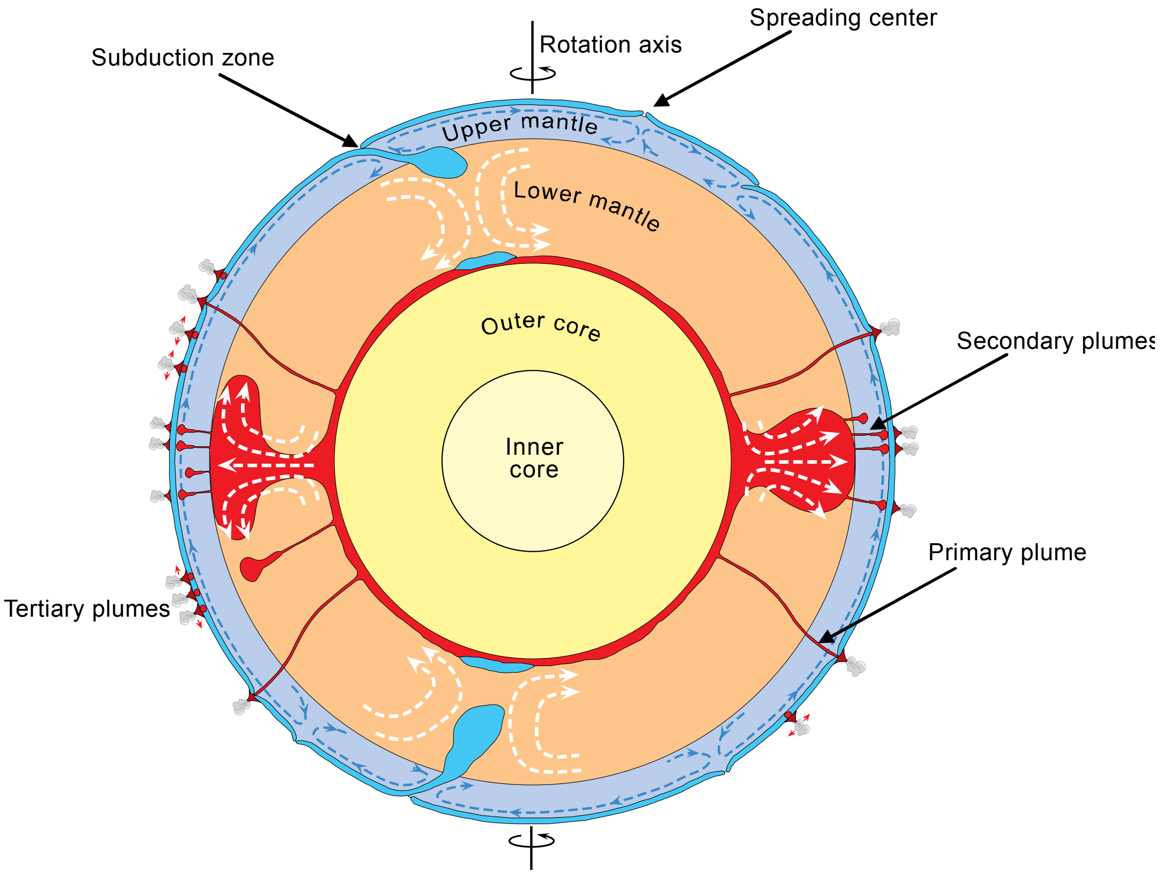


Figure 4. A schematic cross-section of the Earth illustrating three types of mantle plumes. 'Primary' or main, deeper plumes possibly come from the lowermost mantle boundary layer. 'Secondary' plumes possibly come from the top of domes near the depth of the transition zone between the lower and upper mantle. 'Tertiary' hotspots may have a near surface origin, linked to tensile stresses in the lithosphere and decompression melting. Dashed lines with arrows show flow directions of rock within the layers. Modified from Courtillot and others, (2002).

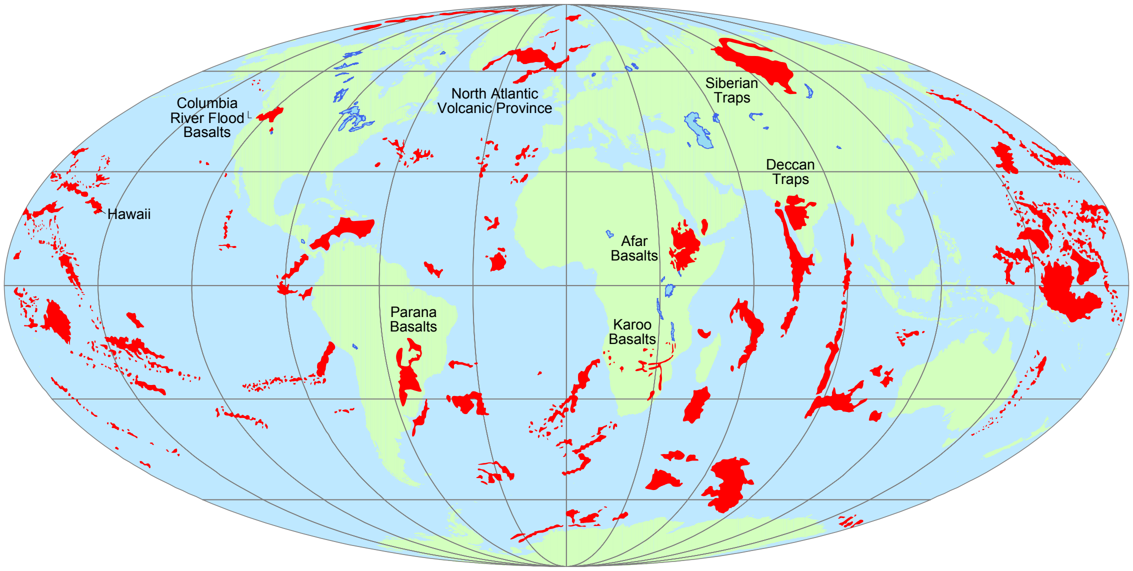


Figure 5. A map of the globe showing the distribution of the igneous rocks associated with selected large igneous provinces (*red regions*) that formed in the last 250 million years. These rocks are related to mantle plumes and are widely distributed on both continental and oceanic crust. Modified from Coffin and Eldholm (1993).

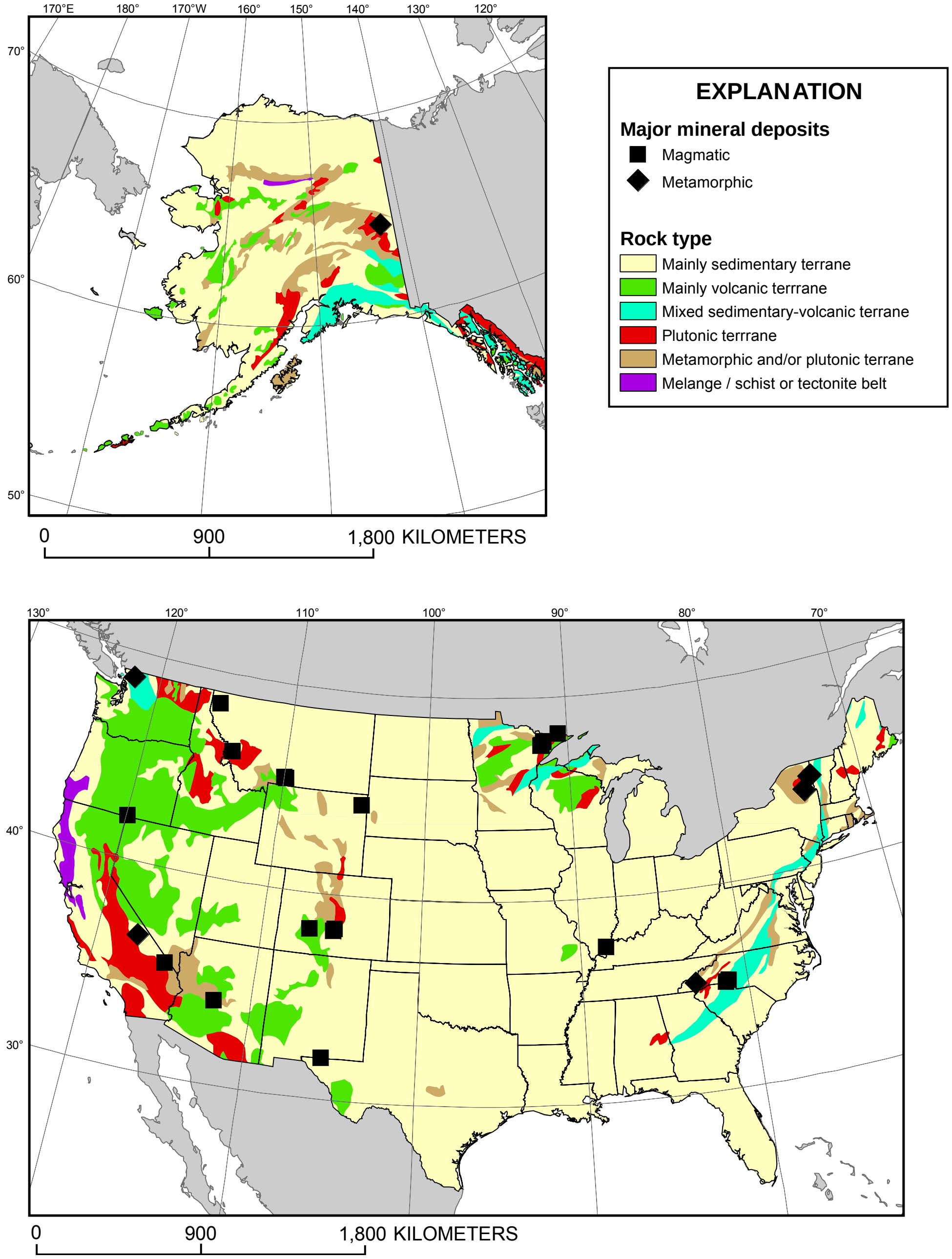


Figure 6. Map showing the location of the major magmatic and metamorphic mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995).

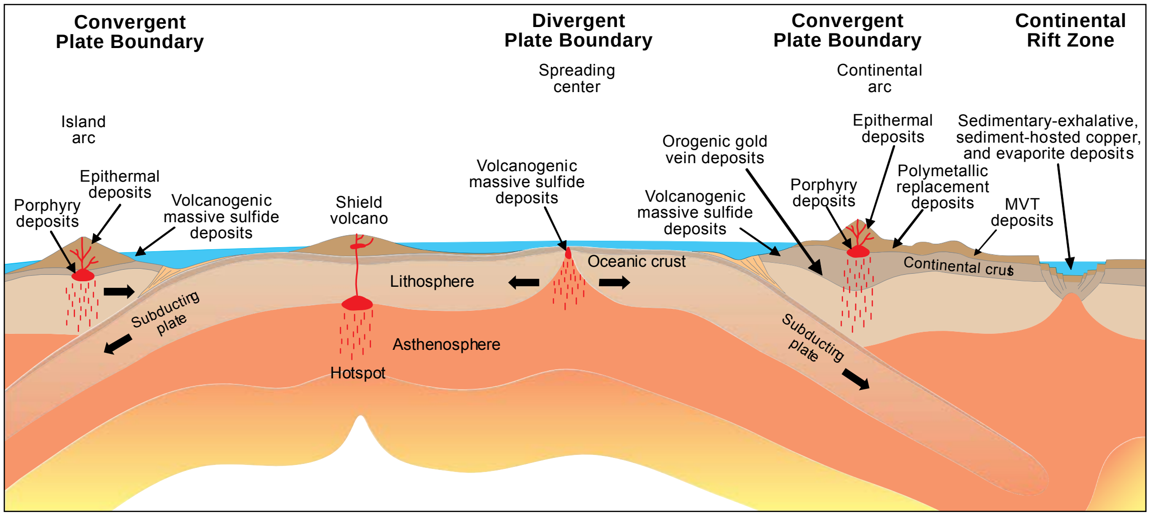


Figure 7. Cross section of the uppermost layers of the Earth illustrating the distribution of mineral deposits in relation to the main types of tectonic plate boundaries.

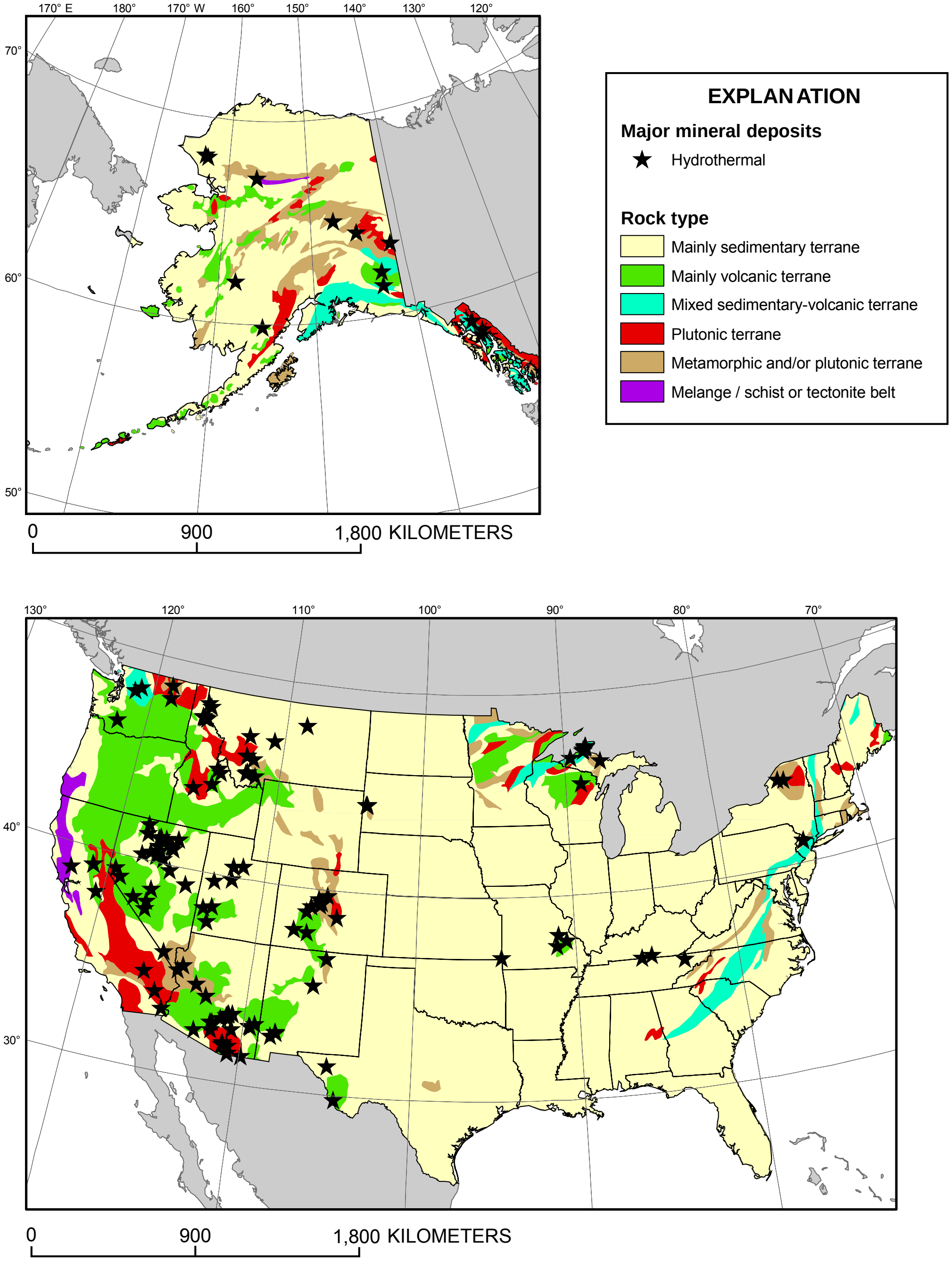


Figure 8. Map showing the location of the major hydrothermal mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995).

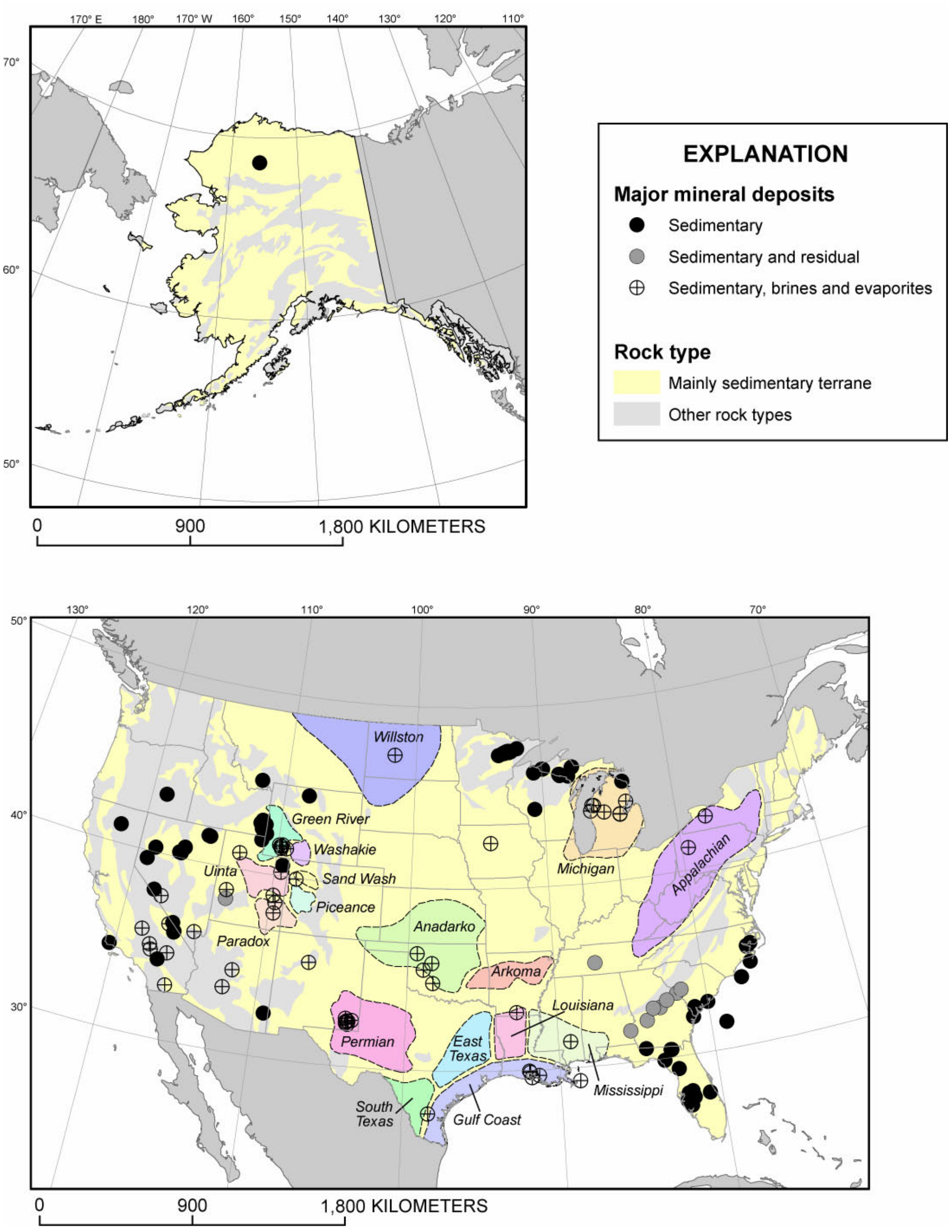


Figure 9. Map showing the location of the major sedimentary mineral deposits of United States listed in appendix 1. The map also shows the extent of sedimentary basins mentioned in the report. Geologic base is derived from Geological Survey of Canada (1995) and sedimentary basins are from St. John (2000).

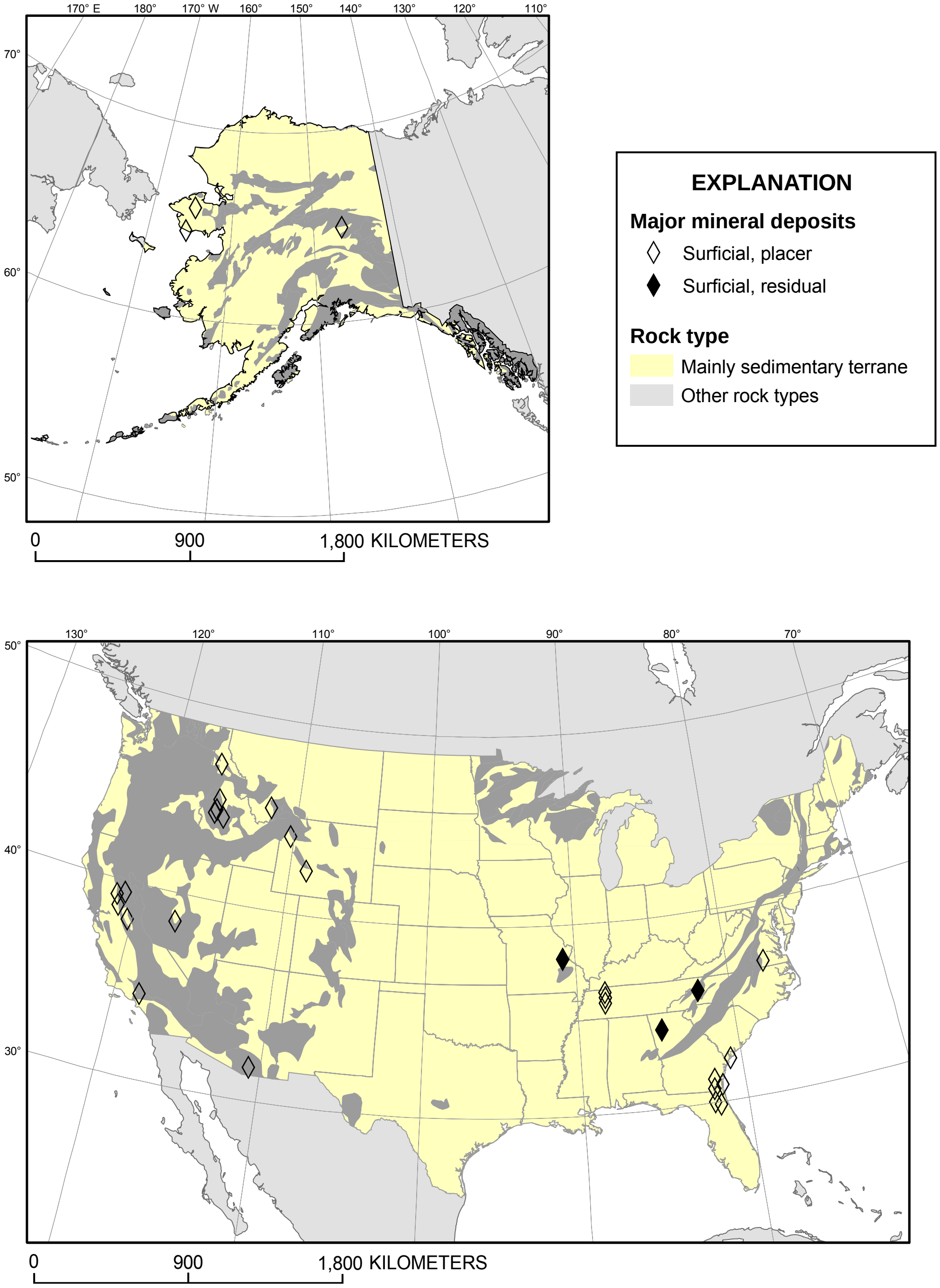
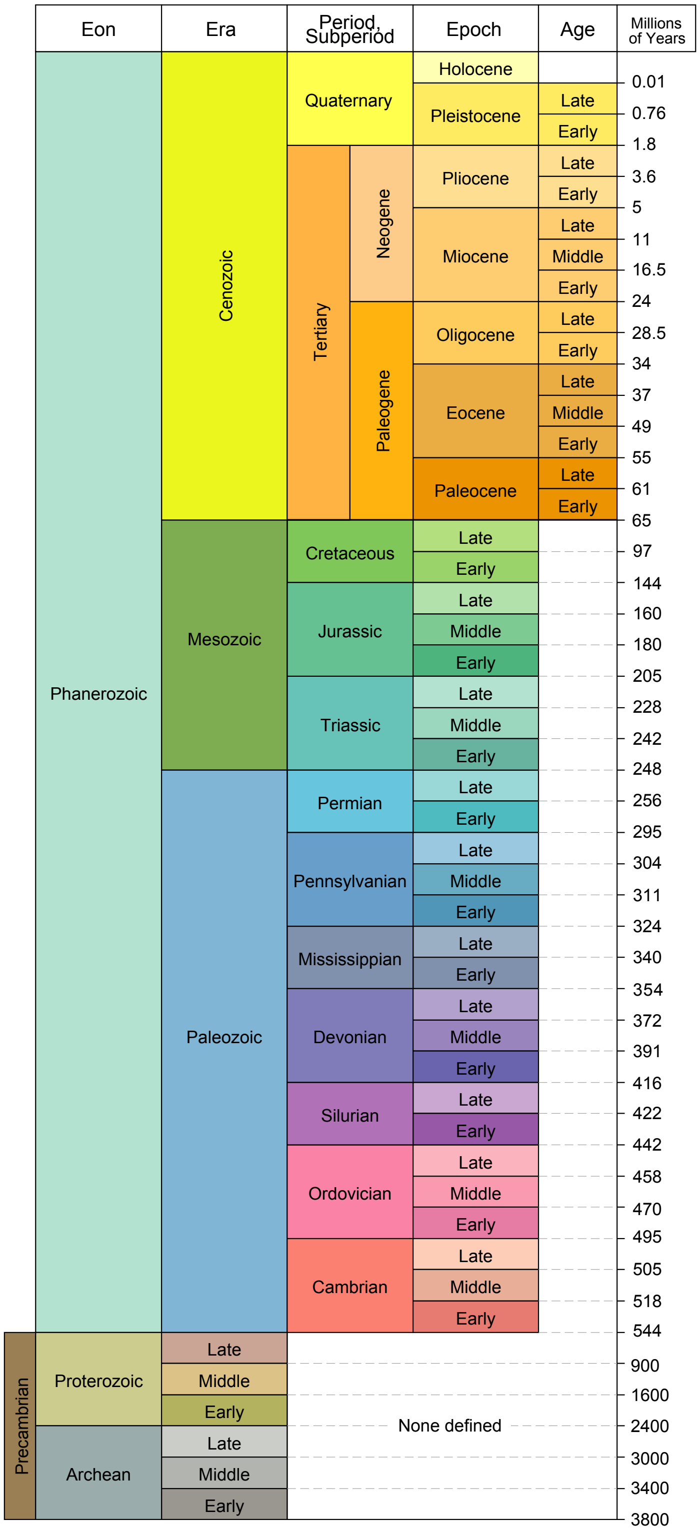


Figure 10. Map showing the location of the major surficial mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995).



Eon	Era	Period, Subperiod	Epoch	Age	Millions of Years
Phanerozoic	Cenozoic	Quaternary	Holocene		0.01
			Pleistocene	Late	0.76
				Early	1.8
		Tertiary Neogene	Pliocene	Late	3.6
				Early	5
			Miocene	Late	11
				Middle	16.5
				Early	24
		Paleogene	Oligocene	Late	28.5
				Early	34
			Eocene	Late	37
				Middle	49
				Early	55
			Paleocene	Late	61
				Early	65
	Mesozoic	Cretaceous	Late		97
			Early		144
		Jurassic	Late		160
			Middle		180
			Early		205
		Triassic	Late		228
			Middle		242
			Early		248
	Paleozoic	Permian	Late		256
			Early		295
		Pennsylvanian	Late		304
			Middle		311
			Early		324
		Mississippian	Late		340
			Early		354
		Devonian	Late		372
			Middle		391
			Early		416
		Silurian	Late		422
			Early		442
		Ordovician	Late		458
			Middle		470
			Early		495
		Cambrian	Late		505
			Middle		518
			Early		544
Precambrian Proterozoic	Late	None defined			900
	Middle				1600
	Early				2400
Archean	Late				3000
	Middle				3400
	Early				3800

Figure 11. Relative geologic time units used in this report (modified from Hansen, 1991 and Haq and Van Eysinga, 1998).

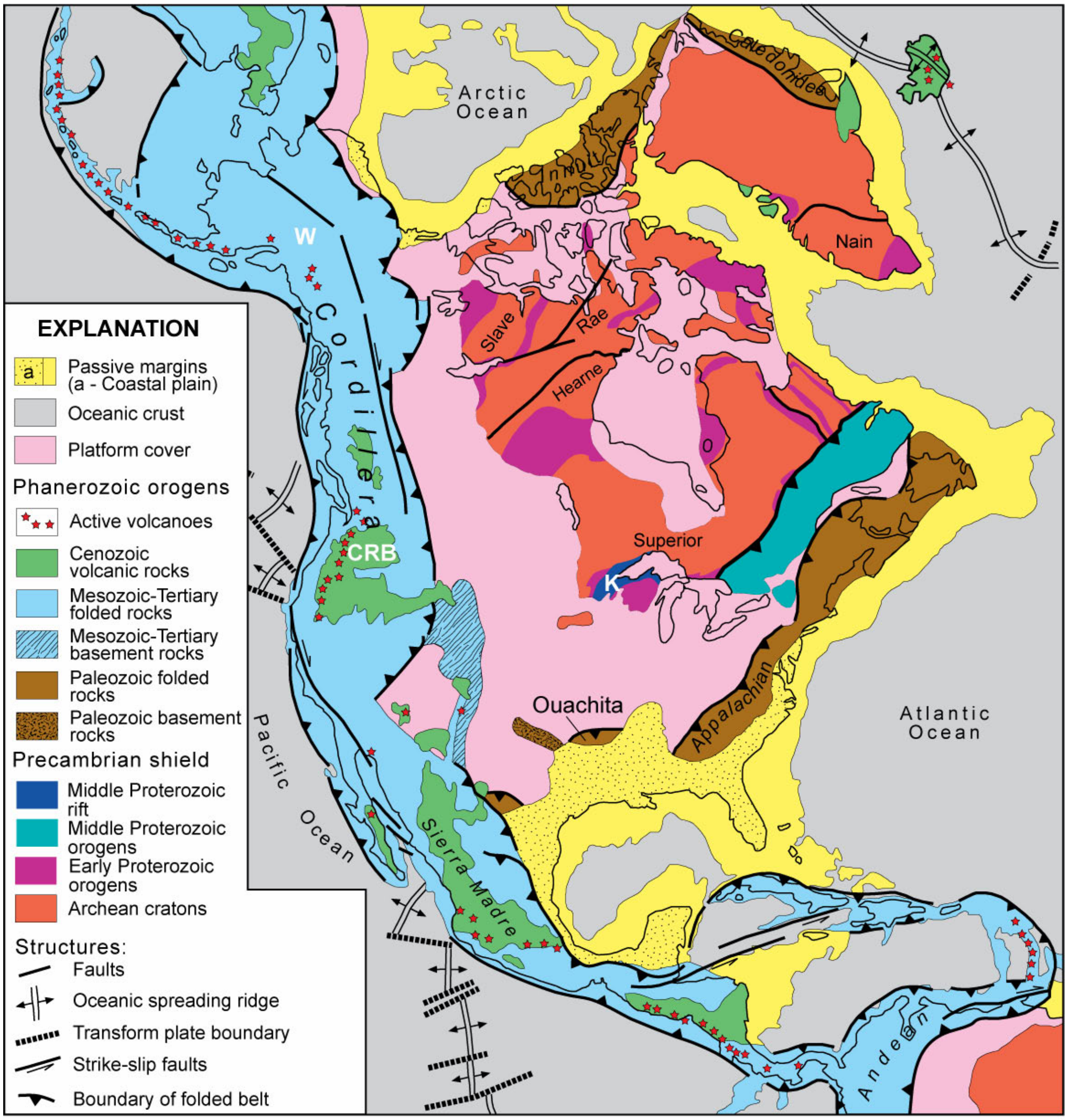


Figure 12. Simplified geologic map of North America. Modified from Bally and others (1989) and Hoffman (1989). White labels are: CRB – Columbia River flood basalt province; K – Keweenawan flood basalt province; and W, Wrangellia flood basalts.

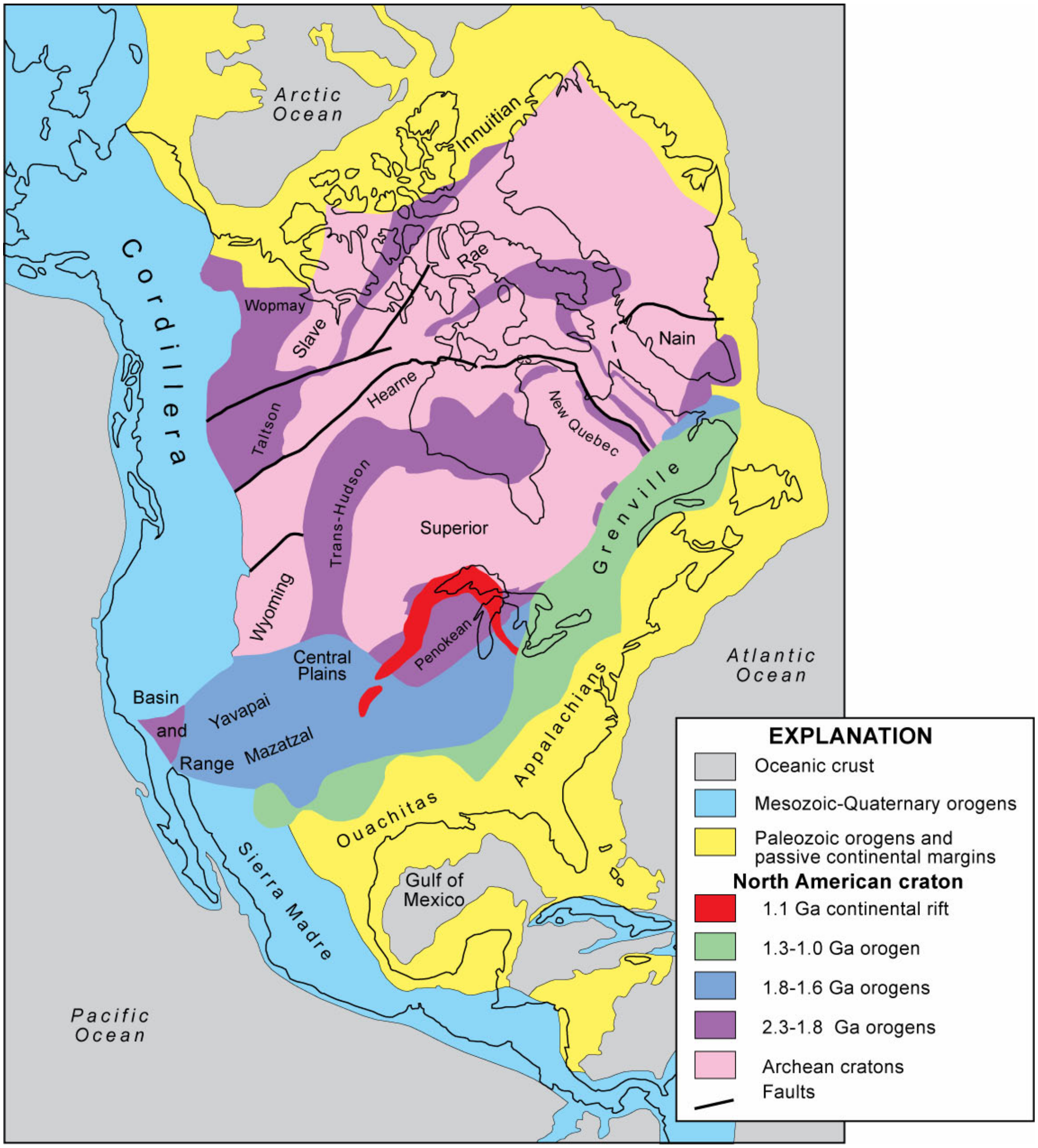


Figure 13. Map of North American showing the geology of the North American craton underlying the sedimentary rocks that cover much of the continent. Modified from Hoffman (1989).

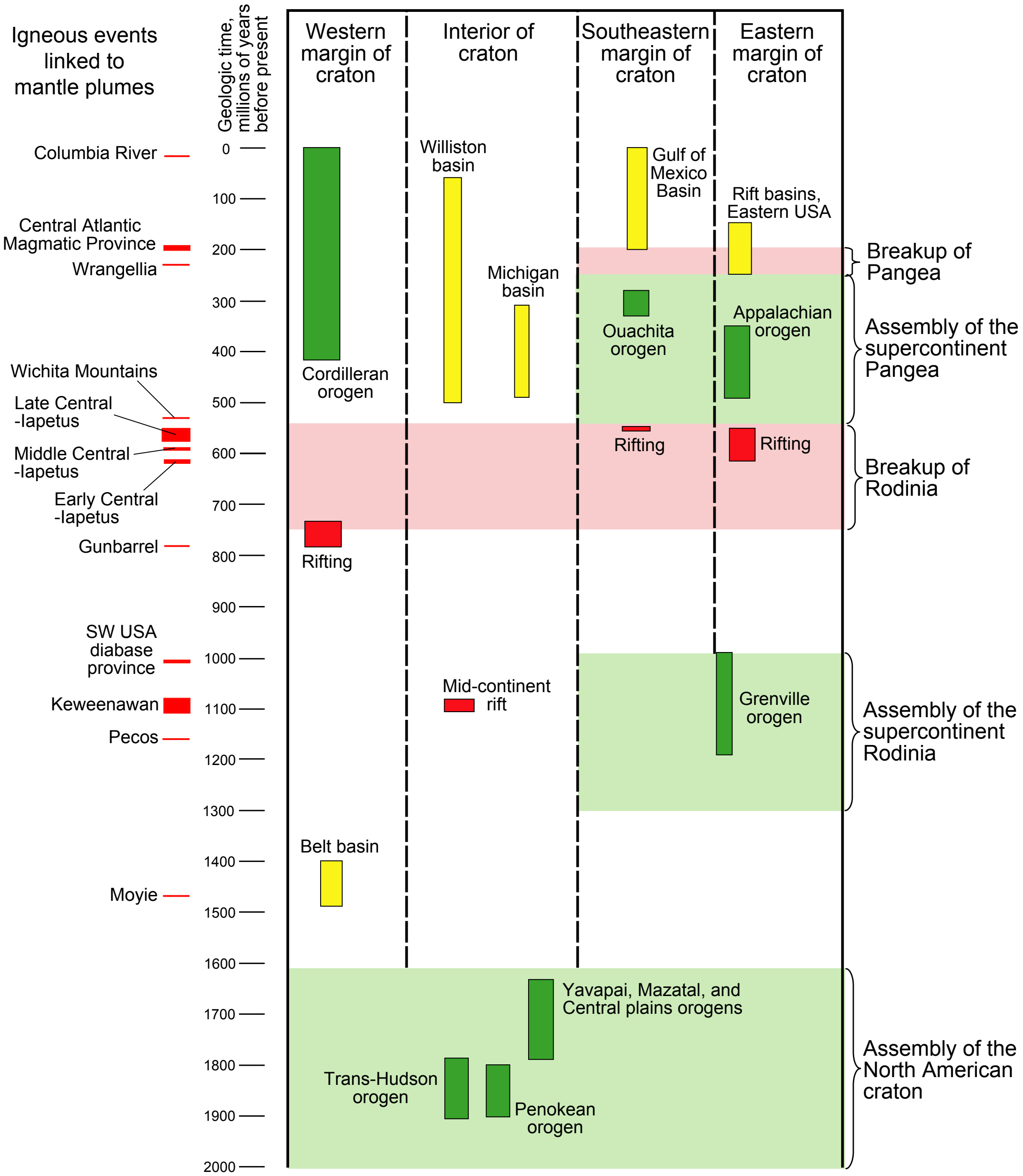


Figure 14. Summary of selected geologic events and features for the North American craton in the last 2,000 million years. Large igneous events from Ernst and Buchan (2001).

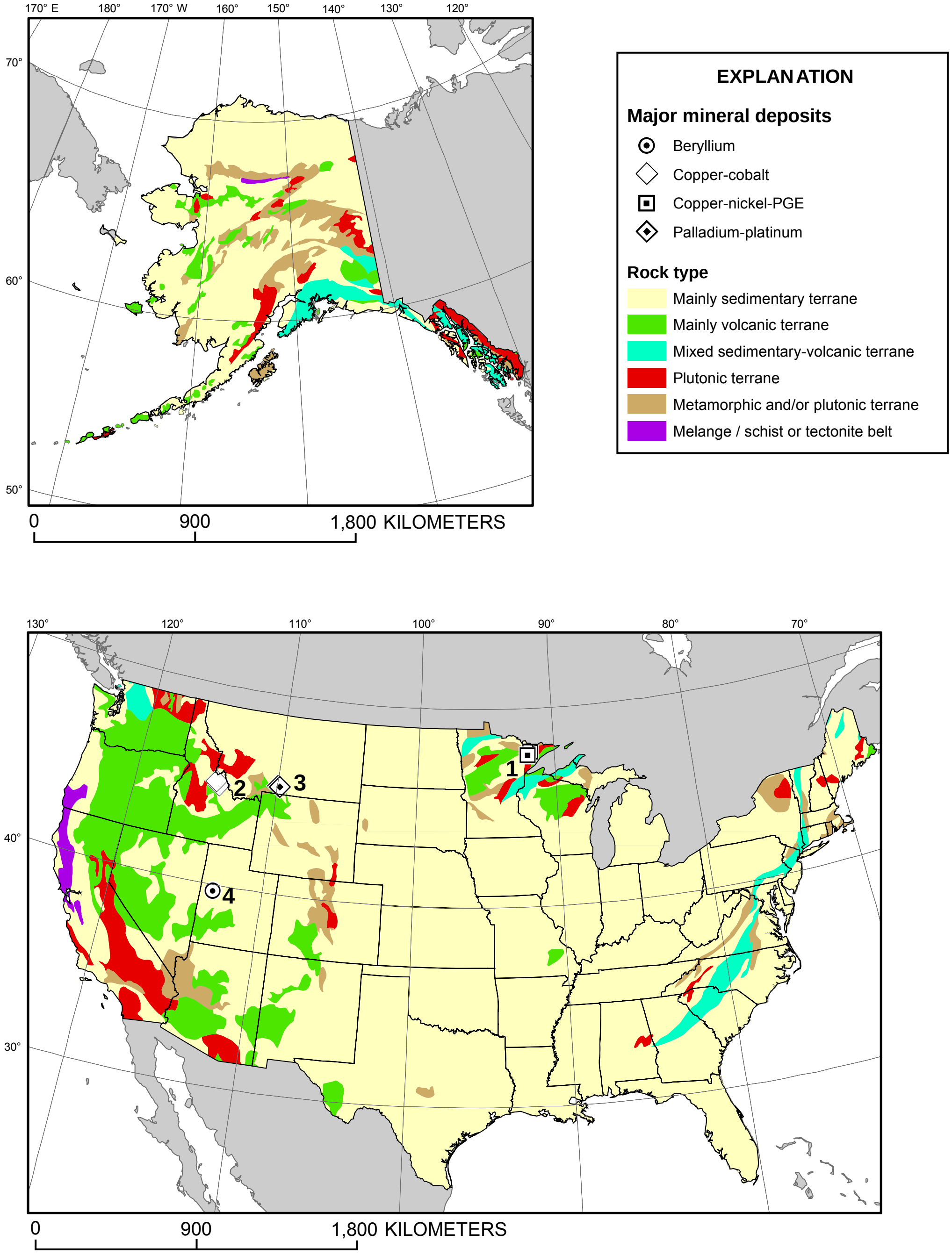


Figure 15. Map showing the location of the major beryllium, copper-cobalt, copper-nickel-PGE, and platinum-palladium mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Babbitt, Dunka Road, and Maturi; 2 – Idaho Cobalt belt (Blackbird, Ram and Sunshine); 3 – East Boulder and Stillwater mines; and 4 – Spor Mountain.

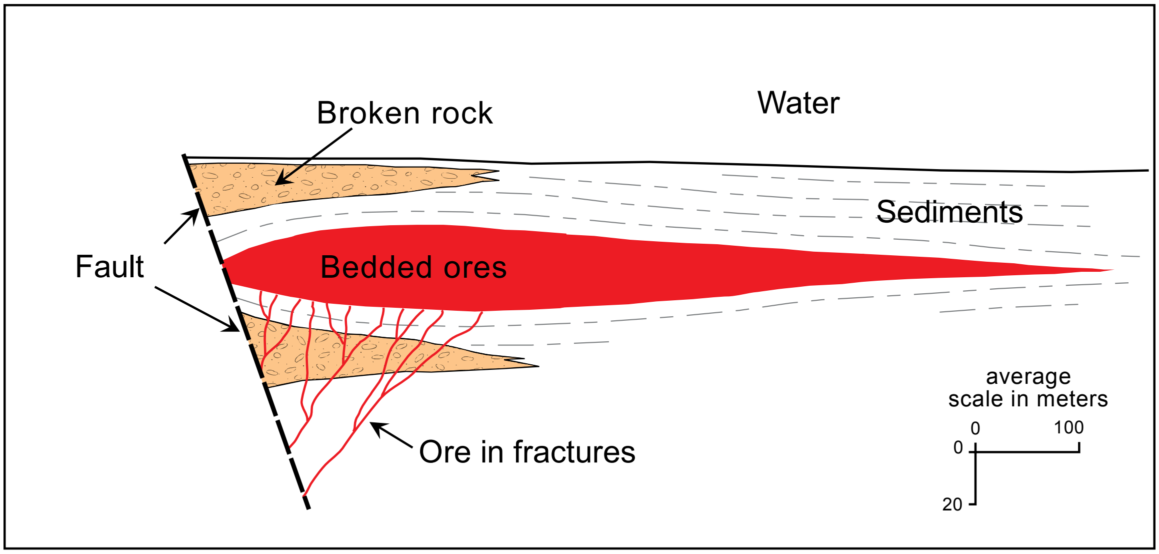


Figure 16. Cross section schematically illustrating the characteristic features of an idealized sedimentary-exhalative (sedex) mineral deposit. Modified from Lydon (1996).

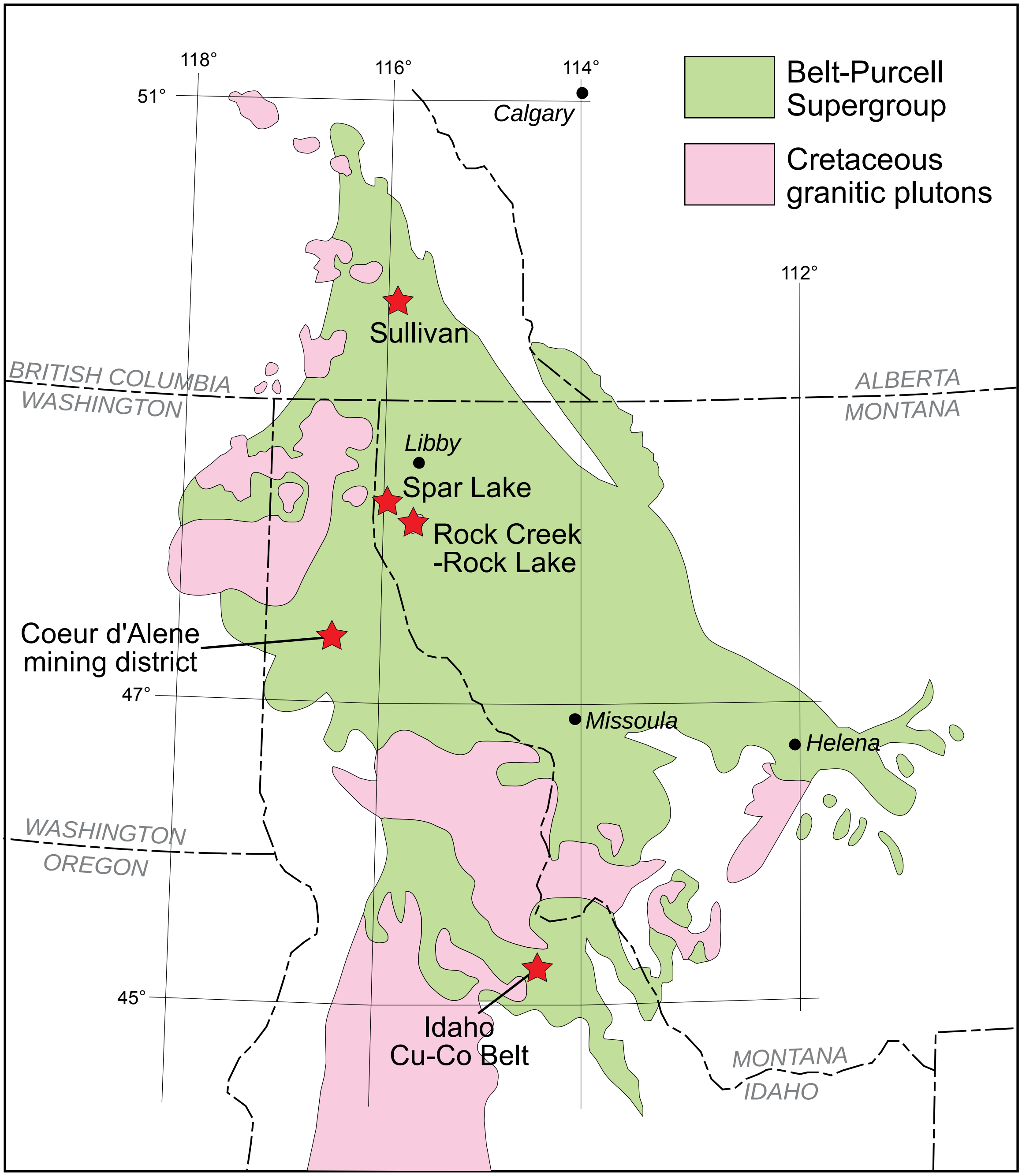


Figure 17. Simplified geologic map showing the distribution of metamorphosed sedimentary rocks (Belt-Purcell Supergroup) deposited in the Middle Proterozoic Belt basin and Cretaceous igneous rocks related to the Cordilleran orogen. Mineral deposits shown in this diagram are discussed in the text. Modified from Price and Sears (2000).

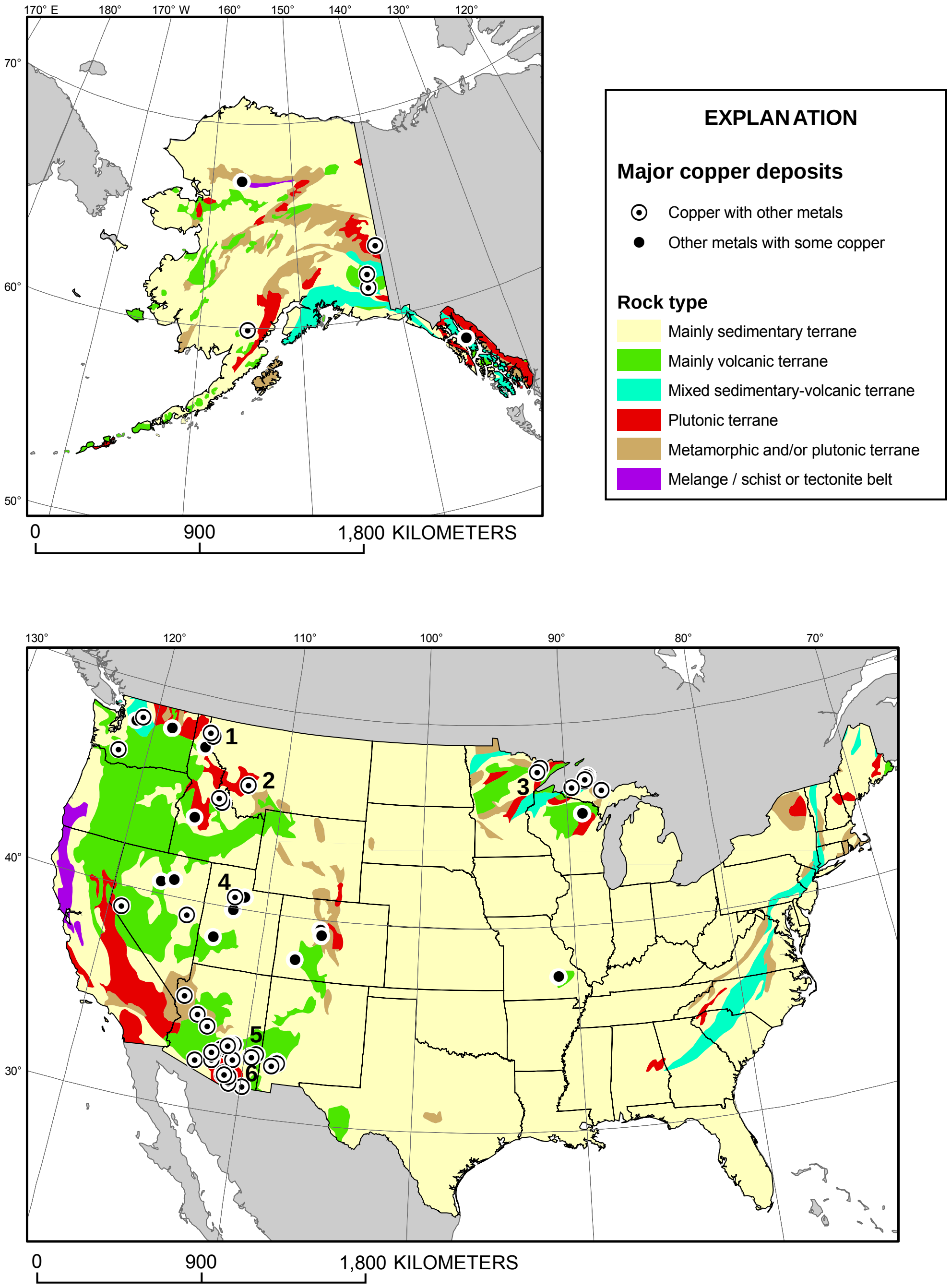


Figure 18. Map showing the location of the major copper mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Rock Creek/Rock Lake; 2 – Continental/Butte; 3 – Babbit, Dunka Road, and Maturi; 4 – Bingham Canyon; 5 – Morenci/Metcalf; and 6 – Safford.

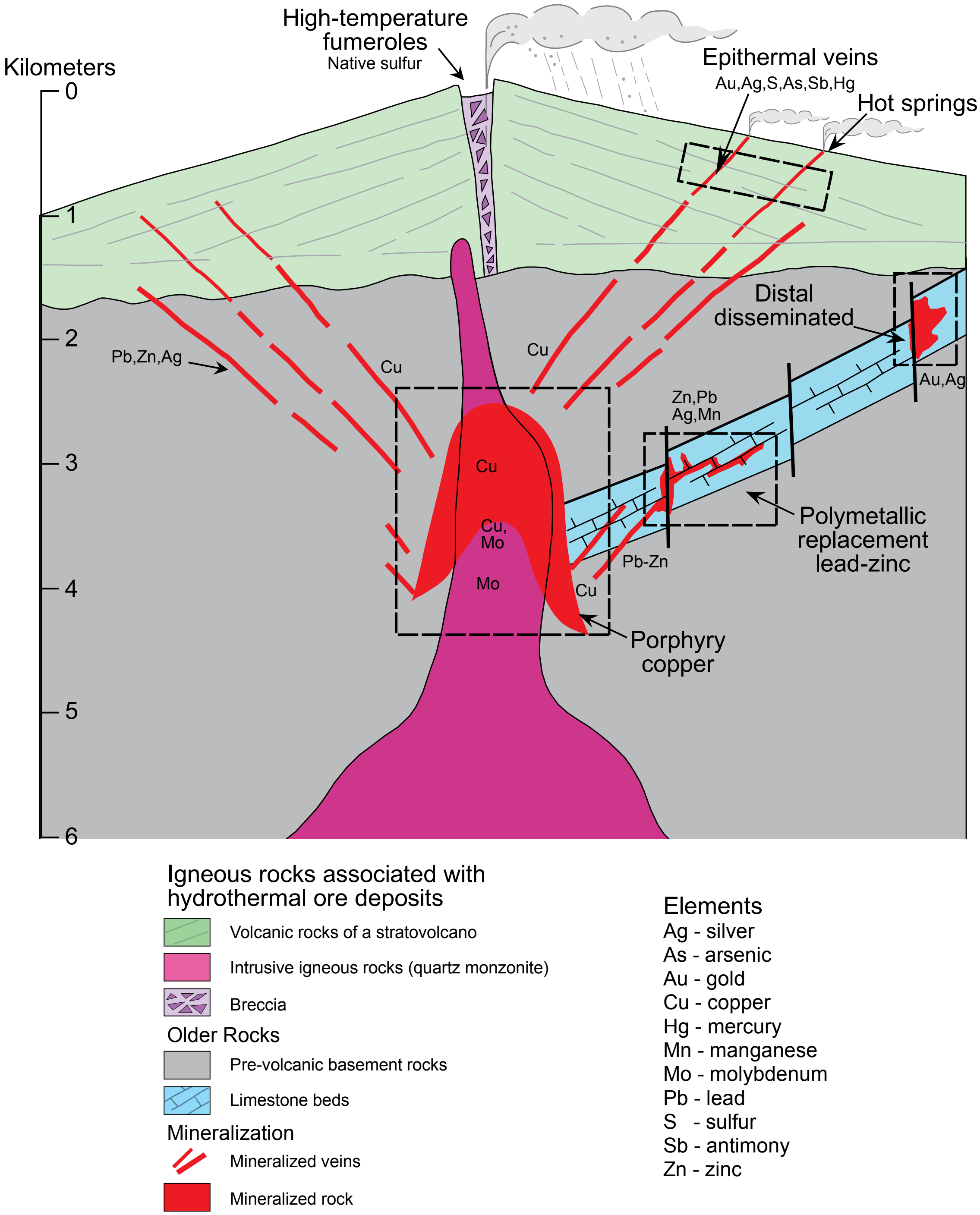


Figure 19. Cross section through an idealized stratovolcano, showing various styles of related mineralization.

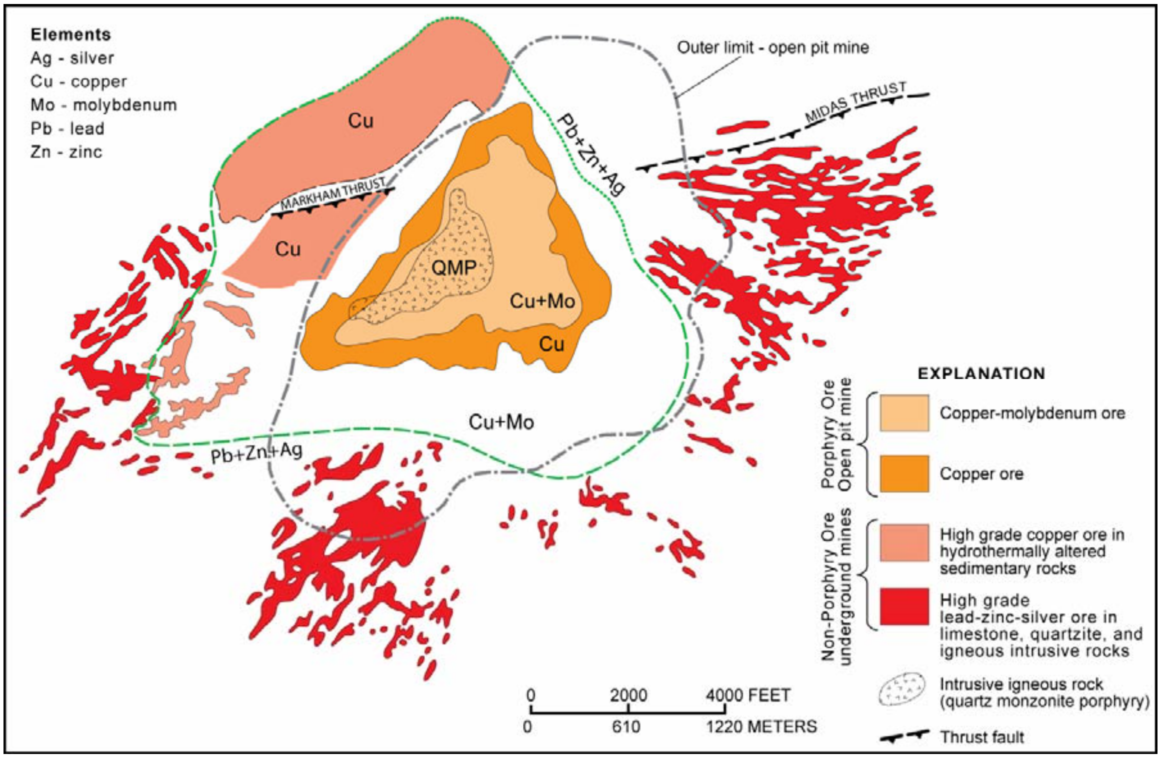


Figure 20. Map illustrating changes in metal content of mineralized rock and ore deposits in the Bingham district, Utah. The map was created by vertically projecting underground features to the surface. Copper and copper+molybdenum mineralization is associated with a porphyry copper deposit. The igneous intrusion responsible for forming these hydrothermal deposits is labeled as QMP on the map. Hydrothermal solutions related to the porphyry copper deposit moved into and reacted with adjacent sedimentary rocks to form copper deposits and lead-zinc-silver deposits. Modified from Atkinson and Einaudi (1978).

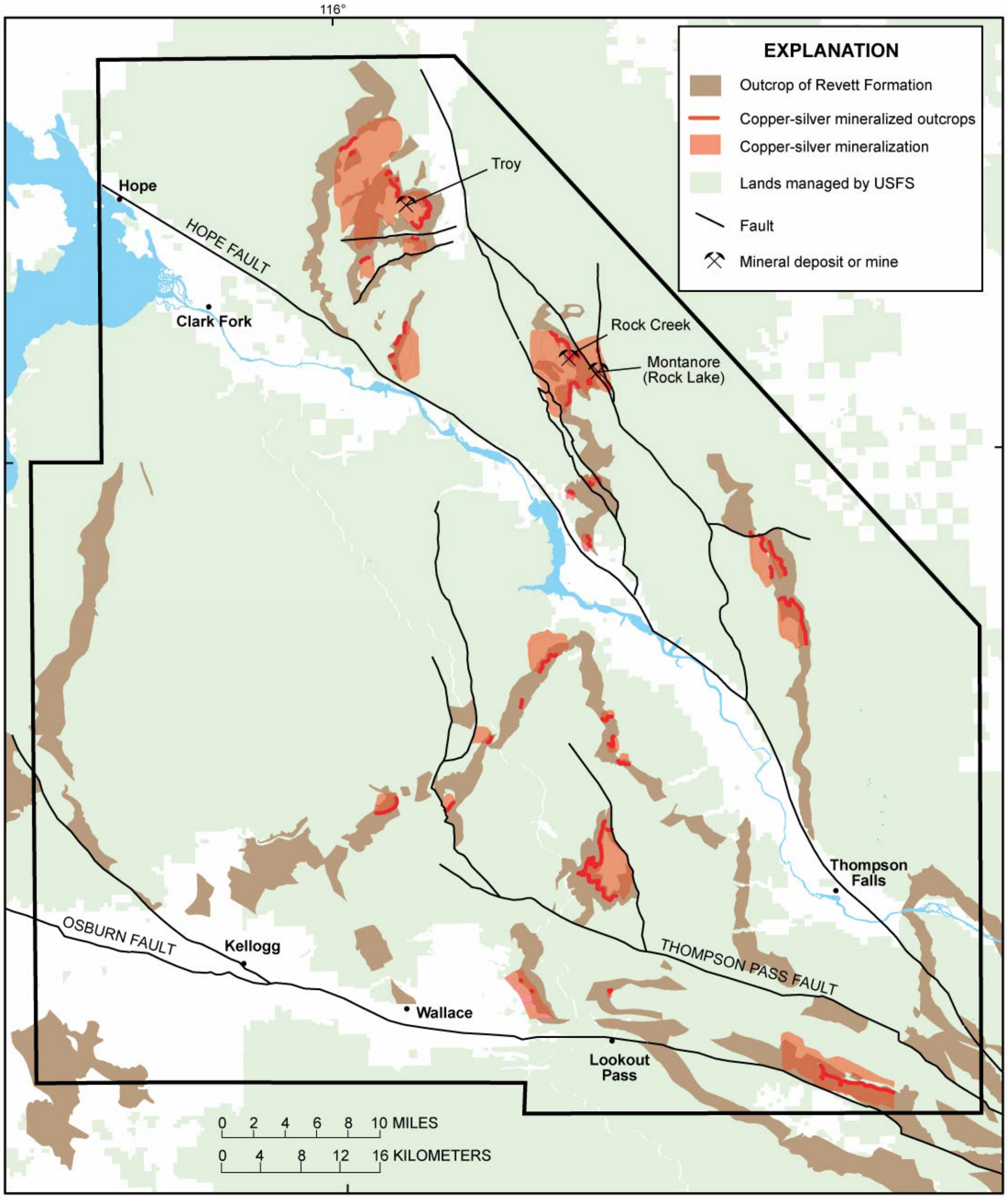


Figure 21. Map showing the distribution of the Middle Proterozoic Revett Formation and associated hydrothermal copper-silver mineralization in northwestern Montana and northern Idaho.

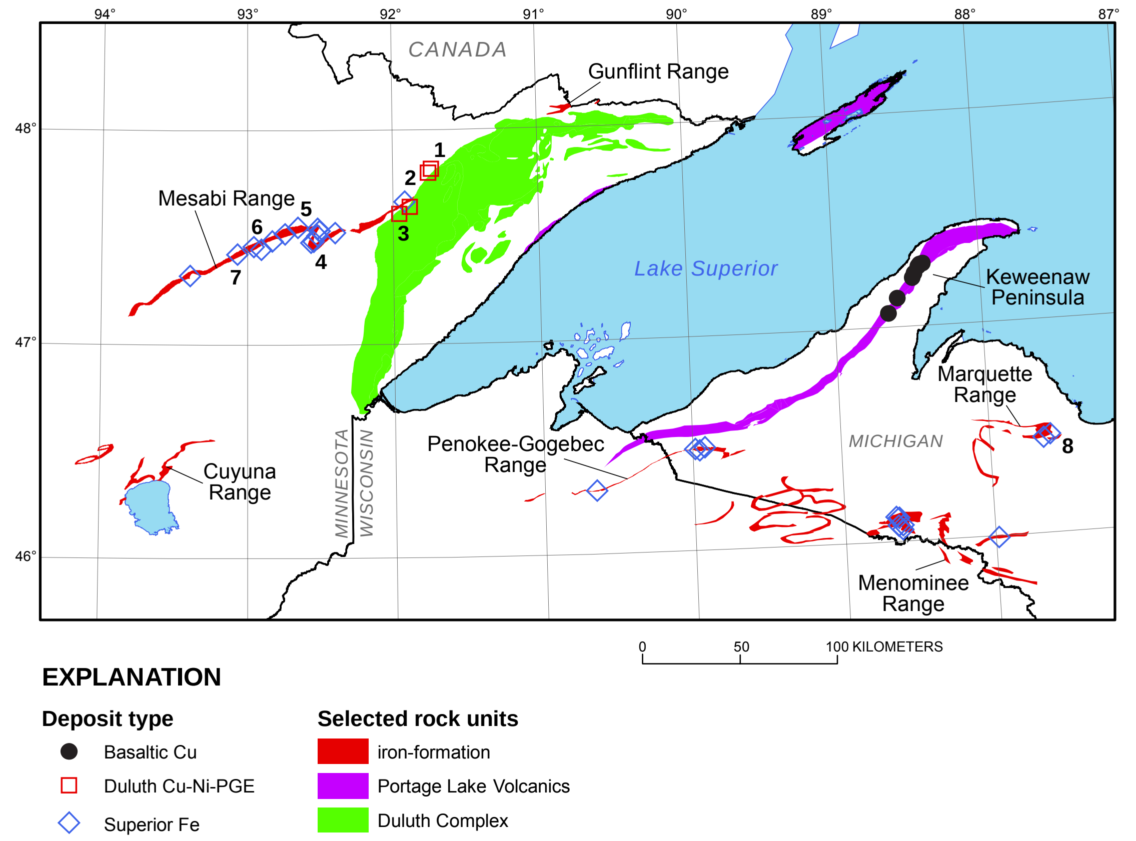


Figure 22. Map showing selected geologic features and the location of major sedimentary iron deposits (banded iron formation), magmatic copper-nickel-PGE deposits, and hydrothermal copper deposits in basalt. Map derived from Cannon and others (1997). Numbered deposits are discussed in the report: 1 – Birch Lake; 2 – Maturi; 3 – Dunka Road; 4 – Thunderbird; 5 – Minntac; 6 – Hibbing Taconite; 7 – National Steel; and 8 – Empire and Tilden.

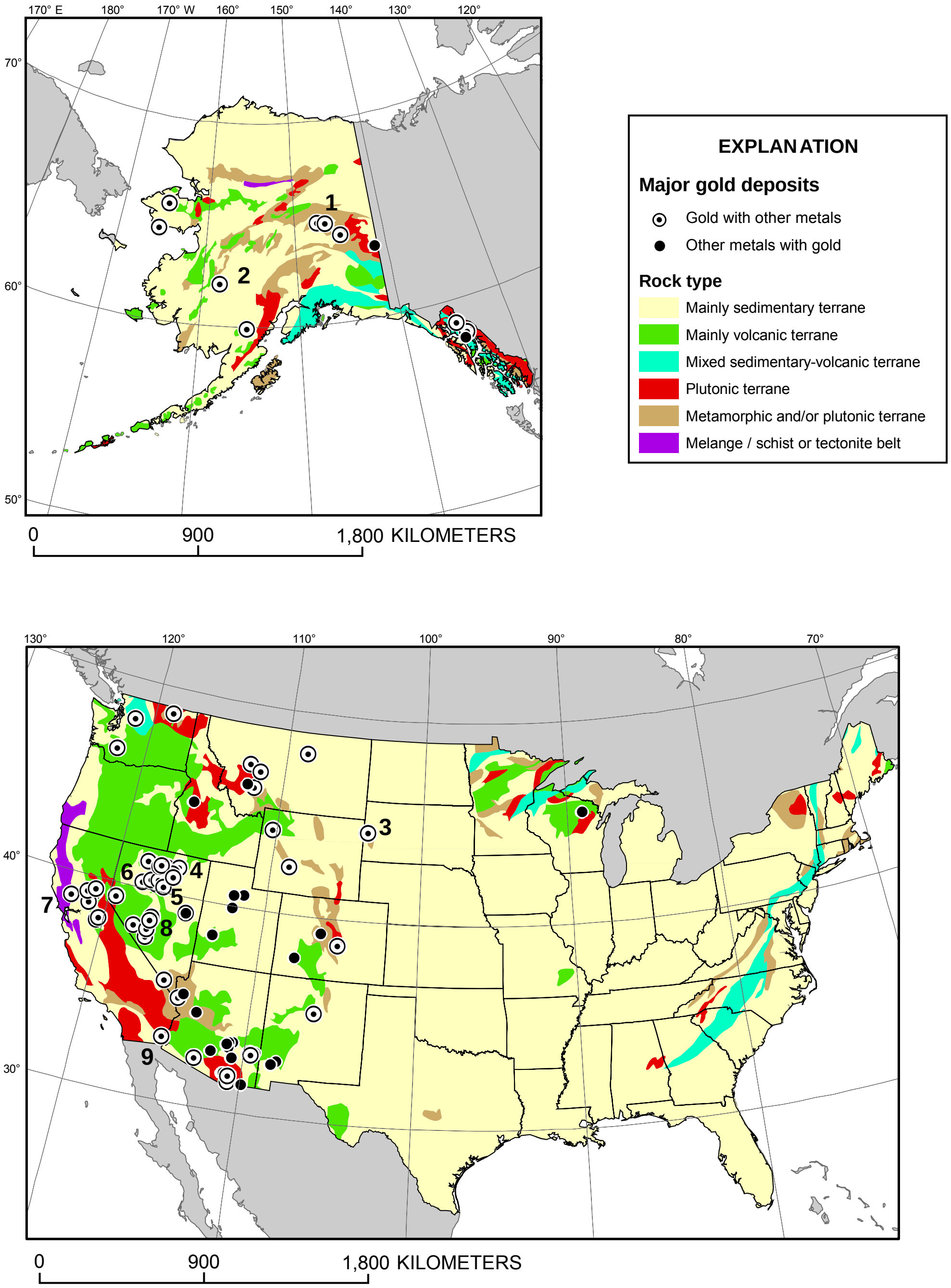


Figure 23. Map showing the location of the major gold mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Fort Knox; 2 – Donlin Creek; 3 – Homestake; 4 – Betze/Post; 5 – McCoy/Cove; 6 – Rochester; 7 – McLaughlin; 8 – Round Mountain; and 9 – Mesquite.

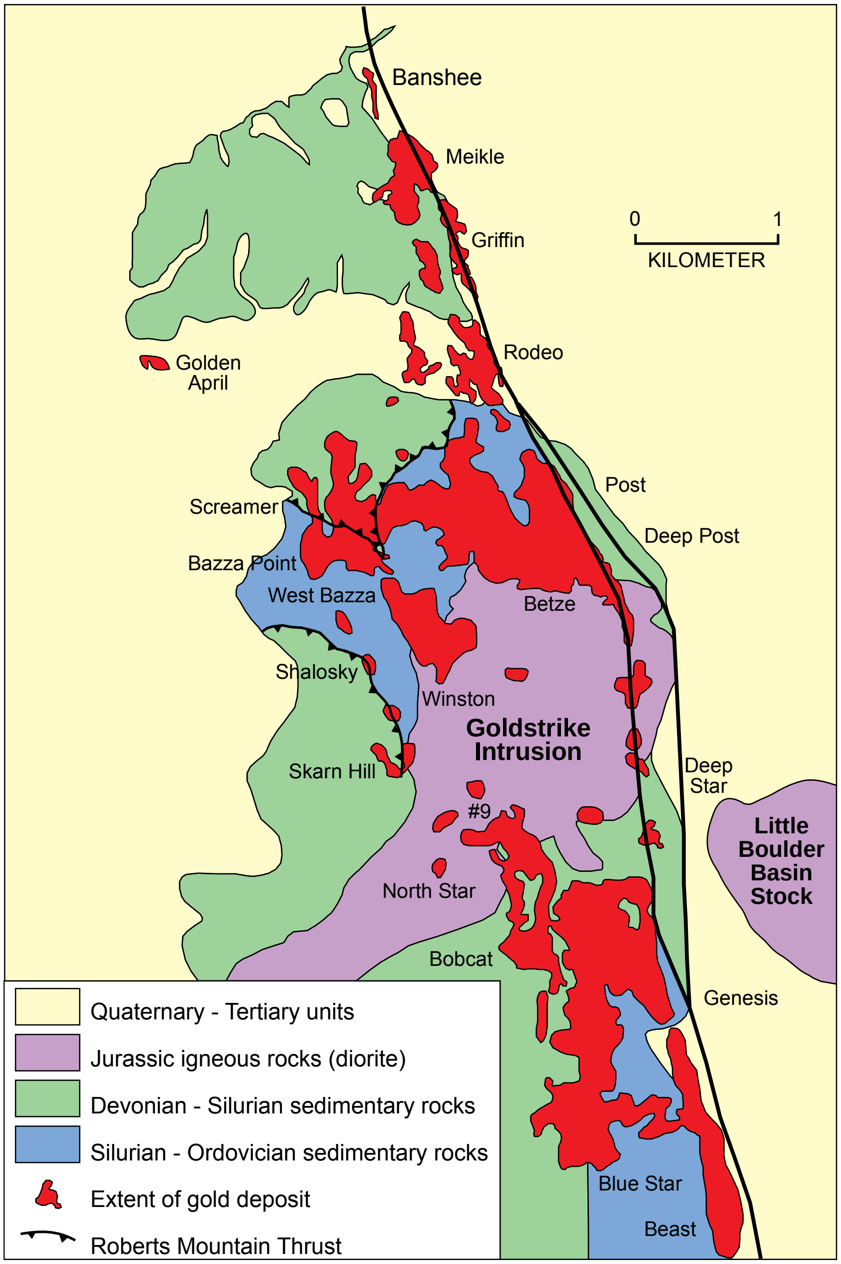


Figure 24. Map showing the distribution of sedimentary rock-hosted gold deposits and mineralization of the Blue-Star area of the Carlin Trend, Nevada. The extent of the gold deposits and igneous intrusions on the map was created by vertically projecting underground features to the surface. Modified from Bettles (2002).

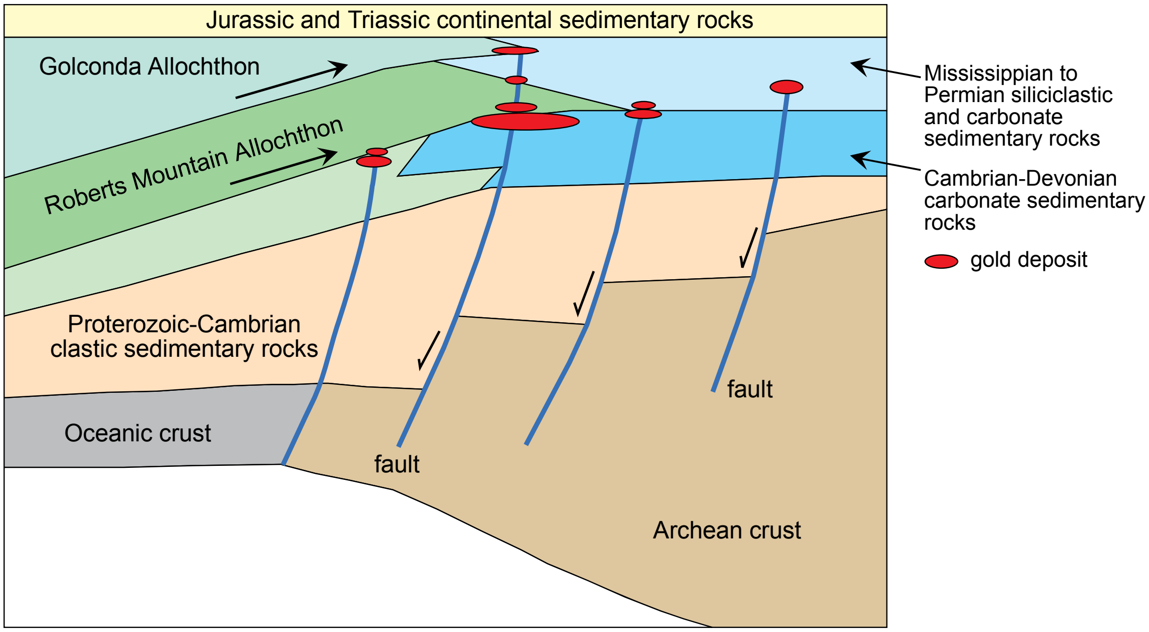


Figure 25. Schematic east-west cross section of northern Nevada and northwest Utah showing the location of Carlin-type gold deposits in relation to large tectonic features. The transition from Archean crust to oceanic crust formed during the breakup of the supercontinent Rodinia. Rifting that led to the development of a new continental margin formed large faults that progressively thin the continental crust to the west. Different sequences of sediments were deposited or faulted on this rifted continental margin. Allochthons are packages of rocks that have been transported away from their origin site of origin along faults. Later deformation caused the rift-related faults to move and break through the younger rocks. Sedimentary rock-hosted ore deposits in northern Nevada appear to be clustered along linear trends that overlie these older faults. Modified from Hofstra and Cline (2000).

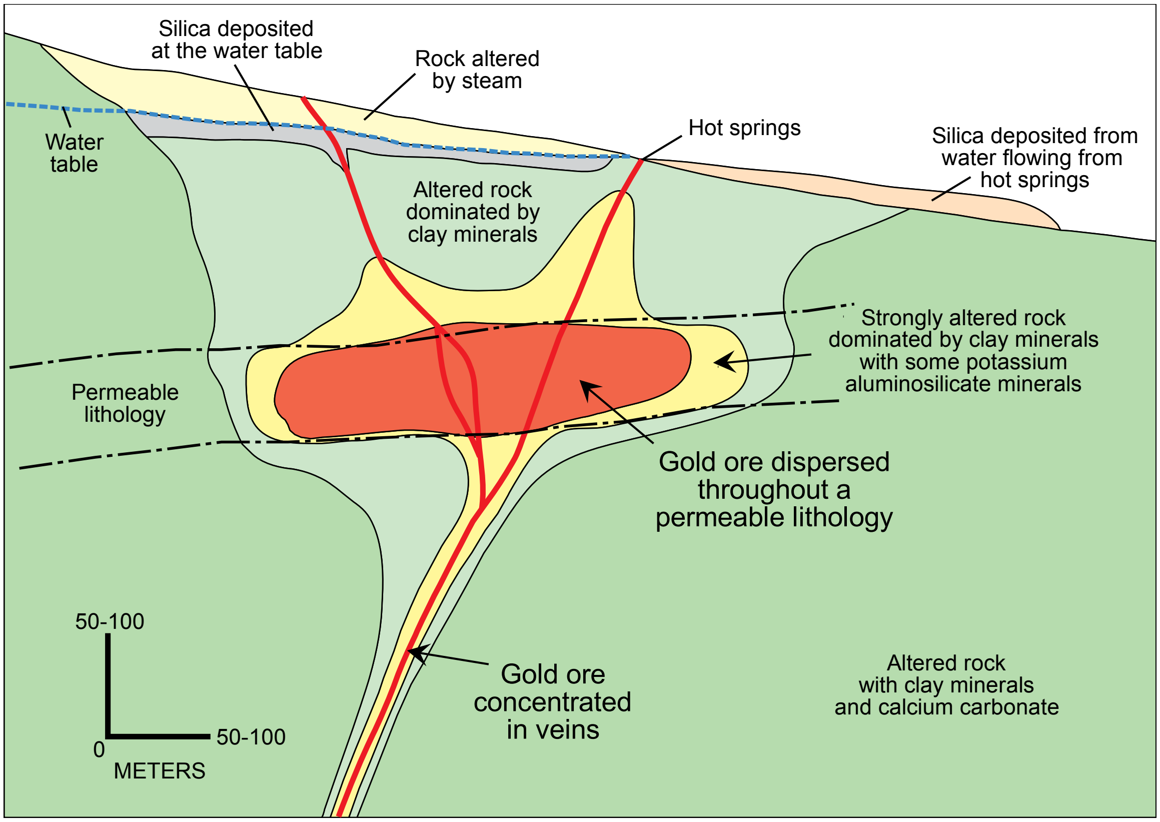


Figure 26. Schematic cross section that illustrates generalized patterns of alteration and mineralization of epithermal gold deposits. Modified from Hedenquist and others (2000).

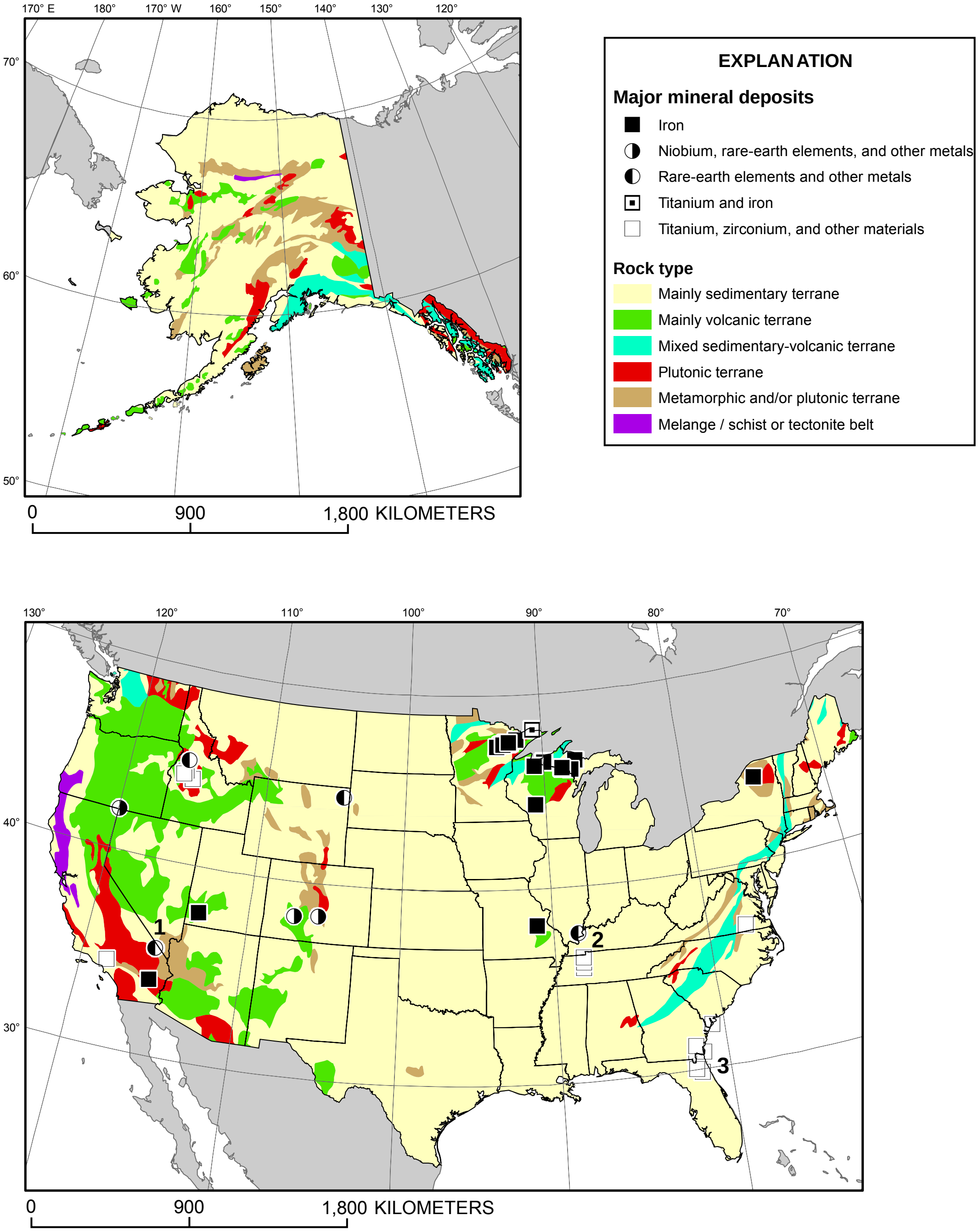


Figure 27. Map showing the location of the major iron, niobium, rare-earth metals, and titanium mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Mountain Pass; 2 – Hicks Dome; and 3 – Trail Ridge.

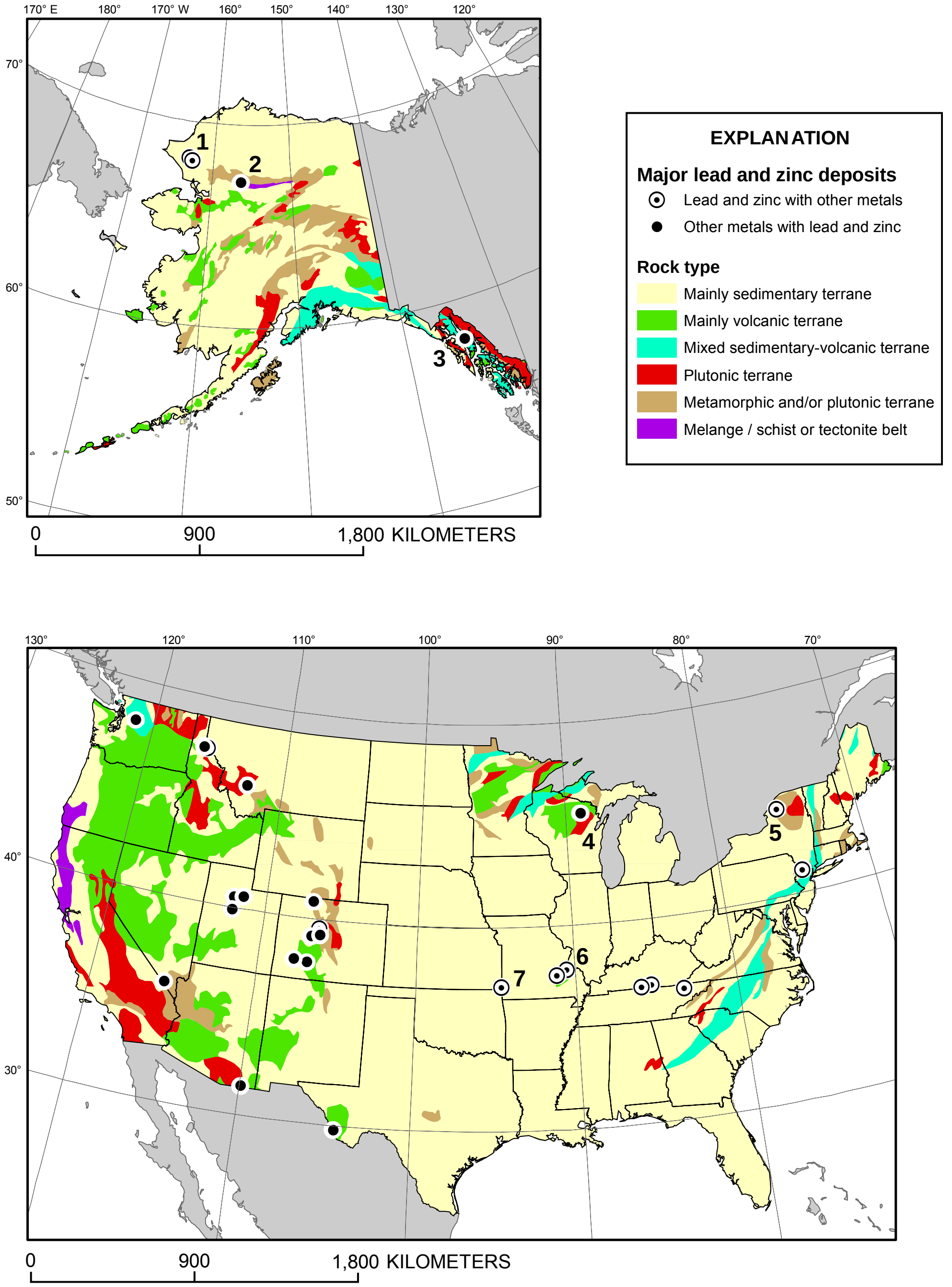


Figure 28. Map showing the location of the major lead and zinc mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Red Dog and Su-Lik; 2 – Arctic Camp; 3 – Greens Creek; 4 – Crandon; 5 – Pierre/Balmat/Edwards; 6 – Viburnum Trend and Old Lead Belt; and 7 – Tri-State.

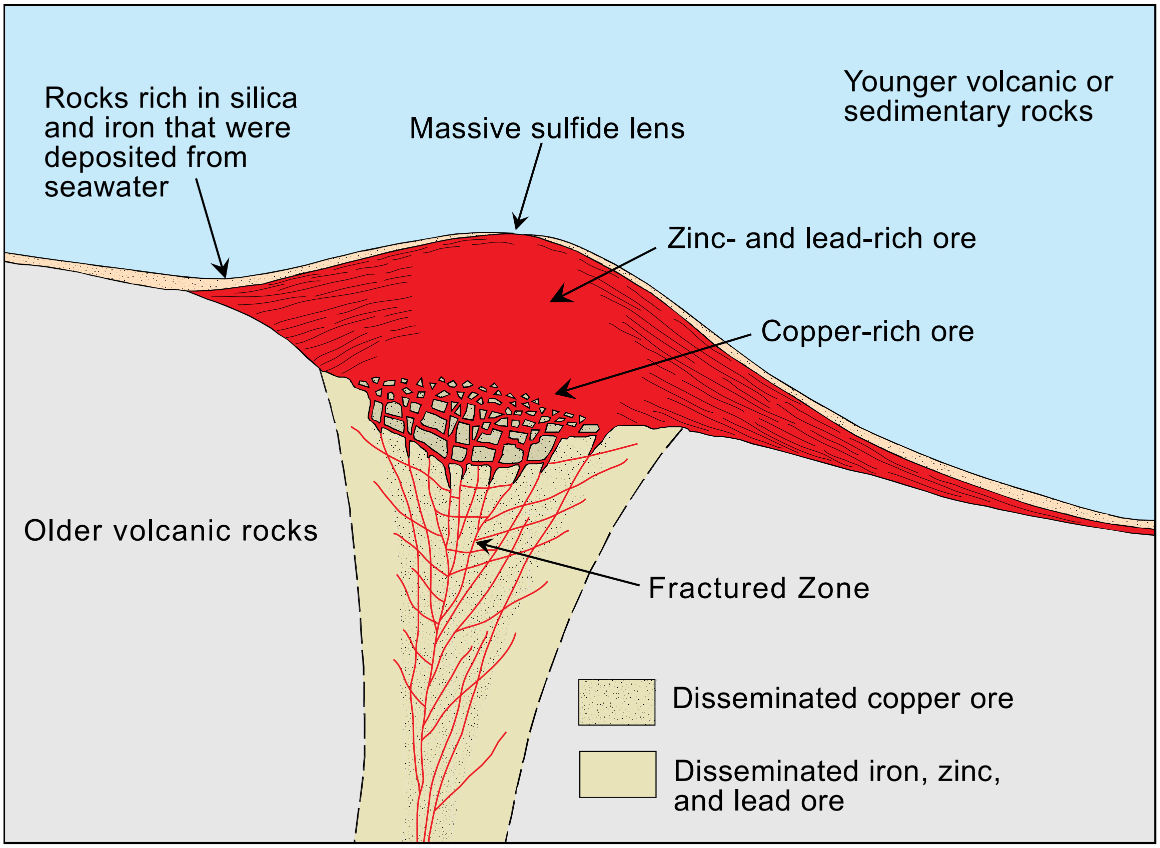


Figure 29. Cross section illustrating the essential features of an idealized volcanogenic massive sulfide deposit. Modified from Lydon (1988).

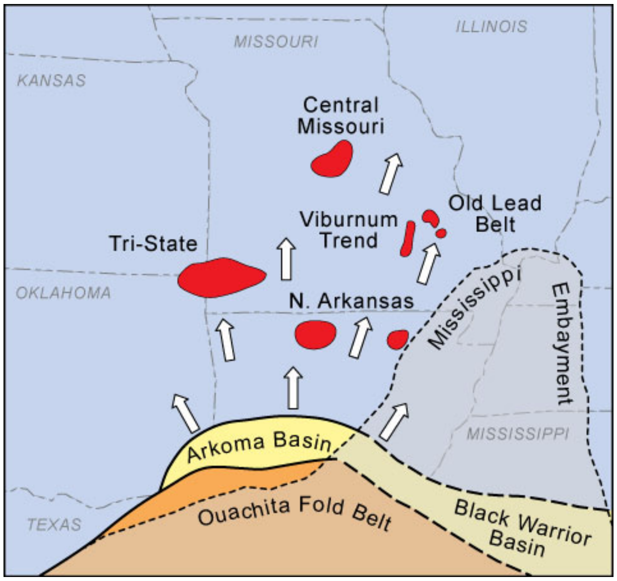


Figure 30. Map showing the location of MVT lead-zinc districts in the Ozark region of the United States. Arrows refer to inferred flow direction of ore fluid believed to have been derived from the Ouachita fold belt. Modified from Leach and Sangster (1993).

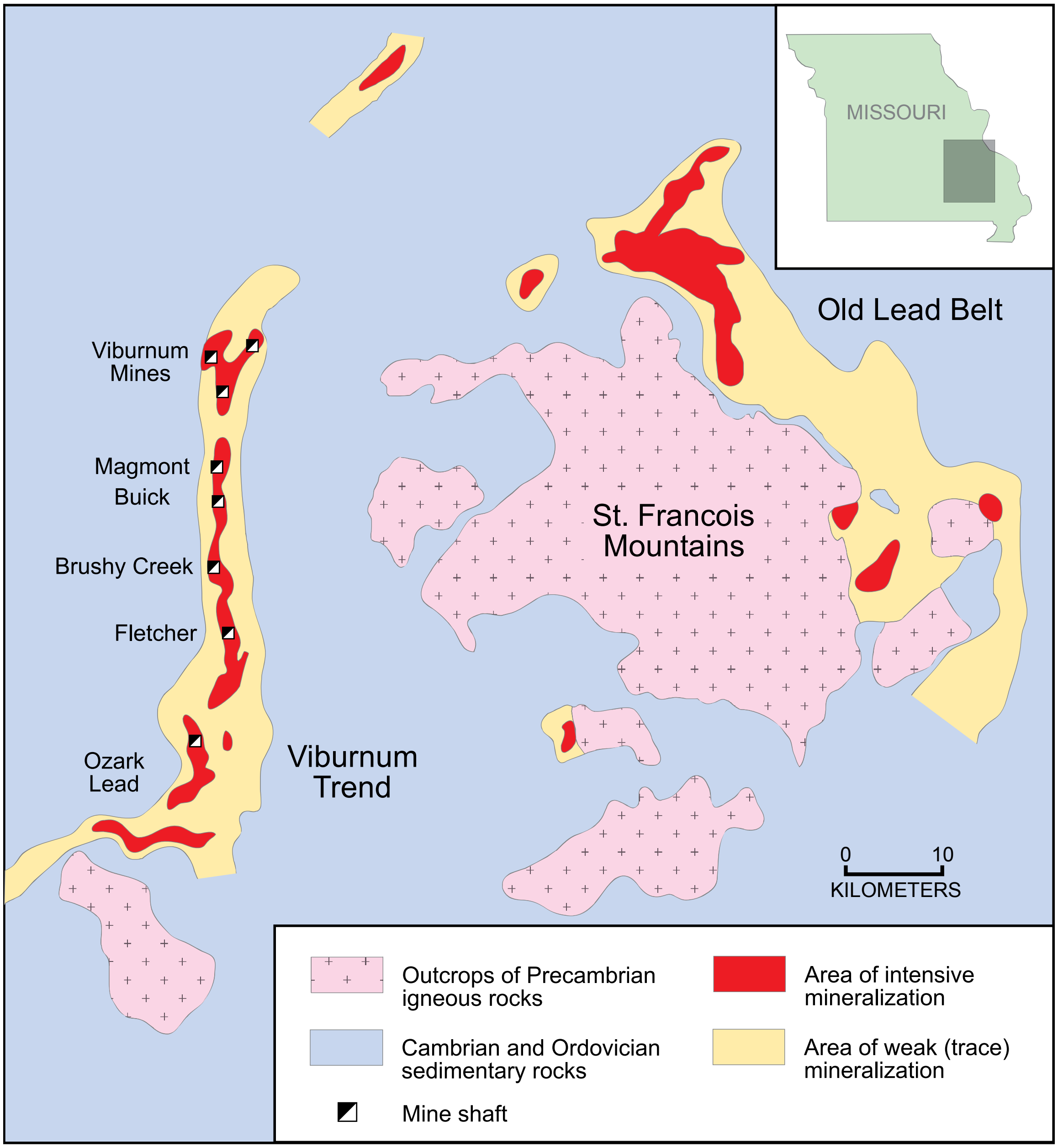


Figure 31. Map of southeast Missouri showing location of major Mississippi Valley ore districts surrounding outcrops of Precambrian igneous rocks in the St. Francois Mountains. The extent of mineralization associated with the Viburnum Trend shown on the map was created by vertically projecting underground features to the surface. Modified from Sawkins (1984).

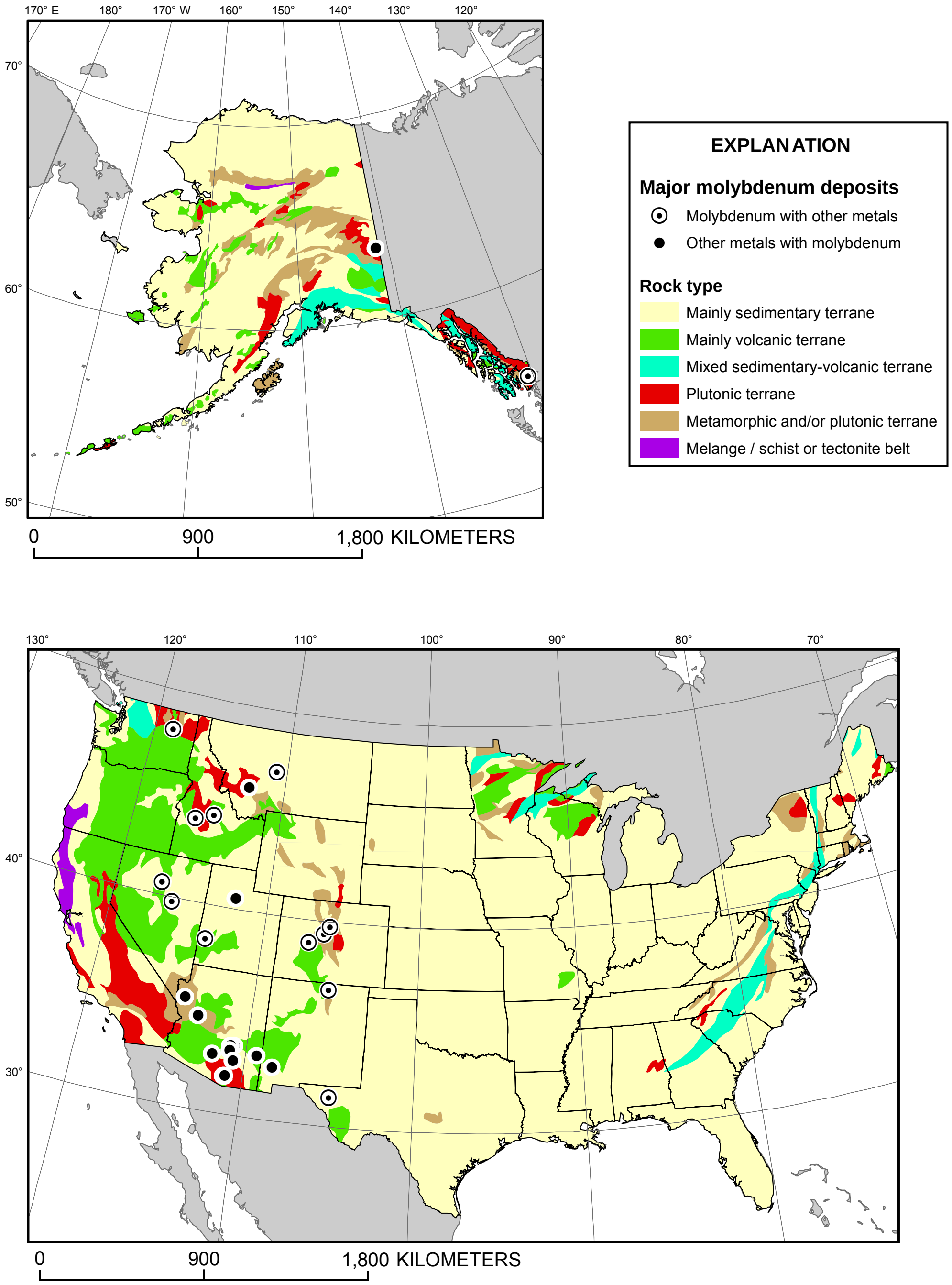


Figure 32. Map showing the location of the major molybdenum mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995).

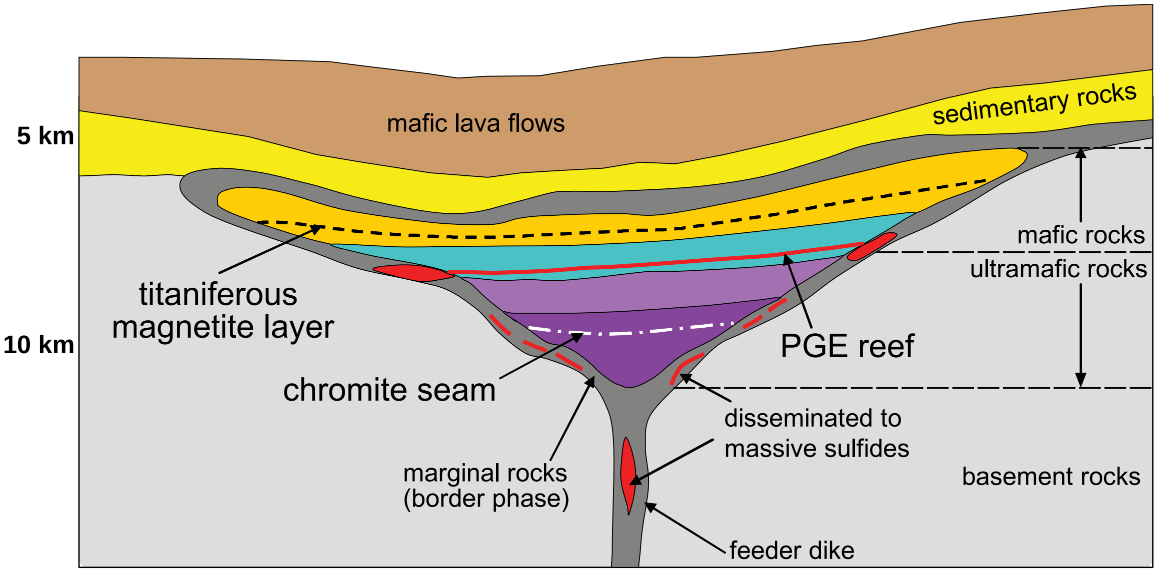


Figure 33. Idealized section through an ultramafic-to-mafic layered igneous intrusion showing the distribution of magmatic ore deposits.

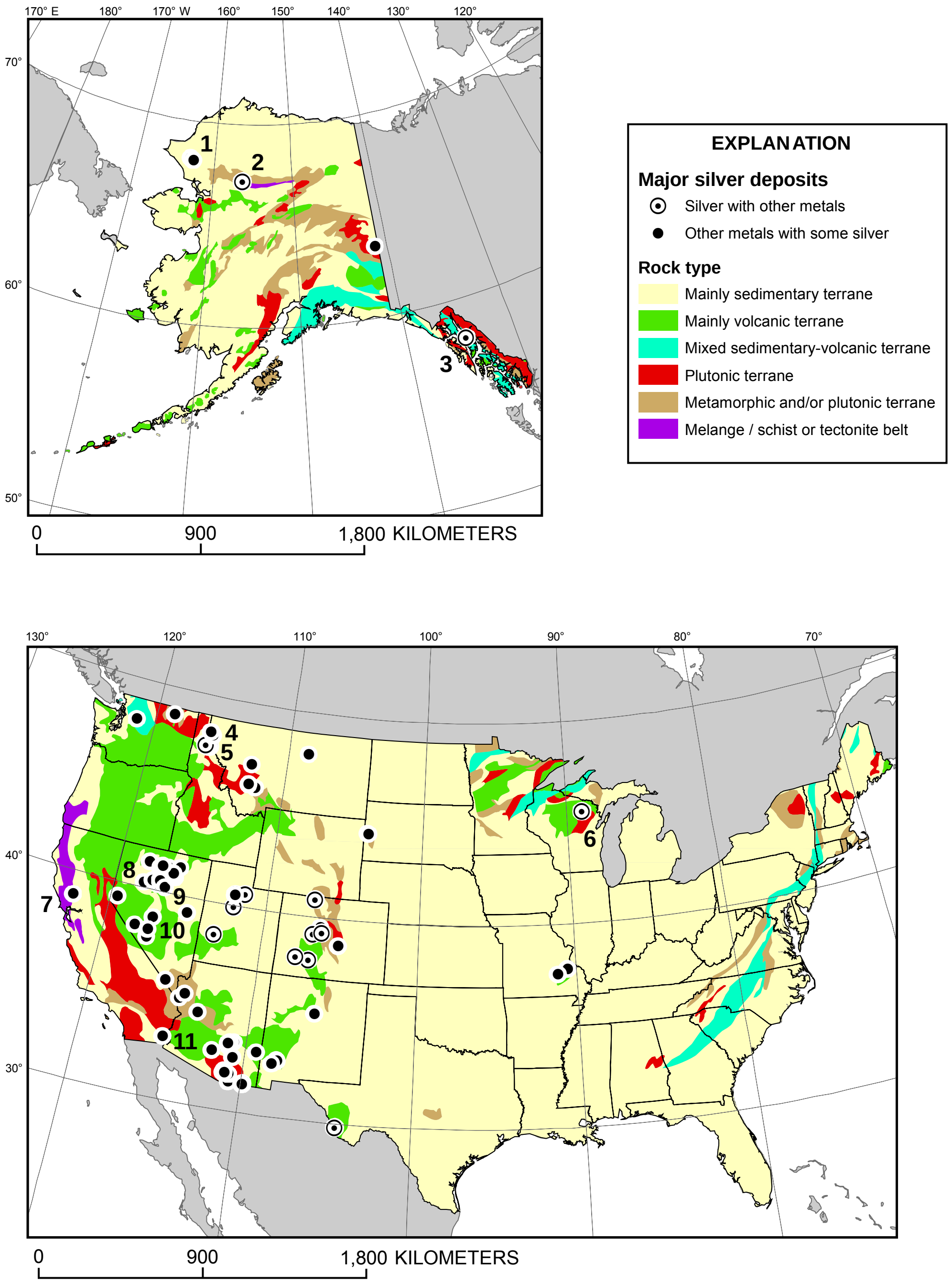


Figure 34. Map showing the location of the major silver mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Red Dog and Su-Lik; 2 – Arctic Camp; 3 – Greens Creek; 4 – Rock Creek/Rock Lake; 5 – Galena and Lucky Friday mines, Coeur d’Alene mining district; 6 – Crandon; 7 – McLaughlin, and 8 – Rochester; 9 – McCoy/Cove; 10 – Round Mountain; and 11 - Mesquite.

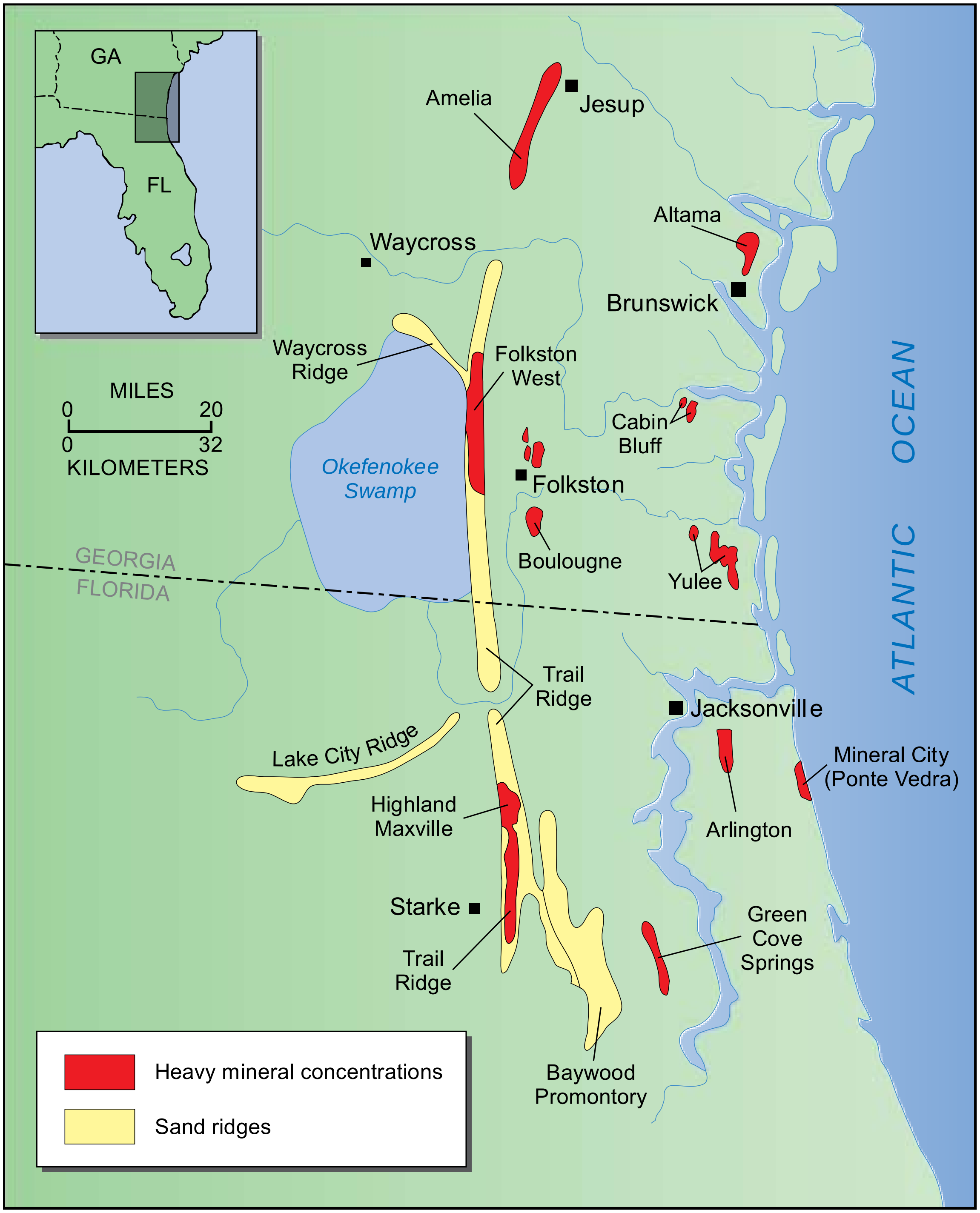


Figure 35. Map showing heavy mineral deposits in northeastern Florida and southeastern Georgia. Sand ridges are shown in yellow. Heavy mineral concentrations are colored red. Modified from Pirkle and others (1993).

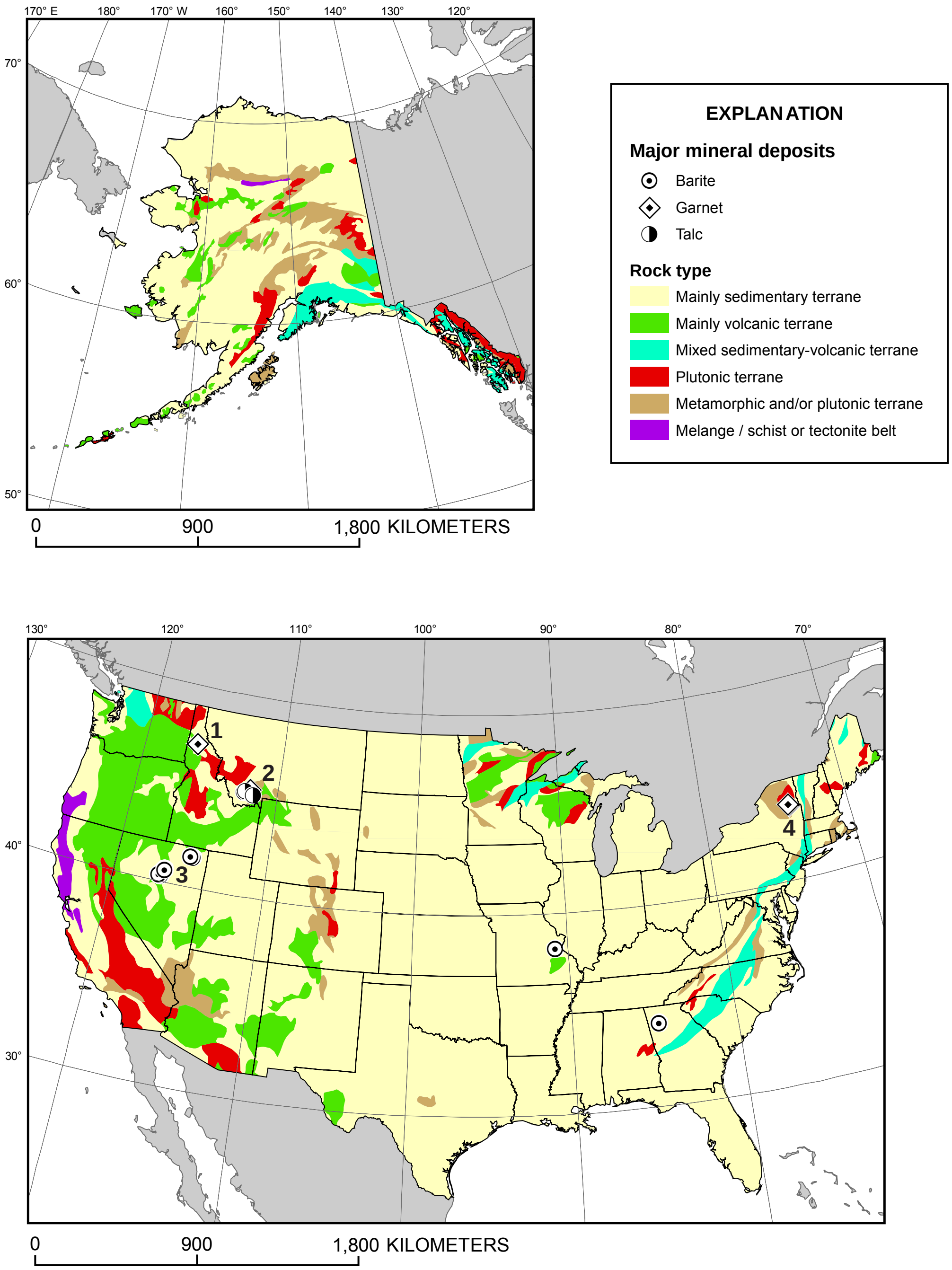


Figure 36. Map showing the location of the major barite, garnet, and talc mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Emerald Creek; 2 – Yellowstone; 3 – Greystone, and 4 – North Creek.

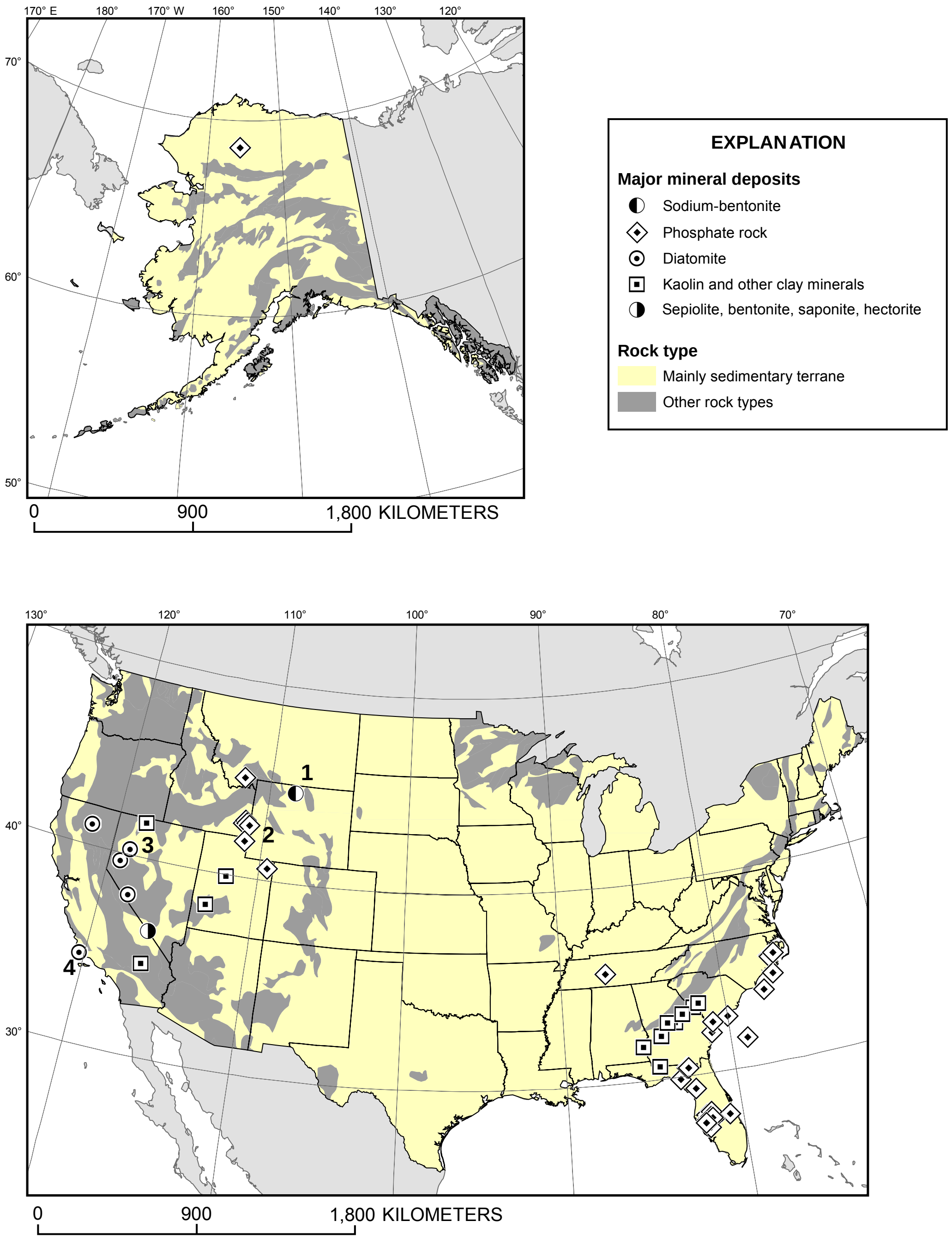


Figure 37. Map showing the location of the major sodium bentonite, phosphate rock, diatomite, kaolin, and limestone mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Hardin; 2 – Western Phosphate field; 3 – Lovelock; and 4 – Lompoc.

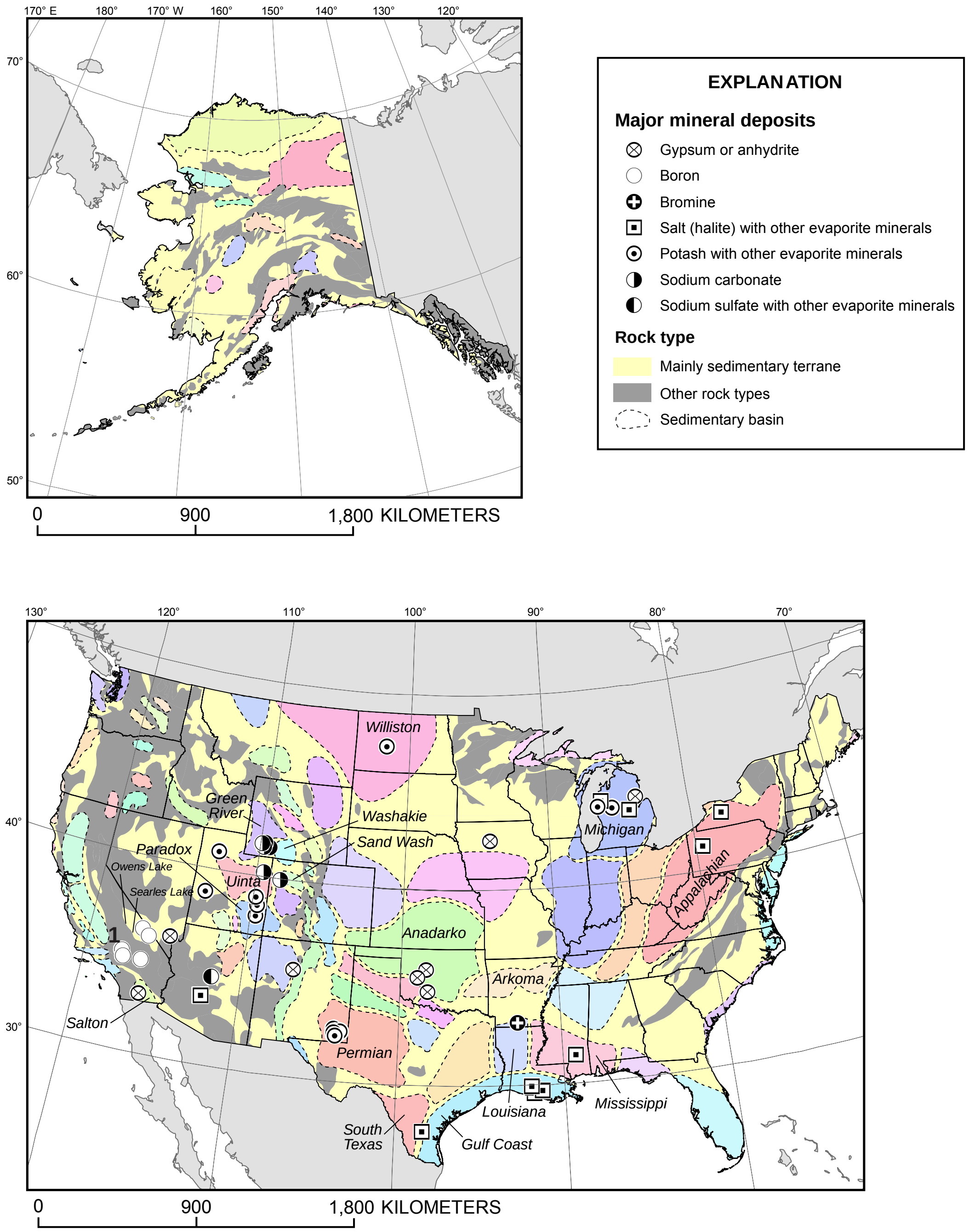


Figure 38. Map showing the location of the major gypsum, boron, bromine, salt, potash, and sodium carbonate mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Sedimentary basins are shown in color; labeled basins are discussed in the text. Sedimentary basins from St. John (2000). Numbered deposit is discussed in the report: 1 – Boron.

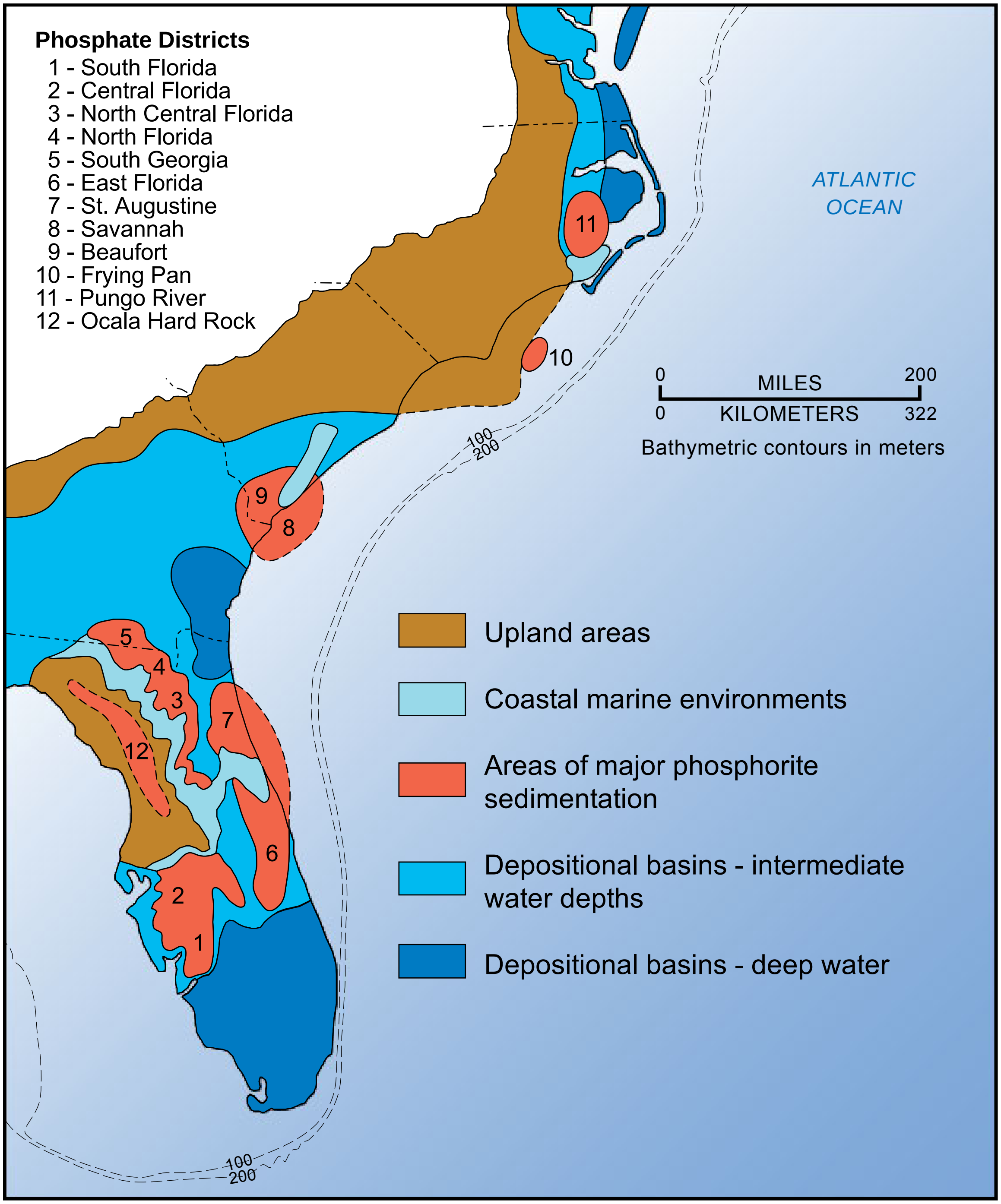


Figure 39. Map showing the location of the major phosphorite deposits relative to the Miocene geologic framework of the southeast Atlantic Coastal Plain-continental shelf system. Modified from Riggs (1979).

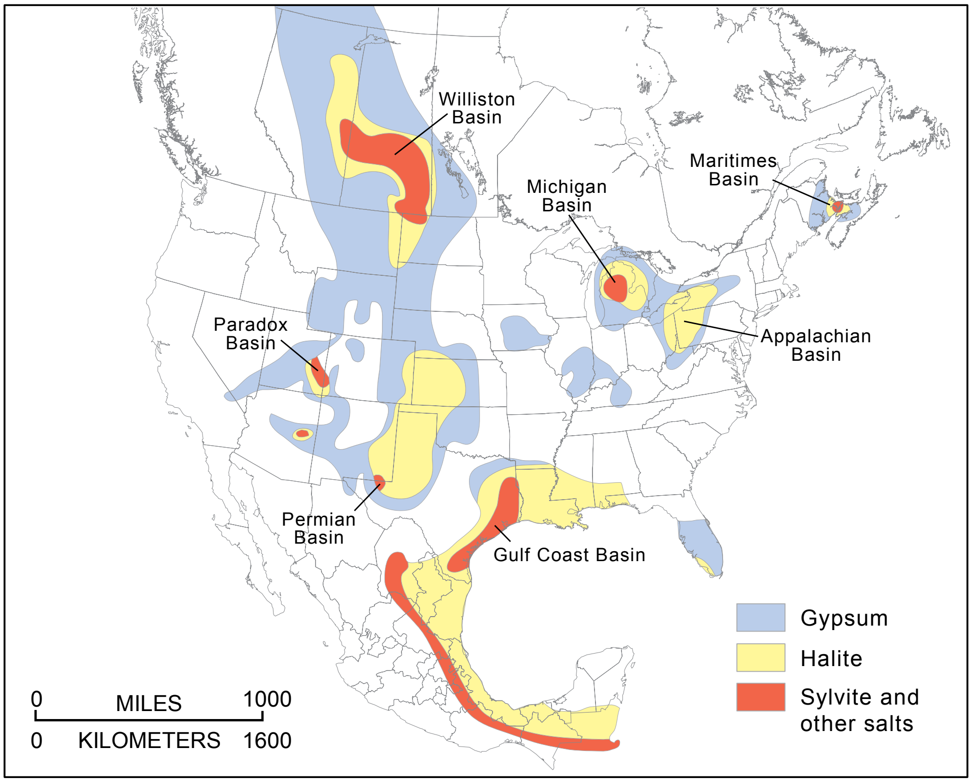


Figure 40. Map showing the distribution the location of major salt and potash deposits in evaporite basins in North America showing. Modified from Kesler (1994).

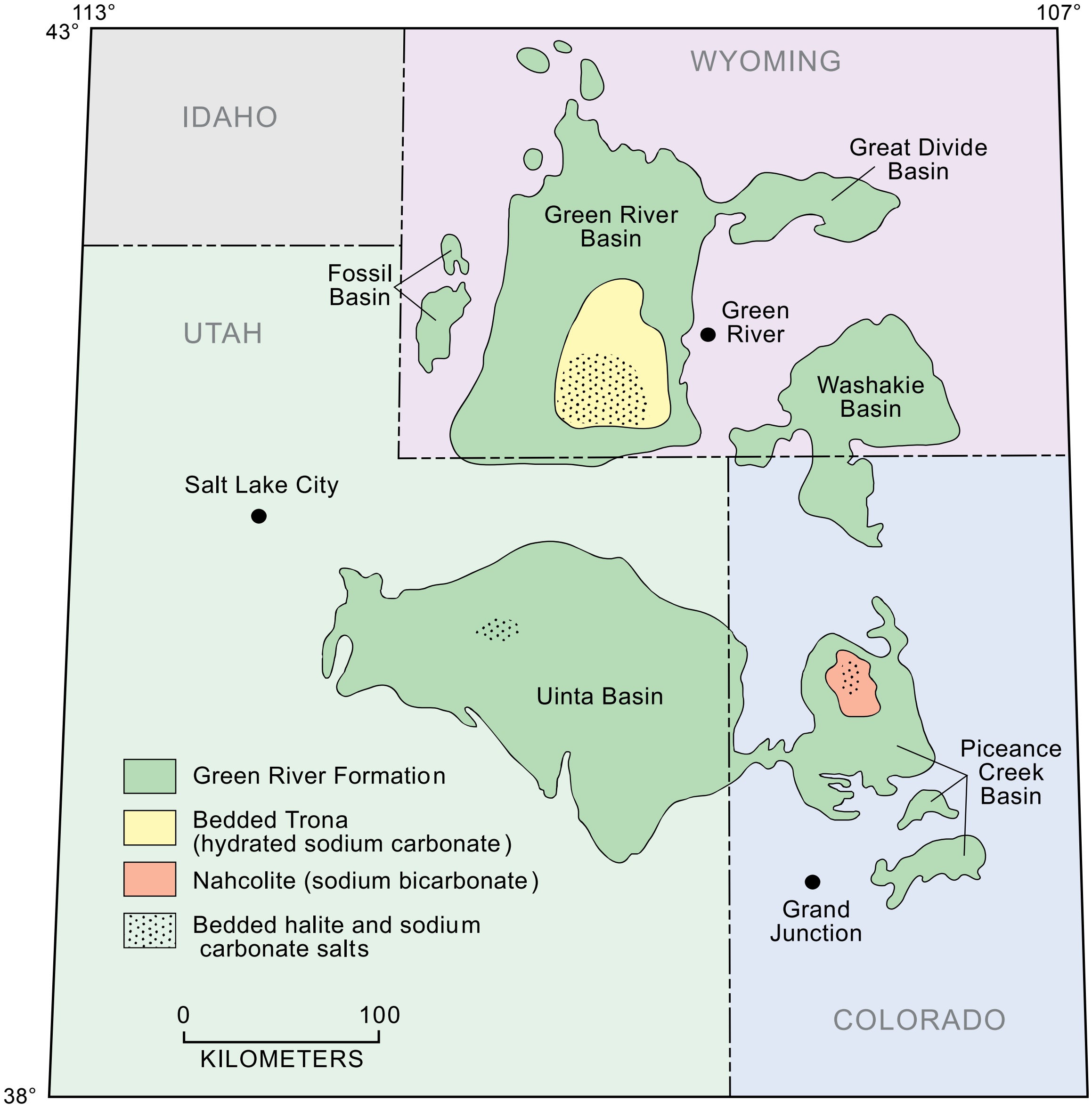


Figure 41. Map showing the distribution of the Green River Formation and the location of sodium carbonate deposits in Utah, Colorado, and Wyoming. Modified from Dyni (1996).

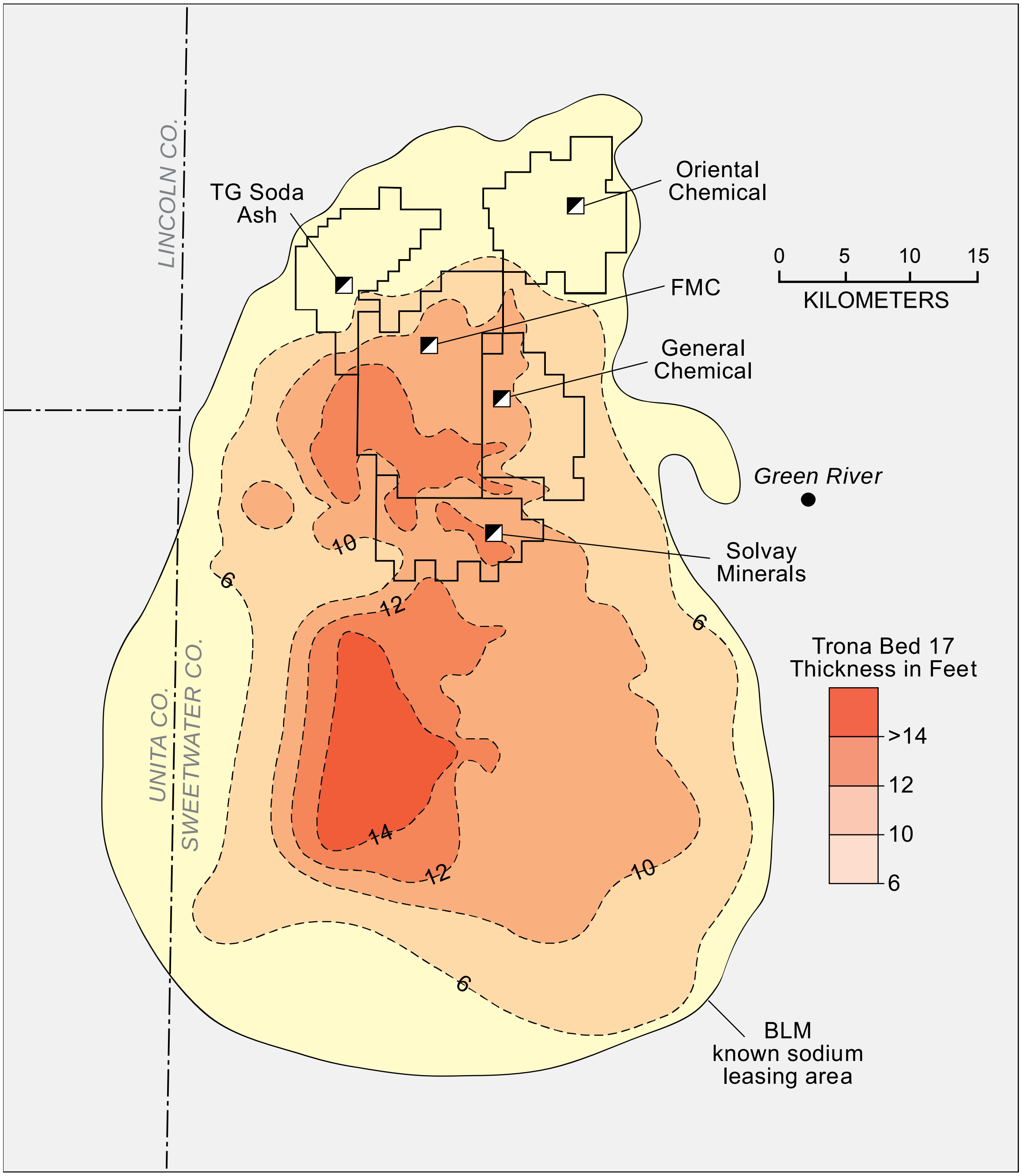


Figure 42. Map showing the thickness of trona bed 17 and Wyoming state mine permit areas. Modified from Dyni (1996).

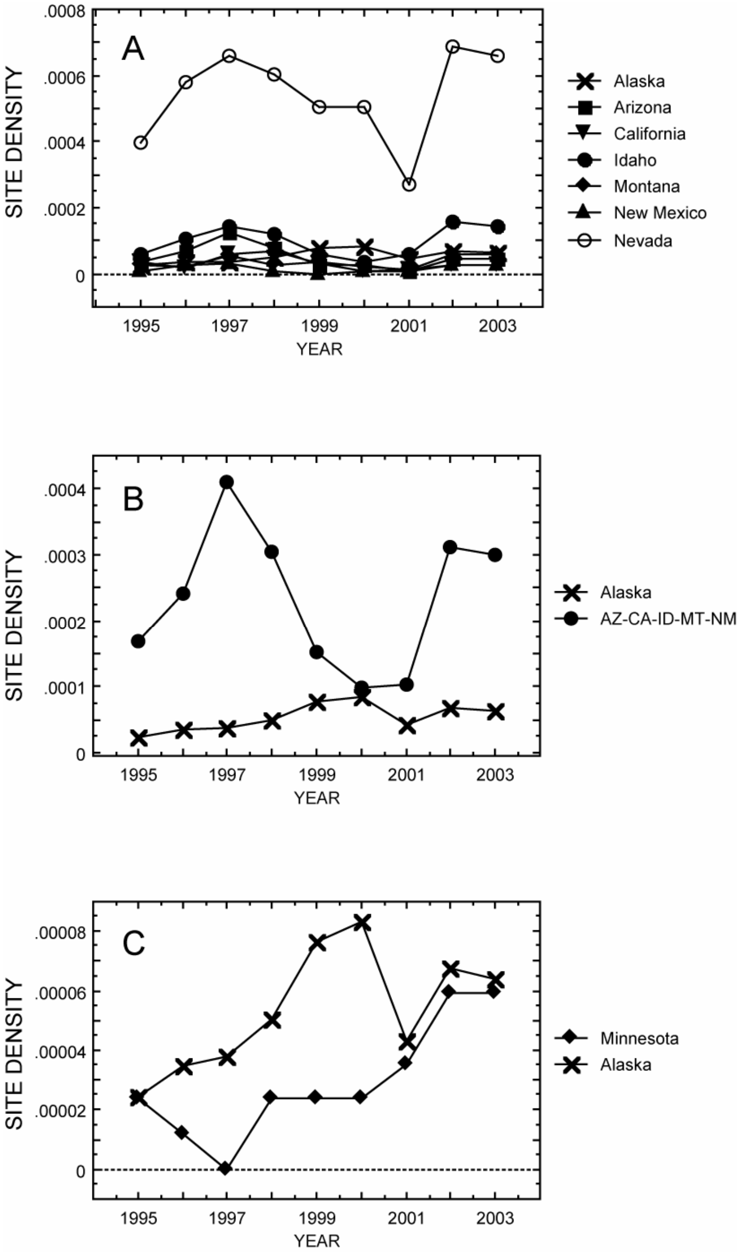


Figure 43. Charts showing the density of exploration sites for selected regions of the United States. The density represents the number of sites for a state as described in literature from 1994 to 2003 divided by the area of the state. A) Density of sites in Nevada, Alaska, Arizona, California, Idaho, Montana, and New Mexico. B) Density of sites in Alaska relative to Arizona, California, Idaho, Montana, and New Mexico (combined). C) Density of sites in Alaska and Minnesota. Source of information – D. Wilburn (written comm., 2003).

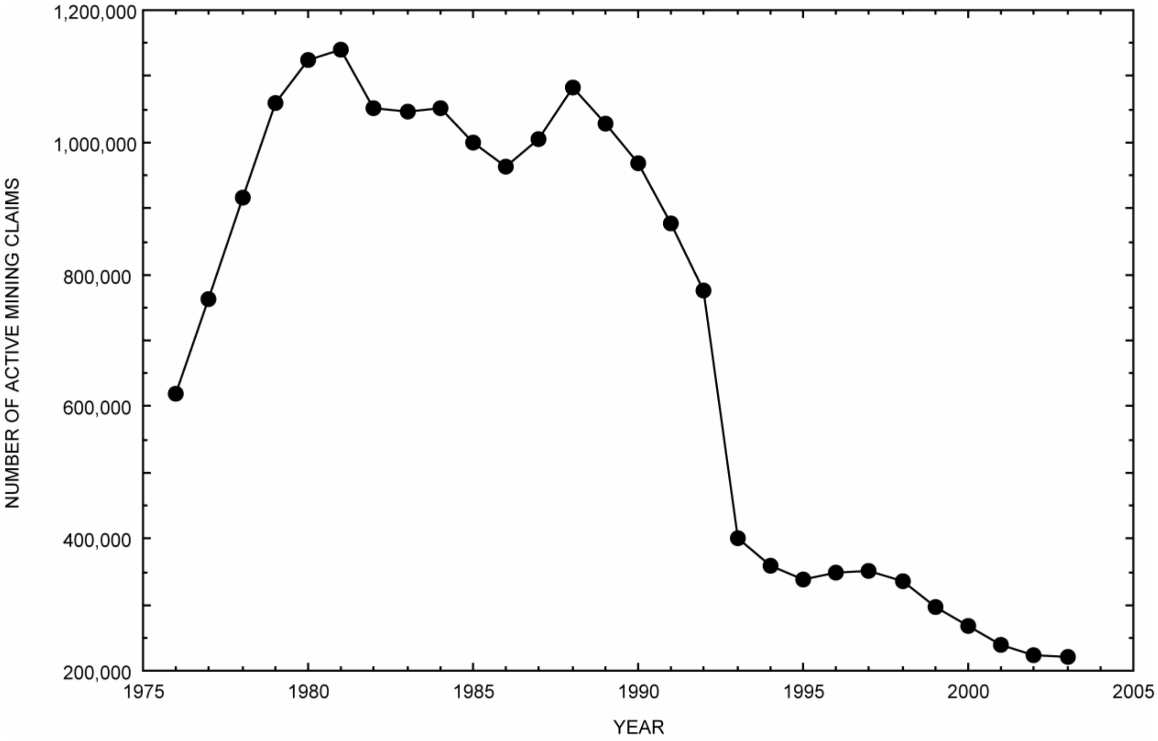


Figure 44. Graph showing the number of active mining claims held on public lands in the United States from 1976 to 2003. Source of information – D.C. Causey (written comm., 2004).

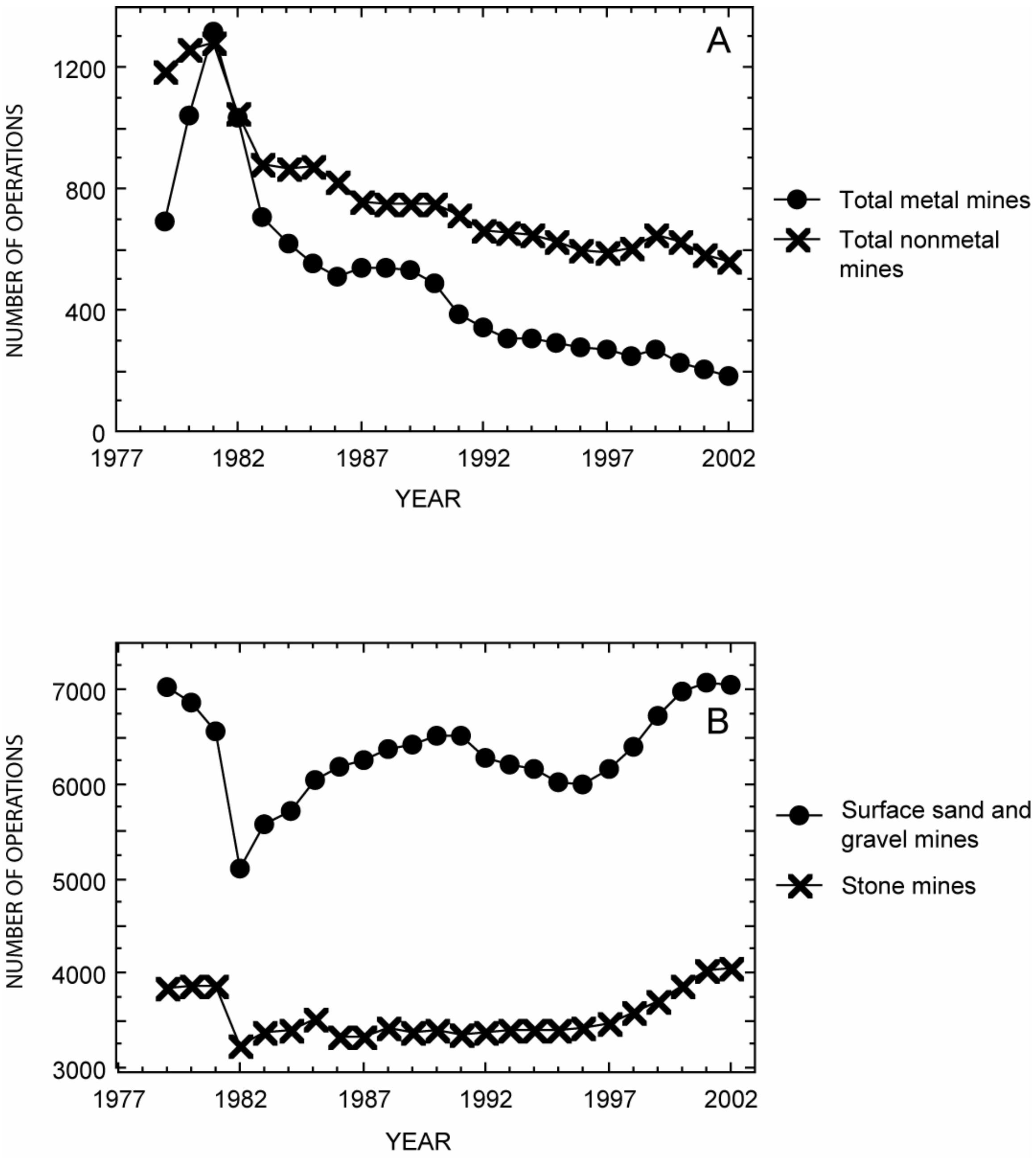


Figure 45. Graph showing the number of active mining operations in the United States from 1979 to 2002. A) Total number of metal and nonmetal mines. B) Total number of stone and surface sand and gravel mines. Data from National Mining Association (2003b).

Appendix 1. Major mineral deposits in the United States

[The information in this table is organized first by class, then commodity, and finally by deposit name. Latitude and longitude are given in decimal degrees. Positive and negative values of latitude are in the northern and southern hemisphere, respectively. Positive and negative values of longitude are in the eastern and western hemispheres, respectively. “Commodities” is a list of the major metals and materials associated with each deposit. The most important commodities are listed first. The terms in “Class” broadly group the mineral deposits based on how they form; the terms in deposit type are descriptive names given to groups of mineral deposits that form in specific geologic settings. “Model No.” and “Model name” are the number and name of descriptive deposit models published by the U.S. Geological Survey (Stoeser and Heran, 2000). “Reference” provides brief citations for additional information for the mineral deposit.]

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Kennecott	Alaska	61.528	-142.840	copper	hydrothermal	Copper sulfide mineral deposit associated with carbonate sedimentary rocks	--	Kennecott Cu	U.S. Geological Survey National Mineral Resource Assessment Team (2000); Kirkham (1996)
Allouez	Michigan	47.289	-88.404	copper	hydrothermal	Native copper deposits associated with basalt flows	23	Basaltic Cu	Kirkham (1996)
Baltic	Michigan	47.065	-88.634	copper	hydrothermal	Native copper deposits associated with basalt flows	23	Basaltic Cu	Kirkham (1996)
Calumet - Hecla	Michigan	47.246	-88.450	copper	hydrothermal	Native copper deposits associated with basalt flows	23	Basaltic Cu	Kirkham (1996)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Kearsarge	Michigan	47.278	-88.418	copper	hydrothermal	Native copper deposits associated with basalt flows	23	Basaltic Cu	Kirkham (1996)
Kingston Conglomerate	Michigan	47.291	-88.385	copper	hydrothermal	Native copper deposits associated with basalt flows	23	Basaltic Cu	Long and others (1998)
Osceola	Michigan	47.225	-88.459	copper	hydrothermal	Native copper deposits associated with basalt flows	23	Basaltic Cu	Kirkham (1996)
Pewabic	Michigan	47.133	-88.567	copper	hydrothermal	Native copper deposits associated with basalt flows	23	Basaltic Cu	Kirkham (1996)
Bond Creek - Orange Hill	Alaska	62.200	-142.767	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Mutschler and others (1999)
Glacier Peak	Washington	48.198	-120.979	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002); Long and others (1998)
Lakeshore (Cyprus Casa Grande; Cyprus Tohono)	Arizona	32.520	-111.880	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002); Long and others (1998)
Miami East	Arizona	33.420	-110.740	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Long and others (1998)
Poston Butte (Florence)	Arizona	33.117	-111.417	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002); Long and others (1998)
Red Mountain	Arizona	31.490	-110.720	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002)
Santa Cruz	Arizona	32.890	-111.860	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Long and others (1998)
Santa Cruz (Casa Grande) Sacaton	Arizona	32.867	-111.950	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Mutschler and others (1999)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Sheep Mountain	Arizona	34.080	-112.460	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002)
Superior East (Pinal Ranch)	Arizona	33.378	-110.999	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002)
Yerington	Nevada	38.983	-119.183	copper	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Mutschler and others (1999)
Kona Dolomite	Michigan	46.533	-87.450	copper	hydrothermal	Sediment-hosted copper deposit	30b.2	Sediment-hosted copper, reduced-facies subtype	Cox and others (2003); Long and others (1998)
White Pine	Michigan	46.767	-89.567	copper	hydrothermal	Sediment-hosted copper deposit	30b.2	Sediment-hosted copper, reduced-facies subtype	Cox and others (2003); Long and others (1998)
Blackbird	Idaho	45.121	-114.339	copper, cobalt	hydrothermal	Sedimentary exhalative copper-cobalt deposit	24d	Blackbird Co-Cu	Spanski (2004)
Iron Creek	Idaho	44.962	-114.115	copper, cobalt	hydrothermal	Sedimentary exhalative copper-cobalt deposit	24d	Blackbird Co-Cu	Spanski (2004)
Ram (Idaho Cobalt Project)	Idaho	45.140	-114.360	copper, cobalt	hydrothermal	Sedimentary exhalative copper-cobalt deposit	24d	Blackbird Co-Cu	Spanski (2004)
Ajo (New Cornelia)	Arizona	32.360	-112.850	copper, gold	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002); Long and others (1998)
Dos Pobres	Arizona	32.970	-109.650	copper, gold	hydrothermal	Porphyry copper deposit	20c	Porphyry Cu-Au	Long and others (1998)
Ely (Robinson, Ruth)	Nevada	39.260	-114.999	copper, gold	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002); Mutschler and others (1999)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Lone Star	Arizona	32.930	-109.600	copper, gold	hydrothermal	Porphyry copper deposit	20c	Porphyry Cu-Au	Long and others (1998)
Margaret (Earl)	Washington	46.356	-122.081	copper, gold	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002); Long and others (1998)
Pebble Copper (Pebble Beach)	Alaska	59.898	-155.296	copper, gold	hydrothermal	Porphyry copper deposit	20c	Porphyry Cu-Au	Singer and others (2002)
Safford (Lone Star, includes Dos Pobres, San Juan)	Arizona	32.933	-109.600	copper, gold	hydrothermal	Porphyry copper deposit	20c	Porphyry Cu-Au	Singer and others (2002); Long and others (1998)
Bagdad	Arizona	34.580	-113.170	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002)
Bingham Canyon	Utah	40.540	-112.140	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Long and others (1998)
Butte (Continental, Berkeley etc.)	Montana	46.020	-112.526	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Long and others (1998)
Casa Grande West (Santa Cruz)	Arizona	32.867	-111.950	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002)
Esperanza - Sierrita	Arizona	31.869	-111.120	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002)
Miami - Inspiration (includes Bluebird, Copper Cities, Globe, Van Dyke)	Arizona	33.420	-110.740	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002); Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Mineral Park	Arizona	35.367	-114.150	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Kirkham and Sinclair (1996a)
Morenci - Metcalf	Arizona	33.090	-109.340	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002); Long and others (1998)
Pinto Valley - Castle Dome	Arizona	33.400	-110.950	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Long and others (1998)
Ray	Arizona	33.160	-110.970	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002); Long and others (1998)
San Manuel - Kalamazoo	Arizona	32.670	-110.670	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002); Long and others (1998)
Taurus	Alaska	63.521	-141.324	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Long and others (1998)
Twin Buttes	Arizona	31.880	-111.030	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002)
Tyrone	New Mexico	32.633	-108.367	copper, molybdenum, silver, gold	hydrothermal	Porphyry copper deposit	21a	Porphyry Cu-Mo	Singer and others (2002)
Bisbee (Warren)	Arizona	31.433	-109.900	copper, silver	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Mutschler and others (1999)
Castle Dome (Pinto Valley, includes Carlota - Cactus)	Arizona	33.400	-110.950	copper, silver	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Hannover Mountains (Fierro - Hannover)	New Mexico	32.833	-108.083	copper, silver	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002)
Helvetia (Rosemont, includes Rosemont, Peach - Elgin, Broadtop Butte, and Copper World)	Arizona	31.830	-110.760	copper, silver	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002)
Mission - Pima - San Xavier	Arizona	31.983	-111.067	copper, silver	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002); Long and others (1998)
Rosemont - Peach - Elgin - Broadtop Butte	Arizona	31.830	-110.760	copper, silver	hydrothermal	Porphyry copper deposit	18a	Porphyry Cu, skarn-related	Long and others (1998)
Rock Creek (includes Rock Lake, Montanore, Copper Gulch, Horizon Basin, Rock Peak)	Montana	48.079	-115.677	copper, silver	hydrothermal	Revett copper deposit	30b.4	Revett Cu	Cox and others (2003); Long and others (1998)
Spar Lake (Troy mine)	Montana	48.230	-115.905	copper, silver	hydrothermal	Revett copper deposit	30b.4	Revett Cu	Cox and others (2003)
Bingham Canyon (skarn)	Utah	40.540	-112.140	copper, silver, gold	hydrothermal	Copper skarn deposit	18b	Skarn, Cu	Long and others (1998)
Robinson	Nevada	39.260	-115.000	copper, silver, gold	hydrothermal	Porphyry copper deposit	18a	Porphyry Cu, skarn-related	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Santa Rita (Chino, includes Groundhog - Pewabic - Empire (skarns))	New Mexico	32.792	-108.067	copper, silver, gold	hydrothermal	Porphyry copper deposit	17	Porphyry Cu	Singer and others (2002)
Magma	Arizona	33.306	-111.093	copper, silver, gold	hydrothermal	Porphyry-related copper veins	gsc17	Vein, polymetallic, porphyry Cu-related	Kirkham and Sinclair (1996b)
Butte (Veins)	Montana	46.020	-112.530	copper, silver, zinc, gold, lead	hydrothermal	Porphyry-related copper veins	gsc17	Vein copper deposits (Vein, polymetallic, porphyry Cu-related)	Long and others (1998)
Donlin Creek	Alaska	62.075	-158.217	gold	hydrothermal	Intrusion-related gold deposit	43	Plutonic porphyry Au	Long and others (1998)
Fort Knox	Alaska	64.967	-147.367	gold	hydrothermal	Intrusion-related gold deposit	43	Plutonic porphyry Au	Long and others (1998)
Pogo (Liese zone)	Alaska	64.283	-144.883	gold	hydrothermal	Intrusion-related gold deposit	43	Plutonic porphyry Au	Mutschler and others (1999)
Alaska - Juneau (A.J., Perseverance)	Alaska	58.308	-134.345	gold	hydrothermal	Orogenic gold veins	36a	Low-sulfide Au-quartz vein	Long and others (1998)
Empire - North Star	California	39.206	-121.045	gold	hydrothermal	Orogenic gold veins	36a	Low-sulfide Au-quartz vein	Long and others (1998)
Homestake	South Dakota	44.360	-103.770	gold	hydrothermal	Orogenic gold veins	36b	Homestake Au	Long and others (1998)
Idaho - Maryland - Eureka - Brunswick	California	39.224	-121.038	gold	hydrothermal	Orogenic gold veins	36a	Low-sulfide Au-quartz vein	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Jamestown	California	37.946	-120.437	gold	hydrothermal	Orogenic gold veins	36a	Low-sulfide Au-quartz vein	Long and others (1998)
Kensington - Jualin	Alaska	58.866	-135.087	gold	hydrothermal	Orogenic gold veins	36a	Low-sulfide Au-quartz vein	Long and others (1998)
Candelaria	Nevada	38.150	-118.080	gold, silver	hydrothermal	Distal disseminated gold deposit	19c	Distal disseminated Ag-Au	Long and others (1998)
Hardshell	Arizona	31.460	-110.720	gold, silver	hydrothermal	Distal disseminated gold deposit	19c	Distal disseminated Ag-Au	Long and others (1998)
Lone Tree - Stonehouse	Nevada	40.830	-117.210	gold, silver	hydrothermal	Distal disseminated gold deposit	19c	Distal disseminated Ag-Au	Long and others (1998); Tingley (2002)
McCoy - Cove	Nevada	40.340	-117.210	gold, silver	hydrothermal	Distal disseminated gold deposit	19c	Distal disseminated Ag-Au	Long and others (1998)
Rochester	Nevada	40.280	-118.150	gold, silver	hydrothermal	Distal disseminated gold deposit	19c	Distal disseminated Ag-Au	Long and others (1998)
Bald Mountain (Wharf, Trojan, Portland)	South Dakota	44.344	-103.842	gold, silver	hydrothermal	Epithermal gold deposit	22b	Alakaline Au-Te (Au-Ag-Te veins)	Long and others (1998)
Black Hills Tertiary (includes Gilt Edge, Golden Reward, Annie Creek (Foley Ridge), Richmond Hill, Green Mountain)	South Dakota	44.333	-103.767	gold, silver	hydrothermal	Epithermal gold deposit	25a-d	Epithermal vein	Mutschler and others (1999)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Comstock Lode	Nevada	39.320	-119.590	gold, silver	hydrothermal	Epithermal gold deposit	25c	Epithermal vein, Comstock	Long and others (1998)
Cripple Creek	Colorado	38.717	-105.133	gold, silver	hydrothermal	Epithermal gold deposit	22b	Alakaline Au-Te (Au-Ag-Te veins)	Long and others (1998)
Goldbanks	Nevada	40.465	-117.604	gold, silver	hydrothermal	Epithermal gold deposit	25a	Hot-spring Au-Ag	Long and others (1998)
Golden Sunlight	Montana	45.906	-112.014	gold, silver	hydrothermal	Epithermal gold deposit	22b	Alakaline Au-Te (Au-Ag-Te veins)	Long and others (1998); Mutschler and others (1999)
Goldfield	Nevada	37.710	-117.210	gold, silver	hydrothermal	Epithermal gold deposit	25e	Epithermal quartz-alunite Au	Long and others (1998)
Ken Snyder (Midas) mine (Gold Circle district)	Nevada	41.250	-116.790	gold, silver	hydrothermal	Epithermal gold deposit	25c	Epithermal vein, Comstock	Long and others (1998); Tingley (2002)
McDonald	Montana	47.000	-112.525	gold, silver	hydrothermal	Epithermal gold deposit	25a	Hot-spring Au-Ag	Long and others (1998)
McLaughlin	California	38.836	-122.357	gold, silver	hydrothermal	Epithermal gold deposit	25a	Hot-spring Au-Ag	Long and others (1998)
Mesquite	California	33.098	-114.963	gold, silver	hydrothermal	Epithermal gold deposit	25a	Hot-spring Au-Ag	Long and others (1998)
Oatman	Arizona	35.100	-114.447	gold, silver	hydrothermal	Epithermal gold deposit	25c	Epithermal vein, Comstock	Long and others (1998)
Ortiz Mountains (Old Placers)	New Mexico	35.317	-106.167	gold, silver	hydrothermal	Epithermal gold deposit	25a-d	Epithermal vein	Mutschler and others (1999)
Republic District (Knob Hill etc.)	Washington	48.673	-118.758	gold, silver	hydrothermal	Epithermal gold deposit	25c	Epithermal vein, Comstock	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Round Mountain	Nevada	38.700	-117.080	gold, silver	hydrothermal	Epithermal gold deposit	25a	Hot-spring Au-Ag	Long and others (1998)
Sleeper	Nevada	41.330	-118.050	gold, silver	hydrothermal	Epithermal gold deposit	25a	Hot-spring Au-Ag	Long and others (1998); Tingley (2002)
Tonopah	Nevada	38.070	-117.230	gold, silver	hydrothermal	Epithermal gold deposit	25c	Epithermal vein, Comstock	Long and others (1998)
Zortman - Landusky	Montana	47.929	-108.586	gold, silver	hydrothermal	Epithermal gold deposit	22b	Alakaline Au-Te (Au-Ag-Te veins)	Long and others (1998)
Battle Mountain (Tomboy - Minnie - Fortitude - Northeast Ext. - Iron Canyon - Midas - Phoenix)	Nevada	40.530	-117.120	gold, silver	hydrothermal	Gold skarn deposit	18f	Skarn, Au	Long and others (1998); Mutschler and others (1999); Tingley (2002); Newmont (2003)
Betze - Post (Betze, Screamer, and Deep Post)	Nevada	40.977	-116.358	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998); Bettles (2002)
Carlin - Hardie	Nevada	40.912	-116.320	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998)
Chimney Creek South - Rabbit Creek	Nevada	41.280	-117.157	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Singer and others (1993)
Cortez (Cortez, Pipeline, South Pipeline, Pediment, Gap, Gold Acres, and Horse Canyon)	Nevada	40.248	-116.740	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998); Tingley (2002); Placer Dome (2002a)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Genesis - Blue Star - Beast - Bobcat - Northstar	Nevada	40.952	-116.352	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998); Bettles (2002)
Getchell (Getchell, Turquoise Ridge, North Zone)	Nevada	41.210	-117.260	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998); Placer Dome (2002b)
Gold Quarry South Layback (Maggie Creek district)	Nevada	40.825	-116.225	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998); Newmont (2003)
Jerritt Canyon (Burns Basin, Enfield Bell, Pattani Springs)	Nevada	41.340	-116.010	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998)
Leeville (West Leeville, Four Corners, Turf)	Nevada	40.930	-116.320	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998); Newmont (2003)
Meikle (Purple Vein) (Meikle, South Meikle, Griffin, and Rodeo)	Nevada	41.010	-116.360	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998); Bettles (2002)
Twin Creeks (Chimney Creek and Rabbit Creek)	Nevada	41.280	-117.170	gold, silver	hydrothermal	Sediment-hosted gold deposit	26a.1	Sediment-hosted Au	Long and others (1998)
Goodsprings	Nevada	35.850	-115.500	gold, silver, zinc, lead	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Pride of the Mountains	Washington	47.981	-121.369	gold, silver, zinc, lead, copper	hydrothermal	Polymetallic veins	22c	Polymetallic veins	Long and others (1998)
Dragon Mine	Utah	39.918	-112.104	halloysite (clay mineral with tube-like crystals)	hydrothermal	Hydrothermal kaolin (halloysite) deposit	25l.2	Hydrothermal kaolin	Industrial Minerals (2004a)
Hector	California	34.755	-116.431	hectorite (lithium-rich clay mineral)	hydrothermal	Hydrothermal lithium-rich clay deposit	25l.3	Lithium -rich clays	Harben and Kužvart (1996)
Montana Mountains	Nevada	41.767	-118.108	hectorite (lithium-rich clay mineral)	hydrothermal	Hydrothermal lithium-rich clay deposit	25l.3	Lithium -rich clays	Odom (1992)
Eagle Mountain	California	33.883	-115.542	iron	hydrothermal	Iron skarn deposit	18d	Skarn Fe	Singer and others (1993)
Iron Springs	Utah	37.683	-113.250	iron	hydrothermal	Iron skarn deposit	18d	Skarn Fe	Singer and others (1993)
Benson	New York	44.179	-75.006	iron	hydrothermal	Magnetite deposits in volcanic rocks	25i	Volcanic-hosted magnetite	Singer and others (1993)
Pea Ridge	Missouri	38.125	-91.042	iron	hydrothermal	Magnetite deposits in volcanic rocks	25i	Volcanic-hosted magnetite	Singer and others (1993)
Burkesville	Kentucky	36.775	-85.335	lead, zinc	hydrothermal	Mississippi Valley-type deposit (MVT)	32b	Mississippi Valley, Appalachian Zn	Long and others (1998)
Tri - state (Galena, Joplin, Picher)	Kansas, Missouri, Oklahoma	37.083	-94.650	lead, zinc	hydrothermal	Mississippi Valley-type deposit (MVT)	32a	Mississippi Valley, S.E. Missouri Pb-Zn	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Star - Morning	Idaho	47.468	-115.812	lead, zinc, silver	hydrothermal	Coeur d' Alene-type polymetallic vein	--	Coeur d' Alene-type polymetallic vein, Revett-St. Regis subtype	Long and others (1998)
Old Lead Belt	Missouri	37.842	-90.534	lead, zinc, silver	hydrothermal	Mississippi Valley-type deposit (MVT)	32a	Mississippi Valley, S.E. Missouri Pb-Zn	Long and others (1998)
Viburnum Trend	Missouri	37.583	-91.167	lead, zinc, silver, copper	hydrothermal	Mississippi Valley-type deposit (MVT)	32a	Mississippi Valley, S.E. Missouri Pb-Zn	Long and others (1998)
Big Ben - Niehart	Montana	46.950	-110.733	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999)
Cave Peak	Texas	31.433	-104.883	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999)
Climax	Colorado	39.367	-106.167	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999)
Henderson - Urad	Colorado	39.750	-105.833	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999)
Mount Emmons - Redwell Basin	Colorado	38.883	-107.067	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999)
Mount Hope	Nevada	39.783	-116.167	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Pine Grove	Utah	38.336	-113.606	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Singer and others (1993)
Quartz Hill	Alaska	55.400	-130.467	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999); Singer and others (1993)
Questa	New Mexico	36.683	-105.500	molybdenum	hydrothermal	Climax-type molybdenum deposit	16	Climax Mo	Mutschler and others (1999)
Thompson Creek	Idaho	44.333	-114.583	molybdenum	hydrothermal	Porphyry molybdenum deposit	21b	Porphyry Mo, Low-F	Mutschler and others (1999)
Buckingham	Nevada	40.617	-117.075	molybdenum, copper	hydrothermal	Porphyry molybdenum deposit	21b	Porphyry Mo, Low-F	Long and others (1998)
Cumo	Idaho	44.000	-115.783	molybdenum, copper	hydrothermal	Porphyry molybdenum deposit	21b	Porphyry Mo, Low-F	Mutschler and others (1999)
Mount Tolman	Washington	48.050	-118.700	molybdenum, copper	hydrothermal	Porphyry molybdenum deposit	21b	Porphyry Mo, Low-F	Mutschler and others (1999)
Copper Queen	Arizona	31.430	-109.910	silver, copper, gold, zinc, lead	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)
Arctic Camp	Alaska	67.181	-156.386	silver, copper, zinc	hydrothermal	Volcanogenic massive sulfide deposit (VMS)	28a	Massive sulfide, Kuroko	Long and others (1998)
Rocky Range	Utah	38.450	-113.063	silver, gold, copper	hydrothermal	Copper skarn deposit	18b	Skarn, Cu	Long and others (1998)
Leadville	Colorado	39.250	-106.250	silver, gold, lead, zinc, copper	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Greens Creek	Alaska	58.077	-134.619	silver, gold, zinc, lead	hydrothermal	Volcanogenic massive sulfide deposit (VMS)	28a	Massive sulfide, Kuroko	Long and others (1998)
Red Mountain - Sneffels - Telluride	Colorado	37.958	-107.750	silver, gold, zinc, lead, copper	hydrothermal	Polymetallic veins	22c	Polymetallic veins	Long and others (1998)
Presidio	Texas	29.810	-104.330	silver, lead	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)
Bunker Hill - Last Chance	Idaho	47.536	-116.138	silver, lead, zinc	hydrothermal	Coeur d' Alene-type polymetallic vein	--	Coeur d' Alene-type polymetallic vein, Revett-St. Regis subtype	Long and others (1998)
Galena	Idaho	47.477	-115.965	silver, lead, zinc	hydrothermal	Coeur d' Alene-type polymetallic vein	--	Coeur d' Alene-type polymetallic vein, Revett-St. Regis subtype	Long and others (1998)
Lucky Friday	Idaho	47.471	-115.780	silver, lead, zinc	hydrothermal	Coeur d' Alene-type polymetallic vein	--	Coeur d' Alene-type polymetallic vein, Revett-St. Regis subtype	Long and others (1998)
Creede (Amethyst, Bulldog etc. veins)	Colorado	37.875	-106.933	silver, lead, zinc	hydrothermal	Epithermal gold deposit	25b	Epithermal vein, Creede	Long and others (1998)
Aspen	Colorado	39.167	-106.833	silver, lead, zinc	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Sunshine	Idaho	47.501	-116.068	silver, lead, zinc, copper	hydrothermal	Coeur d' Alene-type polymetallic vein	--	Coeur d' Alene-type polymetallic vein, Revett-St. Regis subtype	Long and others (1998)
Bingham Canyon (polymetallic replacement)	Utah	40.540	-112.140	silver, lead, zinc, gold, copper	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)
Park City	Utah	40.620	-111.510	silver, lead, zinc, gold, copper	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)
Tintic - East Tintic	Utah	39.910	-112.100	silver, lead, zinc, gold, copper	hydrothermal	Polymetallic replacement deposit	19a	Polymetallic replacement	Long and others (1998)
Crandon	Wisconsin	45.483	-88.926	silver, zinc, gold, copper, lead	hydrothermal	Volcanogenic massive sulfide deposit (VMS)	28a	Massive sulfide, Kuroko	Long and others (1998)
Beaverhead	Montana	45.224	-112.301	talc	hydrothermal	Hydrothermal talc deposit	18m	Metasomatic and metamorphic replacement talc	Spanski (2004)
Regal (Keystone)	Montana	45.172	-112.425	talc	hydrothermal	Hydrothermal talc deposit	18m	Metasomatic and metamorphic replacement talc	Spanski (2004)
Treasure (Treasure State, Treasure Chest	Montana	45.228	-112.309	talc	hydrothermal	Hydrothermal talc deposit	18m	Metasomatic and metamorphic replacement talc	Spanski (2004)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Yellowstone (Johnny Gulch, Cyprus, Cameron, Montana Talc)	Montana	45.077	-111.730	talc	hydrothermal	Hydrothermal talc deposit	18m	Metasomatic and metamorphic replacement talc	Spanski (2004)
Franklin	New Jersey	41.120	-74.590	zinc	hydrothermal	Sedimentary exhalative zinc-lead deposit	31a	Sedimentary exhalative Zn-Pb	Long and others (1998)
Sterling Hill	New Jersey	41.080	-74.600	zinc	hydrothermal	Sedimentary exhalative zinc-lead deposit	31a	Sedimentary exhalative Zn-Pb?	Long and others (1998)
Fountain Run	Kentucky	36.704	-85.943	zinc, lead	hydrothermal	Mississippi Valley-type deposit (MVT)	32b	Mississippi Valley, Appalachian Zn	Long and others (1998)
Mascot - Jefferson City	Tennessee	36.400	-83.350	zinc, lead	hydrothermal	Mississippi Valley-type deposit (MVT)	32b	Mississippi Valley, Appalachian Zn	Long and others (1998)
Pierrepont, Edwards, and Balmat	New York	44.252	-75.400	zinc, lead	hydrothermal	Sedimentary exhalative zinc-lead deposit	31a	Sedimentary exhalative Zn-Pb	Long and others (1998)
Lik - Su	Alaska	68.167	-163.200	zinc, lead, silver	hydrothermal	Sedimentary exhalative zinc-lead deposit	31a	Sedimentary exhalative Zn-Pb	Long and others (1998)
Red Dog	Alaska	68.067	-162.824	zinc, lead, silver	hydrothermal	Sedimentary exhalative zinc-lead deposit	31a	Sedimentary exhalative Zn-Pb	Long and others (1998)
Gilman	Colorado	39.533	-106.376	zinc, silver, copper, lead	hydrothermal	Lead-zinc skarn deposit	18c	Skarn Zn-Pb	Dawson (1996)
Birch Lake	Minnesota	47.817	-91.733	copper	magmatic	Magmatic copper-nickel deposit near base of mafic igneous intrusion	5a	Duluth Cu-Ni-PGE	Long and others (1998)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Babbit (Minnamax) - Mesaba project	Minnesota	47.641	-91.883	copper, nickel, PGE	magmatic	Magmatic copper-nickel deposit near base of mafic igneous intrusion	5a	Duluth Cu-Ni-PGE	Long and others (1998); Miller, Severson, and others (2002)
Dunka Road - Northmet project	Minnesota	47.610	-91.960	copper, nickel, PGE	magmatic	Magmatic copper-nickel deposit near base of mafic igneous intrusion	5a	Duluth Cu-Ni-PGE	Long and others (1998); Cannon and others (1997)
Maturi	Minnesota	47.801	-91.756	copper, nickel, PGE	magmatic	Magmatic copper-nickel deposit near base of mafic igneous intrusion	5a	Duluth Cu-Ni-PGE	Long and others (1998); Miller, Severson, and others (2002)
Bessemer City	South Carolina	35.333	-81.167	lithium	magmatic	Pegmatite	13b	Li pegmatites	Anstett and others (1990)
Kings Mountain	North Carolina	35.250	-81.342	lithium mica	magmatic	Pegmatite rich in lithium	13b	Li pegmatites	Harben and Kužvart (1996)
Black Canyon	Arizona	34.120	-112.210	mica feldspathic sand	magmatic	Pegmatite rich in mica	13f	Mica pegmatites	Industrial Minerals (1999c); Industrial Minerals (2002)
Wind Mountain	New Mexico	32.025	-105.515	nepheline syenite	magmatic	Igneous rock rich in nepheline	na	no model	Industrial Minerals (1995)
McClure Mountain Complex	Colorado	38.350	-105.467	niobium	magmatic	Mineralization associated with carbonatite igneous complex	10	carbonatite	Crockett and Sutphin (1993)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Iron Hill (Powderhorn, Cebolla Creek)	Colorado	38.250	-107.050	niobium, rare-earth elements, barium, fluorite, phosphorus, titanium	magmatic	Mineralization associated with carbonatite/alkalic igneous complex	10	carbonatite	Woolley (1987)
Deep Creek	Oregon	42.050	-119.950	niobium, rare-earth elements, phosphorus, fluorium, stronium	magmatic	Mineralization associated with carbonatite igneous complex	10	carbonatite	Woolley (1987)
J - M Reef - East Boulder mine	Montana	45.403	-110.007	palladium, platinum	magmatic	Reef-type PGE deposit	2b	Merensky Reef PGE	Spanski (2004); Zientek and others (2002)
J - M Reef - Stillwater mine	Montana	45.389	-109.874	palladium, platinum	magmatic	Reef-type PGE deposit	2b	Merensky Reef PGE	Spanski (2004); Zientek and others (2002)
Gem Park	Colorado	38.267	-105.550	phosphorus, niobium, vermiculite, rare-earth elements, thorium, copper, barium	magmatic	Mineralization associated with carbonatite/alkalic igneous complex	10	carbonatite	Woolley (1987)
Mountain Pass	California	35.483	-115.533	rare-earth elements, barium	magmatic	Mineralization associated with carbonatite igneous complex	10	carbonatite	Woolley (1987)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Hicks Dome	Illinois	37.600	-88.400	rare-earth elements, fluorite	magmatic	Mineralization associated with carbonatite igneous complex	10	carbonatite	Jackson and Christiansen (1993)
Bear Lodge Mountains (southern)	Wyoming	44.483	-104.450	rare-earth elements, thorium	magmatic	Mineralization associated with carbonatite igneous complex	10	carbonatite	Woolley (1987)
Tucker - Poplar Lake deposit	Minnesota	48.167	-90.667	titanium, magnetite	magmatic	Layers of ilmentite and titanomagnetite in ferrogabbroic and anothositic rocks	3	Bushveld Fe-Ti-V	Towner and others (1988)
Hamilton	Montana	46.262	-113.888	vermiculite	magmatic	Vermiculite associated with ultramafic igneous rocks	na	no model	Industrial Minerals (1999a)
Zonolite (Rainy Creek, Vermiculite Mountain, Libby)	Montana	48.434	-115.406	vermiculite	magmatic	Vermiculite associated with ultramafic igneous rocks	na	no model	Spanski (2004)
Eagle (Slate Creek)	Alaska	64.567	-142.500	asbestos	metamorphic	Asbestos in metamorphosed ultramafic igneous rock	8d	Serpentine-hosted asbestos	Foster (1969)
Gore Mountain	New York	43.679	-74.054	garnet	metamorphic	Garnet in metamorphosed igneous rocks	na	no model	Harben and Kužvart (1996); New York State Department of Environmental Conservation (undated)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Ruby Mountain Quarry	New York	43.736	-74.112	garnet	metamorphic	Garnet in metamorphosed igneous rocks	na	no model	New York State Department of Environmental Conservation (undated)
Addie (Smoky Mtns.)	North Carolina	35.399	-83.159	olivine	metamorphic	Dunite	na	no model	Harben and Kužvart (1996)
Twin Sisters Mountain (Cascade Mtns.)	Washington	48.708	-121.958	olivine	metamorphic	Dunite	na	no model	Harben and Kužvart (1996)
Hunter Mountain	California	36.533	-117.517	wollastonite	metamorphic	Wollastonite in metamorphosed sedimentary rocks	18g	Skarn wollastonite	Bauer and others (1994)
Oak Hill Mine Site	New York	44.304	-73.580	wollastonite	metamorphic	Wollastonite in metamorphosed sedimentary rocks	18g	Skarn wollastonite	New York State Department of Environmental Conservation, (undated); Bauer and others (1994)
Willsboro Mine (Fox Knoll Mine)	New York	44.346	-73.432	wollastonite, garnet	metamorphic	Wollastonite in metamorphosed sedimentary rocks	18g	Skarn wollastonite	New York State Department of Environmental Conservation (undated); Harben and Kužvart (1996)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Meigs - Attapulgus - Quincy district	Georgia, Florida	30.667	-84.417	attapulgite (palygorskite, fuller's earth)	sedimentary		34e	Palygorskite	Harben and Kužvart (1996); Hosterman and Patterson (1992)
Argenta	Nevada	40.633	-116.733	barite	sedimentary	Marine exhalative deposit -barite	31b	Bedded barite	Orris (1985); Papke (1984)
Greystone	Nevada	40.281	-116.901	barite	sedimentary	Marine exhalative deposit -barite	31b	Bedded barite	Orris (1985); Papke (1984)
Mountain Springs	Nevada	40.315	-117.041	barite	sedimentary	Marine exhalative deposit -barite	31b	Bedded barite	Orris (1985); Papke (1984)
Rossi	Nevada	40.599	-116.719	barite	sedimentary	Marine exhalative deposit -barite	31b	Bedded barite	Orris (1985); Industrial Minerals (1992)
Snoose Creek	Nevada	41.502	-115.039	barite	sedimentary	Marine exhalative deposit -barite	31b	Bedded barite	Harben and Kužvart (1996)
Stormy Creek	Nevada	41.523	-115.198	barite	sedimentary	Marine exhalative deposit -barite	31b	Bedded barite	Harben and Kužvart (1996)
Basalt	Nevada	38.011	-118.219	diatomite	sedimentary	Lacustrine biogenic deposit - diatomite	31s	Lacustrine diatomite	Taylor (2004)
Burney	California	41.033	-121.683	diatomite	sedimentary	Lacustrine biogenic deposit - diatomite	31s	Lacustrine diatomite	Taylor (2004)
Fernley	Nevada	39.600	-119.250	diatomite	sedimentary	Lacustrine biogenic deposit - diatomite	31s	Lacustrine diatomite	Taylor (2004)
Lovelock	Nevada	40.267	-118.797	diatomite	sedimentary	Lacustrine biogenic deposit - diatomite	31s	Lacustrine diatomite	Taylor (2004)
Vale	Oregon			diatomite	sedimentary	Lacustrine biogenic deposit - diatomite	31s	Lacustrine diatomite	Taylor (2004)
Lompoc	California	34.582	-120.345	diatomite	sedimentary	Marine biogenic deposit - diatomite	na	no model	Taylor (2004)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Black River Falls	Wisconsin	44.293	-90.725	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Gogebic Range - Eureka - Asteroid Mine	Michigan	46.476	-89.984	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Gogebic Range - Plymouth Mine	Michigan	46.470	-89.957	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Gogebic Range - Sunday Lake Group Mines	Michigan	46.483	-89.920	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Gogebic Range - Wakefield Mine	Michigan	46.469	-89.951	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Gogebic Range - West Gogebic Taconite Deposit	Wisconsin	46.297	-90.653	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Marquette Range - Empire Mine	Michigan	46.461	-87.597	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Marquette Range - Tilden Mine	Michigan	46.447	-87.642	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Menominee Range - Buck Mine	Michigan	46.059	-88.618	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Menominee Range - Cannon Mine	Michigan	46.077	-88.615	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Menominee Range - Groveland Mine	Michigan	45.993	-87.981	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Menominee Range - Hiawatha Mine #1	Michigan	46.075	-88.645	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Menominee Range - Homer Mine	Michigan	46.116	-88.657	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Menominee Range - Iron River - Sherwood Mine	Michigan	46.112	-88.641	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Menominee Range - Wauseca - Aronson Mine (Konwinski)	Michigan	46.111	-88.647	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Gross - Nelson Mine	Minnesota	47.478	-92.564	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Hibbing Taconite	Minnesota	47.460	-92.958	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Mckinley Mine	Minnesota	47.522	-92.400	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Minntac Mine	Minnesota	47.545	-92.654	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Minorca Mine	Minnesota	47.543	-92.519	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - National Steel Pellet Plant Mine	Minnesota	47.423	-93.069	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Peter Mitchell Mine	Minnesota	47.666	-91.917	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Plummer Mine	Minnesota	47.321	-93.396	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Rana Mine	Minnesota	47.520	-92.744	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Mesabi Range - Rouchleau Mine	Minnesota	47.511	-92.523	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Sherman Mine	Minnesota	47.483	-92.831	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Thunderbird Mine	Minnesota	47.482	-92.548	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Whitney Mine	Minnesota	47.448	-92.910	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Mesabi Range - Wyoming Mine	Minnesota	47.531	-92.507	iron	sedimentary	Banded iron formation	34a	Superior Fe	Cannon and others (1997)
Atlantic coastal plain phosphate province	Florida	27.888	-82.036	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Blake Plateau/Charleston Bump	South Carolina	31.500	-79.000	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Riggs (1989)
Atlantic coastal plain phosphate province, Charleston - Beaufort District	South Carolina	32.750	-80.000	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	British Sulphur Corporation (1964)
Atlantic coastal plain phosphate province, East Florida phosphate district	Florida	27.800	-80.781	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Atlantic coastal plain phosphate province, Gardinier Mine (Cargill Mine)	Florida	27.667	-81.763	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Hopewell	Florida	27.925	-82.106	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Orris and Chernoff (2002); Chernoff and Orris (2002)
Atlantic coastal plain phosphate province, Land Pebble district, Fort Green	Florida	27.668	-82.007	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Land Pebble district, Fort Meade Mine (Mobil)	Florida	27.766	-81.807	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Land Pebble district, Four Corners	Florida	27.664	-82.091	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Land Pebble district, Haynsworth Mine	Florida	27.758	-82.014	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Atlantic coastal plain phosphate province, Land Pebble district, Hookers Prairie	Florida	27.781	-81.939	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Land Pebble district, Payne Creek	Florida	27.690	-81.941	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Jasinski (1998)
Atlantic coastal plain phosphate province, Land Pebble district, Rockland	Florida	27.754	-81.867	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Land Pebble district, Saddle Creek	Florida	28.033	-81.834	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Land Pebble district, Silver City	Florida	27.800	-81.903	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	British Sulphur Corporation (1987)
Atlantic coastal plain phosphate province, Land Pebble district, South Fort Meade	Florida	27.667	-81.763	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Griffiths (1995)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Atlantic coastal plain phosphate province, Noranda	Florida			phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and McClellan (1990)
Atlantic coastal plain phosphate province, North Carolina district, Lee Creek Mine	North Carolina	35.384	-76.794	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and McClellan (1990)
Atlantic coastal plain phosphate province, North Carolina district, North Carolina Phosphate Corp.	North Carolina	35.333	-76.771	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Riggs (1989)
Atlantic coastal plain phosphate province, North Florida - South Georgia district, Swift Creek Mine	Florida; Georgia	30.452	-82.857	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Ona	Florida	27.520	-81.980	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Jasinski (2000)
Atlantic coastal plain phosphate province, Onslow Embayment/Frying Pan Phosphate District	North Carolina	33.750	-77.500	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Riggs (1989)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Atlantic coastal plain phosphate province, Onslow Embayment/Northeast Onslow Bay District	North Carolina	34.500	-76.750	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Riggs (1989)
Atlantic coastal plain phosphate province, Pine Level	Florida	27.250	-81.991	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Jasinski (2000)
Atlantic coastal plain phosphate province, Raine	Florida	27.725	-81.811	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Atlantic coastal plain phosphate province, Savannah District	Georgia	32.050	-81.083	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	British Sulphur Corporation (1964)
Atlantic coastal plain phosphate province, South Florida phosphate district	Florida	27.519	-82.208	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	McFaul and others (2000)
Atlantic coastal plain phosphate province, Suwanee River Mine	Florida; Georgia	30.437	-82.777	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Van Kauwenbergh and others (1990)
Aurora District	North Carolina	35.500	-76.500	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34d	Phosphate, warm current type	Griffiths (1995)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Lisburne Group	Alaska	68.633	-155.750	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock			Cathcart and others (1984)
Western Phosphate Field, Uinta Mountains, Park City Formation, Vernal	Utah	40.607	-109.491	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock	34c	Phosphate, upwelling type	Jasinski (2000)
Atlantic coastal plain phosphate province, Bronson (East Ocala Hard Rock) District	Florida	29.333	-82.500	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34d	Phosphate, warm current type	British Sulphur Corporation (1964)
Atlantic coastal plain phosphate province, Ridgeland Basin - Beaufort District	South Carolina	32.583	-80.917	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34d	Phosphate, warm current type	British Sulphur Corporation (1964)
Atlantic coastal plain phosphate province, Steinhatchee (N. Ocala Hard Rock) District	Florida	29.900	-83.317	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34d	Phosphate, warm current type	Foose (1993)
Western Phosphate Field, Phosphoria Formation, Conda	Idaho	42.728	-111.527	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34c	Phosphate, upwelling type	McFaul and others (2000)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Western Phosphate Field, Phosphoria Formation, Deseret Basin - - Laketown	Utah	41.827	-111.290	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34c	Phosphate, upwelling type	McFaul and others (2000)
Western Phosphate Field, Phosphoria Formation, Enoch Valley	Idaho	42.881	-111.407	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34c	Phosphate, upwelling type	Jasinski (1998); Jasinski (2000)
Western Phosphate Field, Phosphoria Formation, Montana phosphate district	Montana	45.041	-111.957	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34c	Phosphate, upwelling type	McFaul and others (2000)
Western Phosphate Field, Phosphoria Formation, Smoky Canyon	Idaho	42.670	-111.130	phosphate rock	sedimentary	Marine biogenic-chemical sediment - phosphate rock; residual enrichment	34c	Phosphate, upwelling type	Jasinski (1998)
Amargosa Valley	Nevada	36.450	-116.433	sepiolite, bentonite, saponite, hectorite	sedimentary	Altered volcanic ash beds	na	no model	Harben and Kužvart (1996)
Hardin district	Wyoming	44.580	-108.170	sodium-bentonite	sedimentary	Altered volcanic ash beds	28e.1	Sedimentary bentonite, sodium	Harben and Kužvart (1996)
Northern Black Hills district	Wyoming, South Dakota	44.580	-108.170	sodium-bentonite	sedimentary	Altered volcanic ash beds	28e.1	Sedimentary bentonite, sodium	Harben and Kužvart (1996)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Sublette Range (combined)	Wyoming	42.200	-110.983	vanadium, phosphate rock	sedimentary	Marine biogenic-chemical sediment - banasium-rich phosphate rock			British Sulphur Corporation (1987)
Ash Meadows	California	35.950	-116.250	zeolite	sedimentary	Lacustrine deposit - zeolite	25o.2	Sedimentary zeolites: Zeolites in tuffs of saline, alkaline-lake deposits	Holmes (1994)
Bear River	Idaho	42.424	-111.381	zeolite	sedimentary	Lacustrine deposit - zeolite	25o.2	Sedimentary zeolites: Zeolites in tuffs of saline, alkaline-lake deposits	Industrial Minerals (2004b)
Bowie	Arizona	32.450	-109.367	zeolite	sedimentary	Lacustrine deposit - zeolite	25o.2	Sedimentary zeolites: Zeolites in tuffs of saline, alkaline-lake deposits	Eyde and Eyde, 1987
Harney Lake	Oregon	43.228	-118.943	zeolite	sedimentary	Lacustrine deposit - zeolite	25o.2	Sedimentary zeolites: Zeolites in tuffs of saline, alkaline-lake deposits	Holmes (1994)
Atlas	Utah	38.337	-113.141	halloysite (clay mineral with tube-like crystals)	sedimentary and residual	Sedimentary kaolin (halloysite) deposit	na	no model	Industrial Minerals (2004a)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Aiken district	South Carolina	33.642	-81.628	kaolin	sedimentary and residual	Laterites developed on sedimentary deposits; sedimentary deposits derived from laterites	31k	Sedimentary kaolin	Harben and Kužvart (1996)
Andersonville district	Georgia	32.200	-84.133	kaolin	sedimentary and residual	Laterites developed on sedimentary deposits; sedimentary deposits derived from laterites	31k	Sedimentary kaolin	Harben and Kužvart (1996)
Augusta district	Georgia	33.467	-81.967	kaolin	sedimentary and residual	Laterites developed on sedimentary deposits; sedimentary deposits derived from laterites	31k	Sedimentary kaolin	Harben and Kužvart (1996)
Macon district	Georgia	32.833	-83.633	kaolin	sedimentary and residual	Laterites developed on sedimentary deposits; sedimentary deposits derived from laterites	31k	Sedimentary kaolin	Harben and Kužvart (1996)
Wrens district	Georgia	33.182	-82.675	kaolin	sedimentary and residual	Laterites developed on sedimentary deposits; sedimentary deposits derived from laterites	31k	Sedimentary kaolin	Harben and Kužvart (1996)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Eufaula district	Alabama	31.754	-85.272	kaolin, bauxite	sedimentary and residual	Laterites developed on sedimentary deposits; sedimentary deposits derived from laterites	31k	Sedimentary kaolin	Harben and Kužvart (1996)
Irwinton district	Georgia	32.812	-83.174	kaolin, bauxite	sedimentary and residual	Laterites developed on sedimentary deposits; sedimentary deposits derived from laterites	31k	Sedimentary kaolin	Harben and Kužvart (1996)
Brown - rock phosphate district	Tennessee	35.659	-87.185	phosphate rock	sedimentary and residual	Marine biogenic-chemical sediment - phosphate rock; residual enrichment			Krauss and others (1984)
Anadarko Basin - Weatherford - Clinton district	Oklahoma	35.540	-98.930	anhydrite	sedimentary, brines and evaporites	Marine evaporite deposit - anhydrite			Ham and Curtis (1958)
Death Valley	California	36.342	-116.684	boron	sedimentary, brines and evaporites	Lacustrine evaporite deposit - borate	35b.3	Lacustrine borates	Harben and Bates (1990); Evans and others (1976)
Fort Cady	California	34.754	-116.402	boron	sedimentary, brines and evaporites	Lacustrine evaporite deposit - borate	35b.3	Lacustrine borates	O'Driscoll (1990)
Gerstley I, II	California	36.018	-116.232	boron	sedimentary, brines and evaporites	Lacustrine evaporite deposit - borate	35b.3	Lacustrine borates	Evans and others (1976)
Kramer (Boron)	California	35.041	-117.687	boron	sedimentary, brines and evaporites	Lacustrine evaporite deposit - borate	35b.3	Lacustrine borates	Roskill Information Services (1993)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Rho (Kramer Junction)	California	34.767	-117.547	boron	sedimentary, brines and evaporites	Lacustrine evaporite deposit - borate	35b.3	Lacustrine borates	Evans and others (1976)
Smackover Formation	Arkansas	33.220	-92.660	bromine	sedimentary, brines and evaporites	Bromine in connate water (brine)	35a.14	Naturally occurring bromine brines	Harben and Kužvart (1996)
Apex	Nevada	36.221	-114.880	gypsum	sedimentary, brines and evaporites	Lacustrine evaporite deposit - gypsum	35b.4	Lacustrine gypsum	Papke (1987)
Anadarko Basin - Blaine Formation	Oklahoma	35.925	-98.364	gypsum	sedimentary, brines and evaporites	Marine evaporite deposit - gypsum	35a.5	Bedded gypsum: marine evaporite gypsum	Harben and Bates (1984)
Anadarko Basin - Cloud Chief Formation	Oklahoma	34.832	-98.255	gypsum	sedimentary, brines and evaporites	Marine evaporite deposit - gypsum	35a.5	Bedded gypsum: marine evaporite gypsum	Harben and Bates (1984)
Fort Dodge area	Iowa	42.493	-94.156	gypsum	sedimentary, brines and evaporites	Marine evaporite deposit - gypsum	35a.5	Bedded gypsum: marine evaporite gypsum	Harben and Kužvart (1996)
Michigan Basin - Tawas	Michigan	44.263	-83.675	gypsum	sedimentary, brines and evaporites	Marine evaporite deposit - gypsum	35a.5	Bedded gypsum: marine evaporite gypsum	Roskill Information Services (1992)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Plaster City	California	33.033	-116.088	gypsum	sedimentary, brines and evaporites	Marine evaporite deposit - gypsum	35a.5	Bedded gypsum: marine evaporite gypsum	Harben and Kužvart (1996)
White Mesa	New Mexico	35.520	-106.797	gypsum	sedimentary, brines and evaporites	Marine evaporite deposit - gypsum	35a.5	Bedded gypsum: marine evaporite gypsum	Austin and others (1982)
Appalachian Basin	New York, Pennsylvania, Ohio, West Virginia	41.233	-79.533	halite (salt)	sedimentary, brines and evaporites	Marine evaporite deposit - salt	35a.3	Bedded salt: marine evaporite salt	Harben and Kužvart (1996)
Appalachian Basin - Retsoff	New York	42.778	-77.858	halite (salt)	sedimentary, brines and evaporites	Marine evaporite deposit - salt	35a.3	Bedded salt: marine evaporite salt	Roskill Information Services (1983); Harben and Kužvart (1996)
Mississippi Basin	Mississippi	31.460	-89.210	halite (salt)	sedimentary, brines and evaporites	Marine evaporite deposit - salt dome	35a.4	Salt domes: diapiric salt structures	Harben and Kužvart (1996)
Texas - Louisiana Coastal Basin - Avery Island	Louisiana	29.893	-91.909	halite (salt)	sedimentary, brines and evaporites	Marine evaporite deposit - salt dome	35a.4	Salt domes: diapiric salt structures	Roskill Information Services (1983)
Texas - Louisiana Coastal Basin - Belle Isle (Patterson)	Louisiana	29.709	-91.351	halite (salt)	sedimentary, brines and evaporites	Marine evaporite deposit - salt dome	35a.4	Salt domes: diapiric salt structures	Roskill Information Services (1983)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Texas - Louisiana Coastal Basin - Jefferson Island	Louisiana	29.971	-91.969	halite (salt)	sedimentary, brines and evaporites	Marine evaporite deposit - salt dome	35a.4	Salt domes: diapiric salt structures	Roskill Information Services (1983)
Texas - Louisiana Coastal Basin	Louisiana, Texas	29.600	-91.817	halite (salt), gypsum	sedimentary, brines and evaporites	Marine evaporite deposit - salt dome	35a.4	Salt domes: diapiric salt structures	Harben and Kužvart (1996)
Michigan Basin - Detroit River Group	Michigan	44.241	-86.180	halite (salt), gypsum, magnesia, bromine	sedimentary, brines and evaporites	Marine evaporite deposit - salt	35a.3	Bedded salt: marine evaporite salt	Harben and Kužvart (1996)
Michigan Basin	Michigan, Indiana	43.617	-84.233	halite (salt), gypsum, potash, bromine, iodine, magnesia	sedimentary, brines and evaporites	Marine evaporite deposit and brine	35a.3	Bedded salt: marine evaporite salt	Hite (1967); Harben and Kužvart (1996)
Michigan Basin - Salina	Michigan			halite (salt), potash	sedimentary, brines and evaporites	Marine evaporite deposit - salt	35a.3	Bedded salt: marine evaporite salt	British Sulphur Corporation (1979)
Supai Salt Basin	Arizona	33.537	-112.338	halite (salt), potash	sedimentary, brines and evaporites	Marine evaporite deposit - salt	35a.3	Bedded salt: marine evaporite salt	Garrett (1996)
South Texas Basin - Palangana Salt Dome	Texas	27.648	-98.394	halite (salt), potash	sedimentary, brines and evaporites	Marine evaporite deposit - salt dome	35a.4	Salt domes: diapiric salt structures	Williams-Stroud and others (1994)
Anadarko Basin - Morrowan Formation	Oklahoma	36.433	-99.383	iodine	sedimentary, brines and evaporites	Iodine in connate water (brine)	35a.13	Naturally occurring iodine brines	Harben and Kužvart (1996); Roskill Information Services (1994)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Silver Peak (Clayton Valley)	Nevada	37.750	-117.633	lithium, potash	sedimentary, brines and evaporites	Playa brine - lithium and potash	35b.13	Lithium-rich Playa brines	Garrett (1996)
Searles Lake	California	35.777	-118.400	lithium, potash, sodium carbonate, boron	sedimentary, brines and evaporites	Lacustrine evaporite deposit	35b.13	Li-rich playa brine	British Sulphur Corporation (1985); Russell (1988); Roskill Information Services (1989)
Michigan Basin - Manistee Operation	Michigan	44.243	-86.308	magnesia	sedimentary, brines and evaporites	Magesia from brine associated with marine evaporite deposit	na	no model	Harben and Kužvart (1996)
Cane Creek (Moab Salt Operation)	Utah	38.523	-109.658	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Carlsbad Potash District	New Mexico	32.490	-103.938	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Carlsbad Potash District - Eddy County Mine	New Mexico	32.542	-103.878	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	British Sulphur Corporation (1985)
Carlsbad Potash District - Hobbs	New Mexico	32.505	-103.780	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Roskill Information Services (1989)
Carlsbad Potash District - IMC Mine (T22S, R29E)	New Mexico	32.413	-103.937	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Carlsbad Potash District - IMC Mine (T23S, R30E)	New Mexico			potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Carlsbad Potash District - Lea Mine	New Mexico	32.571	-103.552	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Carlsbad Potash District - MCC	New Mexico	32.490	-103.938	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Roskill Information Services (1989)
Carlsbad Potash District - Nash Draw	New Mexico	32.337	-103.832	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Carlsbad Potash District - New Mexico Potash	New Mexico			potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Carlsbad Potash District - Western Ag - Minerals (T20S,R30E)	New Mexico			potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Carlsbad Potash District - Western Ag - Minerals (T22S,R29E)	New Mexico			potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Garrett (1996)
Michigan Basin - Hershey	Michigan	43.825	-85.425	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Roskill Information Services (1989)
Paradox Basin	Utah, Colorado, Arizona	37.960	-109.670	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Hite (1967)
Salt Valley Anticline	Utah	38.922	-109.836	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	Hite (1964)
Williston Basin	Montana, North Dakota	47.250	-101.750	potash	sedimentary, brines and evaporites	Marine evaporite deposit - potash	35a.2	Potash-bearing bedded salt	British Sulphur Corporation (1979)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Michigan Basin - Midland Operation	Michigan	43.600	-84.232	potash, bromine, iodine, magnesia	sedimentary, brines and evaporites	Marine evaporite - potash-rich brine	35a.2	Potash-bearing bedded salt	British Sulphur Corporation (1979)
Michigan Basin - Ludington Operation	Michigan	43.939	-86.433	potash, bromine, lithium, magnesia	sedimentary, brines and evaporites	Marine evaporite - potash-rich brine	35a.2	Potash-bearing bedded salt	British Sulphur Corporation (1979)
Great Salt Lake	Utah	40.914	-112.733	potash, magnesia, lithium, sodiuum sulfate	sedimentary, brines and evaporites	Lacustrine evaporite deposit	na	no model	Warren (1999)
Sevier Lake	Utah	38.813	-113.201	potash, sodium sulfate, sodium chloride	sedimentary, brines and evaporites	Playa brine	na	no model	Garrett (1996)
Green River Formation	Wyoming	41.528	-109.368	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	Garrett (1992)
Green River Formation, FMC Westvaco Mine #1,#2	Wyoming	41.622	-109.814	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	USGS (1997)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Green River Formation, General Chemical Corp., Allied Chemical	Wyoming	41.599	-109.740	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	USGS (1997)
Green River Formation, OCI Chemical Corp., Big Island	Wyoming	41.718	-109.692	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	USGS (1997)
Green River Formation, Solvay Minerals, Inc.	Wyoming	41.500	-109.760	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	USGS (1997)
Green River Formation, Texas Gulf, Inc.	Wyoming	41.679	-109.908	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	USGS (1997)
Piceance Creek	Colorado	39.957	-108.360	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	Garrett (1992); Industrial Minerals (1999b)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Uinta Basin	Utah	40.225	-109.542	sodium carbonate	sedimentary, brines and evaporites	Lacustrine evaporite deposit - sodium carbonate	35b.1	Sodium carbonate in bedded lacustrine evaporites: Green River	Garrett (1992)
Camp Verde	Arizona	34.545	-111.874	sodium sulfate, halite (salt), gypsum	sedimentary, brines and evaporites	Lacustrine evaporite deposit	na	no model	Garrett (2001)
Texas - Louisiana Coastal Basin - Main Pass	Louisiana	29.275	-88.772	sulfur	sedimentary, brines and evaporites	Marine evaporite deposit - salt dome	35a.7	Salt dome sulfur	Edwards and others (1992)
Alder Gulch	Montana	45.324	-112.002	garnet	surficial, placer	Fluvial placer garnet deposit	na	no model	O'Driscoll (1993)
Emerald Creek - Carpenter Creek Emerald Placers	Idaho	47.072	-116.326	garnet	surficial, placer	Fluvial placer garnet deposit	na	no model	Spanski (2004)
Columbia	California	38.061	-120.319	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Fairbanks	Alaska	64.917	-146.500	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Folsom	California	38.684	-121.175	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Greaterville	Arizona	31.763	-110.753	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Hammonton	California	39.204	-121.415	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Kougarok	Alaska	65.750	-164.830	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Manhatten Alluvial Fan	Nevada	38.533	-117.150	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Orris and Bliss (1985)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Nome	Alaska	64.500	-165.500	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
North Bloomfield	California	39.394	-120.915	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Oregon Gulch	Wyoming	42.317	-108.833	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Pass Peak Formation	Wyoming	43.988	-110.292	gold	surficial, placer	Placer gold deposit	39a	Placer Au-PGE	Long and others (1998)
Ruby Meadows	Idaho	45.233	-115.881	rare-earth elements, gold, titanium	surficial, placer	Fluvial placer deposit	na	no model	Industrial Minerals (1987)
Gold Fork - Little Valley	Idaho	44.683	-115.967	titanium, zirconium, garnet, gold, rare-earth elements	surficial, placer	Fluvial placer deposit	na	no model	Jackson and Christiansen (1993)
Bear Valley	Idaho	44.350	-115.400	titanium, zirconium, garnet, niobium, rare-earth elements	surficial, placer	Fluvial placer deposit	na	no model	Jackson and Christiansen (1993)
Natchez Trace deposit	Tennessee	35.833	-88.200	titanium, zirconium, rare-earth elements	surficial, placer	Ancient marine titanium placer deposit	39c	Shoreline placer Ti	Towner (1992)
North Camden (Kerr - McGee deposit)	Tennessee	36.117	-88.183	titanium, zirconium, rare-earth elements	surficial, placer	Ancient marine titanium placer deposit	39c	Shoreline placer Ti	Towner (1992)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Oak Grove	Tennessee	36.383	-88.167	titanium, zirconium, rare-earth elements	surficial, placer	Ancient marine titanium placer deposit	39c	Shoreline placer Ti	Jackson and Christiansen (1993)
Old Hickory (Stony Creek)	Virginia	36.917	-77.567	titanium, zirconium, rare-earth elements	surficial, placer	Ancient marine titanium placer deposit	39c	Shoreline placer Ti	Pearson (1999)
Pearsol Creek	Idaho	44.517	-116.083	titanium, zirconium, rare-earth elements	surficial, placer	Fluvial placer deposit	na	no model	Jackson and Christiansen (1993)
San Gabriel Mountains - Soledad Canyon	California	34.434	-118.375	titanium, zirconium, rare-earth elements	surficial, placer	Fluvial placer deposit		no model	Roskill Information Services (1988)
Boulougne	Florida	30.734	-81.984	titanium, zirconium, rare-earth elements	surficial, placer	Marine titanium placer	39c	Shoreline placer Ti	Neary and Highley (1984)
Cumberland Island	Georgia	30.900	-81.450	titanium, zirconium, rare-earth elements	surficial, placer	Marine titanium placer	39c	Shoreline placer Ti	Jackson and Christiansen (1993)
Green Cove Springs - Maxville	Florida	29.867	-81.717	titanium, zirconium, rare-earth elements	surficial, placer	Marine titanium placer	39c	Shoreline placer Ti	Jackson and Christiansen (1993)
Hilton Head Island	South Carolina	32.200	-80.733	titanium, zirconium, rare-earth elements	surficial, placer	Marine titanium placer	39c	Shoreline placer Ti	Jackson and Christiansen (1993)

Appendix 1. Major mineral deposits in the United States – continued.

Deposit name	State	Latitude	Longitude	Commodities	Class	Deposit type	Model No.	Model name	Reference
Spor Mountain	Utah	39.707	-113.217	beryllium	hydrothermal	Epithermal beryllium deposit	na	no model	Harben and Kužvart (1996)
Lulaton	Georgia	31.217	-81.900	titanium, zirconium, rare-earth elements	surficial, placer	Marine titanium placer	39c	Shoreline placer Ti	Industrial Minerals (2003)
Trail Ridge	Florida	30.033	-82.033	titanium, zirconium, rare-earth elements	surficial, placer	Marine titanium placer	39c	Shoreline placer Ti	Towner (1992)
Cartersville district	Georgia	34.150	-84.767	barite	surficial, residual	Residual	na	no model	Harben and Kužvart (1996)
Washington County	Missouri	38.250	-90.833	barite	surficial, residual	Residual	na	no model	Harben and Kužvart (1996)
Spruce Pine	North Carolina	35.933	-82.133	feldspar, mica, kaolin. niobium, tantalum	surficial, residual	Igneous, residual	38h	Residual kaolin	Harben and Kužvart (1996)
York	Montana	46.721	-111.750	gold	unclassified	Unclassified		Unclassified	Long and others (1998)
Mike	Nevada	40.806	-116.247	gold, copper	unclassified	Unclassified		Unclassified	Long and others (1998)
Hahns Peak	Colorado	40.842	-106.929	silver, lead, zinc	unclassified	Unclassified		Unclassified	Long and others (1998)
Mountain Green	Utah	41.150	-111.783	zeolite					Holmes (1994)
Rome	Oregon	42.867	-117.700	zeolite					
No Agua Peaks (El Grande, Tres Piedras)	New Mexico	36.750	-105.950	perlite		Volcanic rock	na	no model	Harben and Kužvart (1996)

Appendix 2. Selected criteria used to identify major mineral deposits listed in Table 2 of this report

Commodity	Amount of contained metal (in metric tons)	Reference
Cobalt	10,000	This study
Copper	2,000,000	Giant deposit category, Singer (1995)
Gold	100	Giant deposit category, Singer (1995)
Iron ore	56,142,000 (metric tons iron)	75th percentile of iron for deposits in Singer and others (1993) or "large" deposit in Cannon and others (1997)
Lead	1,000,000	Giant deposit category, Singer (1995)
Molybdenum	300,000	Giant deposit category, Long (written comm.)
Nickel	1,262,300	This study
Platinum-group elements	520	Medium-large deposit, Laznicka (1999)
Silver	2,400	Giant deposit category, Singer (1995)
Tin	200,000	Giant camp, Mutschler and others (1999)
Tungsten	100,000	Giant camp, Mutschler and others (1999)
Zinc	1,700,000	Giant deposit category, Singer (1995)

Appendix 3. Resource-reserves definitions (USGS, 2004)

Resource.—A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

Identified Resources.—Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence.

Reserve Base.—That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth.

Reserves.—That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative.