Geology and Nonfuel Mineral Deposits of Latin America and Canada

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Open File Report 2005 –1294B

U.S. Department of the Interior
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Suggested citation:
Cunningham, C.G., Zientek, M.L., Bawiec, W.J., and Orris, G.J., 2005, Geology and nonfuel mineral deposits of Latin America and Canada: U.S. Geological Survey Open-File Report 2005-1294B, 104 p. [URL http://pubs.usgs.gov/of/2005/1294/b].

Contents

Contents iii

Abstract 1

Introduction 2

Regional geologic framework 3

- Major geologic provinces and structures 3
- Overview of geologic and tectonic history 4

Principal commodities and mineral deposits 7

- Metals 7
  - Aluminum 8
  - Antimony 8
  - Columbium (Niobium) 9
  - Copper 10
  - Gold 11
  - Iron ore 13
  - Lead and Zinc 14
  - Manganese 17
  - Molybdenum 18
  - Nickel and Cobalt 19
  - Platinum-group elements 21
  - Silver 22
  - Tin 23
  - Titanium 23
  - Tungsten 25
- Industrial minerals 26
  - Asbestos 26
  - Barite 26
  - Boron 27
  - Clay (Kaolin) 28
  - Gemstones 28
  - Fluorspar 30
  - Graphite 30
  - Gypsum 31
  - Lithium 31
  - Limestone and other carbonate rocks 32
  - Magnesium 32
  - Phosphate 33
  - Potash (Potassium) 34
  - Halite (salt) 34
  - Strontium 35
  - Sulfur 36

Regional exploration history and significant recent discoveries 36

Potential for undiscovered mineral resources 39
Acknowledgements 43
References Cited 43
Tables 60
Figures 78

Tables

Table 1. Principal nonfuel mineral commodities produced in Latin America and Canada 60
Table 2. Mineral deposit name, location, principal commodities, type, and references for the principal mineral deposits in Latin America and Canada 62
Table 3. Mineral deposit types and examples 77
Table 4. Bauxite - proportion of world mine production, reserves, and reserve base for countries covered by this report 8
Table 5. Antimony - proportion of world mine production, reserves, and reserve base for countries covered by this report 9
Table 6. Columbium - proportion of world mine production, reserves, and reserve base for countries covered by this report 9
Table 7. Copper - proportion of world mine production, reserves, reserve base, and resource base for countries covered by this report 10
Table 8. Gold - proportion of world mine production, reserves, and reserve base for countries covered by this report 11
Table 9. Iron ore - proportion of world mine production, reserves, and reserve base for countries covered by this report 13
Table 10. Lead - proportion of world mine production, reserves, and reserve base for countries covered by this report 14
Table 11. Zinc - proportion of world mine production, reserves, and reserve base for countries covered by this report 15
Table 12a. Manganese - proportion of world mine production, reserves, and reserve base for countries covered by this report 17
Table 12b. Manganese resources in the ocean 18
Table 13. Molybdenum - proportion of world mine production, reserves, and reserve base for countries covered by this report 19
Table 14. Nickel - proportion of world mine production, reserves, and reserve base for countries covered by this report 19
Table 15. Cobalt - proportion of world mine production, reserves, and reserve base for countries covered by this report 20
Table 16. Platinum-group elements - proportion of world mine production, reserves, and reserve base for countries covered by this report 21
Table 17. Silver - proportion of world mine production, reserves, and reserve base for countries covered by this report 22

Table 18. Tin - proportion of world mine production, reserves, and reserve base for countries covered by this report 23
Table 19. Titanium concentrate (ilmenite) - proportion of world mine production, reserves, and reserve base for countries covered by this report 24
Table 20. Tungsten - proportion of world mine production, reserves, and reserve base for countries covered by this report 25
Table 21. Asbestos - proportion of world mine production, reserves, and reserve base for countries covered by this report 26
Table 22. Barite - proportion of world mine production, reserves, and reserve base for countries covered by this report 27
Table 23. Boron - proportion of world mine production, reserves, and reserve base for countries covered by this report 27
Table 24. Fluorspar - proportion of world mine production, reserves, and reserve base for countries covered by this report 30
Table 25. Graphite - proportion of world mine production, reserves, and reserve base for countries covered by this report 30
Table 26. Gypsum - proportion of world mine production for countries covered by this report....31
Table 27. Lithium - proportion of world mine production, reserves, and reserve base for countries covered by this report 32
Table 28. Magnesium compounds - proportion of world mine production, reserves, and reserve base for countries covered by this report 33
Table 29. Phosphate rock - proportion of world mine production, reserves, and reserve base for countries covered by this report 33
Table 30. Potassium - proportion of world mine production, reserves, and reserve base for countries covered by this report 34
Table 31. Salt - proportion of world mine production for countries covered by this report 35
Table 32. Strontium - proportion of world mine production for countries covered by this report....35

Figures

Figure 1. Areas of the regional reports....78
Figure 2. Location of countries covered in this report and the names of states and provinces in Latin America and Canada. 79
Figure 3. Digital elevation image of North and South America 80
Figure 4. Principal layers of the Earth....81
Figure 5. Diagram illustrating the plate tectonic setting in which mineral deposits are formed....82
Figure 6. Geologic map of Latin America and Canada showing the age and distribution of principal rock units, and the location of tectonic plates and plate boundaries.....83
Figure 7. Map showing selected geologic and tectonic features of North America.....84
Figure 8. Map showing selected geologic and tectonic features of South America discussed in the text. 85
Figure 9a. Distribution of principal nonfuel mineral deposits in Latin America and Canada by deposit type....86
Figure 9b. Location and deposit type of major deposits of copper, lead, and zinc. 87
Figure 9c. Location and deposit type of major deposits of antimony, fluorspar (fluorite), gold, and silver 88

Figure 9d. Location and deposit type of major deposits of boron, diatomite, gypsum, halite, iodine, iron, kaolin, limestone, lithium, manganese, phosphate, potash, sodium carbonate, strontium, and uranium. 89
Figure 9e. Location and deposit type of major deposits of aluminum, columbium, gemstones, mica, molybdenum, nickel, palladium, platinum, sulfur, syenite, tantalum, tin, and titanium. 90
Figure 9f. Location and deposit type of major deposits of asbestos, barite, graphite, magnesium, pyrophyllite, talc, tungsten, and wollastonite. 91
Figure 10a. Schematic laterite profile showing the progression of weathering effects on rock. 92
Figure 10b. Cross section of a stratovolcano showing the relative locations of porphyry copper deposits, lead-zinc veins, gold-silver veins, and sulfur deposits. 93
Figure 10c. Formation of placer gold deposits. 94
Figure 10d. Extensional tectonic setting where plates are moving away from each other. 95
Figure 10e. Cross section schematically illustrating the characteristic features of volcanogenic massive sulfide (VMS) deposits 96
Figure 10f. Cross section schematically illustrating the characteristic features of sedex lead and zinc deposits 97
Figure 10g. Longitudinal section through the West Field, Santa Eulalia mining district of Mexico showing the distribution and shape of silver-zinc-lead ore bodies relative to sedimentary rock units. 98
Figure 10h. Pink rhodochrosite (manganese, carbon, and oxygen) from Argentina 99
Figure 10i. Simplified geologic map of the Sudbury Igneous Complex, showing locations of some of the more important nickel-copper mines 100
Figure 10j. Chalcopyrite-rich veins (yellow) cutting gneiss in the Sudbury Igneous Complex, Strathcona mine, Ontario 101
Figure 10k. Cerro Rico de Potosi, Bolivia, the world's biggest silver deposit 102
Figure 10l. Purple amethyst quartz crystal from Brazil 103
Figure 10m. Model of a diamond kimberlite pipe 104

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Abstract

A nation's endowment of nonfuel mineral resources, relative to the world's endowment, is a fundamental consideration in decisions related to a nation's economic and environmental well being and security. Knowledge of the worldwide abundance, distribution, and general geologic setting of mineral commodities provides a framework within which a nation can make decisions about economic development of its own resources, and the economic and environmental consequences of those decisions, in a global perspective. The information in this report is part of a U.S. Geological Survey (USGS) endeavor to evaluate the global endowment of both identified and undiscovered nonfuel mineral resources. The results will delineate areas of the world that are geologically permissive for the occurrence of undiscovered selected nonfuel mineral resources together with estimates of the quantity and quality of the resources. The results will be published as a series of regional reports; this one provides basic data on the identified resources and geologic setting, together with a brief appraisal of the potential for undiscovered mineral resources in Latin America and Canada. 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 and the annual Mineral Commodity Summaries (available at http://minerals.usgs.gov/minerals).

The region covered in this report is a major producer of mineral commodities like copper (53 percent of world production in 2004), silver (48 percent), zinc (30 percent), nickel (32 percent), molybdenum (43 percent), iron ore (29 percent), gold (21 percent), lead (18 percent), primary aluminum (17 percent), salt (19 percent), and manganese (12 percent). In addition, the countries in the region are among the world's major producers, or have significant reserves of antimony, asbestos, barium, beryllium, bismuth, boron, cobalt, fluorite, graphite, gypsum, indium, iodine, kaolin, magnesite, niobium, nitrate, potash, selenium, strontium, tellurium, tin, titanium, and tungsten. The United States does not produce enough of some mineral commodities to supply all of its current domestic demand, and it relies on imports to satisfy these needs. In 2004, the United States imported 100 percent of its arsenic, asbestos, bauxite and alumina, columbium (niobium), fluorspar, graphite, indium, manganese, mica, industrial quartz crystal, rare earths, rubidium, strontium, thallium, thorium, vanadium, and yttrium from sources that include countries in this region. Although Latin America and Canada are rich in mineral resources (both identified and undiscovered), increasing concerns about the environmental and societal impacts of minerals

development in the region are increasingly affecting the progress of new exploration and development activities.

A recurrent theme of this report is that mineral deposits are associated with large-scale geologic processes that reoccur in time and place. Mineral deposits do not occur randomly; their distribution is intimately related to the geologic history of each continent. 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 answer where new deposits will be found and what they will contain.

Introduction

This regional report is one of a series that summarizes current knowledge of the world's nonfuel mineral resources. These reports are designed to provide the non-earth scientist with information about the major known mineral commodities, their locations, and their general geologic setting. The reports are organized by the five regions shown in figure 1. Additional information, such as production statistics, economic factors that affect the mineral industries of the region, and historical information, is available in U.S. Geological Survey (USGS) publications such as the annual Minerals Yearbook and the Mineral Commodity Summaries (available at http://minerals.usgs.gov/minerals) and through the detailed references provided at the end of this report. In addition, 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 both identified and undiscovered nonfuel mineral resources of the world at a scale of 1:1,000,000 (Briskey and others, 2001, 2002). Results of the assessment will delineate areas of the world that are geologically permissive for the occurrence of undiscovered selected nonfuel mineral resources, together with estimates of the quantity and quality of the resources. Also, the global assessment will provide information to assist in efforts to maintain a world supply of essential mineral resources while minimizing the global environmental and other societal impacts of mining.

Information in this report covers the 42 countries that constitute North America and South America, excluding the United States (fig. 2; table 1). Latin America and Canada are major producers of mineral commodities such as copper (53 percent of world production in 2004), silver (48 percent), zinc (30 percent), nickel (32 percent), molybdenum (43 percent), iron ore (29 percent), gold (21 percent), lead (18 percent), primary aluminum (17 percent), salt (19 percent), and manganese (12 percent). In addition, some of the countries are among the world's major producers, and/or have significant reserves of many of the world's major commodities including antimony, asbestos, barium, beryllium, bismuth, boron, cobalt, fluorite, graphite, gypsum, indium, iodine, kaolin, magnesite, niobium, nitrate, potash, selenium, strontium, tellurium, tin, titanium, and tungsten (table 1; Petersen, 1977). Many of the small Caribbean countries have only a limited amount of mineral resources, but some do have major deposits of gold, aluminum, and nickel. The United States does not produce enough of many mineral commodities to supply all of its current domestic demand, and it relies on imports to satisfy these needs. In 2004, the United States imported 100 percent of its arsenic, asbestos, bauxite and alumina, columbium (niobium), fluorspar, graphite, indium, manganese, mica, industrial quartz crystal, rare earths, rubidium, strontium, thallium, thorium, vanadium, and yttrium from sources that include countries in this region. Although the region is rich in mineral resources (both identified and undiscovered), increasing concerns about the environmental and societal impacts of minerals development in the region are increasingly affecting the progress of new exploration and development activities.

The mineral commodities present are very much dependent upon the geology. Different kinds of mineral deposits are found in different geologic settings; some minerals are formed within mountains and are related to the crystallization of molten rock, some are precipitated on the bottom of the ocean, and some only become economically important if they are concentrated by tropical weathering. This large region of Latin America and Canada has great geologic diversity. Throughout geologic time, mountains were eroded and became ocean basins, continents collided and pushed up new mountains, and even the belt of tropical weathering associated with the equator has shifted its position around the globe. The region covered by this report ranges in latitude from the equator to 83° north and to 56° south, and in longitude from 32° west to 141° west. It varies in elevation from sea level to a lofty 6,962 meters at Mount Aconcagua in the Argentina Andes, the second highest peak in the western hemisphere.

Regional geologic framework

The geologic evolution of Latin America and Canada is recorded in a complex array of rocks that range in age from some of the oldest found on Earth to the present. The oldest rocks formed during the Archean Eon if they formed before 2,500 million years ago (abbreviated Ma), or Proterozoic Eon if they formed between 2,500 Ma and about 540 Ma. This is a long period of time, especially when viewed from the perspective that the Earth is about 4.5 billion (4,500 million) years old. In many cases, these old rocks record the conditions of their formation and subsequent evolution, such as the accumulation of sediments in ancient oceans to form shale, limestone, or sandstone; changing (metamorphism) of these sediments by deep burial under conditions of high heat and pressure into metamorphic rocks (e.g., shale into slate or limestone into marble); and mountain building, sometimes accompanied by the melting and emplacement of igneous (molten rock, also called magma) rocks. These processes lead to a new cycle of erosion and deposition of sediments in the ocean. Specific types and textures of rocks are formed by different geologic processes, and likewise, specific types of mineral deposits are associated with different rocks and processes. With knowledge of the distribution in time and space of rock types, mineral occurrences, and other geologic information, mineral resource specialists can reasonably estimate the likely occurrence and size of undiscovered mineral deposits in a region.

The geologic evolution of the Earth is expressed in many ways, one of which is differences in the elevation of the land surface, or topography. Figure 3 is a digital elevation map that shows what the Earth would look like if all the water was drained out of the oceans and areas were colored according to their elevation. Dark blue shows the distribution of the ocean floor and light blue indicates the distribution of undersea mountains. Green shows relatively low-lying areas of the continents, brown shows the higher elevations of mountains. Lets explore these different areas, learn how they formed, and investigate the implications for the distribution of mineral resources, both discovered, and those that have yet to be found. For general background information and perspectives, the reader is referred to recent compendiums that provide excellent overviews of the geologic evolution and mineral resources of Latin America and Canada. They include Bally and Palmer (1989), Salas (1991), Eckstrand and others (1995), Camus (2002), Gurmendi and others (1999), Skinner (1999), Cordani and others (2000), Sherlock and Logan (2000), Albinson and Nelson (2001), and Zapppettini and others (2001).

Major geologic provinces and structures

The Earth consists of three main parts, like an egg (Kious and Tilling, 1996; fig. 4). The *crust,* or outermost layer (like the shell of the egg), is rigid and very thin compared with the other two layers. It ranges in thickness from 0 to 100 km. Below the crust is the *mantle* (like the white of the egg), a dense, hot layer of semi-solid rock approximately 2,900 km thick. At the center of the Earth is the *core* (like the yoke of the egg), that is composed of both solid and liquid iron-nickel alloy. The crust and solid outermost part of the mantle compose the lithosphere, that is broken into a dozen or more large and small tectonic plates that are moving relative to one another as they ride on top of hotter, more mobile mantle material. A tectonic plate is a massive, irregularly shaped slab of solid rock, composed generally of both continental and oceanic lithosphere. Plates can vary greatly in size, from a few hundred to several thousands of kilometers across. Plate thickness also varies greatly, ranging from less than 15 km for young oceanic plates to about 200 km or more for ancient, continental plates (for example, the interior parts of North and South America). These plates move relative to each other, sometimes spreading apart (divergent plate boundary), sometimes colliding with each other (convergent plate boundary), sometimes scraping past each other, and different types of mineral deposits formed with the different processes (fig. 5).

Latin America and Canada are part of several large tectonic plates (fig. 6), the history of whose movements about the Earth's surface is recorded in their rocks and major faults and other geologic structures. North America consists mostly of one large plate, called the North American Plate, that has been moving slowly westward from an axis, or spreading center, located in the Atlantic Ocean approximately midway between Europe and North America and continuing south between Africa and South America (figs 3, 5 and 6). This spreading center is where the plates are moving away from each other and new magma (molten rock) is extruded, forming a ridge of undersea mountains that sometimes reach the surface to form volcanic islands, such as Iceland (fig. 3) in the north Atlantic Ocean. Because of the geometry of the plate motions, North America abuts and slides mostly tangentially against the Pacific Plate along the San Andreas fault (fig. 7) and thereby causes earthquakes in California. In North America, the folded Appalachian Mountains (figs. 3, 6, and 7) record the history of past collisions between continents. The Andes Mountains (figs. 3, 6, and 8), the most prominent topographic feature of South America, is a range of high mountains along the western margin of the continent. There, the rocks were bent, crumpled, and forced upward while being pushed against the rocks of the Nazca Plate (fig. 6). In addition, magmas formed at depth and rose to form prominent volcanoes along the Andes as the oceanic Nazca Plate moved eastward beneath (subducted) the continental South American Plate (figs. 6 and 8) at a rate of about 78 mm/yr (Ramos and Aleman, 2000). This is a "convergent plate boundary" of the "continental-arc" type shown by generalized example in figure 5. The South American Plate (fig. 6) is bounded on the north by a ("transform") fault that separates it from the Caribbean Plate, and on the south by another fault that separates it from the Antarctic Plate. Volcanoes and earthquakes commonly are located at plate margins where convergent plates are being subducted or where the plates move laterally past each other along transform faults (figs. 5, 6, 7, and 8).

Overview of geologic and tectonic history

The rocks exposed in North and South America record a long history of tectonic plate collisions and amalgamation of continental crust. In general, the interiors of the continents consist of Archean (before 2,500 Ma) and Proterozoic (2,500-540 Ma) continental crust that has been structurally stable for a prolonged period of time. These old rocks are called "cratons". The cratons usually have broad convex topographic surfaces that are at higher elevation than the surrounding rocks (compare figures 3, 6, 7, and 8) and are usually called "shields". The ancient rocks of the cratons are surrounded by belts of younger rocks. These outer, younger, gently curving belts of deformed rocks are usually accompanied by metamorphic and igneous rocks called "orogens". 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. Here, plate tectonic processes provide heat to generate magmas and hydrothermal fluids (hot, salty water containing metals in solution) together with fractures and faults that focus their flow. Many types of ore deposits are spatially and temporally associated with orogenic belts. The discussion that follows describes the global plate-tectonic setting, origin, and evolution of major orogens containing important mineral resources described later in this report.

South America has three major shields (figs. 6 and 8) that are the exposed surface of a craton that is continuous beneath the cover of younger sedimentary rocks. Some of the oldest rocks in Latin America are present in Brazil and have been dated at 3.35 Ga [Ga means billion years old; the G stands for Giga. One billion years (1 Ga) equals 1,000 million years (Ma)] (Barbosa, 1996). Proterozoic rocks in South America are dominated by metamorphosed volcanic rocks, the remnants of former volcanic island chains or arcs. They are now called greenstone belts, because of the green color of certain minerals in these rocks (Lobato and others, 2000). There are many old rocks in the Andes, but so far, those dated have yielded mostly Proterozoic (2500 – 540 Ma), rather than Archean, (older than 2.5 Ga) ages (Cordani and others, 2000).

Canada has five major Archean continental blocks, called "provinces"(fig. 7): the Rae, Nain, Hearne, Rae, and Slave: all experienced strong compression, magmatism, and metamorphism between 2.8 and 2.6 Ga (Hoffman, 1989). These provinces were joined together in the Early Proterozoic to form the Canadian Shield (fig. 6) by 1.7 Ga. Younger, mostly sedimentary rocks were formed in basins on the Canadian Shield about 1.7 Ga and are shown on figure 7 as "platform cover".

The Earth's tectonic plates and continents have not always been dispersed around the globe as they are today. Geologic evidence indicates that many, if not all, of the major continents were joined together during Middle Proterozoic (about 1.3 to 1.0 Ga) and Paleozoic times (between about 540 and 248 Ma) forming the supercontinents called Rhodinia and Pangea, respectively (Condie, 1997). The Middle Proterozoic Grenville orogen (fig. 7) is exposed from eastern Canada to Mexico and formed during the series of plate collisions that created Rhodinia. This supercontinent broke apart between 750 to 600 Ma. The part of the Paleozoic Appalachian orogen in eastern Canada formed during the assembly of Pangea. Although largely complete by the late Proterozoic, Pangea continued to amalgamate small crustal blocks during the early Paleozoic (Ramos and Aleman, 2000). Throughout most of Paleozoic time, several major basins developed on the shield area in South America (fig. 8) and were filled with shallow water sediments (Milani and Filho, 2000). Three major basins formed on the shield area in Canada during the Paleozoic and Mesozoic (fig. 7).

Pangea began to break up during late Triassic (227 to 206 Ma) and Jurassic (206 to 144 Ma) times when the dinosaurs roamed the Earth (Ramos and Aleman, 2000). North America split from Europe to form the North Atlantic. This splitting apart of the continents resulted in the formation of elongate basins, related to the opening of the Atlantic Ocean, that filled with red-colored sedimentary rocks and basaltic volcanic rocks. South America and Africa also split apart and moved away from each other; the geologic correlation between the facing shores on the opposite sides of the southern Atlantic ocean was documented almost a century ago (Wegener, 1912). A chain of volcanic islands was formed as the result of subduction of the Caribbean Plate (figs. 6 and 7). Pieces of oceanic crust were forced upwards onto continental rocks and are locally preserved in northwestern South America and parts of Central America.

Subduction of oceanic crust beneath the western margin of the South American Plate has created vast mineral resources there. This process began in the Late Proterozoic time (900 to 540 Ma; Ramos, 1988), but the main activity started in late Paleozoic and continued throughout Cenozoic time. Subduction here continues to the present day (Condie, 1997). The Cordilleran

Orogen in western Canada, the Sierra Madre Orogen in western Mexico, (fig. 7) and the many large mineral deposits associated with both, also formed as a result of subduction beneath the western margin of North America (Bally and Palmer, 1989). Today, these zones of subduction are marked by a prominent deep ocean trench extending along the western side of the Andes to southern Mexico, and another one off the coast of Oregon, Washington, and British Columbia. Sediment-filled basins formed along the east side of the trench and in South America extend from Venezuela to Tierra del Fuego (Milani and Filho, 2000). Subduction also is accompanied by active volcanism (figs. 5 and 8) and earthquakes (Thorpe and Francis, 1979). The location and inclination of the modern subduction zone is marked by variations in seismic activity, with relatively higher seismic energy zones corresponding to areas of relatively shallow inclinations of the subduction zones (Gutscher and Malavieille, 1999; Ramos and Aleman, 2000). Above the subduction zone, magma commonly is formed and works its way toward the surface. If magma reaches the surface, it may form volcanoes. The magma contains dissolved gasses that can erupt violently, showering the countryside with ash. Magmas also contain metals that commonly are transported by hot magmatic fluids into cracks where the fluids cool and precipitate metals to form mineral deposits.

Today, off the coast of South America, the oceanic Nazca Plate (fig. 6) is pushing into and subducting under the continental part of the South American Plate. In turn, the overriding South American Plate is being lifted up, creating the Andes Mountains. This convergence of oceanic and continental plates also generates magma that is erupted to form active stratovolcanoes and mineral deposits (fig. 8). The linear belts of modern volcanic activity along the western margins of North and South America are caused by the subduction process. Stratovolcanoes typically are steep-sided, symmetrical cones of large dimension, built of alternating layers of lava flows, volcanic ash, and coarser fragmental material. They may rise as much as 2,500 m above their bases (Kious and Tilling, 1996). Some of the most dramatic mountains in the world are stratovolcanoes, including Mount Fuji in Japan, Mount Cotopaxi in Ecuador, and Mount Rainier in Washington. Stratovolcanoes commonly are associated with mineral deposits at depth and are not randomly distributed over the Earth's surface. Most of these volcanoes and their mineral deposits are concentrated on the edges of continents or along island chains. More than 270 stratovolcanoes active in the last 10,000 years occur in linear belts along the western coasts of North and South America (figs. 7 and 8; Siebert and Simkin, 2002).

In summary, the western margins of the North and South American continents have been a convergent plate boundary (fig. 5) where the Earth's tectonic plates have been moving toward each other for at least the last 300 Ma. Subduction and destruction of oceanic crust along this boundary has created linear belts of igneous (crystallized from molten magma) rocks and related mineral deposits on the continental crust that makes up the western side of the North and South American continents. The position, duration, and intensity of these belts of igneous activity have shifted somewhat with time. Uplift and erosion have cut through the volcanic rocks to expose underlying igneous intrusions that may host copper, molybdenum, gold, and other mineral deposits. In the Andes, these deposits are present in seven north-trending parallel belts that formed over a span of millions of years (Benavides-Cáceres, 1999; Petersen, 1999; Camus, 2002). The heat from the subduction process caused many igneous intrusions (bodies of magma) to be formed and emplaced in the Cordillera orogens of North and South America. So far, exploration geologists have found over 300 porphyry-type copper deposits in a linear belt along the western margins of these continents (Singer and others, 2002; Camus, 2003). These deposits are large concentrations of copper associated with solidified magma in the throat of a stratovolcano. The obvious relations between geologic processes and the location of copper deposits attest to the importance of understanding the geology in order to predict the location and abundance of undiscovered resources.

Principal commodities and mineral deposits

Deposits of metals and industrial minerals have formed throughout the history of the Earth and form a highly diverse assemblage of commodities and mineral deposit types in Latin America and Canada (table 2; fig.9). Older rocks commonly are deformed and recrystallized and are associated with a different assemblage of mineral deposits than are younger rocks. The old Archean and Proterozoic rocks that compose the cratons are associated with large iron and nickel-copper deposits. Enormous quantities of copper are present in the much younger, and less eroded, Andes. Gold deposits are found in rocks of many types and ages. However, some deposits, called placer deposits, are concentrated by running water and thus are generally associated with young stream and river channels or sometimes with older "fossil" channels. Mineral deposits vary by geologic environment as well as age. The central Andes contain several prominent sub parallel belts of mineral deposits. Nearest to the Pacific coast is an iron belt, followed inward by the copper, polymetallic (usually lead and zinc), and tin belts, each belt containing deposits of different ages and deposit types (Oyarzun, 2000), but reflecting the continuation of similar geologic processes throughout time.

Table 2 is a compilation of the major commodities and the deposits from which they were produced throughout Latin America and Canada. The table documents major commodities from more than 400 major mineral deposits in the region thereby underscoring the importance and diversity of these mineral deposits and their geologic environments as sources of commodities for our modern society. Mineral deposits of a particular commodity commonly form in similar ways throughout time and space, so particular geologic features can be used to find mineral deposits and then to classify them into various types. Table 3 briefly describes how the deposits identified in table 2 are classified by type, and how the deposits formed, and gives examples of these deposits. The principal mineral deposits are shown by location, principal commodity, and type of deposit in figure 9a-f. Simplified geologic settings for each of the mineral deposit models are shown in figure 10. Comparison of these features with the geology and tectonics (figs. 5, 6, 7, and 8) shows a strong correlation between geology, commodity, deposit type, and mountain-building processes.

Metals

Metals can be concentrated to form a mineral deposit in the Earth's crust by a variety of mechanisms. If the metals are concentrated enough to make their extraction economical, the concentration is called an ore deposit. Thus, a mineral deposit is a more general term. Mineral deposits form as the result of a combination of factors, including the availability of metals in a source area, a means to transport the metals, and a mechanism to concentrate and deposit them. Similar geological characteristics of the source areas, and in the transportation and concentration processes, result in similar features among the deposits. These features permit mineral deposits to be grouped, described, measured, modeled, and discovered. The mineral deposit models allow predictions to be made of the abundance and location of undiscovered deposits. These models can be defined as the systematic arrangement of the essential characteristics of a group of similar mineral deposits. The models present the features that a group of mineral deposits have in common and that are essential to form a concentration of metals. A collection of mineral deposit models published by Cox and Singer (1986) is used to organize deposits by type in this report. Selected descriptive models are used to illustrate the diagnostic features that deposits have in common. The following paragraphs briefly outline the use, nature of occurrence, and location of significant deposits considered in this report. The data for the tables are modified slightly from the 2003 data presented in Mineral Commodity Summaries 2004 (USGS, 2004). The term "reserve base" is defined as 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 are that part of the reserve base that can be economically produced (USGS, 2004).

Aluminum

Aluminum is a very light but strong metal. Because aluminum is ductile, it can be drawn into wires or pressed into sheets or foil. Its light weight and resistance to corrosion make it ideal for use in aircraft, automobiles, beverage containers, and buildings. Aluminum makes up 8 percent of the Earth's crust; only silicon and oxygen are more plentiful. Although aluminum is a common element in many rocks, it is economical to mine and process only in rocks where the aluminum has been concentrated. Bauxite, an impure mixture of highly-aluminous minerals, is the principal raw material used to make aluminum. Known global resources of bauxite are estimated to be 55 to 75 billion metric tons, located primarily in South America (33 percent), Africa (27 percent), Asia (17 percent), Oceania (13 percent), and elsewhere (10 percent) (USGS, 2004). The United States imported almost all of the bauxite it consumed in 2003; however, the country has nearly inexhaustible subeconomic resources of non-bauxite aluminum.

Table 4. Bauxite - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Brazil	9.4	3	8.2	7.5
Jamaica	9.3	4	8.6	7.5
Venezuela	3.5	7	1.4	1.1
Suriname	3.1	8	2.5	1.8
Guyana	1.0	10	3.0	2.7

Bauxite is a surficial deposit (table 3) that can form by weathering of any aluminum-bearing rock in an area that has a tropical climate with alternating wet and dry seasons and a terrain with high relief and good drainage, all of which promote chemical leaching and the resulting concentration of aluminum (fig. 10a). This concentration occurs when silicate minerals (rock-forming minerals that contain silica) and clays are decomposed and silica is removed, leaving a soil relatively enriched in aluminum. A similar concentration process occurs for nickel and iron. Figure 9e shows that almost all of the aluminum deposits are in close proximity to the equator. The deposits in the Caribbean are formed on limestone; those in South America are derived from a variety of igneous, sedimentary, and metamorphic rocks in and near the Guyana Shield and the Central Brazilian Shield (Harben and Kužvart, 1996). Many of these deposits formed during Tertiary time (65 to 2 Ma).

Antimony

Antimony is a brittle, silvery-gray semimetal used principally for flame retardants. It also is used in ammunition and automotive batteries and as a decolorizing agent in glassmaking. It is present with gold and silver in certain hydrothermal-type mineral deposits. Antimony deposits, mainly composed of the mineral stibnite (antimony and sulfur), are important in Bolivia (fig. 9c) and formed where black, organic-rich rocks provided a favorable chemical environment for the transport and deposition of hydrothermal fluids carrying antimony. There was no United States mine production of antimony in 2003; domestic antimony production was derived entirely from the recycling of lead-acid batteries (USGS, 2004).

Table 5. Antimony - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Bolivia	1.7	5	17.6	8.2

Columbium (Niobium)

Columbium and niobium are synonymous names for the chemical element with atomic number 41. Almost all columbium is used to make specialty steels and superalloys. Most of the world's identified resources of this element are in two deposits in Brazil (fig. 9e). Brazil and Canada are the first and second producers of columbium in the world. World resources are more than adequate to supply demand, and there was no significant United States mine production in 2003 (USGS, 2004).

Table 6. Columbium - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Brazil	87.2	1	97	100
Canada	11.4	2	2	

The world's largest sources of columbium are associated with carbonatites. Carbonatites are igneous rocks that contain more than 50 percent by volume carbonate minerals. These are minerals containing a molecule that is one part carbon and three parts oxygen. Magmas that can crystallize large amounts of carbonate minerals are unusual; about 330 carbonatites are known worldwide (Wooley, 1989). Igneous intrusions with carbonatite occur mainly on continents; they are rarely in an oceanic setting. The intrusions generally are found near large fractures in continental crust because at the time the magmas were emplaced plate tectonic activity was stretching or extending the continental crust.

Brazilian columbium production mainly is from the Araxá mine (Mariano, 1989). The Araxa deposit is an intensely weathered carbonatite intrusion where the rocks were extensively weathered to a depth of 250 m. This deposit is the largest known reserve and is the principal producer of columbium in the world. This intrusion lies along an old, northwest-trending fault zone separating the Atlantic shield from the adjoining basin (Wooley, 1989). In Canada, columbium production is mainly from the St. Honore igneous intrusion, also a carbonatite complex

(Wooley, 1987; Mariano, 1989). For more than 25 years, the Niobec mine furnished about 15 percent of the world supply of columbium from this deposit (Cambior, Inc., 2003).

Copper

Copper is mined mainly from ore minerals also containing iron and sulfur. Because of copper's high ductility, malleability, thermal and electrical conductivity, and resistance to corrosion, it has become a major industrial metal; it ranks third after iron and aluminum in terms of quantities consumed. About one-half of the copper produced is used in building construction, and about one-fourth in electrical and electronic products. World resources are estimated to be in excess of 1.6 billion metric tons of copper, and 2003 world production was about 13.9 million metric tons (USGS, 2004). The Andes justifiably are famous for their copper deposits (fig. 9b), with Chile and Peru supplying over 40 percent of the world's production of copper. Canada supplies 4.2 percent of the World copper and is that country's fifth ranked mineral by value of production (Mining Association of Canada, undated).

Table 7. Copper - proportion of world mine production, reserves, reserve base, and resource base for countries covered by this report (USGS, 2004; Singer, 1995).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base	Percent of world discovered resources
Chile	35.1	1	31.6	38.4	20.7
Peru	6.1	5	6.3	6.4	3.4
Canada	4.2	7	1.5	2.1	6.8
Mexico	2.4	11	5.7	4.3	2.3

Most of the copper production in North and South America is derived from large, relatively low-grade ore deposits called porphyry copper deposits. They form beneath stratovolcanoes (fig. 10b) where copper becomes concentrated in hot, salty fluids (hydrothermal fluids) within the molten igneous rock of the volcano. The copper either is deposited in the cooling and solidifying molten rock and (or) is expelled with the hydrothermal fluids and deposited in adjacent rocks as the fluids cool and release their metal load. An average porphyry copper ore body contains 140 million metric tons of ore containing 0.5 percent copper (Singer and others, 2002). The largest deposit of this type, El Teniente in Chile, contains over 11 billion metric tons of ore averaging 0.9 percent copper. Other large deposits in Chile include Chuquicamata, La Escondida, and Rio Blanco. These ore bodies also are an important source of molybdenum and gold. Most porphyry copper deposits have been found in rocks younger than 300 million years. These deposits form relatively near the surface of the Earth, and older ones tend to be eroded away.

The largest porphyry copper deposits in Mexico are Cananea, La Caridad, and El Arco (fig. 9b). These deposits are associated with subduction-related igneous rocks in northwestern Mexico in the Sierra Madre Occidental magmatic arc (Singer and others, 2002; Staude and Barton, 2001). Most copper reserves in British Columbia, Canada are also in porphyry copper deposits, which are found in the Canadian Cordilleran Orogen. Examples include: Valley Copper, Bethlehem, and Lornex (Singer and others, 2002). Gaspé Copper in Quebec is a rare example of a porphyry copper deposit located in the Appalachian orogen. In contrast, copper in Ontario is principally associated with the nickel sulfide ores found with the Sudbury Igneous Complex discussed in the section on nickel-cobalt later in this document. Other kinds of copper deposits also form where hot, salty fluids derived from sea water circulate through fractures in the rocks beneath the sea floor and dissolve metals. The metals subsequently are precipitated when the fluids rise to the bottom of the sea and are cooled and diluted thereby depositing their contained minerals (see discussion under lead and zinc section).

Gold

Gold is a metallic element that is beautiful, durable, and easily worked. It has been used throughout human history for jewelry and as currency. It is chemically stable, does not corrode or rust, and efficiently conducts heat and electricity. Gold is easily hammered into thin foils and drawn into long, thin wires. Gold is used primarily in coins and jewelry and is stored by many countries to support their currencies. It is also used in dentistry and in electrical and electronic applications.

About 190,000 metric tons of gold have been discovered in deposits around the world throughout history (Singer, 1995), enough to form a cube of gold 22 m on an edge. About 5 percent of this gold is in Canada, 3.9 percent in Brazil, 1.2 percent in Chile, 1.0 percent in Mexico, and 0.78 percent in Columbia. Major deposits are shown in figure 9c. Total remaining world gold resources are currently estimated to be about 100,000 metric tons (USGS, 2004).

Table 8. Gold - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Canada	6.3	7	3.0	4.0
Peru	5.7	8	0.5	0.7

Gold is Canada’s leading mineral by value of production (Mining Association of Canada, undated). Mines in Ontario and Quebec have the largest amounts of gold identified in reserves in operating mines or deposits committed for production (Mining Association of Canada, undated). Eighty-five percent of Canadian gold production is from hydrothermal deposits consisting of veins that occur near major fault zones in metamorphic rocks (Robert, 1996). The veins are composed mainly of the mineral quartz, with less abundant carbonate minerals. Pyrite (iron, sulfur) and arsenopyrite (iron, arsenic, and sulfur) constitute less than 5 percent of the veins. The main ore mineral in most deposits is native (pure) gold. These quartz-carbonate-gold veins have been found in metamorphic rocks of all ages. However, most of the veins in Canada have been found in Archean greenstone belts of the Canadian Shield (figs. 7 and 9c). Examples include: Hemlo, Dome, Hollinger-McIntyre, Kerr-Addison in Ontario and Horne-Quemont and Sigma-Lamaque in Quebec. Quartz-carbonate-gold veins also have been discovered in fragments of oceanic crust and deep-water sedimentary rocks exposed in the Canadian Cordillera and Appalachian orogens shown in figures 3 and 5.

Groups of rocks called “greenstone belts” are important host rocks for gold deposits worldwide. During the 19th century, geologists discovered these areas of deformed and metamorphosed volcanic and sedimentary rocks surrounded by granites in what is now recognized as the oldest continental crust in North America, Southern Africa, India, and Australia (DeWit and Ashwahl, 1997). The predominance of green-colored metamorphosed volcanic rocks led to these areas being called greenstone belts. Greenstone belts are linear to irregular in shape and consist of groups of volcanic rock-rich metamorphosed rocks that average 20 to 100 km in width and extend for distances of several hundred kilometers (Windley, 1977). Most greenstone belts formed in a variety of geologic and tectonic settings early in Earth's history at the time when continental crust was developing. Commonly, more than one tectonic setting is represented in a single greenstone belt. Some belts appear to have formed by plate tectonic processes at continental margins – others did not. Within a greenstone belt, the hydrothermal gold vein deposits are spatially clustered near large fault zones (Robert, 1996; Roberts, 1988; Yeats and Vanderhor, 1998). These fault zones are up to several kilometers wide, can be over 100 km long, and are nearly vertical. The vein deposits occur in faults, fractures, and folds that developed near the large fault zones and formed late in the sequence of events that compressed and metamorphosed the greenstone belts. Mineralization in some veins can be traced over two kilometers in depth. The fault zones were the pathways for flow of the hydrothermal fluids that formed the vein deposits. The gold vein deposits potentially can occur in any deformed and metamorphosed volcanic, plutonic, or clastic sedimentary rock. However, gold is more commonly concentrated if the rocks next to the veins are iron-rich and difficult to deform, such as banded iron formation. Banded iron formation is described in the section on iron in this document. Examples of quartz-carbonate-gold veins associated with banded iron formation include the Lupin Mine in the Northwest Territories and the Morro Velho gold deposit of the Quadrilátero Ferrifero in Brazil. Archean greenstone belts with hydrothermal quartz-carbonate-gold vein deposits are found on all continents. However, the greenstone belts found in the south-central part of the Canada's Superior Province in Ontario and Quebec are some of the largest in the world and the quartz-carbonate-gold vein deposits there (figs. 7 and 9c) are the largest and most productive such deposits of all the Archean shields. The Superior Province has yielded over 5,000 metric tons of gold from hundreds of deposits.

Gold (and silver) deposits also are commonly associated with igneous and hydrothermal processes related to volcanic rocks throughout the Cordilleran Orogen in the Andes, Mexico, and Canada (fig. 3 and 7). Significant quantities of gold are recovered from mining porphyry copper deposits (see copper discussion) and certain other types of sulfide deposits (see lead-zinc discussion). In Mexico, where gold-bearing hydrothermal fluids permeated the rock, they produced dispersed, low-grade deposits of extremely fine-grained gold. These deposits, called Carlin-type deposits after the Carlin mine in Nevada, generally are mined by bulk-mining techniques in large open-pit mines (Thompson, 2002; Bettles, 2002). Some very rich gold deposits form in the roots of ancient hot-spring systems, usually as veins in volcanic rocks (Cunningham and Eyzaguirre, 1996). An example is the El Indio gold deposit of the Chilean Andes, with the famous "3,500 vein", so called because it contained 3,500 grams of gold per metric ton of ore (Jannas and others, 1999); this means that a block of rock from this vein that would easily fit in a wheelbarrow would be worth about $1.5 million at today's gold price. These veins are fractures in which metal-bearing hydrothermal fluids circulated and eventually deposited gold. The veins commonly formed less than 1,500 meters below ground. The gold mineralization in the veins can extend laterally for several kilometers, but typically it is limited to about 600 meters vertically.

Prospectors were quick to recognize that gold's high density and resistance to breaking were properties that caused gold nuggets to be concentrated by running water in modern and ancient stream beds. These are called placer deposits (fig. 10c). The prospectors panned stream gravels in search of the gold in placer deposits, and then followed the gold upstream in search of the veins that were the source of the gold. Eventually, miners realized that if they could sift through larger amounts of rock, they could recover more gold. Thus, water cannons were used to break up placer deposits, and dredges were used to sift through many metric tons of the resulting sediment in a day.

Iron ore

Iron is one of the most abundant elements on Earth, but it does not occur in nature in its useful pure-metallic form. "Iron ore" is the term applied to a natural iron-bearing mineral or rock in which the content of iron is sufficiently high to be commercially extractable. Iron ore is the source of primary iron for the world's iron and steel industries. World resources are estimated to exceed 800 billion metric tons of crude ore containing more than 230 billion metric tons of iron. Brazil is ranked second in the world in iron ore production (China is now first) and has about 6 percent of the world reserve base (table 9; USGS, 2004).

Table 9. Iron ore - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Brazil	19.2	2	5.2	5.8
Canada	2.9	9	1.2	1.2
Venezuela	1.5	10	2.7	1.8

The iron mined in Brazil comes from iron-rich sedimentary rocks called banded iron formation. These deposits are not unique to this region. More than 95 percent of the world's iron resources occur in banded iron formation (Gross, 1996a). Banded iron formation is characterized by alternating iron-rich and quartz-rich layers and has greater than 15 percent metallic iron by weight. The thickness of individual layers varies from less than a millimeter to meters; overall, these layered rocks may be 100's of meters thick. The principal iron minerals are hematite and magnetite (Dardenne and Schobbenhaus, 2000). Banded iron formation has been found on all continents except Antarctica.

Although iron deposits are widespread geographically, the largest ones formed almost exclusively during the Precambrian time (Gross, 1996a). The extensive deposits of banded iron formations are associated with marine sedimentary units and formed during the Late Archean to Early Proterozoic (2.7 to 1.8 Ga). The oldest deposits tend to be smaller and are associated with volcanic rocks.

The iron resources are large because the deposits are laterally extensive. The iron minerals were precipitated from ocean water and were deposited uniformly over large areas. At the time they were formed, the deposits of iron formation associated with sedimentary rocks may have covered over 100,000 km^2 (Trendall, 2002). Individual layers can be traced for over 100 km (Trendall, 2002). The deposits may have formed on submerged continental shelves surrounding Archean continents.

The origin of banded iron formation is still unresolved. These deposits often are studied because they provide insight into the early evolution of the Earth's atmosphere and oceans (Konhauser and others, 2002). They also provide insight on biological processes early in the Earth's history because of their close association with early biological organisms. The iron minerals we see today are not those that were chemically deposited from seawater. These rocks were buried in sedimentary basins, where they formed new minerals because of increased temperature and pressure. Subsequently, these rocks were exposed by erosion were weathering in tropical climates leached silica from some deposits thereby enriching the iron content in these rocks and changed the original iron minerals to those we mine today.

The largest deposits of banded iron formation in South America are the Cerro Bolivar/ San Isidro deposits in the eastern Guyana Shield of Venezuela, the Carajás deposit in the Central Brazil Shield of Brazil, and a group of deposits in the Quadrilátero Ferrifero, Minas Gerais, located on the Atlantic Shield of eastern Brazil (table 2; fig. 9d). These huge deposits contain upwards of 10 billion metric tons of ore at about 40 to 60 percent iron. In Canada, banded iron formation is associated with the Labrador-Quebec fold belt (fig. 7) that extends 1,200 km along the eastern margin of the Superior craton (fig. 7; Gross, 1996a). The principal iron-formation unit forms a continuous stratigraphic unit along the fold belt. Iron ore mined from these deposits is Canada's sixth ranked mineral by value of production (Mining Association of Canada, undated).

A recently recognized but poorly understood type of iron deposit is the iron oxide-copper-gold-type deposit that appears to be represented by several outstanding deposits in Latin America and Canada. The Candelaria deposit in central Chile and perhaps the Carajás deposit in Brazil share common features with the huge Olympic Dam deposit of this type in Australia. The deposits are characterized by having large concentrations of iron in the minerals magnetite or hematite along with copper-iron sulfide minerals (generally chalcopyrite) and pyrite (iron sulfide). The deposits contain light rare earth elements, thorium, and cerium (Haynes, 2002).

Lead and Zinc

Lead is a blue-gray, dense, ductile, malleable, very corrosion-resistant metal. More than three-fourths of the lead produced is used by the transportation industry, mainly for lead-acid batteries. Remaining uses include ammunition, electrical, electronic, and communication applications, and radiation shields. Lead and zinc minerals commonly occur together in polymetallic deposits; hence, they are considered together here.

Zinc also is a blue-gray metallic element. Because of its anticorrosion properties, more than one-half of zinc metal 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 (Singer, 1995). About 15 percent of this amount is in Canada. Estimates of discovered lead for other countries included in this report are: Mexico (3.2 percent), Peru (1.9 percent), Chile (1.2 percent), and Brazil (0.8 percent). Identified lead resources of the world total more than 1.5 billion metric tons (USGS, 2004). The United States ranks third in lead production for 2003 with 450,000 metric tons, compared to Australia with 715,000 metric tons and China with 650,000 metric tons (USGS, 2004).

Table 10. Lead - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Peru	10.9	4	5.3	2.9
Mexico	4.9	5	2.3	1.4
Canada	2.8	6	3.0	6.5

About 710 million metric tons of zinc has been discovered (Singer, 1995). About 18 percent of the total zinc discovered is in Canada. Estimates of discovered zinc for other countries covered by this report include: Mexico (3.3 percent), Peru (2.1 percent), Chile (1.0 percent), and Brazil (0.7 percent). Identified zinc resources of the world are about 1.9 billion metric tons (USGS, 2004). Zinc is Canada's eighth ranked commodity by value of production (Mining Association of Canada, undated). Worldwide, the United States ranks fifth in production of zinc but is one of the largest consumers (USGS, 2004).

Table 11. Zinc - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Peru	14.8	3	7.3	4.3
Canada	11.8	4	5.0	6.7
Mexico	5.9	6	3.6	5.4

Zinc and lead commonly occur in ore deposits that form from low-temperature hydrothermal fluids. Several types of deposits can be explored for and recognized based on how the hydrothermal fluids were generated and where they moved, the distribution of ore minerals in the ore deposit, and the geologic setting.

Two deposit types formed on or near ancient ocean floors where hydrothermal fluids move upward toward the bottom of the ocean floor along fractures and formed hot springs where they vented into the ocean (fig10d). The hydrothermal solutions mixed with ocean water and deposited large quantities of iron, zinc, and lead minerals onto mounds and layers on the sea floor. One of these deposit types is called a volcanogenic massive sulfide (VMS) deposit (fig. 10e). It forms where cooling magma (molten igneous rock), either as volcanic rocks erupted on the ocean floor or emplaced at depth in shallow intrusions, supply the heat needed to generate and mobilize hydrothermal solutions. For the type called sedimentary exhalative (sedex) deposits (fig.10f), the hydrothermal solutions are generated as water-rich sediments are deeply buried in basins within the Earth, later to be expelled when pressure is released during folding and faulting.

Like porphyry copper deposits, VMS deposits are associated with magmas generated at convergent plate boundaries. However, the volcanogenic deposits are associated with the eruption of volcanic rocks under water. Unlike porphyry copper deposits, these deposits are found in rocks of all ages. The oldest deposits, in Archean-age rocks, have less lead than younger deposits. Deposits of all ages also may contain recoverable amounts of copper, gold, and silver.

VMS deposits are a common deposit type and are widely distributed. They are classified as hydrothermal deposits in figure 9b. Franklin (1996) identifies over 260 VMS deposits in Canada; 20 are large enough to include in this compilation. Deposits occur in western Canada in the Cordilleran Orogen in British Columbia and in the Yukon Territory; the Paleozoic Appalachian Orogen in New Brunswick and Newfoundland; the southern part of the Archean shield in Saskatchewan and Manitoba; the southern part of the Archean Superior Province in Ontario and Quebec, and the Archean Slave Province in the Northwest Territories and Nunavut. VMS deposits in New Brunswick, Ontario, and Quebec (fig. 2) have the largest reserves of zinc in operating mines and deposits committed for production in Canada (Mining Association of Canada, undated). Fitch (1999) and Moss and Hall (2001) describe VMS deposits that occur in Mexico. In Latin

America, VMS deposits are present in Precambrian to recent rocks but the greatest number, in terms of average size and contained metal, are in Jurassic to Lower Cretaceous (about 200 Ma-100 Ma) volcanic arcs (Sherlock and Michaud, 2000). The average size tends to be small, but there are notable exceptions, such as Tambo Grande (Peru) and San Nicolás (Mexico). Modern VMS deposits are forming today on the ocean floor at spreading centers where the crust is being pulled apart off the coasts of Mexico and South America (figs. 5 and 6). A summary of the geology of Latin American VMS deposits is available in Sherlock and Michaud (2000), and detailed descriptions are found in Sherlock and Logan (2000).

Sedimentary exhalative lead and zinc deposits, called sedex deposits, are a type of hydrothermal deposit found in sedimentary basins (figs. 9b and 10f); Lydon, 1988; Lydon, 1996). These basins commonly form as continents are pulled apart by rifting. Sedex deposits typically occur in large basins filled with more than 10 km of sediments. Silver, and less commonly copper, may be present in economic amounts in sedex deposits. Globally, sedex deposits are younger than 1,800 million years. No sedex deposits older than 1,500 million years are known from Canada. These deposits occur less frequently than VMS deposits. Lydon (1996) lists 17 sedex deposits in Canada; 5 are large enough to include in this report (Sullivan, Cirque, Dy, Faro, and Howards Pass; table 2). The largest number of deposits occurs in the Selwyn basin in the Yukon (fig. 7). At this time, few reserves are identified in operating mines or deposits committed for production in Canada (Mining Association of Canada, undated). One of the more important mines developed on a sedex deposit, Sullivan, shut down recently after 92 years of operation.

Another type of lead-zinc deposit also forms from hydrothermal fluids related to sedimentary basins. However, in these deposits, the hydrothermal fluids move through aquifers, mix with other fluids, and deposit minerals in open cavities in carbonate sedimentary rocks such as limestone. These ore bodies are referred to as Mississippi Valley type (MVT). The geology of these deposits, especially in Canada, was described by Sangster (1996). The movement of hydrothermal fluids in the sedimentary basins is driven by forces resulting from plate boundary interactions. These deposits form in the relatively undeformed sedimentary rocks that generally occur inland from the orogenic belts formed at convergent plate margins (fig. 5). The known MVT deposits are younger than 500 million years. Seven deposits have been described in Canada (Sangster, 1996); three deposits in Nunavut and Northwest Territories are large enough to include in this report (Pine Point, Nanisivik, and Polaris). In the 1980s, MVT deposits accounted for approximately 10 percent of the lead and zinc production in Canada. However, the mines developed on all three of these deposits are now closed. MVT lead-zinc deposits have been discovered in the Andes (Fontboté and Gorzawski, 1990) in the carbonate rocks at the western margin of the Brazil Shield and, to date, have had only moderate production.

Other types of lead and zinc deposits are present in the regions of this report. Many of these deposits occur in favorable carbonate (e.g. limestone) sedimentary rocks throughout the Andes Mountains, and are especially important in Peru and Argentina where these rocks are thickest. These deposits are called “polymetallic replacement” deposits. This deposit type commonly forms near intrusions of molten igneous rock where hydrothermal fluids emanating from the intrusion selectively replace the adjacent carbonate rocks with ore and other associated minerals (Nelson, 1996). This replacement process forms orebodies having a variety of irregular shapes (e.g., figure 10g). Orebodies deposited parallel to sedimentary layering in carbonate rocks often are called “mantos”, which is the Spanish word for blanket. Conversely, orebodies that form in fractures, and other inhomogeneous parts of the sedimentary rock, that cut across the sedimentary layers. Have a variety of names, including: “veins”, when they form sheet-like and tabular masses in fractures; and “pipes”, or “chimneys”, when they have the shape of nearly vertical cylinders. Polymetallic replacement deposits contain variable amounts of silver, lead, zinc, and other metals. Bismuth may be a significant byproduct of mining lead. The silver-bearing Aguliar polymetallic deposit in Argentina (fig. 9c) is one of the largest metal deposits in South America.

Manganese

Manganese is a very brittle, but hard metallic element that is essential for improving the properties of iron and steel. Manganese is also used in aluminum alloys, batteries, colorants, and fertilizers.

Table 12a. Manganese - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Brazil	11.9	3	13.9	1.1
Mexico	1.1	9	2.4	0.2

Almost the entire supply of manganese for North America comes from sedimentary deposits in the Molango area of Mexico (table 2; fig. 9d). The source of the manganese at Molango is a manganese-enriched limestone that was deposited in a Jurassic (206 Ma-144 Ma) sea (Harben and Kužvart, 1996). The enrichment process, which concentrated the manganese and made it economical to mine, was the intense chemical weathering of the deposit that occurred during the Cenozoic (65 Ma-present). Reserves in Brazil, the other major producer in the region, are in Mato Grosso do Sul. Rhodochrosite, the manganese carbonate mineral, forms in hydrothermal veins and stalagtites. It is a beautiful, pink and white banded ornamental stone (fig. 10h) and is the official mineral of Argentina. Manganese also precipitates as nodules on the sea floor.

Large submarine deposits of manganese and a number of other nonfuel mineral resources are known and much studied by scientists but are not the focus of these reports of on-land mineral resources. An example of the largest, or one of the largest, of these marine resources is the enormous amount of metal estimated to occur in deposits of manganese nodules that form on the deep ocean floor. The possible magnitude of these resources is represented in the following table by manganese nodules sampled from in what is know as the North Pacific high-grade area:

Table 12b. Manganese resources in the ocean.

Metal	Manganese nodules North Pacific high-grade area Six million km^2 (Mero, 1977)	USGS on-land reserve base Million metric tons (USGS, 2003)
Manganese	11,000	5,000
Cobalt	115	13
Nickel	650	140
Copper	520	950
Zinc	53	450
Molybdenum	23	0.019

Manganese nodules form in two separate regions of the oceans in different ways (Gill, 2003, and French Research Institute for Exploitation of the Sea, 2000): (1) as hydrothermal deposits above basalt lavas that form mid-oceanic ridges along spreading centers like those shown in figures 3 and 5; and (2) away from spreading centers in sea floor sediments where the nodules form by slow deposition of metals and other chemical elements directly from seawater, or by a variety of secondary processes that remobilize metals from seawater, marine sediments and volcanic rocks, and organic emanations or debris, and redeposit them in nodules at the sediment-seawater interface on the sea floor.

Although interest is greatest for the economic potential of nickel, copper, and cobalt in the nodules, their development is unlikely for several decades (Wiltshire, 2001) because of the high cost of mining, a variety of environmental effects, and global disputes about ownership arising from the occurrence of most nodule fields outside of national Exclusive Economic Zones (Gill, 2003).

Molybdenum

Molybdenum is a metallic element used principally as an alloying agent in cast iron, steel, and superalloys to enhance hardenability, strength, toughness, and wear and corrosion resistance. Identified molybdenum resources of the world are about 18 million metric tons, of which 5.4 million metric tons are located in the United States (USGS, 2004).

Table 13. Molybdenum - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Chile	24.7	2	12.8	13.1
Peru	7.5	4	1.6	1.2
Canada	5.9	5	5.2	4.8
Mexico	2.8	6	1.0	1.2

Chile, Peru, and Canada are the world's second, fourth, and fifth producers of molybdenum, respectively. Generally, molybdenum is produced as a byproduct of mining copper, especially mining of porphyry copper deposits, which are discussed in the section on copper. Molybdenum also is mined in certain types of igneous intrusions in which it is the principal metallic sulfide mineral. The Endako deposit in British Columbia is the largest deposit in the region that is mined principally for molybdenum (fig. 9e).

Nickel and Cobalt

Nickel is a silvery-white metallic element that occurs in rocks that compose the Earth's mantle and are derived from the mantle. About 65 percent of nickel is used to manufacture stainless steels. Twenty percent is used in other steel and non-ferrous (including "super") alloys, often for highly specialized industrial, aerospace, and military applications. About 9 percent is used in plating. The remaining 6 percent has other uses, including coins and a variety of nickel chemicals.

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. Identified on-land resources averaging one percent nickel or greater contain at least 130 million metric tons of nickel (USGS, 2004). Identified world cobalt resources are about 15 million metric tons (USGS, 2004).

Table 14. Nickel - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Canada	12.9	3	8.4	10.6
Cuba	5.4	6	9.1	16.2
Colombia	4.6	7	1.3	0.7
Brazil	3.3	9	7.3	5.8
Dominican Republic	2.8	11	1.2	0.7
Venezuela	1.5	14	1.0	0.4

Table 15. Cobalt - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Canada	10.0	5	1.3	2.5
Cuba	6.8	6	14.3	15.1
Brazil	2.8	8	0.5	0.3

Nickel and cobalt commonly occur together in deposits in Canada and Latin America and therefore are considered together here. The deposits are mined principally for their nickel content. Cobalt is recovered in the process of mining nickel. Most of the nickel and cobalt come from two general types of deposits: nickel laterite and magmatic nickel-sulfide deposits. Nickel laterite (fig. 10a) forms by the weathering of nickel-bearing rock in areas with a tropical climate and good drainage. During this process, silica is leached from the rocks, leaving a soil enriched in nickel, cobalt, and iron. The principal nickel minerals are garnierite (hydrous nickel silicate) and nickeliferous limonite (hydrated nickel-bearing iron oxide). Magmatic nickel-sulfide deposits are found in igneous rocks rich in magnesium, nickel, and chromium; they form as magnesium-rich silicate magmas solidify to form characteristically layered igneous rocks. As the magmas cool and crystallize, a separate dense liquid rich in sulfur, iron, nickel, copper, and occasionally platinum-group elements, can form within the magma. Once formed, the sulfur-rich liquid will not remix with the silicate-rich magma (like the separation of oil and vinegar in a salad dressing). Eventually, the sulfur-iron-nickel-copper-rich liquids accumulate separately and solidify forming a variety of minerals that include pentlandite (iron nickel sulfide), which is mined for its high nickel content.

Nickel laterite deposits are present throughout South America, Central America, and the Caribbean, wherever tropical weathering conditions and rocks rich in nickel exist together. These are the surficial nickel deposits shown in figure 9e. The large nickel laterite deposit at Loma de Hierro, Venezuela, was formed by weathering of peridotite and related rocks. Peridotite is a dark, low-silica rock typical of oceanic crust. Cuba and the Dominican Republic have significant nickel laterite deposits.

All nickel production in Canada comes from nickel sulfide ore deposits which are classified as igneous deposits in figure 9e. These sulfide ores contain important by-product metals such as copper, cobalt, gold, silver, platinum-group elements, selenium, and tellurium. The ores also are used to produce sulfuric acid and liquid sulfur dioxide (McCutcheon, 2003). Most of Canada's nickel production comes from mines developed on the Sudbury Igneous Complex in Ontario (fig. 9e, 10i). The Sudbury Igneous Complex and its ore deposits are unusual geologic features that occur in a 30 km by 60 km elliptical structure thought to result from a meteorite impact approximately 1,850 million years ago (Eckstrand, 1996). The meteorite impact caused the formation of molten igneous rock that filled the crater. A molten ore material greatly enriched in sulfur, iron, nickel, copper, and platinum-group elements separated from this mass of molten rock and collected along its base. Some of the molten igneous rock and ore material also moved into fractures (dikes)that extend outward like the spokes of a wheel (fig. 10j). Of the 170 impact craters recognized on Earth (Earth Impact Database, 2003), only the Sudbury structure is known to be mineralized. The total current value of historic production and present reserves and resources from

Sudbury exceeds $300 billion, making it one of the most valuable mineralized features in the world (FNX Mining Company, undated).

The remainder of Canada's current nickel production comes from deposits in the Thompson nickel belt in Manitoba (Bleeker, 1991) and the Cape Smith fold belt in Quebec (fig. 7; Eckstrand, 1996). Although these two areas are separated by 1,500 kilometers, mineralization in both formed during Early Proterozoic time along the eastern rifted continental margin of the Superior Province (figs. 5, 7; Hoffman, 1989). The ore deposits occur in rocks that formed from magmas (molten igneous rocks) that were usually hot and rich in magnesium. This type of magma is not common in rocks younger than 1,900 million years. These magmas flowed upon the surface of the Earth or forced their way between layered sedimentary rocks to form masses of igneous rock called sills. The deposits formed when dense molten ore material enriched in sulfur, iron, and nickel separated from the magma and collected near the bottoms of the flows or sills. After the deposits in both areas were formed, they complexly deformed and folded during development of an Early Proterozoic orogen. Major nickel deposits similar to those in the Thompson nickel belt and the Cape Smith area are found in other Precambrian shields, including those in western Australia and Zimbabwe.

The development of the newly discovered Voisey's Bay deposit in Labrador is important for the Canadian nickel industry. Starting in 2006, nickel, cobalt, and some copper output from this deposit will offset production declines expected from older mines in Manitoba and Ontario (McCutcheon, 2003). Voisey's Bay is similar to the deposits at Sudbury, Thompson, and Cape Smith because it formed by the separation of dense molten ore material from a magma. Up to 1998, when the deposit was discovered, major nickel deposits were not known to occur in the igneous rock types typical of the area near Voisey's Bay. These types of rocks are widely distributed throughout Labrador and Quebec as well as in other parts of the world. Consequently, discovery of this new geologic setting allows geologists to identify areas around the world that may have been overlooked in previous nickel exploration programs.

Platinum-group elements

The platinum-group elements (PGE) are iridium, osmium, palladium, platinum, rhodium, and ruthenium. In general, platinum-group elements exhibit high density, high electrical conductivity, high melting points, and low reactivity. Platinum is used in automobile pollution abatement systems (catalytic converters) and jewelry, and as a catalyst in the production of industrial chemicals. 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).

Table 16. Platinum-group elements - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Platinum: Percent of world production, 2003	Palladium: Percent of world production, 2003	Rank of world production	PGE: Percent of world reserves	PGE: Percent of world reserve base
Canada	3.7	6.4	3	0.4	0.5

The world resources of PGE that can be economically mined are more than 100 million kilograms, the vast majority being found in South Africa (USGS, 2004). Until 1993, the source of PGE produced in Canada was the nickel ores mined from the Sudbury Igneous Complex. In that year, the Lac des Iles open pit mine (fig. 9e) started production from a palladium-rich body of rock that was discovered in the Archean-age Lac des Iles igneous-rock complex in Ontario in 1963 (North American Palladium, Ltd, 2004). The style of mineralization at Lac des Iles is unique for deposits mined for PGE. Palladium, with minor amounts of platinum, gold, copper, and nickel, is associated with minor sulfide minerals (up to 5 volume percent) in porous, broken rock formed by mixing of magmas. Within 100 kilometers of the deposit, several intrusions similar to the Lac des Iles intrusive complex have been found. Although the factors that controlled formation of the Lac des Iles deposit are not yet well enough understood to be able to effectively explore for similar deposits elsewhere. This new deposit type suggests new exploration opportunities for PGE deposits around the world.

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. 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. Over 1.7 million metric tons of silver have been discovered (Singer, 1995). About 15 percent of total silver discovered is in Mexico. Estimates of discovered silver for other countries include: Canada (9.7 percent), Peru (5.8 percent), Chile (4.8 percent), Bolivia (4.2 percent), Panama (1.1 percent), Brazil (0.7 percent), and Honduras (0.6 percent). Mexico and Peru are the leading producers of silver in the world, each producing about 2.8 million metric tons of silver in 2003; the United States produced about half that amount (USGS, 2004).

Table 17. Silver - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Mexico	14.7	1	13.6	7.0
Peru	14.5	2	13.2	6.5
Chile	6.8	6	0.0	0.0
Canada	6.7	7	5.9	6.2

More than two-thirds of world silver resources are spatially associated with copper, lead, and zinc deposits. The remainder are associated with hydrothermal gold deposits. The world's largest silver deposit, Cerro Rico de Potosi (fig. 10k) is located in a large, volcanic dome in Bolivia (Cunningham and others, 1996). This deposit produced about 60,000 metric tons of silver- enough, it is said, to build a silver bridge all the way to Madrid- and is reputed to have an equal amount in identified reserves and resources. Mining to date has focused on high-grade veins, and the deposit currently is being considered for open-pit mining.

Most Mexican silver production is from epithermal (shallow, low temperature) veins and polymetallic replacement deposits in carbonate rocks (fig. 10g; Albinson and others, 2001;

Cambrubi and others, 2003) and are shown as hydrothermal silver deposits on figure 9c. These deposits are related to linear belts of igneous rocks, called magmatic arcs, which were generated by subduction of oceanic crust beneath the western margin of Mexico (Clark and others, 1982; Cambrubi and others, 2003; and Staude and Barton, 2001). The Sierra Madre Occidental magmatic arc is outlined by the distribution of Cenozoic-age volcanic rocks (fig. 7) in northwestern Mexico and Baja California, where the arc parallels the northwest coastline of Mexico. This arc underlies the Sierra Madre Occidental Mountains. Volcanism was active during late Mesozoic through middle Cenozoic time, approximately 100 Ma to 15 Ma. Magmatism took place continuously throughout this period, but systematically changed location and composition over time. Epithermal vein deposits of silver and gold occur on the western side of the Sierra Madre Occidental mountains, whereas polymetallic epithermal deposits of silver, zinc, and lead generally occur on the eastern side of the mountain range. A linear belt of silver-lead-zinc replacement deposits in carbonate rocks also occurs on the eastern side. Epithermal veins and polymetallic replacement deposits (fig. 10g) are a common deposit type in the Sierra Madre Occidental magmatic arc. Many mines have been discovered and developed in the Sierra Madre orogen (fig. 7) in the last 400 years; 24 epithermal deposits and 16 replacement deposits were large enough to include in this report. However, the abundance of silver-rich deposits in this orogen is higher than other subduction-related orogens of similar age around the Pacific.

Tin

Tin is a silvery-white metallic element that is used predominantly in tinplate for tin cans. It is also used to make a variety of alloys, such as brass, bronze, and solder.

Table 18. Tin - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Peru	24.5	2	11.8	9.0
Brazil	5.3	4	9.0	22.5
Bolivia	5.0	5	7.5	8.1

Tin occurs in large surficial deposits in Brazil, such as the Pitinga and Rondonia deposits (fig. 9e; Thorman and Drew, 1988), where small amounts of tin-bearing minerals disseminated throughout masses of igneous rocks have been concentrated by weathering to form economic placer concentrations. A series of hydrothermal tin deposits called the “tin belt” extends through the Andes from Peru to Bolivia (fig. 9e). The tin belt includes deposits related to tin-bearing granites, such as the Llallagua deposit, and to deposits related to volcanic formations, such as Cerro Rico de Potosi. Both types of deposits are present in Boliva, where they are genetically related to distinctive, aluminum-rich magmas.

Titanium

Titanium is a hard silvery-white metallic element that naturally combines with oxygen to form a variety of oxide minerals. Titanium dioxide is one of the chemical compounds derived from these minerals and the 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 it also is used for coloring in foodstuffs like flour, icing sugar, sweets, cosmetics, and toothpaste. Titanium metal is strong yet lightweight. About 65 percent of titanium metal is used in aerospace applications; the remaining 35 percent is used in medical, sporting goods, and other applications. Ilmenite (iron titanium trioxide) supplies about 90 percent of the world's demand for titanium. World ilmenite resources total about 1 billion metric tons of titanium dioxide (USGS, 2004). Identified world resources of other titanium minerals total about 230 million metric tons of contained titanium dioxide.

Table 19. Titanium concentrate (ilmenite) - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Canada	16.7	3	7.3	4.9

Economic titanium deposits can be formed during the crystallization of igneous rocks. Such deposits are called "primary" deposits. Deposits formed when primary deposits, like these, are reworked and concentrated by weathering and sedimentary processes are called "secondary" deposits. In primary titanium deposits, concentrations of titanium-enriched minerals form during the crystallization of magma (Gross, 1996b). The titanium-bearing minerals can crystallize directly from magma as crystals of titanium oxides and be concentrated into layers or zones in the cooled and crystallized igneous rocks. In some situations, an immiscible liquid will separate during the cooling and crystallization of the magma. The separated liquid is rich in iron, titanium, and phosphorus, and is denser than the magma. Once formed, this liquid seldom remixes with the magma again. The iron-, titanium-, and phosphorus-rich liquid accumulates and solidifies separately. In contrast, secondary deposits form as titanium-rich minerals are weathered from rocks and are transported and concentrated by streams, rivers, and ocean currents. Titanium-enriched minerals are heavier than other minerals. Consequently, flowing water will concentrate these and other minerals (like gold) as placer deposits in sediments, particularly in coastal environments (Harben and Kužvart, 1996).

All current Canadian titanium production comes from the Lac Tio open pit mine (fig. 9e), developed on the Havre-Saint-Pierre deposit near Allard Lake, Quebec (Rio Tinto, 2001; Gross, 1996b). This deposit is the largest primary ilmenite deposit in the world. Even though mining started in 1950, the mine has a life expectancy of at least another half-century. It is a primary igneous titanium deposit that may have formed by the separation of iron-titanium-rich liquids from magma that crystallized to form a distinctive igneous rock called "anorthosite". This unusual rock is composed dominantly of a common rock-forming mineral called "anorthoclase". Large masses of igneous rocks consisting mostly of a single mineral are uncommon in Earth's geologic record. Very large (10,000-20,000 km^2) anorthosite-dominated igneous intrusions appear to have formed only between 0.9 and 1.7 billion years ago and are concentrated in two broad trans-oceanic belts (Windley, 1977). One belt includes anorthosite intrusions in the north-central (Wyoming) and northeastern (New York) United States, eastern Canada, Norway, Sweden, Finland, Latvia, Lithuania, Estonia, Poland, and Ukraine. The other belt includes intrusions in Brazil, Angola, Tanzania, Madagascar, Antarctica, India, and Australia. Iron-titanium ilmenite deposits typically are associated with these belts of igneous anorthosite intrusions.

The anorthosite intrusions were emplaced along major crustal boundaries that represent the zones where tectonic plates have collided. Anorthosite intrusions, like the one that hosts the Havre-Saint-Pierre titanium deposit, form a linear cluster associated with the Grenville Orogen in eastern Canada (fig. 7) (Hoffman, 1989; Windley, 1977). Overall, this orogen extends from southern Sweden, through eastern Canada, to Mexico, and formed by a complex series of plate events associated with the collision of continental plates between 1,300 and 1,000 Ma. The anorthosite intrusions were emplaced late in the development of the orogen. The ascending magmas appear to have collected and crystallized near the base of the Earth's crust. The anorthosite intrusions then were emplaced into higher levels of the crust along major vertical fault zones. Although magmatism is a defining characteristic of the collision of tectonic plates, the unusual composition of these rocks distinguishes them from the igneous rocks found with all other orogenic magmatic arcs.

Known reserves of titanium in Canada also occur in the Natashquan mineral sands deposit, which is located on the North Shore of the St-Lawrence River in the Province of Quebec (Tiomin, 2000). This deposit covers 180 km^2 of surface area and contains a large proportion of heavy minerals derived from the erosion of titanium and iron-rich rock formations of the Grenville geologic province.

A carbonatite deposit at Tapirá, in the state of Minas Gerais in Brazil, has produced concentrates of titanium (in the mineral anatase) and phosphate (in the mineral apatite) (Mariano, 1989; Harben and Kužvart, 1996). The deposit occurs in one of several carbonatite intrusions that were emplaced in a 1,200-km long, northwest-trending belt that formed in the Mesozoic during the opening of the Atlantic Ocean. The intrusions are composed mainly of carbonate minerals that crystallized from magmas; however, they include accessory minerals of economic interest. Deep chemical weathering during the Cenozoic has helped to make the deposit economic.

Tungsten

Tungsten is a gray-white metallic element that has the highest melting temperature of all elements except carbon, and is one of the heaviest elements. Tungsten is used in cemented carbide parts for cutting and wear-resistant materials primarily in the construction, gas and oil drilling industries, metalworking, and mining. Some tungsten also is used to make chemicals for catalysts and pigments, electrodes and other components for the electric and electronic industries, lamp filaments, and steels.

Table 20. Tungsten - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Canada	5.0	3	9.0	7.9
Bolivia	0.8	7	1.8	1.6

Almost all Canadian tungsten production is from hydrothermal skarn deposits. Major examples occur in the northern part of the Canadian Cordillera Orogen and the Bolivian part of the Andes (figs. 7 and 9f). Skarns are coarse-grained mixtures of ore minerals and calcium-and silicon-rich silicate minerals. The deposits commonly are found at the boundary between igneous rocks and calcium-rich sedimentary rocks like limestones. Skarn deposits form where hydrothermal fluids derived from magmas react with these calcium-rich sedimentary rocks. The magmas that form such deposits are part of magmatic arcs that form in response to the subduction of convergent tectonic plates (fig. 5). This setting is analogous to the one described for porphyry copper deposits; however, tungsten skarns form at deeper levels in the Earth's crust and at higher temperatures.

Industrial minerals

Asbestos

"Asbestos" refers to a small number of minerals that form as flexible fibers and have the useful physical property of being very heat and fire resistant. Asbestos is used mainly in gaskets and roofing shingles. Asbestos mineral fibers are flexible and can be woven to make fabrics for heat-resistant and insulating materials. The world has about 200 million metric tons of identified asbestos resources (USGS, 2004).

Table 21. Asbestos - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Canada	13.1	3	Large	Large
Brazil	9.7	5	Moderate	Moderate

In southeast Canada, numerous asbestos deposits are present in a belt between Newfoundland and Quebec (Harben, 2002; Harben and Kužvart, 1996). Deposits such as the Jeffrey mine (table 2; fig. 9f), currently produce about 13 percent of the world's asbestos (Mining Association of Canada, undated). Asbestos deposits typically are associated with magnesium-rich igneous rocks and metamorphic rocks typically found in the Earth's upper mantle (figs. 4 and 5). These rocks represent fragments of oceanic crust that were emplaced into continental crust during the collision of convergent tectonic plates along what is now the western margin of the Appalachian Orogen (fig. 7). The rocks were broken and heated during the collision; hydrothermal fluids generated during this event moved through and chemically altered the rocks. Asbestos minerals grew in fractures and faults during this alteration process.

Barite

Barite is a relatively soft mineral composed of barium and sulfur. It is chemically inert and insoluble and is unusually heavy for a nonmetallic mineral. These properties are responsible for its value in many applications. Nearly 98 percent of the barite used in the United States is used as a weighting agent in oil- and gas-well drilling fluids. Because barite looks opaque on X-ray film, it is used in medicine to diagnose gastrointestinal problems. The world's barite resources are about 2 billion metric tons, but only about 740 million metric tons are in identified reserves.

Table 22. Barite - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Mexico	2.7	6	3.5	1.1
Brazil	0.8	13	1.1	0.7

Barite is a common mineral in veins formed from hydrothermal solutions and as bedded layers chemically precipitated on the sea floor. Two deposits in the Mazatan district and Santa Rosa district of northern Mexico (fig. 9f) are important sources of barite in the western hemisphere.

Boron

Boron is a semimetallic element that is a dark, amorphous (noncrystalline), nonreactive solid. Boron is mined and used principally as a variety of borate minerals and compounds composed mostly of boron and oxygen in combination with sodium, calcium, and magnesium. Borates have a wide variety of uses, including the manufacture of glass, ceramic glazes, fertilizers, fire retardants, and soaps and detergents.

Table 23. Boron - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Chile	9.9	4		
Argentina	3.9	5	1.2	2.2
Bolivia	0.8	7		
Peru	0.2	8	2.3	5.4

Argentina and Chile rank behind Turkey, the United States, and Russia in production of borates. Borate deposits are present in Cenozoic (65 Ma to the present) sediments that have been deposited in nonmarine lakes. These lakes are usually spatially and genetically associated with boron-rich springs, tectonic basins, and contemporaneous Andean volcanism. Late-stage hydrothermal waters from the volcanism, as well as leaching boron from the volcanic rocks by weathering, supplied the boron. Deposits in Argentina, such as the Tincalayu deposit (fig. 9d), are in older sedimentary rocks. In contrast, production in Chile is largely from the salts and brines of modern dry lakes (salars). There is minor production of borate salts from salars in Peru and Bolivia. Large brine resources, such as the Salar de Uyuni in Bolivia, are present throughout the high Andes, and there is the potential that bedded deposits could exist at depth in many of the basins (Ericksen, 1993). In contrast, the areas underlain by Precambrian shields in Canada and South Americas have little potential for the discovery of borate deposits.

Clay (Kaolin)

Kaolin is a term for a group of clay minerals 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 refractory or flint clay. Although best known as the main component in porcelain and other ceramics, kaolin has diverse uses in the production of paper, refractories, cosmetics, bricks, and drain tiles. Kaolin forms by the hydrothermal alteration of rocks by natural acidic solutions and by the weathering and erosion of rocks with the resultant clays accumulating in sedimentary basins. Many of its uses are determined by its whiteness and chemical composition. Kaolin deposits are known to occur in Argentina, Bolivia, Brazil, Canada, Colombia, Ecuador, Guatemala, Guyana, Mexico, Peru, Uruguay, and Venezuela (fig. 9d). Outside of the United States, Brazil is the most significant producer of kaolin in the western hemisphere.

Gemstones

The terms "gem" and "gemstone" mean any mineral or organic material (for example, pearl and petrified wood) used for personal adornment, display, or objects of art because it possesses beauty, durability, and rarity (Mineral Information Institute, USGS, and American Coal Foundation, undated). Examples of minerals that are used as gemstones include amethyst (purple variety of quartz; fig. 10l), beryl, diamond, garnet, malachite, topaz, and tourmaline. Blue topaz is considered a gemstone even though the brilliant blue color usually is produced by irradiation and heating of drab topaz. Because gemstones within the region often are produced by small miners, it can be difficult to identify true production levels or quantify the size of reserves or potential resources.

Diamond is a crystalline form of elemental carbon that forms at extremely high temperature and pressure conditions that are possible only very deep in the Earth's upper mantle. Large diamonds, particularly large diamonds without flaws, are extremely rare and are very valuable as gemstones. The vast majority of diamonds, however, are small, flawed, and colored by dark impurities. These small impure diamonds have a variety of industrial uses, particularly as abrasives to coat saw blades for stone cutting and highway building (Mineral Information Institute, USGS, and American Coal Foundation, undated).

Diamond deposits can be classified as either igneous or surficial (table 3). Igneous deposits are concentrations of diamond in rare and usual mantle-derived igneous rocks called kimberlite or lamproite (fig. 10m). Kimberlites typically have been found in small volcanic pipes, whereas lamproites characteristically form lava flows and pyroclastic (hot, broken rock, or ash) rocks. Surficial deposits are formed by the weathering the igneous deposits and movement of diamonds by water into streams or oceans. About 90 percent of diamond production comes from igneous deposits.

Carbon crystallizes to form diamond in rocks about 150 to 200 kilometers below the Earth’s surface; above that depth, carbon will form the mineral graphite. Diamonds do not form from magmas as the magmas cool to form kimberlite or lamproite (DeBeers, undated; Mitchell, 1986; Mitchell, 1993). Rather, the diamonds are foreign to the body of rock in which they are mined. Small explosive volcanic eruptions of these magmas bring the diamonds to the surface. Kimberlitic magmas are generated at depths far below where diamond can form naturally in rocks. As these magmas move quickly to the surface, they capture fragments and crystals of the rocks encountered en route. In some areas, this includes diamond-bearing rocks. As the magma approaches the Earth’s surface, gases in the magma expand and erupt, forming a carrot-shaped explosion pipe filled with kimberlitic volcanic rock, mantle rock fragments, and, occasionally, some diamonds (fig. 10m).

Diamond-bearing kimberlites appear to be restricted to the oldest continental crust in Precambrian shields. Regionally, the ascent of kimberlitic magma from the upper mantle is not related to interaction of plate boundaries. For reasons that are still unclear, particular regions have been the loci for repeated cycles of kimberlitic magmatism. Kimberlite pipes occur in clusters forming fields and provinces, and locally, their distribution is controlled by fracture and fault zones. Only a small proportion of known kimberlites contain diamonds. Economic concentrations of diamonds only occur in about one per cent of known kimberlites worldwide.

A major kimberlite province containing economic diamond deposits has been discovered in Canada (Atlas of Canada, undated; Northwest Territories Canada, 2003). As early as 1863, diamonds were found in glacial debris in Ontario. However, the first cluster of 25 kimberlite pipes was not discovered until the 1970's in the Northwest Territories and diamond-bearing kimberlite was first discovered in 1991. Following these initial discoveries, over 500 kimberlite occurrences have been found in eight Canadian provinces and territories. Diamond-bearing pipes have been reported from the Northwest Territories, Nunavut, Saskatchewan, Alberta, Quebec, and Ontario. The first diamond mine, the EKATI mine (fig. 9e), went into production in 1998. Three additional diamond mines are expected to begin production by 2006 (Olson, 2002). By 2010, Canada will be the world's third largest diamond producer, accounting for over 12 percent of global diamond production value (Mining Association of Canada, undated).

In South America, diamonds have been found mainly in surficial deposits (fig. 9e). Diamonds have been reported in 12 of Brazil's states; however, much of Brazil's current production of over a million carats per year comes from deposits along rivers in Bahia State. Diamond production in Venezuela and Guyana also is from surficial sources. These diamonds are believed to be derived largely from diamond-rich beds eroded from the Precambrian sandstones and conglomerates.

Brazil is the most important gemstone producer in the region. In addition to diamonds, Brazil produces agate, amethyst, beryl, emerald, ruby, sapphire, topaz, tourmaline, and other gemstones in significant quantities. Colombia is a significant producer of emerald, beryl, and sapphire. Mexico is a significant producer of agate, opal, and topaz.

Emeralds are the deep green, transparent form of the relatively common mineral beryl, which is composed of beryllium, aluminum, silicon, and oxygen. The finest emeralds are from Colombia where they formed in a dark, organic-rich limestone and their color results from the presence of traces of chromium and vanadium (Giuliani and others, 2000). Aquamarine is also a form of beryl but its blue color results from trace impurities of iron. Deposits of beryl are igneous in origin. As granitic magma cools and crystallizes, common rock-forming minerals grow from chemical elements in the magma. Chemical elements that don't fit into the growing mineral's atomic structure, because the atoms are too large or don't have the right electrical charge, remain and concentrate in the residual silicon-rich fluid. This fluid sometimes crystallizes as a rock called pegmatite, which is composed of large mineral crystals that often include beryl, tourmaline, and other exotic minerals.

Amethyst, citrine, rose quartz, and smoky quartz all are color variants of the common mineral quartz, which is composed mainly of silicon and oxygen. Amethyst's purple color (fig. 10l) is due to trace amounts of a special form of iron (Fe^{+4}) that absorbs all colors of light except blue and red, which are reflected back to us (Post, 1997). Most gem amethyst comes from Brazil and Uruguay. These amethyst deposits formed about 130 Ma where lava flows were erupting and degassing as they cooled. These gases formed large cavities in the lava. Later, silicon-bearing waters seeped through the cavities and deposited crystals of amethyst, some of which grew to large size. Beautiful crystals of amethyst often line the inside of these gas cavities.

Fluorspar

Fluorspar is a calcium and fluorine compound formed as a byproduct of industrial processes. The naturally occurring mineral of the same composition is called "fluorite". Most of the use of fluorspar is for the manufacture of hydrofluoric acid, which is a key ingredient in the manufacture of aluminum and uranium. Hydrofluoric acid also can be used to make water fluoridation chemicals that are added to municipal water supplies to help reduce tooth decay. Identified world fluorspar resources were approximately 500 million metric tons of contained fluorspar (USGS, 2004).

Table 24. Fluorspar - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Mexico	11.6	2	13.5	8.4

Mexico ranks second in the production of fluorspar. Most of the deposits are hydrothermal deposits formed by replacement of carbonate rock, such as limestone, near masses of igneous source rock. The major fluorite deposits of Las Cuevas, La Consentida, El Refugio, and El Realito are found in the Zaragoza-Rio Verde District of San Luis Potosi (fig. 9c). Other major fluorite deposits are in the Parral District of Chihuahua, the Encantada-Buenavista and El Tule districts of Coahuila, and in other areas of Mexico. Brazil also is a significant producer of fluorite, with most production coming from the Morro da Fumaca area of Santa Catarina.

Graphite

Graphite is a gray to black, opaque, flexible but not elastic, soft crystalline form of carbon with a metallic luster. Graphite is considered a semimetal because it exhibits the chemical properties of a metal and a nonmetal, which make it suitable for many industrial applications. The metallic properties include thermal and electrical conductivity. The nonmetallic properties include chemical inertness, lubrication qualities, and high thermal resistance. Graphite is used mainly in brake linings and in refractories, which are heat-resistant materials such as those used in the brick lining of furnaces and kilns. Graphite also is an important component in steel. The world's inferred reserve base exceeds 800 million metric tons of recoverable graphite (USGS, 2004).

Table 25. Graphite - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Brazil	8.3	3	0.4	0.3
Canada	3.2	4	NA	NA
Mexico	2.6	6	3.6	1.1

Economic graphite deposits (fig. 9f) are metamorphic deposits in which graphite occurs in three forms that can have different applications. Flake graphite is composed of flat, plate-like grains disseminated in metamorphosed sedimentary rocks. Lump graphite is a high-crystalline form that occurs in veins. Amorphous graphite is a microcrystalline form of graphite that occurs in thermally metamorphosed sediments and coal. Only a small percent of these deposits occur in western industrialized countries. Flake graphite deposits occur in the Canadian Provinces of Quebec and Ontario near the Great Lakes. Other deposits are present in Saskatchewan and British Columbia. Mexico's amorphous graphite deposits in Sonora, in northern Mexico, are the most important graphite resources in the western hemisphere. These deposits may have formed during metamorphism of a coal bed in sedimentary rocks. Flake graphite is produced in southern Mexico. Brazil ranks third in the world in graphite, with flake graphite dominating the production. Graphite also is known to occur in Argentina, Bolivia, and Ecuador, although the economic potential is not clear.

Gypsum

The mineral gypsum is composed of calcium, sulfur, and oxygen in the form of hydrated calcium sulfate. It is the most common of the approximately 150 sulfate minerals (Mineral Information Institute, USGS, and American Coal Foundation, undated). More than two-thirds of the gypsum mined is used for plaster and wallboard in houses and other buildings. Data on world reserves and reserve base are not available.

Table 26. Gypsum - proportion of world mine production for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production
Canada	8.8	3
Mexico	6.7	6
Brazil	1.6	13
Uruguay	1.1	17

The principal resources of gypsum are located in sedimentary deposits. Canada and Mexico rank in the top ten of world gypsum producers and Canada lays claim to the largest gypsum quarry in the world at East Milford, Nova Scotia (table 2; fig. 9d). There also are major gypsum deposits in New Brunswick and Ontario. Mexico has a major gypsum deposit on San Marcos Island, Baja California Sur. There is also significant production from the nearby deposit at Santa Rosalia and from at least six other states in Mexico. In addition, it is claimed that the newly discovered Alejandra deposit in Coahuila will increase world reserves substantially. Smaller gypsum deposits occur and are exploited throughout the region of this report.

Lithium

Lithium is a metallic element that is widely distributed in the Earth's crust at low concentrations. The use of lithium compounds in ceramics, glass, and primary aluminum production represents more than 60 percent of estimated consumption (Mineral Information Institute, USGS, and American Coal Foundation, undated). Other major end uses for lithium are in the manufacture of lubricants and greases, pharmaceuticals, batteries, and synthetic rubber. The identified lithium resources total 760,000 metric tons in the United States and more than 13 million metric tons in other countries (USGS, 2004).

Table 27. Lithium - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Chile	41.5	1	73.3	27.1
Argentina	6.6	4	NA	NA
Canada	4.9	5	4.4	3.3
Brazil	1.7	7	4.6	8.2
Bolivia	NA	NA	NA	48.8

Lithium is concentrated in nature dominantly by two processes, igneous and sedimentary. During the crystallization of magmas of certain compositions, some elements are concentrated into the residual fluid that it the last to crystallize. Lithium is one of those elements. The rock that crystallizes from this residual fluid is characterized by large, exotic minerals and is called a pegmatite. Most lithium that is produced today is from lithium-rich brines in sedimentary basins. These brines that were formed by weathering of certain kinds of volcanic rocks followed by concentration of the solution under conditions of extreme evaporation. Most lithium comes from Chile from the vicinity of the Atacama Desert (fig. 9d). Bolivia has a huge resource of lithium brines in the Salar de Uyuni, but it has not yet been developed.

Limestone and other carbonate rocks

Limestone and other carbonate rocks have diverse uses from high-volume, low-value construction aggregate, to lower-volume, higher-value uses for the production of lime, food, paper and plastic manufacturing, metal-ore processing, and clean air, water, and sewage. These uses are essential to maintain our infrastructure, public health, and industries. For many years, commodities such as limestone have been considered to be common materials that are readily available from nearby deposits. However, a variety of factors are changing that situation, including increased standards for chemical and physical qualities, increasingly diverse uses, depletion of the best local resources, and the economies of large-scale production. Consequently, hugh new quarries are being developed to supply distant markets. The large limestone quarries at Texada Island, British Columbia, Canada and at Sac Tun, Yucatan, Mexico, (fig. 9d) supply construction aggregate to many of the urbanized coastal areas of the United States.

Magnesium

Magnesium is mined mostly as the mineral magnesite (magnesium carbonate) that occurs in metamorphic deposits. Magnesium is also produced from seawater, brines in sedimentary basins, dolomite (iron-magnesium carbonate), and brucite (magnesium hydroxide). Magnesite is mostly used by the refractories industry to make high-temperature bricks for furnaces, for industrial chemicals, for agricultural, chemical, and environmental applications, and as a source of metallic magnesium used for making aluminum alloys. Identified world resources of magnesite total 12 billion metric tons, and of brucite, several million metric tons (USGS, 2004). Resources of dolomite and magnesium-bearing evaporite minerals are enormous, and magnesia-bearing brines are estimated to constitute a resource in billions of metric tons.

Table 28. Magnesium compounds - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Brazil	2.4	11	2.1	1.8

Brazil is the major producer of magnesia in the region. Magnesite is mined from metamorphic deposits at the Catiboaba mine and others deposits in the vicinity of Brumado, Bahia (fig. 9f). The Mount Brussilof deposit in Canada is located in metamorphic rocks, as is the Timmins magnesite deposit. Magnesia and sodium sulfate are produced from brines at Laguna del Rey, Mexico.

Phosphate

Phosphorus is an essential element for plant and animal nutrition and is indispensable for world food production. It is mined from rocks so enriched in phosphorus that they are called phosphate rock. Most phosphate rock mined is converted to phosphate fertilizers.

Table 29. Phosphate rock - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Brazil	3.6	7	1.5	0.7
Canada	0.9	16	0.1	0.4

About 80 percent of the world's phosphate production comes from sedimentary deposits of phosphate rock that form on or near the margins of continents where organic productivity is high and there is a limited influx, and dilution by, other sediments (Harben, 2002; Harben and Kužvart, 1996). High marine biological productivity often is associated with upwelling currents along the western margin of North and South America. These currents bring phosphorus-rich cold waters from deeper ocean levels nearer the surface. This nourishes and stimulates growth of plants and animals whose remains accumulate on the sea bottom as concentrations of phosphorus-rich organic debris. This phosphate-rich debris forms extensive layers that cover thousands of square kilometers and eventually may become phosphate-rock deposits like we mine today. Typical deposits include: San Juan de la Costa and the Santo Domingo Mine in Mexico; Sechura (Bayovar) in Peru; and Patos de Minas – Rochinha in Brazil (fig. 9d).

Brazil produces over three percent of the world's phosphate. However, the deposits in Brazil are formed from the mineral apatite during the intense weathering of igneous rocks of unusual composition (Mariano, 1989). Apatite is composed principally of calcium, phosphorous, carbon, and oxygen, and usually is present in only tiny amounts in most igneous rocks. However, apatite can be abundant in rocks that are low in silicon, such as carbonate-rich igneous rocks known as carbonatite. The deposits at Araxá, Catalao I, Jacupiranga, Maicuru, Patrocino, and Salitre I are formed from apatite-rich igneous intrusions that crystallized to form carbonatites. Intense weathering of these rocks formed soils (laterites) sufficiently enriched in phosphate (see also columbium-niobium and titanium) to be mined.

Potash (Potassium)

"Potash" refers to a group of water-soluble salts that contain the chemical element potassium. Like phosphorous, potassium is an essential element for animal and plant nutrition and food production and is present in every living cell. Over 95 percent of potash production is used for fertilizers. Estimated world resources total about 250 billion metric tons (USGS, 2004).

Table 30. Potassium - proportion of world mine production, reserves, and reserve base for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production	Percent of world reserves	Percent of world reserve base
Canada	31.0	1	53.2	58.6
Chile	1.5	11	0.1	0.3
Brazil	1.4	12	3.6	3.6

Potash is Canada's third ranked mineral by value of production (Mineral Association of Canada, undated). Canada is ranked first in the global production of potash.

The geologic source for about 30 percent of the world's potash production is a sedimentary rock layer called the Prairie Evaporite (fig. 9d) in south-central Canada that was formed during the Middle Devonian (about 380 Ma). It is an evaporate deposit that formed where a part of the sea was isolated in a basin and evaporated forming layers of minerals from the components that were dissolved in the sea water. Production from sedimentary potash deposits in South America is much smaller and comes mainly from the Taquari-Vassouras deposit in Brazil. Other deposits are known to occur in Brazil and Mexico, and one deposit in Argentina is reported to have exceptionally large reserves. Potash production also comes from brine deposits such as that at the Salar de Atacama, Chile. Brine deposits also form by the evaporation of salt water, either sea water or water that has had chemical components dissolved from adjacent rocks and washed into a basin. Brine deposits tend to form in arid climates, are relatively inexpensive to mine, and often have the potential for co-production of other commodities.

Halite (salt)

Salt is necessary to support life. In its most commonly used form, salt occurs as the mineral halite (sodium and chlorine), which forms in sedimentary deposits. The chemical industry produces about 40 percent of the world's salt, which is also a major source of chlorine. About 35 percent of salt produced is for highway deicing (Mineral Information Institute, USGS, and American Coal Foundation, undated). World resources of salt are practically unlimited, and the salt content of the oceans is virtually inexhaustible (USGS, 2004). Data are not available to report individual countries' percent of world production or percent of world reserve base.

Table 31. Salt - proportion of world mine production for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production
Canada	5.9	5
Mexico	3.8	7
Brazil	2.9	9

Halite is crystallized when sea water gets trapped in shallow basins and evaporates. The shallow basins can be tectonically formed collapse features (rifts) at or near continental margins, or interior, tectonic basins that have no egress, such as the Great Salt Lake in Utah. The evaporation process is greatly aided by a dry (arid) climate. Production of salt is by dissolving old, sedimentary layers of salt with hot water and evaporating the solution, or by trapping sea water in shallow ponds on tidal flats. Old salt beds, or layers, also can be mined and the salt that is produced is suitable for highway deicing. Salts are produced at some level by most countries in the region. The Goderich mine in Ontario, Canada, (table 2) is reputed to be the largest in the world. The deposits at Ojibway, Ontario, Madeleine Islands, Quebec, and Pugwash, Nova Scotia, are also believed to be significant (fig. 9d). The largest salt producer in Mexico is at Guerrero Negro on the west coast of Baja California Norte. There, sea water is fed into evaporation ponds to produce a product that is better than 99.7 percent sodium chloride. There are also substantial deposits of salt at Salar de Arizaro, Argentina, and at Salar Grande, Chile that formed from the evaporation of closed basin lakes.

Strontium

Strontium is a metallic element that commonly occurs in nature; however, only two minerals, celestite (strontium, sulfur, and oxygen) and strontianite (strontium, carbon, and oxygen) contain strontium in sufficient quantities to make its recovery practical. Celestite is processed into a variety of strontium chemicals that are used mainly in the faceplate glass of color television picture tubes and to a lesser degree for specialty magnets and pyrotechnics. World resources are thought to exceed 1 billion metric tons, but are not thoroughly evaluated (USGS, 2004).

Table 32. Strontium - proportion of world mine production for countries covered by this report (USGS, 2004).

Country	Percent of world production, 2003	Rank of world production
Mexico	27.1	2
Argentina	0.4	7

Most deposits of celestite formed as sedimentary deposits in lakes and coastal lagoons. It forms in evaporate deposits where it is one of the last minerals to be formed as the salty water (brine) evaporates. The supply is dominated by the deposits in Coahuila, Mexico, which have the world's largest reserves. The largest mine, San Agustin (fig. 9d), produces ore that averages 92 percent celestite. There has been past production of celestite from the San Juan mine in Argentina, and other deposits are known in Argentina. Celestite also has been produced in the past from the Lake Enon deposit in Nova Scotia, Canada. Numerous additional deposits of uncertain potential have been identified in Newfoundland, New Brunswick, Ontario, and British Columbia. Strontianite is a hydrothermal mineral spatially associated with barite and celestite.

Sulfur

Most sulfur is used to manufacture sulfuric acid, which is used to produce agricultural chemicals and for a variety of industrial applications. Sulfur is also used for medicinal purposes, manufacture of plastics, and explosives. Most sulfur is obtained as a byproduct from oil production. Other principal sources of sulfur are sedimentary evaporate deposits, hydrothermal sulfide ore deposits, and native sulfur from volcanoes. Canada and Mexico are among the world's leading producers of sulfur (fig. 9e). Canada produced nine million metric tons of sulfur in 2003 and was second only to the United States in output. Mexico produced 1.5 million metric tons, and Chile produced 1.3 million metric tons during the same period (USGS, 2004).

Regional exploration history and significant recent discoveries

Worldwide expenditures for nonfuel mineral exploration increased significantly in 2003 following 5 years of decline (Wilburn, 2004). The increase results from changing exchange rates, rising commodity prices, low metal inventories, and an improving global economy (Wilburn, 2004). Gold continued to lead exploration activity in 2003, with a budget increase of about 33 percent; nickel increased 29 percent, and platinum-group elements increased 26 percent (Wilburn, 2004). The top three geographic areas for mineral exploration, based on exploration budgets, currently are Latin America, Canada, and Africa. Latin America maintained the top position in expenditures for exploration activities in 2003 with Brazil, Peru, Chile, Mexico, and Argentina in the lead. Gold attracted the greatest interest with 66 percent of the expenditures; lead, zinc, and copper received 18 percent, and silver 10 percent (Wilburn, 2004). Barrick Gold Corporation's discovery of the Alto Chicama gold deposit in Peru in 2002 was a significant impetus to increase exploration expenditures in that region (Wilburn, 2004). Latin America also led the world in exploration activity based on initial, or fundamental, geological and geochemical studies. Canada had the largest budget increase for exploration, with exploration for gold accounting for about 53 percent of the exploration budget and with activity concentrated in Ontario, British Columbia, and Quebec. Copper accounted for 11 percent of exploration activity and nickel about 10 percent. Diamond exploration expenditures also were significant in Canada in 2003 (Wilburn, 2004).

Mineral exploration activity can be divided into low risk and high risk types. Low risk exploration focuses on finding extensions to existing deposits, or new ore bodies, within a known trend or cluster of major deposits. This type of exploration activity often is driven by the depletion of reserves in the known deposits. Examples include discovery of new deposits of nickel and copper in the Sudbury Intrusive Complex in Ontario; nickel in the Thompson Belt in Manitoba and in the Cape Smith fold belt in Quebec; columbium in a carbonatite in Quebec; and gold in veins, and copper and zinc in volcanogenic massive sulfide deposits, both in the greenstone belts of the southern Superior Province (fig. 7). High risk exploration looks for ore deposits where none have been discovered previously. Many discoveries are made as the result of exploration programs based on geologic models that are both descriptive and predictive. An example would be the recent discovery of diamonds in Canada. Others are found serendipitously. The Voisey's Bay nickel deposit in Labrador was found during a survey focused on finding diamonds.

Mineral exploration is cyclical over time. Measures used to assess trends in minerals exploration activities include the number of active exploration properties, number of mining claims staked, expenditures, and number of discoveries. When plotted by year for a given area, these types of information reveal cyclic patterns superimposed on a base level of activity. For example, exploration expenditures from 1969 to 2002 show at least three cycles of activity in Canada (Bouchard, 2001). Some of these cycles appear to be global, others regional.

Cycles of exploration are event-driven. These events include rapid fluctuations in commodity price, new information, new technology, consolidation of the mining industry, changes in the investment climate, and changes in public policy. For example, between 1997 and 2000, the price of palladium increased from less than $200 per ounce to over $1,000 per ounce (Johnson Matthey, 2004). This resulted in a surge of exploration activity in areas where deposits of platinum-group elements can be found. In Canada, this activity was focused principally in Ontario and Quebec, with other projects in Labrador, the Northwest Territories, the Yukon, Manitoba, and Saskatchewan. Although palladium prices have dropped, platinum prices recently increased and will sustain interest in exploration for the platinum-group metals.

New information that can stimulate a cycle of mineral exploration includes the discovery of a well known deposit type in a new area or the discovery of a completely new style of mineralization. An example of a new cycle of exploration stimulated by the discovery of a well known deposit type in a new area is the discovery of diamond-bearing kimberlite deposits in Canada. The association of diamonds with kimberlite pipes has been recognized for decades. However, such pipes were unknown in Canada until 1992. The discovery of the first occurrence prompted an ongoing diamond rush that initially focused on the Northwest Territories and Nunavut; it now includes significant activity and discoveries in Alberta, Saskatchewan, Ontario, and Quebec. This successful exploration program relied largely on methods and geologic concepts used to discover diamonds in southern Africa. In contrast, the Voisey's Bay nickel deposit, discovered in 1994, and the Lac des Iles palladium deposit, developed in 1993, represent completely new styles of nickel and platinum-group-element mineralization. The Voisey's Bay deposit was found with the unusual anorthosite-rich igneous rocks that characteristically are associated with the large iron-titanium deposits described above under the heading "titanium". Previously, nickel deposits were unknown in such rocks. However, the Voisey's Bay discovery has made these rocks new targets for major exploration programs Similarly, the Lac des Ises deposit is unlike any other platinum-group metal deposit in the world. Exploration for additional such deposits has extended to nearby igneous intrusions with similar geology. As these new deposits are developed and studied, new deposit models will be developed that will guide future exploration programs elsewhere.

Systematic collection of many kinds of new geoscience information, both within and outside of areas of known potential for occurrence of undiscovered mineral deposits, can stimulate mineral exploration and new discoveries. Work supported by government, industry, and universities continually is generating and refining the scientific infrastructure needed by the mining industry to find new deposits. Examples include the Targeted Geoscience Initiative (*http://www.nrcan.gc.ca/gsc/tgi_e.html* [January 31, 2004]), the Multinational Andean Project (*http://www.nrcan.gc.ca/gsc/pacific/vancouver/special/smenu-i-3-2_e.htm* [January 31, 2004], and the Thompson nickel belt map compilation project (fig. 7) (*http://www.gov.mb.ca/itm/mrd/geo/tnbmaps.html* [January 31, 2004]). Published compilations of basic geologic, geochemical, and geophysical data, together with site-specific studies of mineralized areas, include U.S. Geological Survey and Servicio Geológico de Bolivia (1992); U.S. Geological Survey and Corporación Venezolana de Guayana, Técnica Minera (1993); and Servicio Geológico de Bolivia (GEOBOL), Servicio Naciional de Geologia y Mineria, Chile (SERNAGEOMIN), Instituto Geológico Minero y Metalúrgico, Perú (Perú), and U.S. Geological Survey (1993).

Technological innovations in exploration methods, information analysis and visualization, mining, and mineral processing also can stimulate exploration activity. For example, new geophysical techniques are being used to indicate the direction and distance to electrically conductive bodies below the Earth's surface and have helped with the discovery of several metal deposits in the Sudbury, Ontario area of Canada. The development of advanced remote sensing technology in satellites and aircraft has led the way to new discoveries in the Andes. There, the dry climate and consequent lack of vegetation in a highly mineralized area have proven ideal for exploration. The discovery of exceptionally rich gold deposits associated with the areas of altered, young volcanic rocks, such as El Indio gold deposit in Chile in 1977, led to the recent discovery of additional similar deposits such as Pascua-Llama along the Chile-Argentine border. The recognition of favorable geologic environments and geochemical anomalies, combined with revisiting old prospects (Sillitoe, 1998), led to the discovery of the Yanacoacha, Pierina, and Alto Chicama gold deposits in Peru. These are a type of gold and silver deposit called "high sulfidation" that contains the sought-after combination of high grade ore together with low mining costs. Cerro Vanguardia in the Patagonia region of southeastern Argentina (fig. 8) is another recent, major, gold discovery of a different type, called "low sulfidation" that has high tonnages of ore at or near the surface.

In recent years, much of the high-profile exploration for industrial minerals in South America has centered on surface and near-surface evaporites and related deposits. These efforts have identified economic commodities in the brines of many of the large salars. Brine operations have been developed at the Salar de Atacama, Chile (lithium, potassium, other commodities), and at the Salar del Hombre Muerto, Argentina (lithium). The world's largest lithium resource was identified in the brines of the Salar de Uyuni, Bolivia, but remains undeveloped. There also has been extensive identification and development of small to moderate borate deposits associated with many of the salars in Chile, Argentina, and Bolivia. In Chile, deposits rich in nitrate, iodine, and other commodities have been delineated and gone into production. Older and deeper evaporite deposits containing potash and salt have been investigated in Argentina and the Amazon Basin of Brazil.

Much of the industrial mineral exploration in South America has been driven by specific needs. The need for lime for the expanding copper and gold mining industry led to exploration for limestone deposits in Chile and Argentina, while construction needs have driven exploration for limestone (for cement), gypsum, and dimension stone (granite, marble) in Chile and Venezuela. Other recent industrial mineral exploration in South America includes: the discovery and development of two major kaolin (clay) deposits in Brazil; exploration for graphite, kaolin, and other clays in Venezuela; and exploration for sulfur and bentonite (altered volcanic ash) in Argentina. Brazil recently has yielded world-class kaolin discoveries, the Rio Capim and Rio Jari deposits. Lithium brines have been discovered in the Salar de Atacama (Chile), Salar de Uyuni (Bolivia), and Salar del Hombre Muerto (Argentina). Deposits of potash have been discovered in eastern Canada and Argentina. Construction needs in the United States, especially in the coastal urban areas, have driven other exploration and development activity in Canada and Mexico. Huge limestone megaquarries have been developed at Sac Tun, Mexico, and Texada Island, Canada to supply aggregate to the United States and signal a shift away from smaller local quarries. Other recent exploration includes searches for new deposits of barite, gypsum, and graphite.

Finally, government policies and programs can have a significant impact on minerals exploration. As previously discussed, governments can efficiently support exploration by creating scientific information available to all. However, laws on mineral rights, ownership, taxation, and environmental protection have an even stronger effect on stimulating or discouraging mineral exploration. In 1992 and 1996, Mexico revised its mining laws and removed restrictions on the participation of private and foreign companies in the Mexican mining industry while also privatizing State mining companies and decontrolling its mining reserves (Torres, 2001). As a result, the number of mining companies operating in Mexico rose from one or two dozen to around 300 in 1998 (Fitch, 1999). The total lands under active exploration increased from 2.8 million hectares in 1992 to 25.9 million hectares in September, 1998. Exploration companies are unwilling to invest in areas favorable for the discovery of new mineral deposits if laws and regulations do not allow the economic development of deposits. Since 1997, annual surveys have been conducted by the Fraser Institute to assess how mineral endowments and public policy factors affect exploration investment. The survey results represent the opinions of exploration managers in mining companies operating around the world and indicate where they plan to invest in exploration in the future. The 2002-2003 assessment gave the highest ratings to Ottawa, Ontario, and Manitoba in Canada, as well as to Mexico, Brazil, and Chile (Fredrickson, 2002).

Potential for undiscovered mineral resources

Do undiscovered mineral resources remain to be found in Latin America and Canada? Without a doubt, the answer is yes. Mineral resources are produced there from some of the largest and richest ore deposits in the world. The mere presence of an ore deposit suggests that others are likely to exist because the processes that mineralize rock commonly form clusters and linear belts of ore deposits. We should be asking different questions. Where will new deposits be found? What commodities will be present? How difficult will it be to find them? What are the environmental and societal issues related to discovering and developing new deposits, and how can they be addressed?

From our discussion of mineral commodities, we hope the reader has come away with two major points. **First,** ***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 ore deposits. **Second,** ***Mineral deposits do not occur randomly; their distribution is intimately related to the geologic history of each continent.*** The movement of molten and solid rocks in the mantle and tectonic plates is responsible for the development of cratons, orogens, faults, 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 ore 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 answer where new deposits will be found and what they will contain.

Our ability to find undiscovered deposits is affected by many factors. For example, how well has the geology of the continent been mapped? There still are large parts of the world where the geologic framework of the continents is poorly mapped or largely unknown. Terrain and access limit field investigations; in other regions, thick vegetation, soils, and younger rocks conceal the underlying geology that might suggest the presence and locations of undiscovered mineral deposits. In some 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 that ore deposits are left undiscovered. Northern Canada and the Amazon area of Brazil and Peru are exploration frontiers; the basic geologic framework has been established, but the remoteness of these areas, together with overlying deposits of glacial material in Canada, and cover by vegetation and young sediments in the Amazon, obscure much detail.

How well are the types of deposits of interest understood? 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 deposits may occur. Porphyry copper deposits and volcanogenic massive sulfide deposits are well understood styles of mineralization. It is hard to create effective models for styles of mineralization known from only one or two ore bodies. The nickel deposit at Voisey's Bay occurs in a unique geologic setting; geologists still are unsure how to extend their knowledge about this deposit to find others like it in other Proterozoic-age anorthosite provinces.

How difficult will it be to find new deposits? The approach that involves the least apparent risk to the exploration companies is to search in well known areas with known ore deposits, well characterized geology, and experience that has identified what exploration techniques work well. 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 ore deposits have been found previously. However, the opportunities for these "grass-roots" discoveries usually are in those areas where we have the least amount of information, which increases the cost of exploration and reduces the chances for a major discovery.

The geology of an area, and our knowledge of it, are paramount. The basic requirements to form an ore deposit involve source and process. There must be a source area of the mineral material, a mechanism to transport it, and a means to concentrate and preserve it. If any part of this ore-forming system is missing, an ore deposit will not be formed or exist today. Certain types of ore deposits are only found in specific geologic settings. If that setting is not present, that type of ore deposit will not be found. The geologic evolution of each continent has developed a unique set of environments in which ore deposits may be found. Some of the major geologic features in Latin America and Canada that define the distribution and types of ore deposits, and are likely to host undiscovered mineral deposits include:

1. The geologically young subduction-related orogens along the western side of the continents (figs. 6, 7 and 8). New discoveries of hydrothermal and igneous deposits of copper, molybdenum, gold, lead, zinc, silver, and tungsten related to emplacement and cooling of molten igneous rocks will continue to be made in these orogens. Volcanogenic massive sulfide (VMS) deposits will be found in submarine volcanic rocks now preserved on land in British Columbia, the Yukon, south-central Mexico, and the Andes.
2. Large Precambrian-age shield areas consisting of Archean-age shields, greenstone belts, and sedimentary and volcanic rocks preserved in Early Proterozoic-age orogens. Volcanogenic massive sulfide deposits and quartz-carbonate-gold veins will continue to be discovered in the greenstone belts in the Archean-age shields. In Canada, nickel deposits associated with high magnesium volcanic rocks will continue to be discovered adjacent to the Trans-Hudson orogen in the Thompson belt (a well-explored exploration terrain) and the Cape Smith fold belt (fig. 7; a terrain with "grass-roots" opportunities). Kimberlite intrusions have brought up diamonds formed in mantle beneath the Archean-age shields, and more deposits are likely to be discovered in a large area extending from the Northwest Territories to Alberta to Quebec, as well as in the cratons of South America.
3. The Sudbury Igneous Complex in Canada (figs. 9e and 10i) which is a meteorite crater filled with igneous rocks. Although this is a well explored feature, discoveries will continue as more sophisticated tools are developed to image rocks associated with mineral deposits at depth.

4. Mid-Proterozoic-age anorthosite (a rock formed dominantly of calcium feldspar) provinces in Canada (fig. 7). The discovery of the Voisey's Bay nickel deposit identified these rocks as a new geologic setting for giant nickel deposits. Exploration can be expected for these deposits for the first time in the belt of rocks in Labrador that host the Voisey's Bay deposit, as well as other belts of anorthosite rock like those associated with the Grenville orogen (fig. 7).
5. The Appalachian Orogen in Canada (fig. 7). Undiscovered volcanogenic massive sulfide (VMS) deposits and pluton-associated gold deposits may occur in this orogen.
6. Carbonate sedimentary rocks overlying Precambrian shields in both North and South America. The rocks may host undiscovered Mississippi Valley type zinc-lead deposits.
7. Sedimentary basins formed during the extension of continental crust. Hydrothermal fluids generated in these basins could have vented to the ancient seafloor to form sedex zinc-lead deposits. Undiscovered deposits may occur in the Selwyn Basin in the Yukon Territory and the Aldridge-Belt basin in British Columbia (fig. 7).
8. Large provinces of magnesium- and iron-rich igneous rocks emplaced on the continents and not directly related to the development of continental orogens. Upwelling of the Earth's mantle has resulted in the rapid emplacement of large volumes of volcanic flows and igneous intrusions over large parts of North America. Although no significant mineral deposits have been found, undiscovered deposits of nickel and platinum-group metals may exist. One igneous event formed a belt of Mesozoic-age rocks extending from British Columbia through the Yukon Territory to Alaska. A mid-Proterozoic-age event formed volcanic rocks and intrusions in the Northwest Territories that extend 1,200 km from the Northwest Territories to Ontario. Similar igneous rocks in Ontario, Canada formed during a slightly younger mid-Proterozoic-age event.
9. Myriad stratovolcanoes (figs. 8 and 10b) and layers of volcanic ash associated with large collapsed volcano craters (calderas) throughout the Andes. Considering the well-known association between metal deposits and volcanic centers, additional volcanic centers will be identified and explored, especially those that show indications of associated metals or sulfur, or evidence of hydrothermal processes such as hydrothermally altered rocks or explosion features.
10. A relationship between volcanic rocks of a certain aluminum-rich chemistry and major tin-silver deposits. The world's largest silver deposit is Cerro Rico de Potosi, Bolivia (figs. 9c and 10k). It was formed from a 13 Ma hydrothermal system associated with a large, volcanic dome (Cunningham and others, 1996). The largest tin vein deposit in the world, Llallagua, Bolivia, is also associated with rocks of a similar composition (Lehmann, 1990). In Bolivia, some of these aluminum-rich rocks were erupted as volcanic ash-flow sheets that may cover and conceal other tin-silver deposits (Cunningham, 1994; Ericksen and others, 1995).
11. Exploration for ore deposits that may have been eroded, transported, and perhaps concentrated downstream from their original sites to form new deposits. Examples are alluvial gold deposits such as those present along the eastern slopes of the Andes. Most of the known gold in these deposits is apparently derived from gold-quartz veins associated with metamorphosed lower Paleozoic-age rocks. New resources of placer gold along the eastern slope of the Andes may result from the identification of eroded volcanic-center source areas. New deposits should be explored for beneath thin sediment cover further to the east and elsewhere along the eastern slope of the Andes. Geophysical tools, especially sensitive magnetometers, may identify the magnetic mineral magnetite associated with gold in buried stream channels. Platinum also may be concentrated by similar processes and, like placer gold, also be concentrated in rivers and at the edge of the sea downstream from source rocks in the drainage basins.

12. Sedimentary-rock-hosted hydrothermal gold deposits (Carlin-type deposits). These deposits are the major source of gold in the United States. The deposits consist of submicroscopic grains of gold often hosted in black shale, and also contain elevated concentrations of arsenic, mercury, thallium, and antimony. One of the largest sedimentary-rock-hosted gold deposits in the world was discovered partly because of the presence of antimony minerals. Many of the polymetallic deposits in the Andes contain antimony minerals, are hosted in black shales, and have gone through a tectonic and thermal history similar to the sedimentary-rock-hosted deposits in the United States thereby making them excellent candidates for undiscovered sedimentary-rock-hosted gold deposits.
13. Major regional faults that are important controls of the locations of magmatic and hydrothermal systems and their associated metals. Such faults are particularly important in the Andes. Of particular note are the many ore deposits along the Atacama Fault Zone and Domeyko Fault Zone of Chile whose mineralizations may be related in time to differing convergent angles and rates between the continental South American Plate and the opposing oceanic plate (Oyarzun, 2000; fig. 6). Undiscovered igneous and hydrothermal deposits are likely to occur in areas where the fault zones continue under the cover of young sediments or ash flows.
14. The Tapajós area of Brazil, located in the central Brazil shield. This area is the largest gold province in Brazil (Dardenne and Schobbenhaus, 2000). It is situated in an area of regionally low grade metamorphosed rocks. Most of the gold mined so far has been from placer deposits; however, altered volcanic rocks that are scarcely deformed have been recognized recently (Dardenne and Schobbenhaus, 2000; Juliani and others, 2005). These poorly exposed rocks contain the type of alteration minerals that form above well-exposed copper porphyry deposits throughout the world, and greatly increase the potential for porphyry deposits to be found in this terrane.
15. Large, Jurassic-age (206-144 Ma) volcanic ash-flow rocks cover much of Patagonia, southern Argentina (fig. 8). The Cerro Vanguardia gold deposit is a major, recently discovered gold deposit in this ash-flow. The ore is in quartz veins that are exposed at the surface in the form of ridges that extend across country. The origin of the faults that are filled by the veins could be due to the opening of the southern Atlantic Ocean or related to the formation of the calderas, or both. Understanding the structural control, as well as the vertical controls on ore deposition by examining vertical variations in quartz vein textures as a result of ore fluid changes due to pressure changes, could greatly enhance the potential for finding undiscovered gold deposits.
16. Discovery of additional limestone and similar carbonate-rock deposits. The supply of limestone used for the production of cement is variable but generally good. Limestone or other similar carbonate rocks are abundant locally. For example, there are thick Paleozoic-age deposits in the Peruvian Andes. Elsewhere, carbonate rocks are scarce. In the floodplain of the Amazon River, limestone, as well as most bedrock, generally is not well exposed at the surface.
17. Sedimentary basins in the high Andes. Volcanic ash-flow rocks are suspected of being the source rocks for sedimentary accumulations of commodities such as lithium, boron, and beryllium. Glassy tuffs are especially reactive to groundwater; the glass crystallizes, and in the process, releases these elements into the groundwater, ultimately concentrating them in brines in adjacent basins. A major resource of boron and lithium believed to have formed in this manner has been discovered in the Salar de Uyuni, Bolivia, and Salar de Hombre Muertos, Argentina. Many other basins remain to be explored.

Acknowledgements

Dave Wilburn for his assistance providing the 2003 nonfuel mineral exploration data. Kenneth C. Assmus and Dave Sutphin for their assistance with illustrations. Cher Cunningham for her editorial skills. Klaus Schulz, Joe Briskey, and Bob Luedke for their perceptive reviews. John D. Horton (Env. Careers Org./USGS - Reston) for editing illustrations, GIS and compiling this report.

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Tables

Table 1. Principal nonfuel mineral commodities produced in Latin America and Canada.

Country	**Mineral Commodities**
Anguilla	salt, limestone
Antigua and Barbuda	not significant
Argentina	lead, zinc, tin, copper, iron, gold, silver, manganese, uranium, borates, potash, salt
Aruba	not significant
Bahamas, The	salt, aragonite
Belize	not significant
Bermuda	limestone
Bolivia	tin, zinc, tungsten, antimony, silver, iron, lead, gold
Brazil	aluminum, gold, iron, kaolin, manganese, nickel, phosphate, diamond, silver, zinc, platinum, tin, uranium, kaolin, niobium, graphite, barite, cement, gypsum, salt, sulfur
British Virgin Islands	not significant
Canada	iron, nickel, zinc, copper, gold, diamond, platinum, tungsten, sulfur, lead, molybdenum, potash, gypsum, salt, magnesite, silver, titanium
Cayman Islands	not significant
Chile	copper, iron, nitrates, gold, silver, molybdenum, lithium, iodine, nitrate
Colombia	iron, nickel, gold, copper, emeralds, silver, cement, phosphate
Costa Rica	not significant
Cuba	cobalt, nickel, iron ore, copper, manganese, salt, silica
Dominican Republic	nickel, aluminum, gold, silver
Ecuador	gold, silver
El Salvador	not significant
French Guiana	aluminum, gold, mercury, kaolin
Grenada	not significant
Guatemala	nickel
Guyana	aluminum, gold, diamonds
Haiti	aluminum, copper, limestone, gold, marble
Honduras	gold, silver, copper, lead, zinc, iron, antimony, coal
Jamaica	aluminum, gypsum, limestone
Mexico	silver, copper, gold, iron, lead, zinc, barite, cement, gypsum, phosphate, sulfur, celestite, fluorite, manganese, graphite
Netherlands Antilles	phosphates (Curacao only), salt (Bonaire only)
Nicaragua	gold, silver, copper, tungsten, lead, zinc
Panama	copper
Paraguay	iron, manganese, limestone
Peru	copper, silver, gold, iron, phosphate
Puerto Rico	copper, nickel
Saint Kitts and Nevis	not significant
Saint Lucia	Pumice
Saint Vincent/Grenadines	not significant
Suriname	kaolin, aluminum, gold, nickel, copper, platinum, iron
Trinidad and Tobago	not significant

Country	**Mineral Commodities**
Turks and Caicos Islands	not significant
Uruguay	cement, dimension stone
Venezuela	iron, gold, aluminum, diamonds, nickel, cement, phosphate, sulfur
Virgin Islands	not significant

Table 2. Mineral deposit name, location, principal commodities, type, and references for the principal mineral deposits in Latin America and Canada.

Country	Deposit Name	Lat (DD)	Long (DD)	Commodities	Type	Reference
Argentina	Agua Rica/Mi Vida	-27.3708	-66.2800	Copper, molybdenum	Hydrothermal	Landtwing and others, 2002
Argentina	Angela	-42.6667	-69.3333	Silver, lead	Hydrothermal	Mitarbeiterstab der Bergbauabteilung, 1987
Argentina	Bajo de la Alumbrera	-27.3166	-66.6167	Copper, gold	Hydrothermal	Angera, 1999; Guibert, 2000
Argentina	Bajo El Durazno	-27.2833	-66.5833	Copper, gold	Hydrothermal	Long, 1995
Argentina	Barda González	-38.8833	-68.9833	Copper	Sedimentary	Lyons, 1999
Argentina	Capillitas	-27.3500	-66.3700	Rhodochrosite	Hydrothermal	Sasso and Clark, 1998
Argentina	Cerro Granito	-39.2167	-69.8167	Copper	Sedimentary	Lyons, 1999
Argentina	Cerro Pelado	-34.8000	-69.1670	Limestone	Sedimentary	Angelelli and others, 1980
Argentina	Cerro Vanguardia	-48.3888	-68.3111	Gold	Hydrothermal	Schalamuk and others+G124, 1997
Argentina	Cordon Pedernal	-31.9330	-68.7170	Limestone	Sedimentary	Direccion Nacional de Mineria y Geologia, 1991
Argentina	Diablilllos	-25.1700	-66.7800	Gold, silver	Hydrothermal	Germuts and others, 1996
Argentina	El Aguliar	-23.2500	-65.7000	Silver, lead	Hydrothermal	Logan and others, 2000
Argentina	El Pachon	-31.5800	-70.4300	Copper, molybdenum	Hydrothermal	Germuts and others, 1996
Argentina	Farallon Negro	-27.3200	-66.6800	Silver, gold	Hydrothermal	Sasso and Clark, 1998
Argentina	Isabelita, Sulfa	-25.0805	-68.1667	Gypsum	Sedimentary	Godeas and others, 1999
Argentina	Jachal	-30.3830	-68.7170	Limestone	Sedimentary	Angelelli and others, 1980
Argentina	Juaramento	-25.1300	-65.9000	Copper, lead	Sedimentary	Peral and Wormald, 1999
Argentina	Loma Blanca	-23.0583	-66.4416	Boron	Sedimentary	Godeas and others, 1999
Argentina	Los Pelambres	-31.7500	-70.4500	Copper, molybdenum	Hydrothermal	Atkinson and others, 1996
Argentina	Martín Bronce	-24.0000	-64.4167	Copper	Sedimentary	Avila, 1999
Argentina	Nevados del Famatina	-29.0000	-67.7500	Copper, molybdenum	Hydrothermal	Brodtkorb and Schalamuk, 1999
Argentina	Paramillos	-32.4166	-69.0833	Copper	Hydrothermal	Lavandaio and Fusari, 1999
Argentina	Paramillos Sur	-32.4333	-69.2333	Copper, gold	Hydrothermal	Long,1995
Argentina	Pirquitas	-22.6825	-66.5308	Silver, tin	Hydrothermal	Zappettini and others, 2001
Argentina	Rio Colorado	-36.9500	-69.0830	Potash, halite	Sedimentary	Direccion Nacional de Mineria y Geologia, 1991
Argentina	Salar de Arizaro	-24.7000	-67.7500	Halite	Sedimentary	Alonso and others, 1991
Argentina	Salar del Hombre Muerto	-25.3833	-67.1000	Lithium, boron	Sedimentary	Godeas and others, 1999
Argentina	Salina del Gualicho	-40.4000	-65.2500	Halite	Sedimentary	Argentina Mining Secretary, 1993
Argentina	San Jorge	-32.2500	-69.4330	Copper, gold	Hydrothermal	Williams and others, 1999
Argentina	Santa Barbara	-24.2589	-64.4714	Iron	Sedimentary	Angelleli, 1984
Argentina	Serrania de Sijes	-24.5847	-66.6791	Boron	Sedimentary	Godeas and others, 1999

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Argentina	Sonia	-24.6813	-66.6950	Halite	Sedimentary	Blasco and Zappettini, 1996
Argentina	Taca Taca	-24.5830	-67.7330	Copper, gold	Hydrothermal	Rojas and others, 1999
Argentina	Taca Taca Bajo	-24.5769	-66.7377	Copper, gold	Hydrothermal	Godeas and others, 1999
Argentina	Tincalayu	-25.2667	-67.0500	Boron	Sedimentary	Industrial Minerals, 1999
Argentina	Veladero	-29.5000	-66.8800	Gold, silver	Hydrothermal	Bissig and others, 2002
Bolivia	Avicaya-Totoral	-18.5114	-66.8597	Tin, zinc	Hydrothermal	Troëng and Riera-Kilibarda, 1996
Bolivia	Caracoles-Pacuni	-16.9325	-67.3322	Tin, tungsten	Hydrothermal	Gustavson Assoc. and others, 1992
Bolivia	Caracota	-20.0869	-65.9086	Antimony, gold	Hydrothermal	Troëng and Riera-Kilibarda, 2000
Bolivia	Cerro Rico de Potosi	-19.6152	-65.7467	Silver, tin	Hydrothermal	Cunningham and others, 1996
Bolivia	Chacarilla	-17.5833	-68.2000	Copper	Sedimentary	Cox and others, 1992
Bolivia	Chambillaya	-17.0019	-67.2119	Tungsten	Hydrothermal	Troëng and Riera-Kilibarda, 1997
Bolivia	Chicote Grande-Taminani	-17.3153	-66.8497	Tungsten	Hydrothermal	Troëng and Riera-Kilibarda, 1997
Bolivia	Chocaya	-20.9658	-66.3036	Silver, lead	Hydrothermal	Troëng and Riera-Kilibarda, 2000
Bolivia	Chojlla	-16.3980	-67.7808	Tungsten	Hydrothermal	Heuschmidt and others, 2000a,b
Bolivia	Chorolque	-20.9214	-66.0322	Tin, tungsten	Hydrothermal	Troëng and Riera-Kilibarda, 2000
Bolivia	Colquiri	-17.3758	-67.1242	Tin, zinc	Hydrothermal	Troëng and Riera-Kilibarda, 1997
Bolivia	Corocoro	-17.1642	-68.4511	Copper	Sedimentary	Cox, D.P., and others., 1992
Bolivia	Huanuni	-18.2719	-66.8225	Tin, zinc	Hydrothermal	Troëng and Riera-Kilibarda, 1996
Bolivia	Kami	-17.3880	-66.8292	Tungsten	Hydrothermal	Troëng and Riera-Kilibarda, 1997
Bolivia	Kori Kollo	-17.8028	-67.4497	Gold, silver	Hydrothermal	Columba and Cunningham, 1993
Bolivia	Llallagua, Siglo XX	-18.4394	-66.5928	Tin, tungsten	Hydrothermal	Troëng and Riera-Kilibarda, 1996
Bolivia	Pulacayo	-20.3800	-66.6833	Silver, zinc	Hydrothermal	Pinto-Vasquez, 1993
Bolivia	Rincon del Tigre	-18.2500	-63.4000	Platinum	Igneous	Prendergast, 2000
Bolivia	Salar de Uyuni	-20.1666	-67.5000	Lithium, boron	Sedimentary	Troëng and Riera-Kilibarda, 2000
Bolivia	San Cristobal	-21.0975	-67.2061	Silver, lead	Hydrothermal	Kamenov and others, 2002
Bolivia	San Jose	-17.9500	-67.1333	Tin, silver	Hydrothermal	Ericksen and Cunningham, 1993
Bolivia	Tazna	-20.6158	-66.1906	Silver	Hydrothermal	Troëng and Riera-Kilibarda, 2000
Bolivia	Vilico	-16.8719	-67.4903	Tin, tungsten	Hydrothermal	Heuschmidt and others, 2000a,b

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Brazil	Alegira	-20.1667	-43.5000	Iron	Sedimentary	Laznicka, 1999
Brazil	Amazon Valley	-2.0000	-58.0000	Aluminum	Surficial	Azevedo Branco, 1984
Brazil	Aracuai	-16.7170	-41.9330	Lithium	Igneous	Schobbenhaus and others,1984
Brazil	Arari	-3.4670	-44.7830	Potash, halite	Sedimentary	Gurmendi and others, 1999
Brazil	Araxá	-19.6330	-46.9330	Columbium, phosphate, titanium, rare earths	Igneous	Morteani and Preinfalk, 1996
Brazil	Azul/Carajas	-6.1333	-50.3500	Manganese	Surficial	DeYoung and others, 1984
Brazil	Barro Alto	-15.0500	-48.8000	Nickel, cobalt	Surficial	DeYoung and others, 1985
Brazil	Boa Vista	-14.1620	-41.3510	Magnesite	Metamorphic	Azevedo Branco, 1984
Brazil	Boquira	-12.7666	-42.7833	Lead, zinc	Sedimentary	Mitarbeiterstab der Bergbauabteilung, 1987
Brazil	Brumadinho	-9.5500	-62.4167	Tin	Surficial	Sutphin and others, 1990
Brazil	Brumado	-14.1333	-41.6833	Magnesite, talc	Metamorphic	Kendall, 1996
Brazil	Cabeceiras	-14.1570	-41.7010	Magnesite	Metamorphic	Azevedo Branco, 1984
Brazil	Camaquã District	-30.9167	-53.4333	Copper	Sedimentary	Azevedo Branco, 1984
Brazil	Canaan	-22.7500	-43.2667	Nepheline syenite	Igneous	Harben and Kuzvart, 1996
Brazil	Carajas	-6.0333	-50.2000	Iron, copper, gold	Hydrothermal	Haynes, 2002
Brazil	Catalao I	-18.1330	-47.8000	Phosphate, columbium	Igneous	Morteani and Preinfalk, 1996
Brazil	Catiboaba	-14.1810	-41.5800	Magnesite	Metamorphic	Azevedo Branco, 1984
Brazil	Fazenda Brasileiro	-11.4625	-39.0789	Gold	Hydrothermal	Skillings, 1988
Brazil	Felipe Mine (Jari)	-0.5000	-52.3667	Kaolinite	Sedimentary	Harben and Kuzvart, 1996
Brazil	Itabira	-19.6000	-43.2333	Gemstones-emerald	Hydrothermal	Shigley and others, 2000
Brazil	Itabira	-19.6500	-43.2833	Iron	Sedimentary	Gurmendi and others, 1999
Brazil	Jacupiranga	-24.7000	-48.0833	Phosphate, calcium carbonate, columbium, titanium, zirconium	Igneous	Harben and Kuzvart, 1996
Brazil	Jaguarari/ Caraiba	-9.8522	-39.8653	Copper	Hydrothermal	Mitarbeiterstab der Bergbauabteilung, 1987
Brazil	Jari	-0.5000	-52.3670	Aluminum	Surficial	Kendall, 1996
Brazil	Maicuru	-0.4670	-54.2170	Phosphate	Igneous	Pell, 1996
Brazil	Maraba	-5.8333	-50.4167	Gemstones-amethyst	Hydrothermal	Shigley and others, 2000
Brazil	Marau	-14.0833	-38.9333	Gypsum	Sedimentary	Gurmendi and others, 1999
Brazil	Mato Grosso	-18.6667	-43.3833	Iron	Sedimentary	Singer and others, 1993
Brazil	Morro dos Seis Lagos	-0.6330	-66.4000	Columbium, rare earths, beryllium	Igneous	Pell, 1996

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Brazil	Morro Velho	-19.9500	-43.8500	Gold, silver	Sedimentary	Azevedo Branco, 1984
Brazil	Mucuri River Valley	-17.7500	-41.4333	Gemstones- beryl	Igneous	Shigley and others, 2000
Brazil	Niquelandia/Tocantins	-14.5500	-48.3833	Nickel, cobalt	Surficial	DeYoung and others, 1985
Brazil	Nova Era area	-19.5833	-43.0500	Gemstones- emerald	Hydrothermal	Shigley and others, 2000
Brazil	Nova Olinda	-2.2500	-58.0000	Potash, halite	Sedimentary	Azevedo Branco, 1984
Brazil	Ouro Preto	-20.4167	-42.6167	Gemstones- topaz	Hydrothermal	Shigley and others, 2000
Brazil	Ouro Preto	-20.9000	-43.5000	Gold	Hydrothermal	Chauvet and others, 2001
Brazil	Paragominas	-3.6297	-47.6139	Aluminum	Surficial	Azevedo Branco, 1984
Brazil	Patos de Minas - Rochinha	-18.3330	-46.9170	Phosphate	Hydrothermal	Notholt, 1994
Brazil	Patrocino	-18.9833	-46.9667	Titanium, phosphate	Igneous	Gurmendi and others, 1999
Brazil	Pedra Azul (Salto Divisa)	-15.8830	-41.1330	Graphite	Metamorphic	Krauss and others, 1988
Brazil	Pedra Preta	-14.1360	-41.2860	Magnesite, talc	Metamorphic	Azevedo Branco, 1984
Brazil	Pedra Verde	-3.5000	-41.1167	Copper	Sedimentary	Azevedo Branco, 1984
Brazil	Pitinga	-0.6647	-59.9167	Tin	Surficial	Thorman and Drew, 1988
Brazil	Pocos de Caldas	-21.8000	-46.0000	Aluminum	Surficial	Mitarbeiterstab der Bergbauabteilung, 1987
Brazil	Ponta Grossa-Castro	-25.1000	-49.9167	Talc, calcite	Hydrothermal	Harben and Kuzvart, 1996
Brazil	Poteirinha	-16.0000	-42.6833	Iron	Sedimentary	Gurmendi and others, 1999
Brazil	Quadrilátero Ferrífero	-20.4500	-43.9300	Iron	Sedimentary	Dorr, 1973
Brazil	Rio Capim	-2.4170	-47.7830	Kaolinite	Sedimentary	Harben and Kuzvart, 1996
Brazil	Rondonia	-11.0000	-63.0000	Tin	Surficial	Thorman and Drew, 1988
Brazil	Salitre I	-19.0000	-46.7500	Phosphate	Igneous	Companhia de Pesquisa de Recursos Minerais, 1999
Brazil	Salobo	-5.7500	-50.4500	Copper, gold	Hydrothermal	Haynes, 2002
Brazil	Salto da Divisa	-16.0000	-39.9667	Graphite	Metamorphic	Crossley, 2001
Brazil	São Bento	-19.9500	-43.3333	Gold	Hydrothermal	Gurmendi and others, 1999
Brazil	Seis Lagoas	0.3167	-66.6833	Columbium, rare earths	Igneous	Laznicka, 1999
Brazil	Serra de Buritirama	-5.6500	-50.2167	Manganese	Surficial	Gurmendi and others, 1999
Brazil	Serra do Diamante	-6.9167	-38.9167	Copper	Sedimentary	Azevedo Branco, 1984
Brazil	Serra Pelada	-5.9000	-49.7000	Gold, palladium	Surficial	Cabral and others, 2002
Brazil	Serro do Navio/Amapá	-1.0000	-52.0000	Manganese	Surficial	DeYoung and others, 1984
Brazil	Tapira	-19.8670	-46.8330	Phosphate, columbium, titanium, rare earths, vermiculite	Igneous	Companhia de Pesquisa de Recursos Minerais, 1999
Brazil	Taquari-Vassouras	-10.7500	-37.2500	Potash, halite	Sedimentary	Kendall, 1996
Brazil	Trombetas	-1.2500	-56.2500	Aluminum	Surficial	Mitarbeiterstab der Bergbauabteilung, 1987

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Brazil	Urucum mine	-19.1333	-57.5500	Manganese	Surficial	DeYoung and others, 1984
Brazil	Vazante	-17.8833	-46.9333	Zinc	Hydrothermal	White and Nagell, 1975
Brazil	Vera Cruz	-13.0500	-38.7667	Halite	Sedimentary	Gurmendi and others, 1999
Canada	Allan	51.9255	-106.0744	Potash, halite	Sedimentary	Saskatchewan Energy and Mines, 1991
Canada	Aunor-Delnite-Ankerite	48.4369	-81.2972	Gold	Hydrothermal	Ontario Ministry of Northern Development and Mines, 2003b
Canada	Bathurst-Norsemines	47.4000	-66.1330	Zinc, lead, silver, gold, copper	Hydrothermal	Singer and others, 1993
Canada	Belle Plain	50.4500	-105.2170	Potash, halite	Sedimentary	Saskatchewan Energy and Mines, 1991
Canada	Bethlehem	50.4942	-120.9967	Copper, molybdenum	Hydrothermal	Singer and others, 2002
Canada	Big Whopper	50.2667	-94.5000	Lithium, tantalum, rubidium	Igneous	Pedersen and others, 2001
Canada	Birchtree	55.7000	-97.9167	Nickel, copper, platinum, palladium	Igneous	Eckstrand, 1996
Canada	Black Crystal	49.7750	-117.7667	Graphite	Metamorphic	Industrial Minerals, 2004a
Canada	Blue Mountain	44.4333	-77.8833	Nepheline syenite	Igneous	Harries-Rees, 1992
Canada	Boston (Hope Bay)	66.3667	-107.4167	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Bralorne-Pioneer	50.7764	-122.8033	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Brunswick No. 12	47.4667	-65.8833	Zinc, lead, silver, copper	Hydrothermal	Franklin, 1996
Canada	Buchans	48.8167	-56.8833	Zinc, lead, silver, gold, copper	Hydrothermal	Poulsen and Hannington, 1996
Canada	Campbell (Red Lake-Dickenson)	51.0500	-93.7500	Gold	Hydrothermal	Singer and others, 1993
Canada	Caribou	47.5586	-66.2938	Zinc, gold, lead, silver	Hydrothermal	Gower and others, 2001
Canada	Casino	62.7167	-138.8167	Copper, gold, molybdenum	Hydrothermal	Singer and others, 2002
Canada	Cassiar Mountains	59.3167	-129.8167	Gemstones- jade	Metamorphic	Shigley and others, 2000
Canada	Cirque	57.5167	-125.1500	Zinc, lead	Hydrothermal	Lydon, 1996
Canada	Coates Lake	62.6942	-126.6200	Copper	Hydrothermal	Ruelle, 1982
Canada	Cobalt	47.3833	-79.7167	Silver, cobalt, nickel, copper	Hydrothermal	Kirkham and Rafer, 2003
Canada	Colonsay	54.9255	-105.7611	Potash, halite	Sedimentary	Saskatchewan Energy and Mines, 1991
Canada	Con	62.5083	-114.3333	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Copper Cliff	46.4667	-81.0667	Nickel, copper, platinum, palladium, cobalt	Igneous	DeYoung and others, 1985
Canada	Copper Mountain	49.3330	-120.5330	Copper, gold	Hydrothermal	Nokleberg and others, 1997

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Canada	Creighton	46.4667	-81.1833	Nickel, copper, platinum, palladium, cobalt	Igneous	Crockett and others, 1987
Canada	Diavik	64.4583	-110.2333	Gemstones-diamonds	Igneous	Kirkham and Rafer, 2003
Canada	Dome-Paymaster-Preston	48.4636	-81.2425	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Dorchester	45.9286	-64.4764	Copper	Hydrothermal	Brown, 1975
Canada	Doyon-Bousquet-LaRhonde	48.2500	-78.4833	Gold, silver, copper, zinc	Hydrothermal	Poulsen and Hannington, 1996
Canada	Dublin Gulch	64.0333	-115.8333	Gold	Hydrothermal	Mutschler and others, 1999
Canada	Dy	62.2397	-133.1564	Zinc, lead, silver	Hydrothermal	Lydon, 1996
Canada	East Milford	45.0102	-63.4186	Gypsum	Sedimentary	Nova Scotia Dept. of Natural Resources, 1992
Canada	Ekati	64.7200	-110.6000	Gemstones-diamonds	Igneous	Kirkham and Rafer, 2003
Canada	Endako	54.0333	-125.1167	Molybdenum	Hydrothermal	Kirkham and Rafer, 2003
Canada	Equity Silver	54.1667	-126.1167	Silver, copper, gold, antimony	Hydrothermal	Kirkham and Rafer, 2003
Canada	Eskay Creek	56.6167	-130.4667	Zinc, lead, gold, silver	Hydrothermal	Franklin, 1996
Canada	Esterhazy	50.7286	-101.9944	Potash, halite	Sedimentary	Harben and Kuzvart, 1996
Canada	Falconbridge	46.5833	-80.8000	Nickel, copper, platinum, palladium, cobalt	Igneous	DeYoung and others, 1985
Canada	Faro (Anvil)	62.3500	-133.3833	Zinc, lead, silver	Hydrothermal	Lydon, 1996
Canada	Fir Mountain	49.3928	-106.4758	Kaolinite	Sedimentary	Kelley, 2001
Canada	Fish Lake	51.4500	-123.6167	Copper, gold	Hydrothermal	Singer and others, 2002
Canada	Flin Flon	54.7667	-101.8833	Zinc, copper, gold, silver	Hydrothermal	Franklin, 1996
Canada	Frood - Stobie	46.5403	-80.9936	Nickel, copper, platinum, palladium, cobalt	Igneous	DeYoung and others, 1985
Canada	Galore Creek - Copper Canyon/Stikine copper	57.1250	-131.4500	Copper, gold	Hydrothermal	Singer and others, 2002
Canada	Gaspé Copper	48.9667	-65.5167	Copper, molybdenum	Hydrothermal	Singer and others, 2002
Canada	Geco	49.1542	-85.7944	Zinc, silver, copper, lead	Hydrothermal	Franklin, 1996
Canada	Gibraltar	52.5167	-122.2833	Copper, molybdenum, gold	Hydrothermal	Singer and others, 2002
Canada	Glencoe	45.9136	-61.2642	Limestone	Sedimentary	MacDonald and Boehner, 1995
Canada	Goderich Mine	43.7333	-81.7000	Halite	Sedimentary	Gerow and others, 2001
Canada	Heath Steele (B)	47.2833	-66.0833	Zinc, lead, silver, copper	Hydrothermal	Franklin, 1996

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Canada	Hemlo	48.5333	-85.9000	Gold, molybdenum, silver	Hydrothermal	Kirkham and Rafer, 2003
Canada	Hillsborough area	45.9167	-64.6500	Gypsum	Sedimentary	Harben and Kuzvart, 1996
Canada	Hollinger-Mcintryre	48.4732	-81.3132	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Horne (Horne-Quemont)	48.2667	-79.0000	Gold, copper, silver, zinc, selenium, tellurium	Hydrothermal	Kirkham and Rafer, 2003
Canada	Howards Pass	62.4667	-129.1833	Zinc, lead, silver	Hydrothermal	Lydon, 1996
Canada	Hushamu (Expo)	50.6750	-127.8583	Copper, gold, molybdenum	Hydrothermal	Singer and others, 2002
Canada	Jeffrey	45.7667	-71.9500	Asbestos	Metamorphic	Kirkham and Rafer, 2003
Canada	Kellogg Property Deposit	49.8178	-74.0019	Iron, titanium, vanadium	Igneous	Towner and others, 1988
Canada	Kemess North	57.0617	-126.7575	Copper, gold	Hydrothermal	Singer and others, 2002
Canada	Kemess South	57.0061	-126.7489	Copper, gold	Hydrothermal	Singer and others, 2002
Canada	Keno Hill	63.9167	-135.3000	Silver, lead, zinc	Hydrothermal	Kirkham and Rafer, 2003
Canada	Kerr (Kerr-Addison)	48.1333	-79.5667	Gold	Hydrothermal	Ontario Ministry of Northern Development and Mines, 2003a
Canada	Kewstoke	45.9817	-61.2531	Limestone	Sedimentary	MacDonald and Boehner, 1995
Canada	Kidd Creek	48.7000	-81.3667	Zinc, silver, copper, lead	Hydrothermal	Franklin, 1996
Canada	Kirkland Lake (Macassa, Kirkland Lake, Teck Hughes, Lake Shore, Wright Hargreaves, Sylvanite, Toburn)	48.1500	-80.0500	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Knob Lake	53.0217	-66.9750	Iron	Sedimentary	Singer and others, 1993
Canada	Kutcho Creek	58.2000	-128.3330	Zinc, silver, copper, lead	Hydrothermal	Franklin, 1996
Canada	Lac des Iles	49.1667	-89.6167	Palladium, platinum, gold	Igneous	Kirkham and Rafer, 2003
Canada	Lac Tio (Allard Lake)	50.5500	-63.4167	Titanium, iron	Igneous	Kirkham and Rafer, 2003
Canada	Lac Troilus	50.8500	-74.5833	Gold, silver, copper	Hydrothermal	Mutschler and others, 1999
Canada	Lanigan	51.8539	-105.2139	Potash	Sedimentary	Kirkham and Rafer, 2003
Canada	Levack	46.6509	-81.3780	Nickel, copper, platinum, palladium, cobalt	Igneous	DeYoung and others, 1985
Canada	Lochaber Lake	45.4042	-62.0500	Copper	Hydrothermal	Benson, 1974
Canada	Logtung	60.0167	-131.6167	Tungsten, molybdenum	Hydrothermal	Mutschler and others, 1999
Canada	Lornex	50.4500	-121.0500	Copper, molybdenum	Hydrothermal	Singer and others, 2002
Canada	Mactung	63.2833	-130.1833	Tungsten, copper	Hydrothermal	Mutschler and others, 1999

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Canada	Madeleine Archipelago	47.4333	-61.7333	Halite	Sedimentary	Harben and Kuzvart, 1996
Canada	Magpie Mountain	51.3833	-64.0667	Iron, titanium, vanadium	Igneous	Goldberg and others, 1992
Canada	Marysville	49.5778	-115.9747	Magnesite	Metamorphic	Nokleberg and others, 1997
Canada	Matagami Lake	49.7170	-77.7170	Copper, zinc, silver	Hydrothermal	Singer and others, 1993
Canada	McAuley - St. Lazare	50.5000	-101.5000	Potash, halite	Sedimentary	Roskill, 1989
Canada	Mount Brussilof	50.7889	-115.6778	Magnesite	Metamorphic	Hora, 2001
Canada	Mount Milligan	55.1333	-124.0667	Copper, gold	Hydrothermal	Singer and others, 2002
Canada	Mount Wright	52.7330	-67.2500	Iron	Sedimentary	Québec Ministère des Ressources naturelles, 2001
Canada	Murray	46.5167	-81.0667	Nickel, copper, platinum, palladium, cobalt	Igneous	DeYoung and others, 1985
Canada	Musselwhite Mine	52.6128	-90.3636	Gold	Hydrothermal	Placer Dome, Inc., 2002
Canada	Nanisivik	73.0333	-84.5000	Zinc, lead, silver	Hydrothermal	Kirkham and Rafer, 2003
Canada	Natashquan	50.5000	-61.8333	Titanium, iron, zirconium, garnet	Surficial	Kirkham and Rafer, 2003
Canada	Ojibway	42.2667	-83.0833	Halite	Sedimentary	Harben and Kuzvart, 1996
Canada	Orwell	46.3500	-75.5500	Graphite	Metamorphic	Krauss and others, 1988
Canada	Pamour-Hallnor-Broulan	48.5228	-81.1152	Gold	Hydrothermal	Ontario Ministry of Northern Development and Mines, 2003b
Canada	Pine Point District	60.7833	-114.5833	Zinc, lead	Hydrothermal	Sangster, 1996
Canada	Poison Mountain	51.1333	-122.6000	Copper, gold, molybdenum	Hydrothermal	Singer and others, 2002
Canada	Polaris Deposit	75.4333	-96.4167	Zinc, lead	Hydrothermal	Sangster, 1996
Canada	Pollon Lake	56.3830	-103.1170	Graphite	Metamorphic	Krauss and others, 1988
Canada	Pugwash	45.8666	-63.6833	Halite	Sedimentary	Harben and Kuzvart, 1996
Canada	Raglan	61.5500	-73.4500	Nickel, copper, platinum, palladium	Igneous	Eckstrand, 1996
Canada	Red Chris	57.7000	-129.7833	Copper, gold	Hydrothermal	Singer and others, 2002
Canada	Rocanville	50.4625	-101.5425	Potash, halite	Sedimentary	Harben and Kuzvart, 1996
Canada	Schaft Creek (Liard Copper)	57.3500	-131.0000	Copper, molybdenum, gold	Hydrothermal	Singer and others, 2002
Canada	Schubenacadie-Stewiacke	45.1333	-63.3500	Halite	Sedimentary	Nova Scotia Dept. of Natural Resources, 1992
Canada	Sigma-Lamaque	48.1000	-77.7667	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Snake River (Rapitan)	64.0000	-126.0000	Iron	Sedimentary	Kirkham and Rafer, 2003
Canada	Snap Lake	63.6000	-110.8700	Gemstones-diamonds	Igneous	Kirkham and Rafer, 2003
Canada	St. Honore (Niobec)	48.5330	-71.1500	columbium, tantalum	Igneous	Québec Ministère des Ressources naturelles, 2001

Country	Deposit Name	Lat (DD)	Long (DD)	Commodities	Type	Reference
Canada	Strathcona	46.6730	-81.3420	Nickel, copper, platinum, palladium, cobalt	Igneous	DeYoung and others, 1985
Canada	Sullivan	49.7167	-116.0000	Zinc, lead, silver	Hydrothermal	Lydon, 1996
Canada	Sulphurets	56.5000	-130.2500	Copper, gold	Hydrothermal	Singer and others, 2002
Canada	Sulphurets-Kerr	56.5000	-130.2500	Copper, gold, silver	Hydrothermal	Mutschler and others, 1999
Canada	Suzorite	47.9833	-74.3333	Mica, phlogopite	Igneous	Harben and Kuzvart, 1996
Canada	Tanco (Bernic Lake)	50.4333	-95.4500	Tantalum, lithium, cesium, rubidium	Igneous	Bamburak, 2001
Canada	Texada Island	49.6069	-124.3653	Limestone	Sedimentary	Hora, 2001
Canada	Thompson	55.7167	-97.8500	Nickel, copper, platinum, palladium	Igneous	Eckstrand, 1996
Canada	Thor Lake	62.4170	-112.1670	Tantalum-columbium, rare earths, beryllium, zirconium	Igneous	Harben and Kuzvart, 1996
Canada	Tiriruniak	62.9272	-92.1781	Gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Vade	52.0000	-107.2500	Potash	Sedimentary	Harben and Kuzvart, 1996
Canada	Valley Copper	50.4855	-121.0469	Copper, molybdenum	Hydrothermal	Singer and others, 2002
Canada	Voisey's Bay	56.4167	-62.0833	Nickel, copper, cobalt	Igneous	Kirkham and Rafer, 2003
Canada	Windemere	50.4806	-115.8722	Gypsum	Sedimentary	Hora, 2001
Canada	Windy Craggy	59.7333	-137.7333	Copper, cobalt, gold	Hydrothermal	Kirkham and Rafer, 2003
Canada	Wood Mountain	49.3928	-106.3411	Kaolinite	Sedimentary	Kelley, 2001
Canada	Yava (Silvermine)	45.8707	-60.3884	Lead, zinc	Hydrothermal	Singer and others, 1993
Chile	Aguas Blancas	-24.2500	-69.8333	Iodine, sodium sulfate, nitrate	Sedimentary	Kendall, 1997
Chile	Andacollo	-30.2500	-71.4166	Copper, gold	Hydrothermal	Reyes, 1991
Chile	Catedral	-34.1667	-70.1833	Limestone	Sedimentary	Industrial Minerals, 2002
Chile	Cerro Blanco	-28.7167	-71.0667	Titanium	Igneous	Industrial Minerals, 2004b
Chile	Cerro Casale	-27.7833	-69.2333	Copper, gold	Hydrothermal	Sillitoe, 2000
Chile	Cerro Colorado	-20.0455	-69.2880	Copper	Hydrothermal	Bouzari and Clark, 2002
Chile	Chuqui Sur	-22.3233	-68.9017	Copper	Hydrothermal	Boric and others, 1990
Chile	Chuquicamata	-22.2750	-68.9000	Copper, molybdenum	Hydrothermal	Lindsay and others, 1996
Chile	Collahausi	-20.9750	-68.6866	Copper, molybdenum	Hydrothermal	Bisso and others, 1998
Chile	Damiana	-26.2586	-69.5906	Copper	Sedimentary	Munchmeyer, 1996
Chile	Dos Gemelos	-25.3833	-68.7333	Sulfur	Hydrothermal	Gajardo and others, 1999b
Chile	El Abra	-21.9083	-68.8366	Copper	Hydrothermal	Dilles and others, 1997
Chile	El Indio	-29.7683	-69.9833	Gold, silver	Hydrothermal	Jannas and others, 1999
Chile	El Salvador	-26.2542	-69.5505	Copper, gold	Hydrothermal	Cornejo and others, 1997
Chile	El Soldado	-32.6500	-71.1167	Copper	Hydrothermal	El Soldado Geologic Staff, 1996

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Chile	El Teniente	-34.0916	-70.3383	Copper, molybdenum	Hydrothermal	Camus, 1975
Chile	El Tesoro	-22.9439	-69.0614	Copper	Sedimentary	Munchmeyer, 1996
Chile	Gaby	-23.4100	-68.8188	Copper	Hydrothermal	Zappettini and others, 2001
Chile	Gorbea	-25.4333	-68.6000	Sulfur	Hydrothermal	Chong, 1996
Chile	Hydrothermal Verde	-26.5500	-70.3167	Copper	Hydrothermal	Vila and others, 1996
Chile	Hydrothermals Blancos	-23.4416	-70.0694	Copper	Hydrothermal	Ramirez Rodriguez, 1996
Chile	Jardin	-27.7583	-70.1917	Copper	Sedimentary	Kirkham and others, 1994
Chile	La Candelaria	-27.5333	-70.4000	Copper, gold	Hydrothermal	Marschik and Fontbote, 2001; Haynes, 2002
Chile	La Coipa	-26.8125	-69.2583	Silver, gold	Hydrothermal	Diaz and others, 1999
Chile	La Escondida	-24.2650	-69.0716	Copper, gold	Hydrothermal	Lowell, 1991
Chile	La Fortuna	-28.6333	-69.8830	Copper, gold	Hydrothermal	Perello and others, 1996
Chile	Laco	-23.8267	-67.4767	Iron	Hydrothermal	Boric and others, 1990
Chile	Lobo	-27.2000	-69.0333	Gold, copper	Hydrothermal	Vila and Sillitoe, 1991
Chile	Lomas Bayas	-23.4450	-69.5116	Copper	Hydrothermal	Chadwick, 2001
Chile	Los Bronces-Andina	-33.1333	-70.2667	Copper, molybdenum	Hydrothermal	Long,1995
Chile	Los Pelambres	-31.7083	-70.5000	Copper, molybdenum	Hydrothermal	Atkinson and others, 1996
Chile	Manssa Mina	-22.3806	-68.9125	Copper, molybdenum	Hydrothermal	Zentilli and others, 1997
Chile	Manza Mina	-22.3805	-68.9125	Copper	Hydrothermal	Sillitoe and others, 1996
Chile	Pascua	-29.4800	-71.0683	Gold	Hydrothermal	Bissig and others, 2002
Chile	Polan	-21.2333	-68.5667	Sulfur	Hydrothermal	Gajardo and others, 1999a
Chile	Potrerillos	-26.4833	-69.4333	Copper, gold	Hydrothermal	Long,1995
Chile	Potrerillos	-26.4875	-69.4239	Copper, gold	Hydrothermal	Marsh and others, 1997
Chile	Quebrada Blanca	-21.0000	-68.8000	Copper	Hydrothermal	Hunt and others, 1983
Chile	Refugio	-27.3833	-69.2667	Gold, copper	Hydrothermal	Villa and Sillitoe, 1991
Chile	Rio Blanco/ Los Bronces	-33.1333	-70.2666	Copper	Hydrothermal	Davidson and Kamenetsky, 2001
Chile	Salar de Atacama	-23.5539	-68.4072	Lithium, potash	Sedimentary	Chong, 1996
Chile	San Antonio	-26.4858	-69.4239	Copper, gold	Hydrothermal	Diaz and others, 1999
Chile	Spence	-22.6891	-69.1814	Copper	Hydrothermal	Zappettini and others, 2001
Chile	Ticnamar	-18.5933	-69.4500	Copper	Hydrothermal	Zappettini and others, 2001
Chile	Ujina	-20.9961	-68.6050	Copper	Hydrothermal	Bisso and others, 1998
Chile	Volcan Apagado	-22.6117	-67.8683	Sulfur	Hydrothermal	Gajardo and others, 1999a
Chile	Yumbes (Taltal)	-25.4000	-70.4833	Iodine, nitrate	Sedimentary	Kendall, 1997
Colombia	Acandi	8.3333	-77.1700	Copper, molybdenum	Hydrothermal	Long, 1995
Colombia	Cerro Matoso	7.9167	-75.5833	Nickel	Surficial	Gomez and others, 1979
Colombia	Chivor district	4.8667	-73.3667	Gemstones-emerald	Hydrothermal	Shigley and others, 2000

Country	Deposit Name	Lat (DD)	Long (DD)	Commodities	Type	Reference
Colombia	Choco platinum Surficials	5.1000	-76.6667	Platinum, gold	Surficial	Mertie, 1969
Colombia	Coscuez district	5.6500	-74.1667	Gemstones-emerald	Hydrothermal	Shigley and others, 2000
Colombia	Mocoa	1.2417	-76.6660	Copper, molybdenum	Hydrothermal	Sillitoe and others, 1984
Colombia	Muzo district	5.5500	-74.1667	Gemstones-emerald	Hydrothermal	Shigley and others, 2000
Colombia	Pegadorcito-Pantanos	6.7500	-76.5667	Copper	Hydrothermal	Long, 1995
Colombia	San Juan/Atrato Rivers	5.7000	-76.6500	Gold, platinum	Surficial	Wokittel, 1961
Costa Rica	Loma Comastro	10.8090	-85.5000	Diatomite	Sedimentary	Berrange and others, 1990
Cuba	Moa	20.6167	-74.9667	Nickel, cobalt	Surficial	Mitarbeiterstab der Bergbauabteilung, 1987
Cuba	Nicaro	20.6000	-75.6000	Nickel, cobalt	Surficial	Mitarbeiterstab der Bergbauabteilung, 1987
Cuba	Punta Gorda	20.5833	-74.8500	Nickel, cobalt	Surficial	Mitarbeiterstab der Bergbauabteilung, 1987
Dominican Republic	Falconbridge Dominicana	19.1667	-70.3833	Nickel	Surficial	Halderman and others, 1982
Dominican Republic	Pueblo Viejo	18.9700	-70.1794	Gold, silver	Hydrothermal	Sillitoe, 1995
Ecuador	Chaucha	-2.9333	-79.4166	Copper, molybdenum	Hydrothermal	Anonymous, 2000
Ecuador	Junin	0.3333	-78.5833	Copper, molybdenum	Hydrothermal	Gendall and others, 2000
Ecuador	Nambija	-4.0667	-78.7833	Gold, copper	Hydrothermal	Gemuts and others, 1992
Ecuador	Portovelo	-3.6333	-79.5833	Gold, silver	Hydrothermal	Gemuts and others, 1992
Ecuador	San Carlos	-3.6500	-78.4160	Copper	Hydrothermal	Lowell and Quevedo, 2002
Guatemala	EXMIBAL mine	16.5000	-89.3333	Nickel	Surficial	DeYoung and others, 1985
Guatemala	Las Cruces - Las Hormigas	14.8833	-90.2500	Diatomite	Sedimentary	Chou, 1993
Guyana	East Montgomery (Linden)	5.9833	-58.2500	Aluminum	Surficial	Mitarbeiterstab der Bergbauabteilung, 1987
Guyana	Kwakwani (Bermine)	5.2500	-57.7500	Aluminum	Surficial	Mitarbeiterstab der Bergbauabteilung, 1987
Guyana	Omai	5.2000	-59.0000	Gold	Hydrothermal	Voicu and others, 1999
Honduras	El Mochito	14.8500	-88.0667	Silver, lead	Hydrothermal	Williams and others, 1999
Jamaica	Manchester Plateau	17.9500	-77.3833	Aluminum	Surficial	Singer and others, 1993
Jamaica	St. Ann Uplands	18.3167	-77.4000	Aluminum	Surficial	Singer and others, 1993
Mexico	Adair	31.5000	-113.8000	Sodium carbonate	Sedimentary	Harris, 2001
Mexico	Aguachile	29.2970	-102.3390	Fluorite	Hydrothermal	Griffiths, 1988
Mexico	Alamo Dorado	26.7500	-108.6670	Silver	Hydrothermal	Fitch, 2000a
Mexico	Alejandra	25.6667	-103.1667	Gypsum	Sedimentary	Industrial Minerals, 2001

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Mexico	Avino	24.5200	-104.3000	Silver, gold, copper, lead	Hydrothermal	Fitch, 2000a
Mexico	Bacis (Otaez)	24.5700	-105.9000	Gold, silver, lead, zinc, copper	Hydrothermal	Fitch, 2000a
Mexico	Batopilas	27.0167	-107.7667	Silver, lead	Hydrothermal	Albinson and others, 2001
Mexico	Bermejillo North and South	23.8833	-103.6333	Strontium	Sedimentary	Harben and Kuzvart, 1996
Mexico	Bolanos	21.8200	-103.7690	Silver, zinc, lead, copper	Hydrothermal	Fitch, 2000a
Mexico	Campo Morado	18.1670	-100.1670	Zinc, lead, copper, silver, gold	Hydrothermal	Oliver and others, 2001
Mexico	Cananea	30.9542	-110.3167	Copper, molybdenum	Hydrothermal	Singer and others, 2002
Mexico	Catorce	23.6930	-100.8840	Lead, silver, zinc	Hydrothermal	Dawson, 1996
Mexico	Cerro San Pedro	22.2980	-100.7980	Gold, silver, zinc, lead	Hydrothermal	Petersen and others, 2001
Mexico	Colorada (El Creston deposit, La Colorado mine, Gran Central mine, La Verde mine)	29.3667	-111.2833	Silver, gold, lead, zinc, copper	Hydrothermal	Albinson and others, 2001
Mexico	Concepcion del Oro District	24.6080	-101.4290	Silver, lead, zinc, gold, copper	Hydrothermal	Fitch, 2000a
Mexico	Cosala	24.3830	-106.7160	Silver, gold, zinc, lead, copper	Hydrothermal	Fitch, 2000a
Mexico	Dolores	25.9667	-107.1667	Silver, gold	Hydrothermal	Overbay and others, 2001
Mexico	El Arco	28.0333	-113.5667	Copper, gold	Hydrothermal	Singer and others, 2002
Mexico	El Boleo	27.2830	-112.3000	Copper, cobalt, zinc	Hydrothermal	Bailes and others, 2001
Mexico	El Fraile	23.6800	-100.7100	Silver, copper, gold	Hydrothermal	Fitch, 2000a
Mexico	El Oro	19.8020	-100.1290	Silver, gold	Hydrothermal	Albinson and others, 2001
Mexico	El Pilon Mine (San Martin de Bolanos district)	20.9670	-104.7500	Silver, gold, lead, zinc	Hydrothermal	Albinson and Rubio, 2001
Mexico	El Refugio	21.5330	-100.1500	Fluorite	Hydrothermal	Consejo de Recursos Minerales, 1992
Mexico	Encantada-Buenavista	28.5000	-102.5000	Fluorite	Hydrothermal	Griffiths, 1988
Mexico	Francisco I. Madero	22.8060	-102.7000	Gold, zinc, lead, copper	Hydrothermal	Fitch, 2000a
Mexico	Fresnillo/Proano	23.1500	-102.8500	Silver, lead, zinc, gold, copper	Hydrothermal	Trejo, 2001
Mexico	Guanacevi	25.5830	-105.9670	Silver, gold	Hydrothermal	Singer and others, 1993
Mexico	Guanajuato	21.0330	-101.2330	Silver, gold	Hydrothermal	Albinson and others, 2001
Mexico	Guerrero Negro	27.9170	-114.2500	Halite	Sedimentary	Kendall, 1995
Mexico	La Blanca	22.6500	-102.1330	Wollastonite	Metamorphic	Kendall, 1995
Mexico	La Caridad	30.3000	-109.5000	Copper, molybdenum	Hydrothermal	Singer and others, 2002

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Mexico	La Carmen	24.6667	-101.3500	Iron	Hydrothermal	Singer and others, 1993
Mexico	La Colorada (district)	23.3830	-103.7500	Silver, lead, zinc	Hydrothermal	Moller and others, 2001
Mexico	La Encantada mine (Buenevista mining district)	28.6170	-102.3670	Fluorite	Hydrothermal	Kessler, 1977
Mexico	La Herradura	31.1670	-112.9000	Gold	Hydrothermal	Fitch, 2000b
Mexico	La Ilusion-San Pedro	26.1667	-102.5000	Strontium	Sedimentary	Kendall, 1995
Mexico	La Paz	23.6900	-100.7100	Silver, lead, zinc, gold, copper	Hydrothermal	Fitch, 2000a
Mexico	Laguna del Rey	27.0330	-103.4330	Magnesia, sodium sulfate	Sedimentary	Griffiths, 1988
Mexico	Las Cuevas (Zaragoza-Rio Verde district)	22.5330	-101.1000	Fluorite	Hydrothermal	Skillen, 1993
Mexico	Lourdes	28.6000	-110.5000	Graphite	Metamorphic	Kendall, 1995
Mexico	Mazatan district	28.8292	-110.1958	Barite	Hydrothermal	Alatorre and others, 1998
Mexico	Metates	24.9050	-106.3750	Gold, silver, zinc	Hydrothermal	Fitch, 2000a
Mexico	Molango	20.8333	-98.7333	Manganese	Sedimentary	DeYoung and others, 1984
Mexico	Mulatos (district)	28.6500	-108.7417	Gold, copper	Hydrothermal	Staude, 2001
Mexico	Naica	27.8667	-105.5000	Silver, lead, zinc	Hydrothermal	Dawson, 1996
Mexico	Nukay	17.8900	-99.7000	Gold	Hydrothermal	Fitch, 2000a
Mexico	Ojuela-Mapimi	25.8100	-103.7500	Silver, lead, zinc, gold, copper	Hydrothermal	Fitch, 2000a
Mexico	Pachuca	20.1667	-98.7500	Silver, gold	Hydrothermal	Albinson and others, 2001
Mexico	Pachuca-Real de Monte	20.1170	-98.7170	Silver, gold, copper, lead, zinc	Hydrothermal	Singer and others, 1993
Mexico	Parral	26.9700	-105.6900	Silver, lead, zinc, gold, copper	Hydrothermal	Fitch, 2000a
Mexico	Pena Colorado	19.3570	-104.0950	Iron	Hydrothermal	Consejo de Recursos Minerales, 1994
Mexico	Penasquito	24.7900	-101.8200	Silver, lead, zinc, gold	Hydrothermal	Fitch, 2000a
Mexico	Pico Etero District	29.2972	-102.3389	Fluorite	Hydrothermal	Griffiths, 1988
Mexico	Pilares	29.3500	-111.4167	Wollastonite	Metamorphic	Harben and Kuzvart, 1996
Mexico	Pinos	15.9900	-96.3400	Silver, gold	Hydrothermal	Albinson and others, 2001
Mexico	Real de Angeles	23.5000	-103.0000	Silver, lead, zinc	Hydrothermal	Kirkham and Sinclair, 1996
Mexico	Real de Asientos	22.2200	-103.1300	Silver, lead, zinc, copper	Hydrothermal	Fitch, 2000a
Mexico	Real de Catorce	23.7006	-100.8631	Silver, lead	Hydrothermal	Albinson and others, 2001
Mexico	Sac Tun	20.8000	-90.0330	Limestone	Sedimentary	Orris files
Mexico	San Acacio	22.8300	-102.5500	Silver	Hydrothermal	Fitch, 2000a
Mexico	San Agustin	25.5330	-102.0000	Strontium	Sedimentary	Consejo de Recursos Minerales, 1993

Country	Deposit Name	Lat (DD)	Long (DD)	Commodities	Type	Reference
Mexico	San Francisco del Oro	26.8670	-105.8330	Silver, zinc, lead, copper	Hydrothermal	Albinson and others, 2001
Mexico	San Juan de la Costa	24.3825	-110.7022	Phosphate	Sedimentary	Harben and Kuzvart, 1996
Mexico	San Marcos Island	27.2170	-112.1000	Gypsum	Sedimentary	Kendall, 1995
Mexico	San Martin	21.7820	-103.8730	Silver	Hydrothermal	Fitch, 2000a
Mexico	San Martin	23.6553	-103.7372	Silver, zinc, copper, lead	Hydrothermal	Dawson, 1996
Mexico	San Nicolas	22.5950	-101.9340	Copper, zinc	Hydrothermal	Sherlock and Michaud, 2000
Mexico	Santa Barbara	26.8000	-105.8200	Silver, lead, zinc, gold, copper	Hydrothermal	Fitch, 2000a
Mexico	Santa Cruz	24.7330	-106.0980	Gold, silver	Hydrothermal	Fitch, 2000a
Mexico	Santa Eulalia	28.6170	-105.8830	Silver, zinc, lead	Hydrothermal	Dawson, 1996
Mexico	Santa Fe	17.3000	-93.0333	Wollastonite	Metamorphic	Harben and Kuzvart, 1996
Mexico	Santa Rosa district	27.7833	-101.5000	Barite	Hydrothermal	Alatorre and others, 1998
Mexico	Santa Rosalia	27.3330	-112.3500	Copper	Hydrothermal	Staude, John-Mark G., 1990, Personal communication
Mexico	Santa Rosalia	27.3167	-112.2833	Gypsum	Sedimentary	Kendall, 1995
Mexico	Santo Domingo Mine	24.2833	-111.0000	Phosphate	Sedimentary	Krauss and others, 1984
Mexico	Sierra Mojada	27.2750	-103.6730	Silver, zinc, lead, copper	Hydrothermal	Fitch, 2000a
Mexico	Sombrerete	23.6670	-103.6670	Zinc, lead, silver, gold	Hydrothermal	Albinson and others, 2001
Mexico	Taxco	18.6170	-99.5830	Silver	Hydrothermal	Albinson and others, 2001
Mexico	Tayoltita (San Dimas)	24.1000	-105.9333	Silver, gold	Hydrothermal	Albinson and others, 2001
Mexico	Telixtlahuaca	17.3330	-96.8670	Graphite	Metamorphic	Krauss and others, 1988
Mexico	Tocayos	23.6300	-103.6200	Silver, zinc, lead	Hydrothermal	Fitch, 2000a
Mexico	Tonichi	28.6170	-109.5670	Graphite	Metamorphic	Krauss and others, 1988
Mexico	Velardena	25.0667	-103.7333	Silver, copper, zinc, lead	Hydrothermal	Dawson, 1996
Mexico	Zacatecas	22.7500	-102.5830	Silver, lead, zinc, copper, gold	Hydrothermal	Albinson and others, 2001
Panama	Cerro Colorado	8.5000	-81.7833	Copper, molybdenum	Hydrothermal	Nelson, 1995
Panama	Petaquilla-Botija	8.8333	-80.6666	Copper	Hydrothermal	Hunta, 1991
Peru	Alto Chicama	-7.6667	-78.6167	Gold	Hydrothermal	Barrick Gold, 2002
Peru	Antamina	-9.5333	-77.0833	Copper, zinc	Hydrothermal	O'Connor, 2000
Peru	Antapaccay	-14.9172	-71.2688	Copper, gold	Hydrothermal	Zappettini, others, 2001
Peru	Carariaco	-6.0833	-79.2833	Copper	Hydrothermal	Noble and McKee, 1999
Peru	Cerro Corona	-6.8500	-78.6667	Gold, copper	Hydrothermal	Petersen and Vidal, 1996
Peru	Cerro de Pasco	-10.6667	-76.2750	Zinc, lead	Hydrothermal	Einaudi, 1977
Peru	Cerro el Toro	-7.8250	-78.0000	Pyrophyllite	Hydrothermal	MRDS
Peru	Cerro Verde	-16.5188	-71.5719	Copper	Hydrothermal	Bidgood, 2000
Peru	Colquemarca	-14.2667	-72.0500	Iron	Metamorphic	Singer and others, 1993
Peru	Cuajone	-17.0422	-70.6710	Copper	Hydrothermal	Concha and Valle, 2000

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Peru	El Galeno	-7.0167	-78.3166	Copper, gold	Hydrothermal	Davies, 2000
Peru	Huancabamba	-5.2333	-79.4667	Iron	Metamorphic	Singer and others, 1993
Peru	La Granja	-6.3583	-79.1194	Copper	Hydrothermal	Petersen and Vidal, 1996
Peru	Los Pinos	-12.9758	-76.1394	Copper	Hydrothermal	Vidal, 1985
Peru	Michiquillay	-7.3000	-78.3222	Copper, gold	Hydrothermal	Hart, 1991
Peru	Minas Conga	-6.9255	-78.3580	Copper, gold	Hydrothermal	Llosa and Veliz, 2000
Peru	Pierina	-9.4417	-77.5833	Gold, silver	Hydrothermal	Volkert and others, 2000
Peru	Quellaveco	-17.1080	-70.5838	Copper	Hydrothermal	Helberg, 2000
Peru	San Rafael	-14.2328	-70.3217	Tin, copper	Hydrothermal	Arenas, 2000; Kontak and Clark, 2002
Peru	Sechura (Bayovar)	-5.8000	-80.7500	Phosphate	Sedimentary	Harben and Kuzvart, 1996
Peru	Tambo Grande	-4.7633	-79.9900	Copper, zinc	Hydrothermal	Tegart and others, 2000
Peru	Tintaya	-14.8333	-71.3833	Copper	Hydrothermal	Petersen and Vidal, 1996
Peru	Toquepala	-17.2166	-70.6000	Copper, molybdenum	Hydrothermal	Petersen and Vidal, 1996; Mattos and Valle, 2000
Peru	Toromocho	-11.6000	-76.1333	Copper	Hydrothermal	Alvarez A., 2000
Peru	Yanacocha	-6.9030	-78.5156	Gold	Hydrothermal	Harris and others, 1994; Bartra, 2000
Puerto Rico	Tanama	18.2500	-66.8167	Copper, molybdenum	Hydrothermal	Cox, 1985
Surinam	Lelydorp-Onverdacht-Paranam	5.6000	-54.4000	Aluminum	Surficial	Harben and Kuzvart, 1996
Surinam	Moengo	5.6167	-54.4000	Aluminum	Surficial	Harben and Kuzvart, 1996
Surinam	Ricanau	5.6167	-54.3667	Kaolin	Surficial	Industrial Minerals, 1995
Uruguay	Artigas	-30.2600	-57.0700	Gemstones-amethyst	Hydrothermal	Shigley and others, 2000
Venezuela	Cerro Boliva/ San Isidro	7.4578	-63.3980	Iron	Sedimentary	Dorr, 1973
Venezuela	Loma de Hierro	10.3333	-67.3333	Nickel	Surficial	DeYoung and others, 1985
Venezuela	Los Pijiguaos	6.5833	-66.7500	Aluminum	Surficial	Singer and others, 1993

Table 3. Mineral deposit types and examples.

Mineral Deposit Type	Deposit Types and Process of Formation	Examples
Surficial deposits	Deposits that form at the Earth's surface by residual effects of weathering or by the mechanical concentration of minerals by flowing water.	Deposits enriched in residual aluminum, nickel, and clay. Placer deposits of gold, platinum, and titanium.
Sedimentary deposits	Deposits that form from surface waters that chemically precipitated the minerals. Includes evaporite deposits.	Sedimentary layers of salts such as halite and potash, phosphate, most iron deposits, and limestone.
Hydrothermal deposits	Deposits that form mostly from fluids in veins at moderate temperatures.	Some gold and silver deposits and lead-zinc-copper polymetallic veins; hot spring deposits. Porphyry copper deposits.
Igneous deposits	Deposits that form from the crystallization of molten rock.	Nickel deposits, gemstones in pegmatite deposits, rare-earth element deposits.
Metamorphic deposits	Deposits that form when rocks are metamorphosed by heat and pressure.	Graphite, magnesite, talc, and wollastonite deposits.

Figures

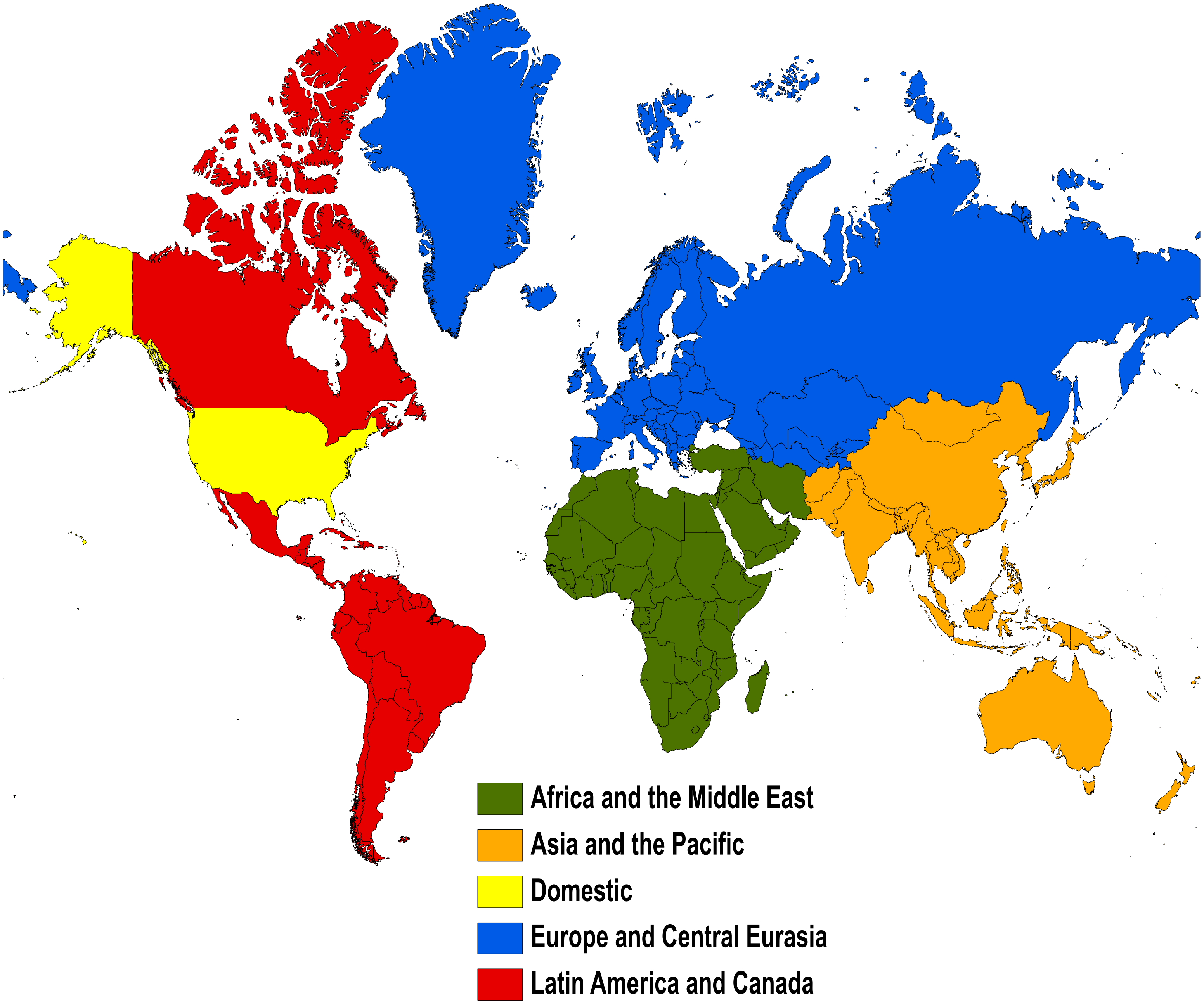

Figure 1. Areas of the regional reports. The area of this report is in red.

Figure 2. Location of countries covered in this report and the names of states and provinces in Latin America and Canada.

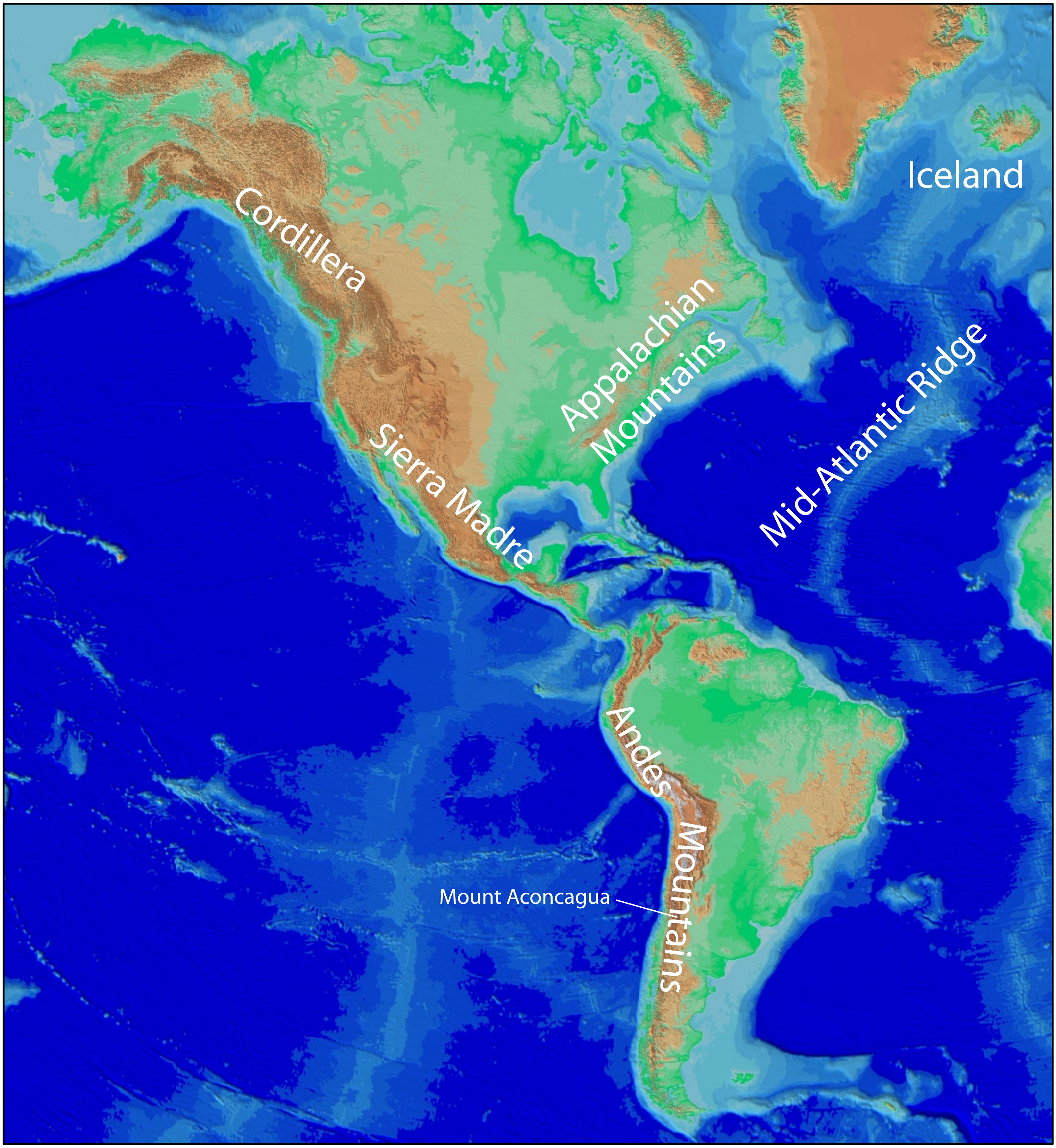

Figure 3. Digital elevation image of North and South America. Major aspects of the geology of the world are evident in the differences in elevation (topography). Folded mountain ranges (orogens) such as the Andes Mountains, volcanic mountain ranges that encircle the globe beneath the sea, and areas formed from geologically old, stable, rocks that are the nuclei of continents (shields) form topographic highs.

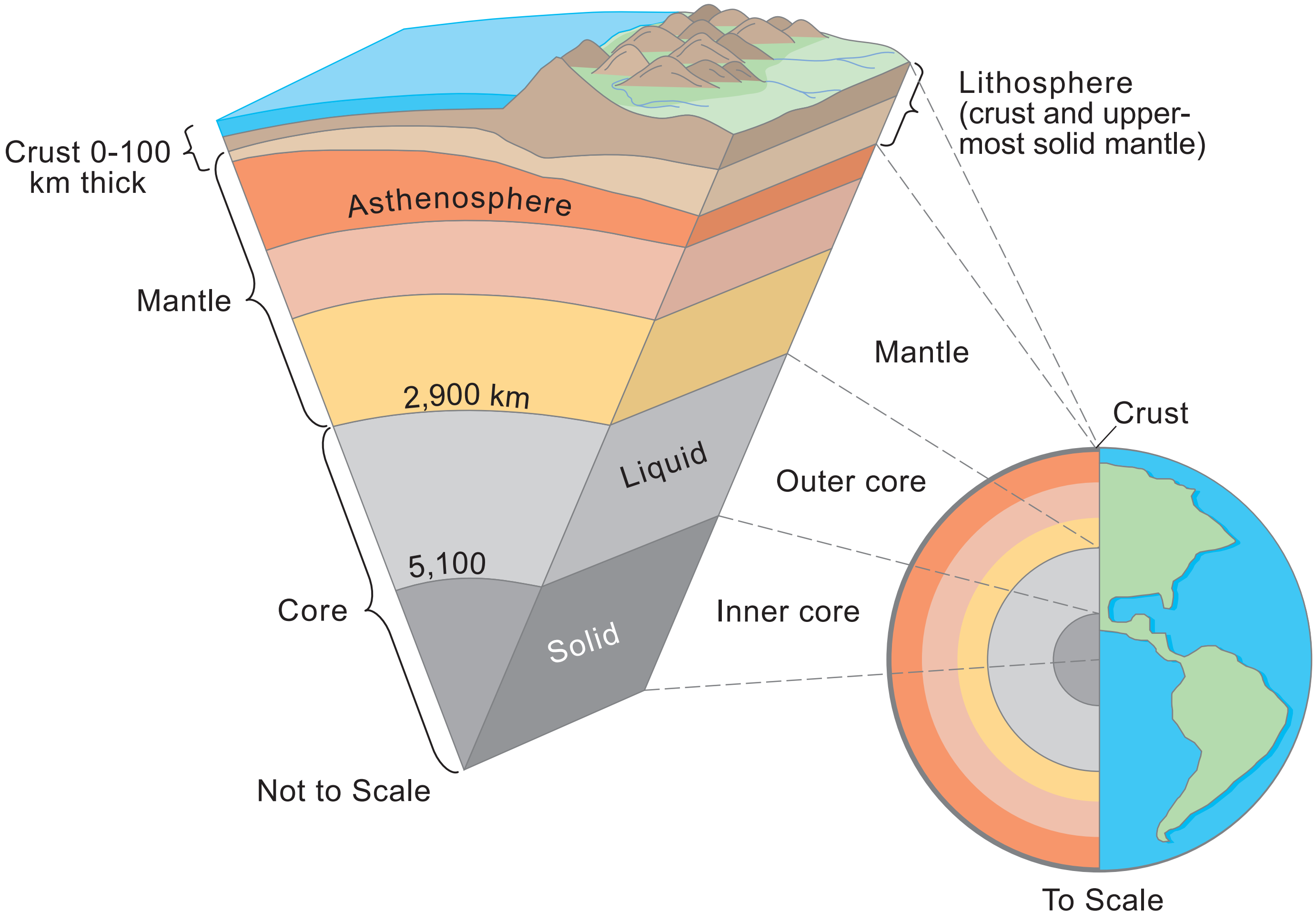

Figure 4. Principal layers of the Earth. The surface is composed of a relatively thin, brittle crust and uppermost solid mantle (lithosphere) that is broken into plates. These plates move slowly over the surface of the Earth. The underlying mantle is a thick, hot, rock layer that deforms like plastic. The core has a liquid outer part and a solid inner part composed of iron and nickel. The Earth's magnetic field is related to the spinning of the core. From Kious and Tilling (1996).

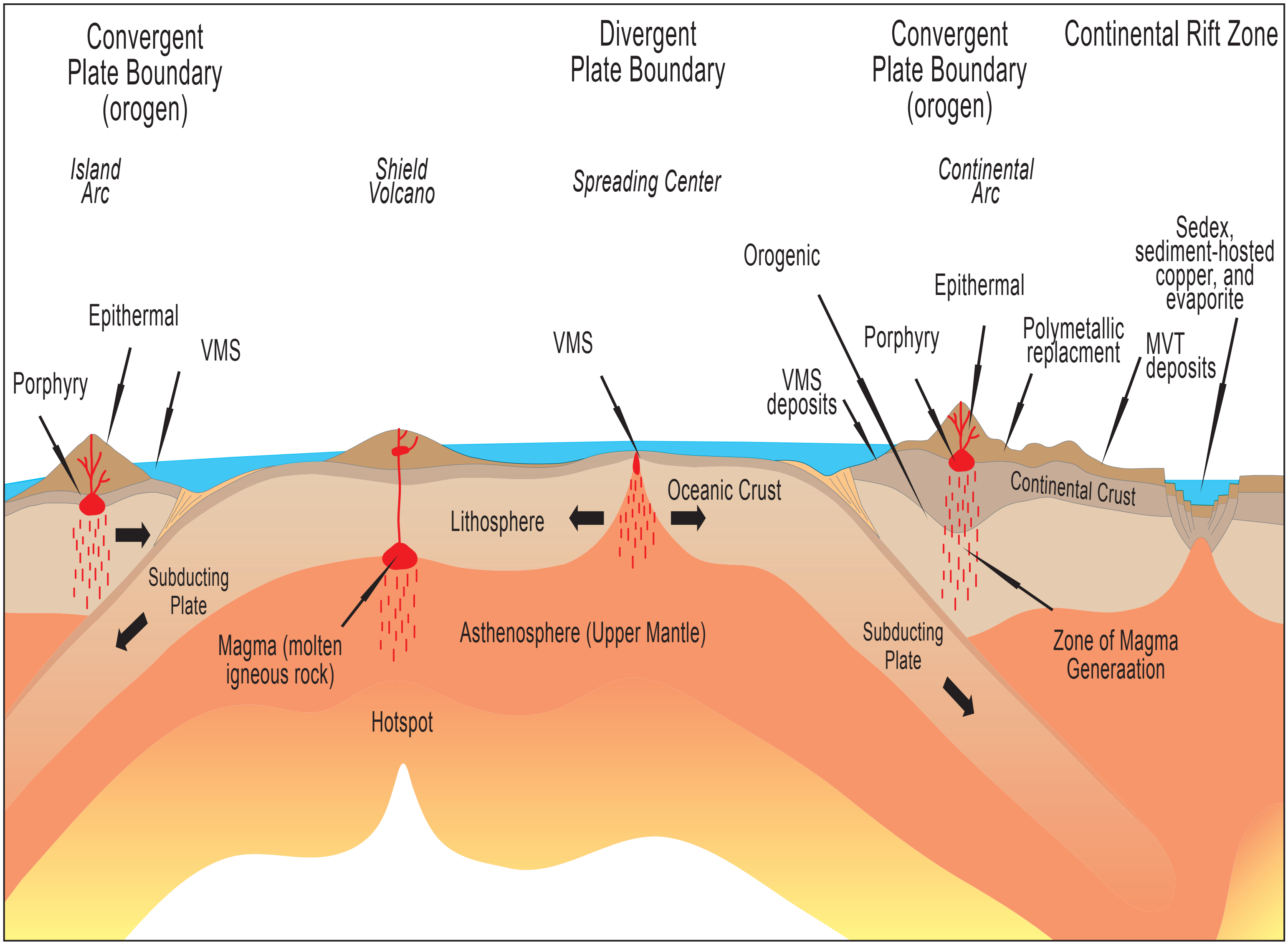

Figure 5. Diagram illustrating the plate tectonic setting in which mineral deposits are formed. The diagram shows a divergent plate boundary (spreading center) where tectonic plates are moving apart from each other and lava flows are extruded on the ocean floor forming a line of undersea volcanoes that encircle the Earth. Iceland, in the mid-Atlantic, is the tip of one part of this mountain range. Volcanogenic massive sulfide (VMS) deposits (described in the text) are an example of mineral deposits that form on the sea floor. Also shown are convergent plate boundries where an oceanic plate is being subducted beneath a continental tectonic plate forming folded and faulted mountains (orogens) with stratovolcanoes. An example is the Andes Mountains along the west coast of South America. The subduction of oceanic tectonic plates is accompanied by strong earthquakes and the generation and movement of molten igneous rock (magma) and hydrothermal fluids that form a variety of mineral deposits, including porphyry copper deposits and associated gold and silver veins described in this report. See text for discussion of the mineral deposit types shown. Modified from Kious and Tilling (1996).

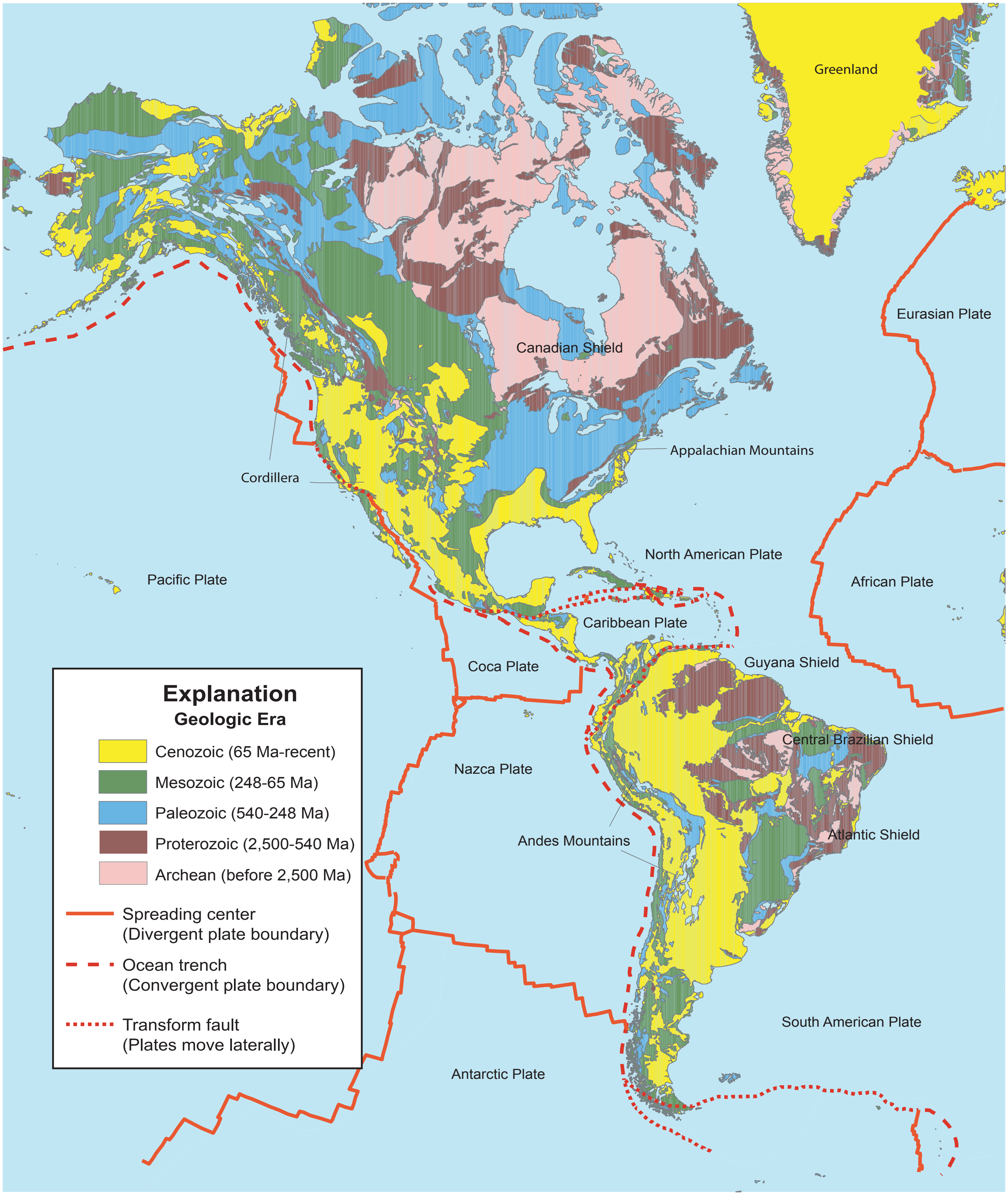

Figure 6. Geologic map of Latin America and Canada showing the age and distribution of principal rock units, and the location of tectonic plates and plate boundaries. Modified slightly from Geological Survey of Canada (1995).

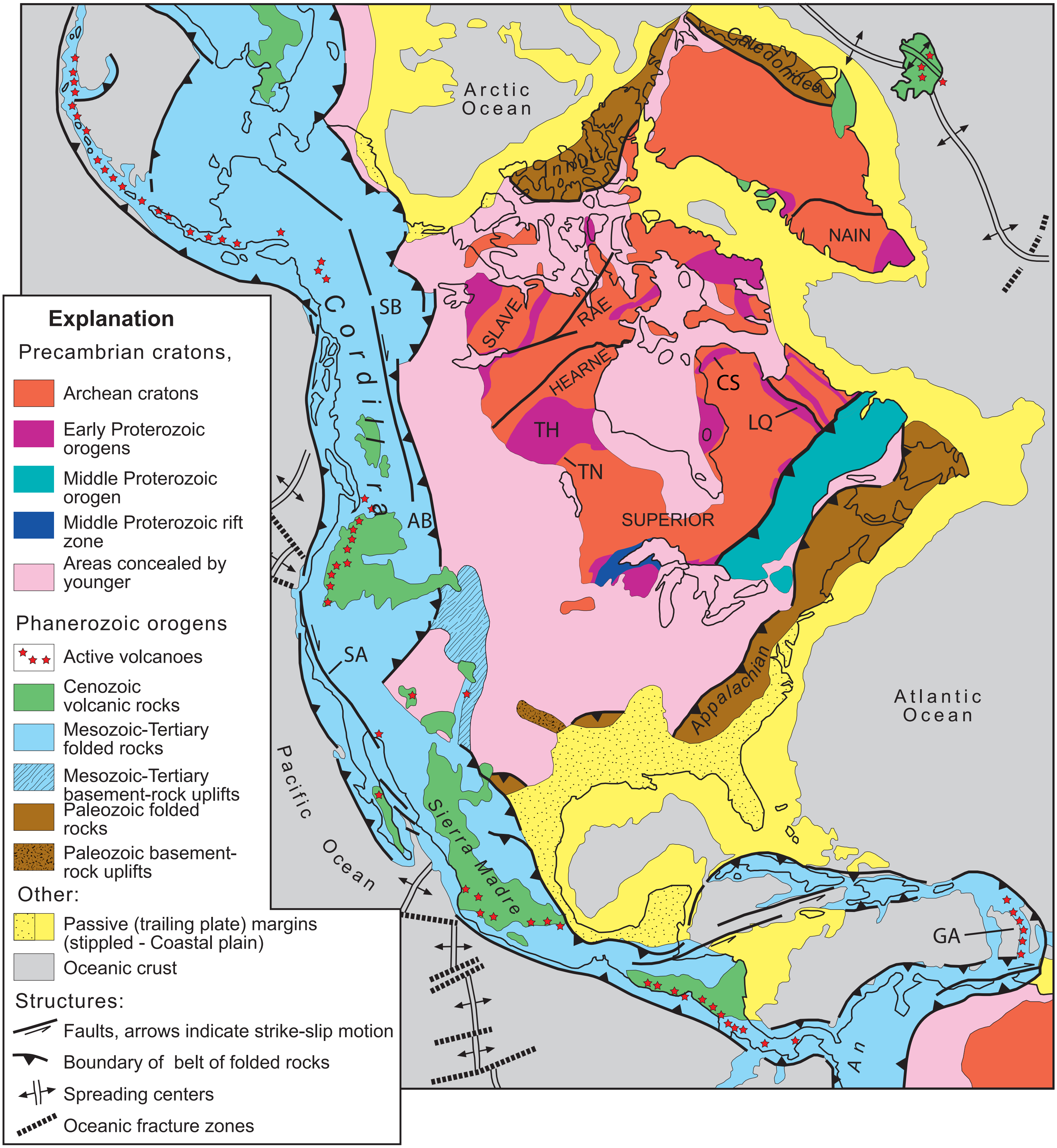

Figure 7. Map showing selected geologic and tectonic features of North America. Names of Middle Proterozoic and younger orogens are shown on the map (Grenville, Appalachian, Caledonides, Innuitian, Cordillera, Sierra Madre, Andean). Archean shield names are given in all-capital type. Other localities abbreviated as follows: AB – Aldridge-Belt basin; CS – Cape Smith fold belt; GA – Greater Antilles chain of volcanic islands; LQ – Labrador-Quebec fold belt; SA – San Andreas fault; SB – Selwyn basin; TH – Trans-Hudson orogen; and TN – Thompson nickel belt. Modified from Bally and others (1989) and Hoffman (1989).

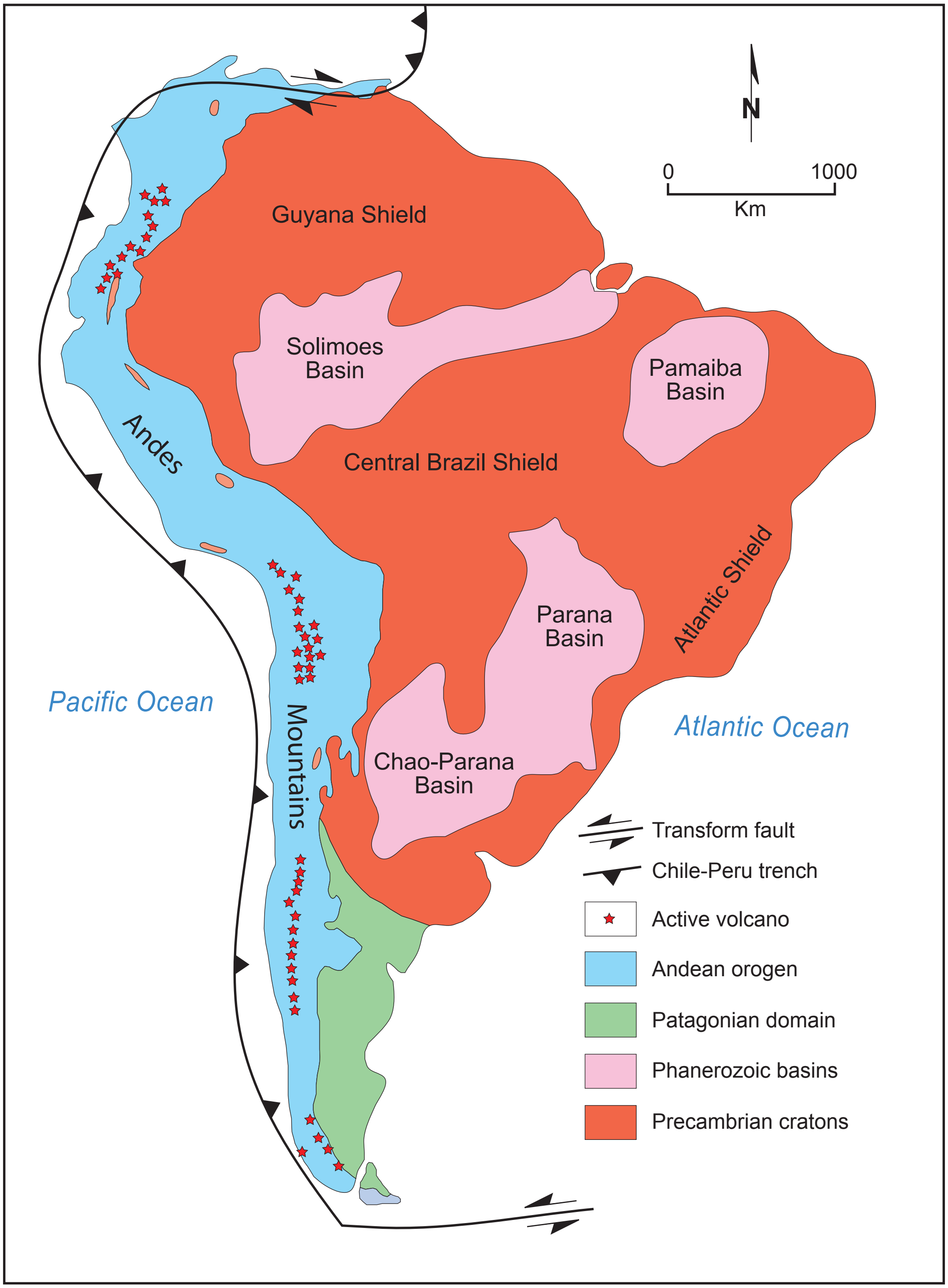

Figure 8. Map showing selected geologic and tectonic features of South America discussed in the text. Modified from Milani and Filho, 2000.

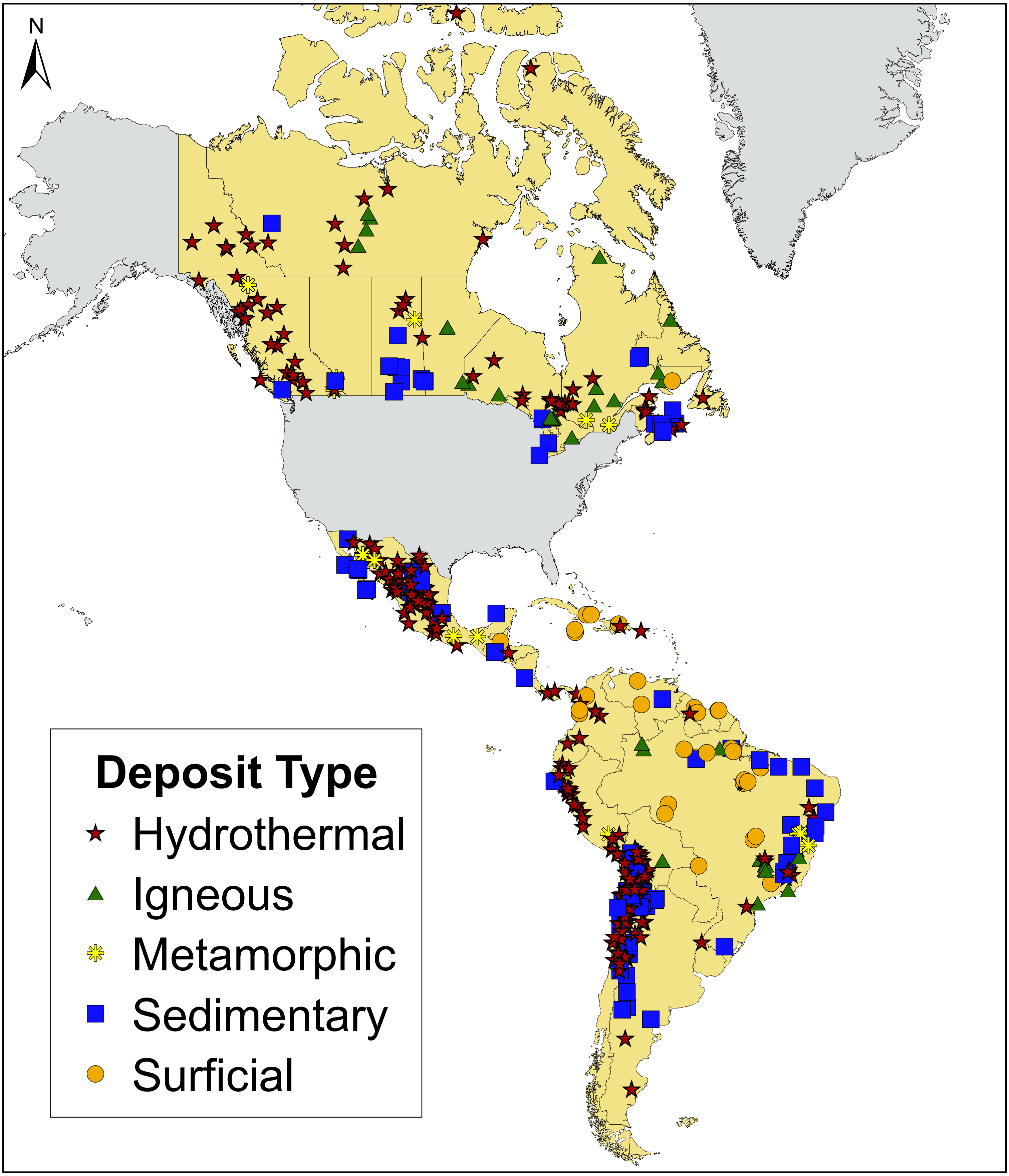

Figure 9a. Distribution of principal nonfuel mineral deposits in Latin America and Canada by deposit type. There is a tendency for surficial deposits to form in tropical settings near the equator, for hydrothermal deposits to be in mountain ranges, and for igneous deposits to be localized in stable shields.

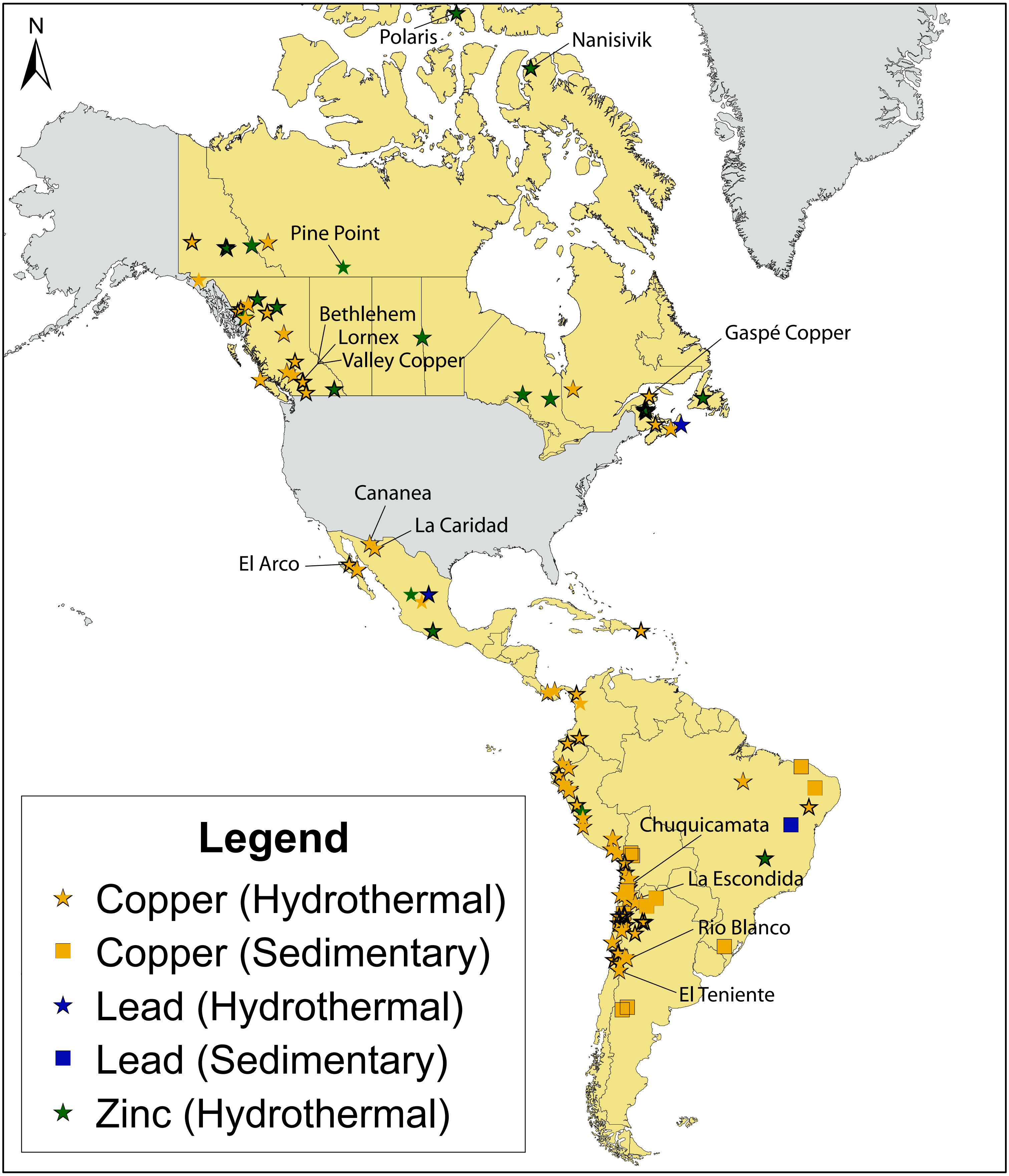

Figure 9b. Location and deposit type of major deposits of copper, lead and zinc.

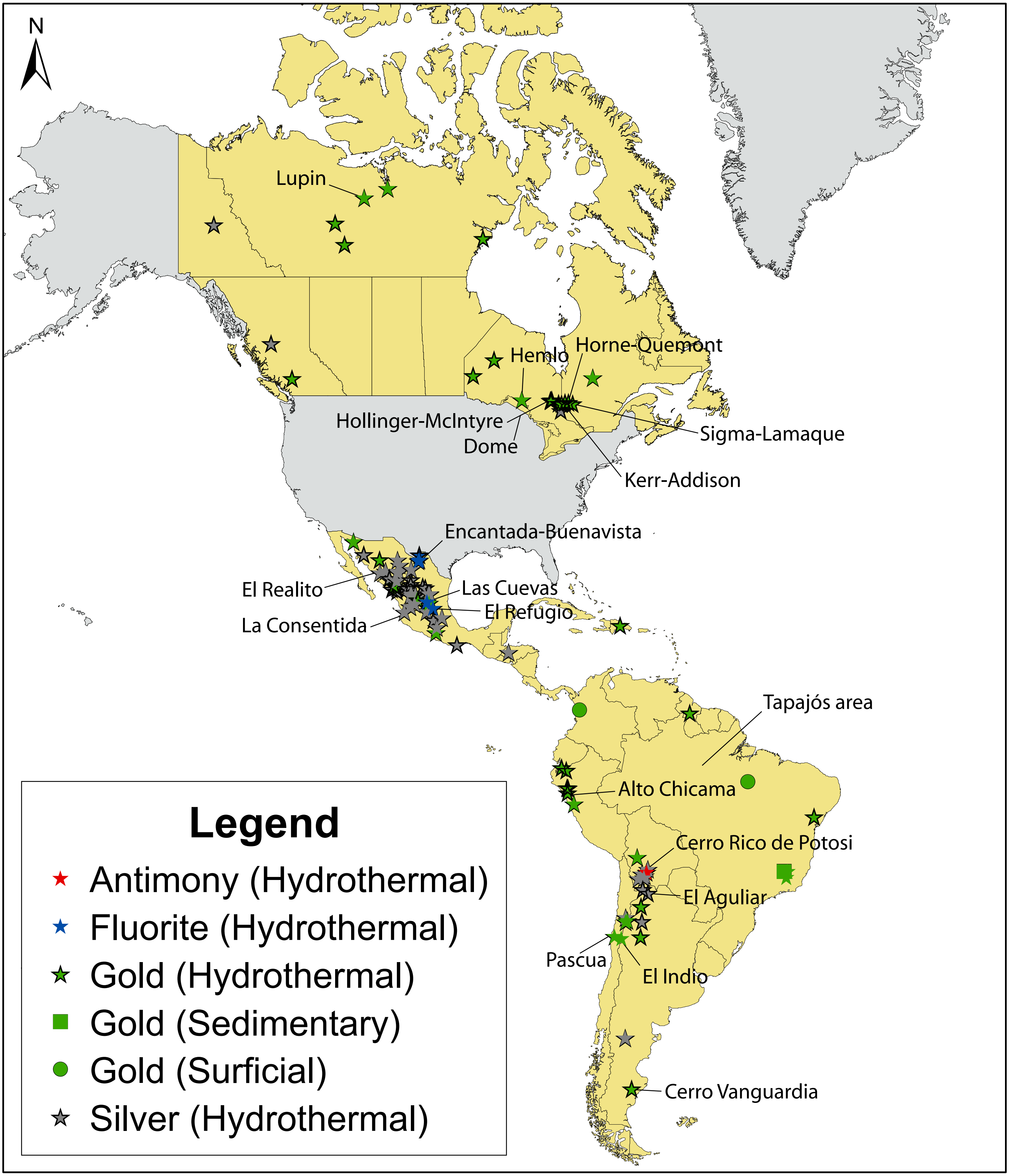

Figure 9c. Location and deposit type of major deposits of antimony, fluorspar (fluorite), gold, and silver.

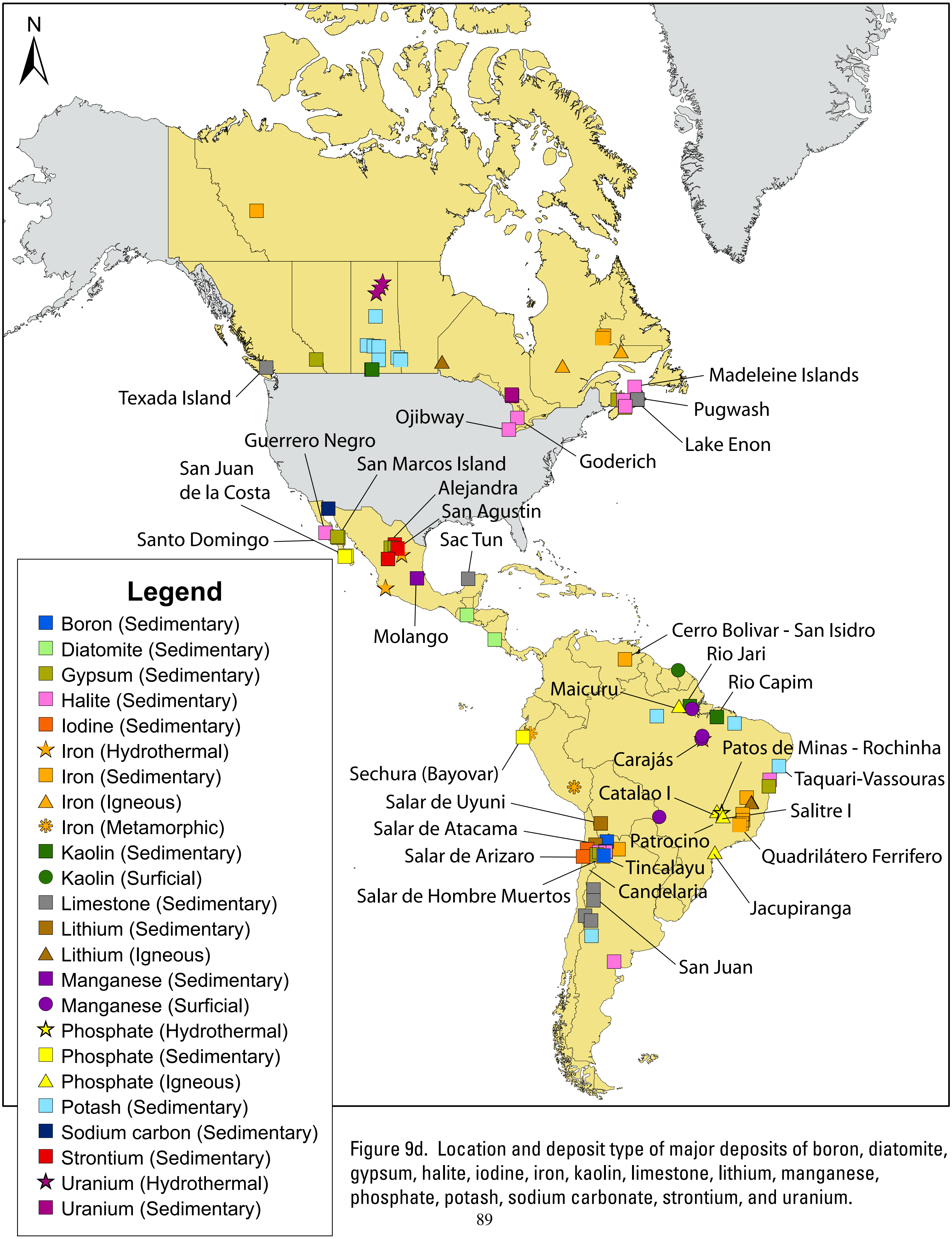

Figure 9d. Location and deposit type of major deposits of boron, diatomite, gypsum, halite, iodine, iron, kaolin, limestone, lithium, manganese, phosphate, potash, sodium carbonate, strontium, and uranium.

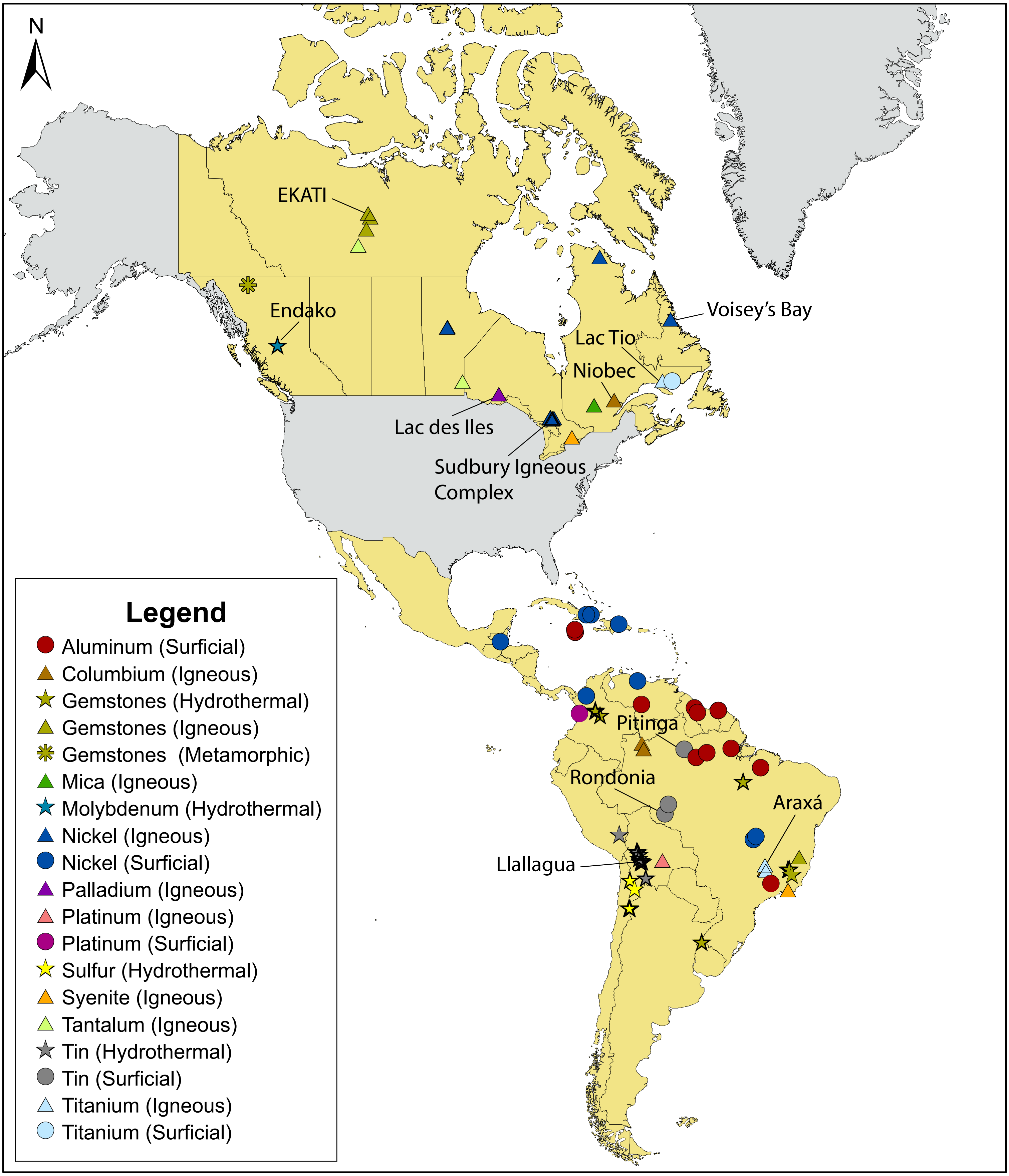

Figure 9e. Location and deposit type of major deposits of aluminum, columbium, gemstones, mica, molybdenum, nickel, palladium, platinum, sulfur, syenite, tantalum, tin, and titanium.

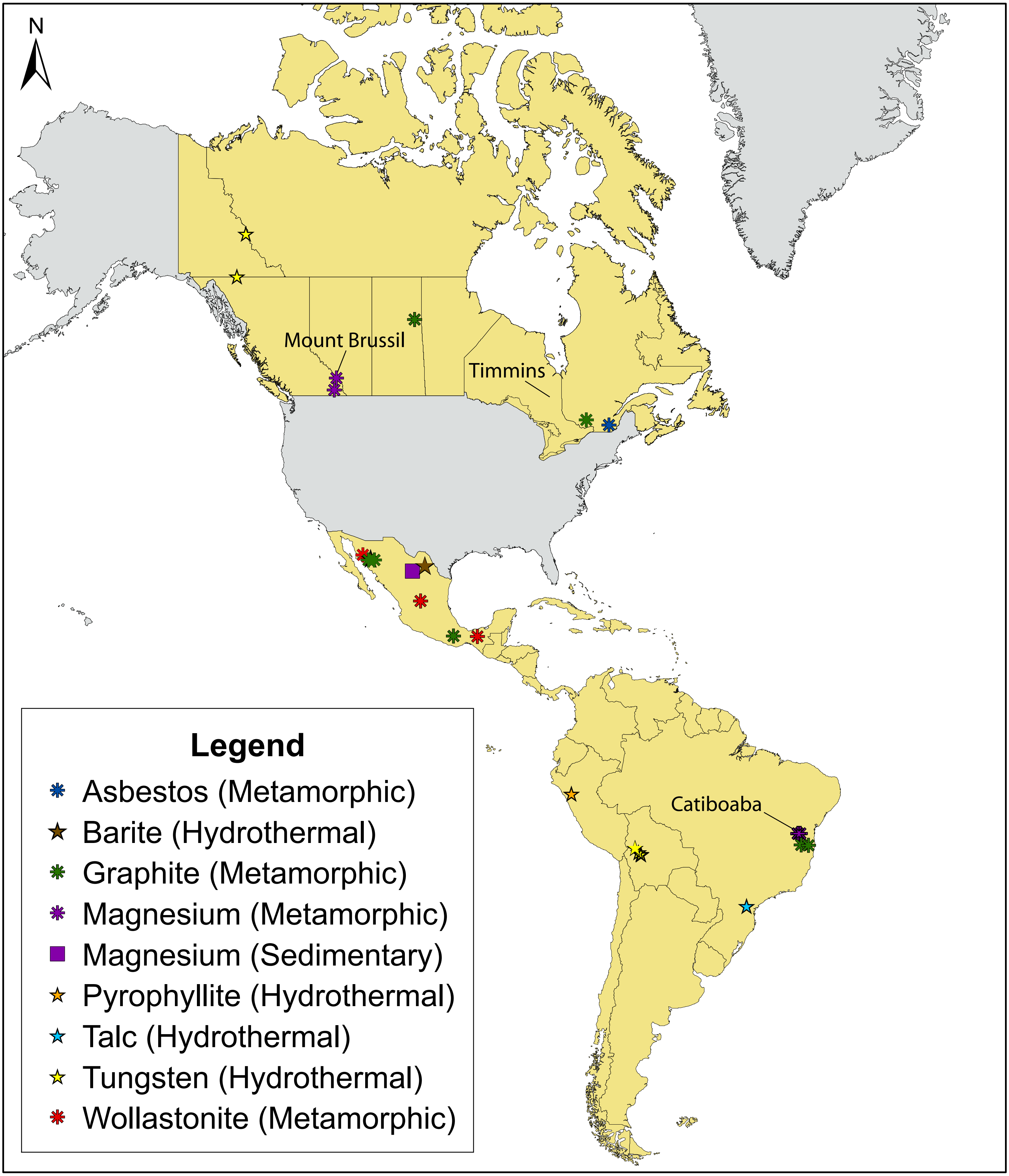

Figure 9f. Location and deposit type of major deposits of asbestos, barite, graphite, magnesium, pyrophyllite, talc, tungsten, and wollastonite.

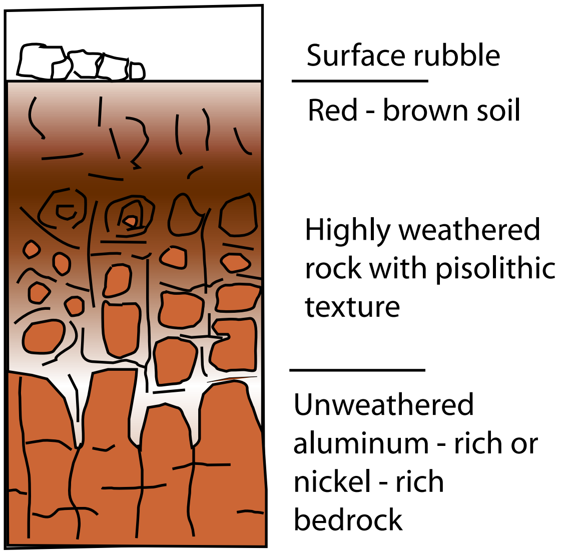

Figure 10a. Schematic laterite profile showing the progression of weathering effects on rock. Some commodities, such as aluminum and nickel, are enriched by weathering. Modified slightly from Elias (2002).

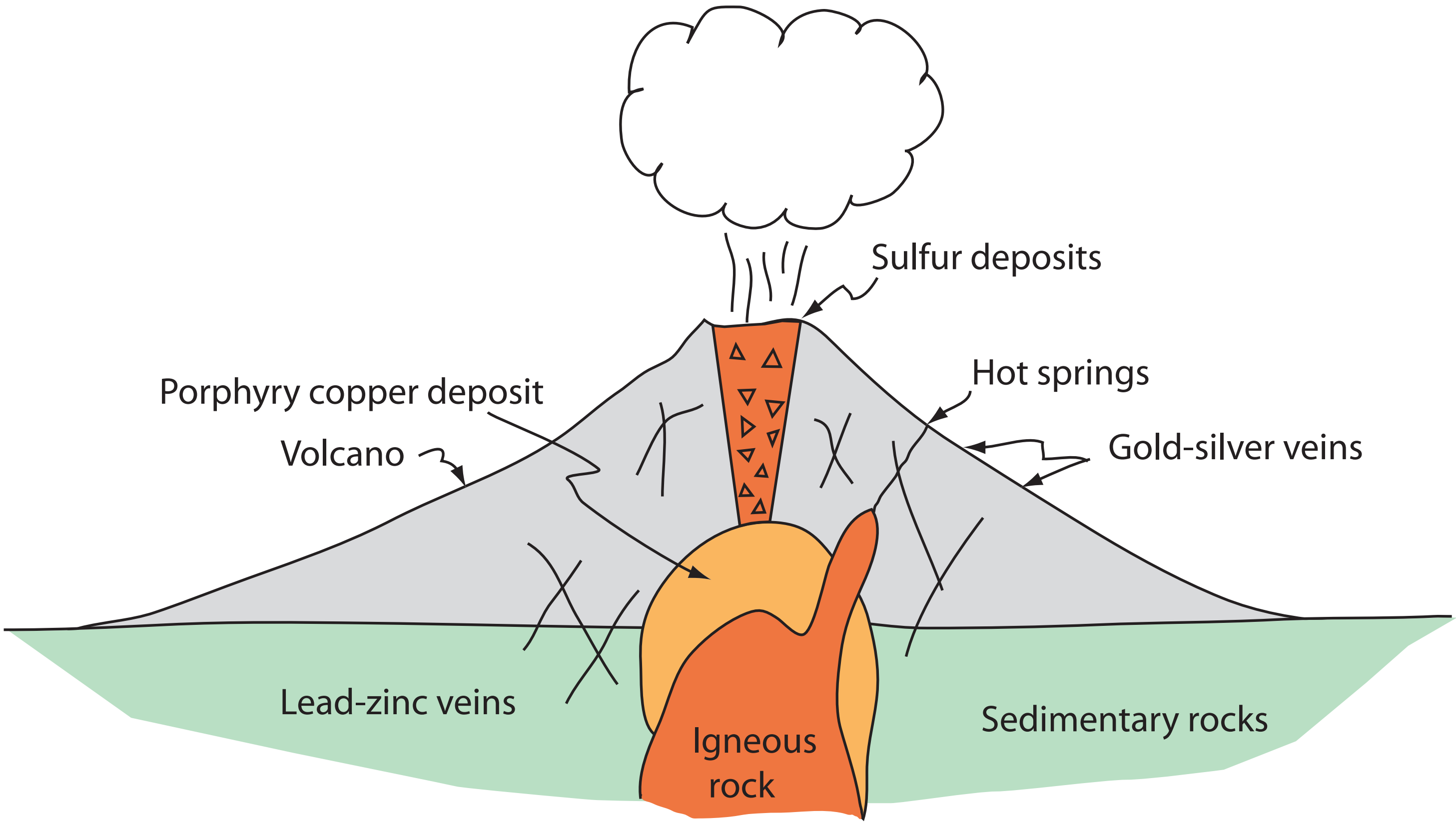

Figure 10b. Cross section of a stratovolcano showing the relative locations of porphyry copper deposits, lead-zinc veins, gold-silver veins, and sulfur deposits.

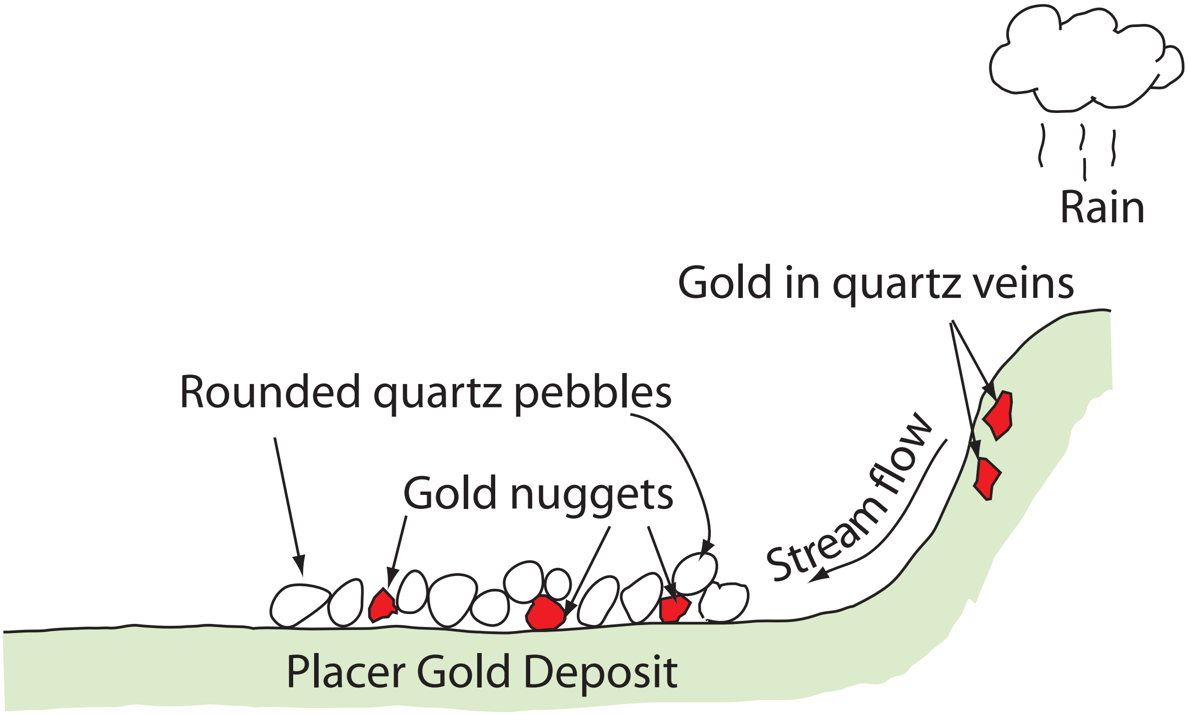

Figure 10c. Formation of placer gold deposits. Most gold is transported in hydrothermal fluids which travel through cracks in the earth. Veins are cracks filled by gold and the other chemical elements carried in by the hydrothermal fluids. Eventually, the veins may be exposed at the surface of the earth by weathering and erosion where running water can concentrate the heavy gold nuggets in placer (alluvial) deposits. These deposits form because of the gold's high weight and can be prospected with a gold pan or mined on a commercial basis with a dredge.

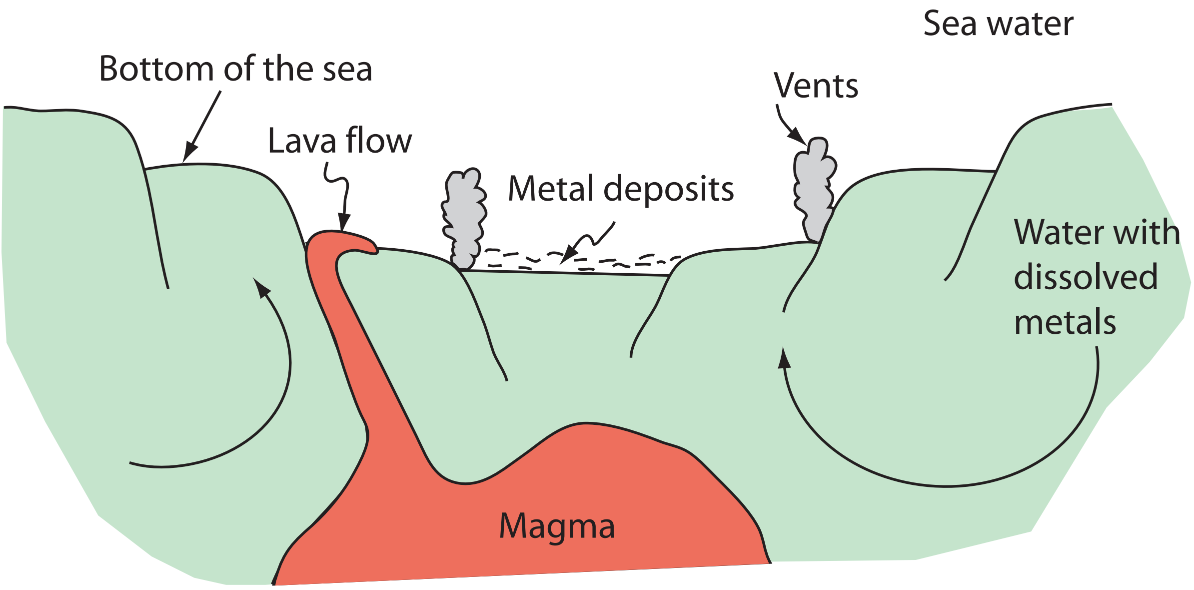

Figure 10d. Extensional tectonic setting where plates are moving away from each other. Magma (molten igneous rock) comes up the cracks and sometimes is erupted as submarine lava flows on the sea floor. The heat from the magma causes hydrothermal fluids (hot, salty water containing dissolved metals) to circulate in fractures in the rocks. The metal-bearing hydrothermal fluids react with the sea water and deposit metals to form mineral deposits.

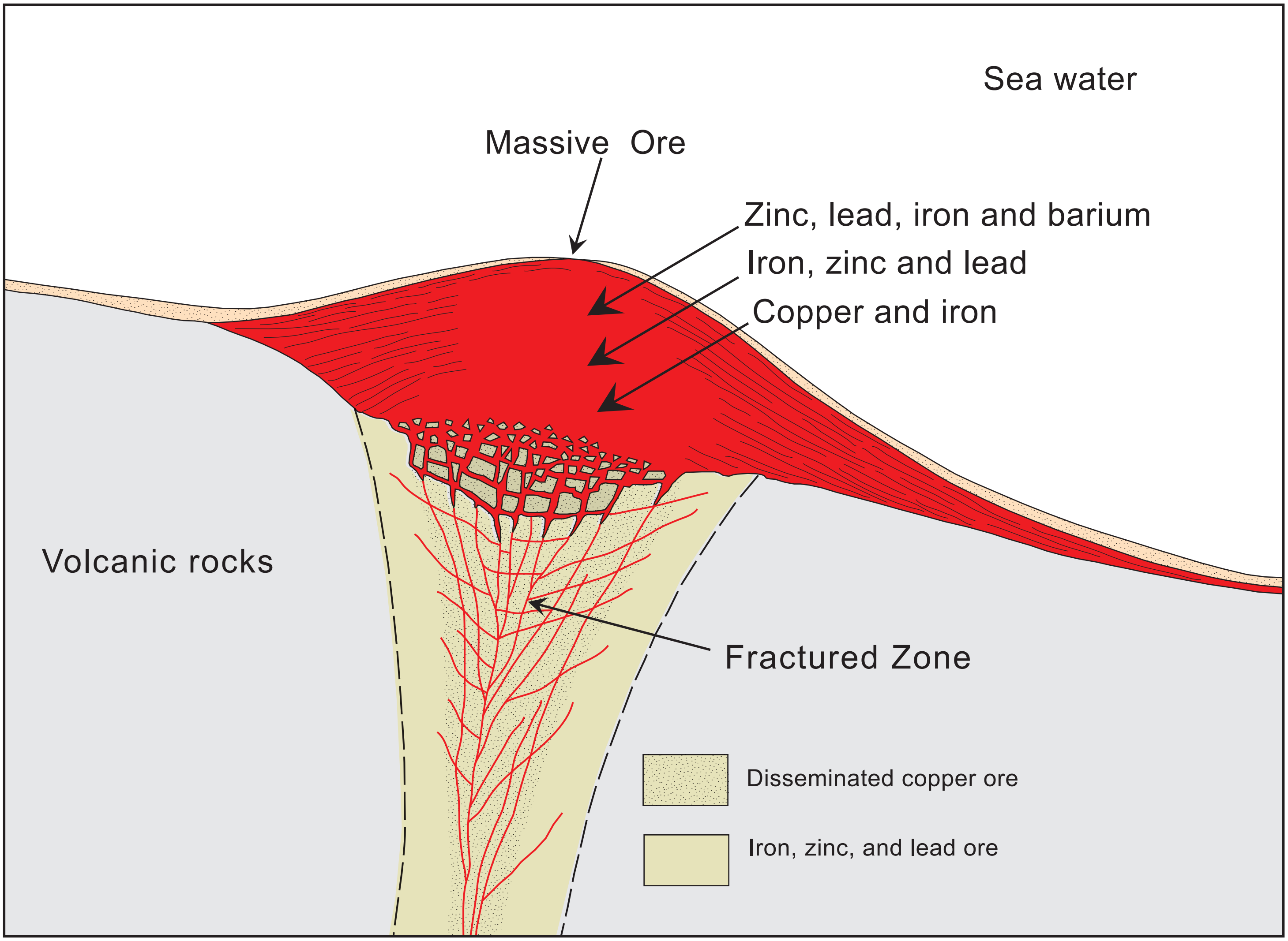

Figure 10e. Cross section schematically illustrating the characteristic features of volcanogenic massive sulfide (VMS) deposits. Hydrothermal fluids move upwards along fractures in volcanic rocks towards open water. When the hot hydrothermal fluids vent and mix with cold ocean water, iron, copper, lead, and zinc sulfide minerals form and collect as a mound on the sea floor. Ore minerals also can form in the fractures underlying the mound of sulfide minerals. Modified from Lydon (1988).

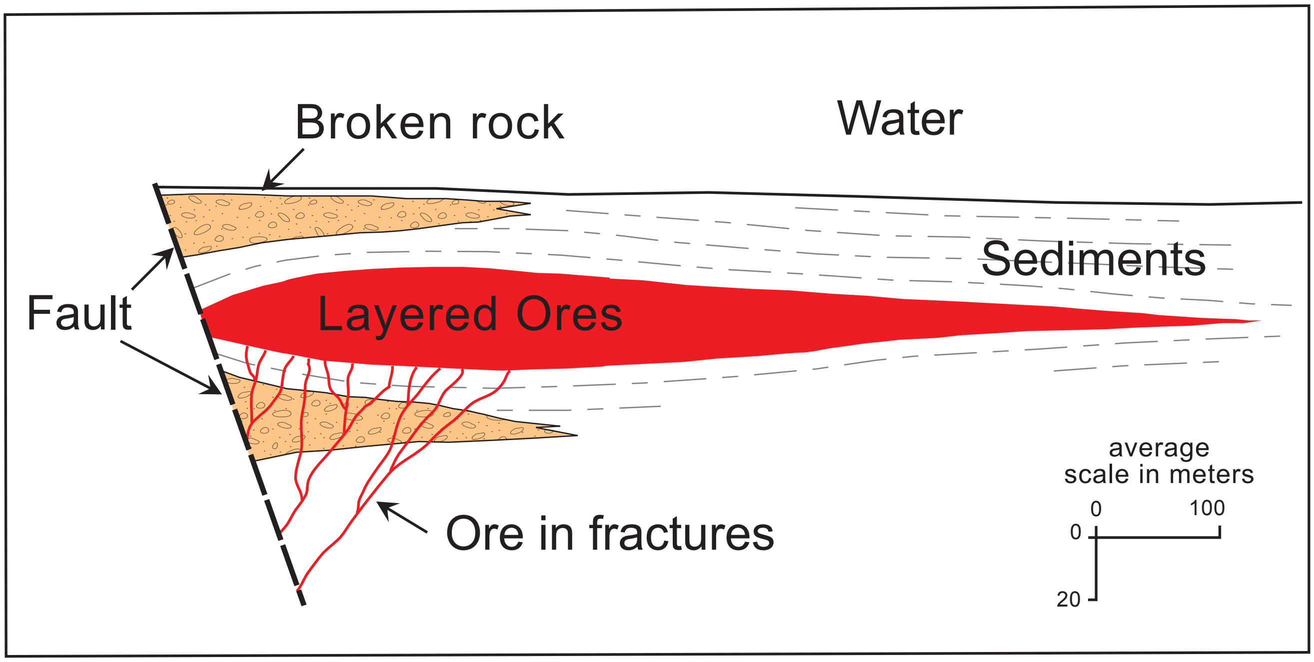

Figure 10f. Cross section schematically illustrating the characteristic features of sedex lead and zinc deposits. The fault is active during accumulation of the sediments and the ore minerals. Hydrothermal fluids move upwards along the fault and other fractures towards open water. Beds of broken rock form near the active fault by erosion of fault scarps or by explosions related to the venting of hydrothermal fluids into open water. Bedded ores consist of iron, lead, and zinc sulfide minerals that formed at or near the bottom of the sea from hydrothermal fluids that vented into open water from faults and fractures. Ores in fractures consist of iron, lead, and zinc minerals that were deposited by hydrothermal fluids moving through sediments. Modified from Lydon (1996).

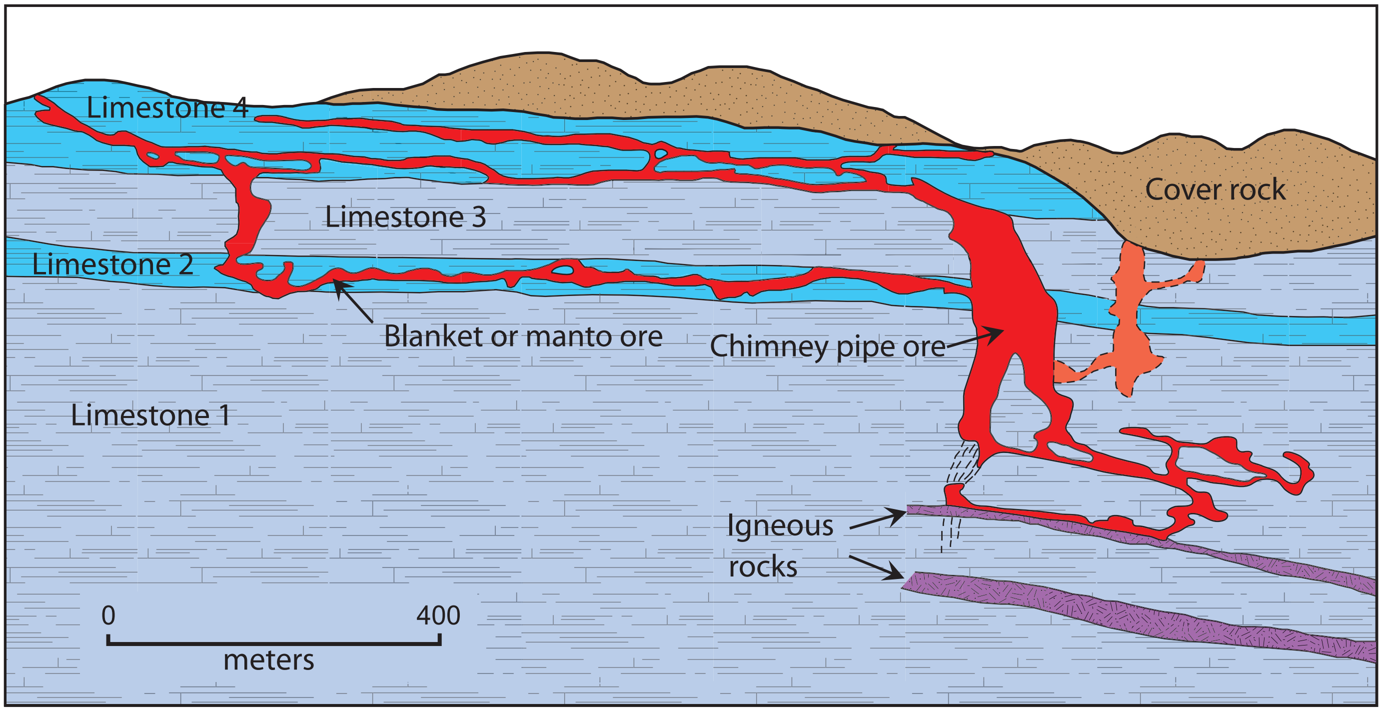

Figure 10g. Longitudinal section through the West Field, Santa Eulalia mining district of Mexico showing the distribution and shape of silver-zinc-lead ore bodies relative to sedimentary rock units. Hydrothermal solutions moved upward across all units forming vertical orebodies called chimneys. Hydrothermal solutions also moved preferentially along beds in limestone units 2 and 4, forming sheetlike orebodies called mantos. Modified from Maldonado (1991).

Figure 10h. Pink rhodochrosite (manganese, carbon, and oxygen) from Argentina. Polished slice through a stalactite shows growth rings. Pen for scale.

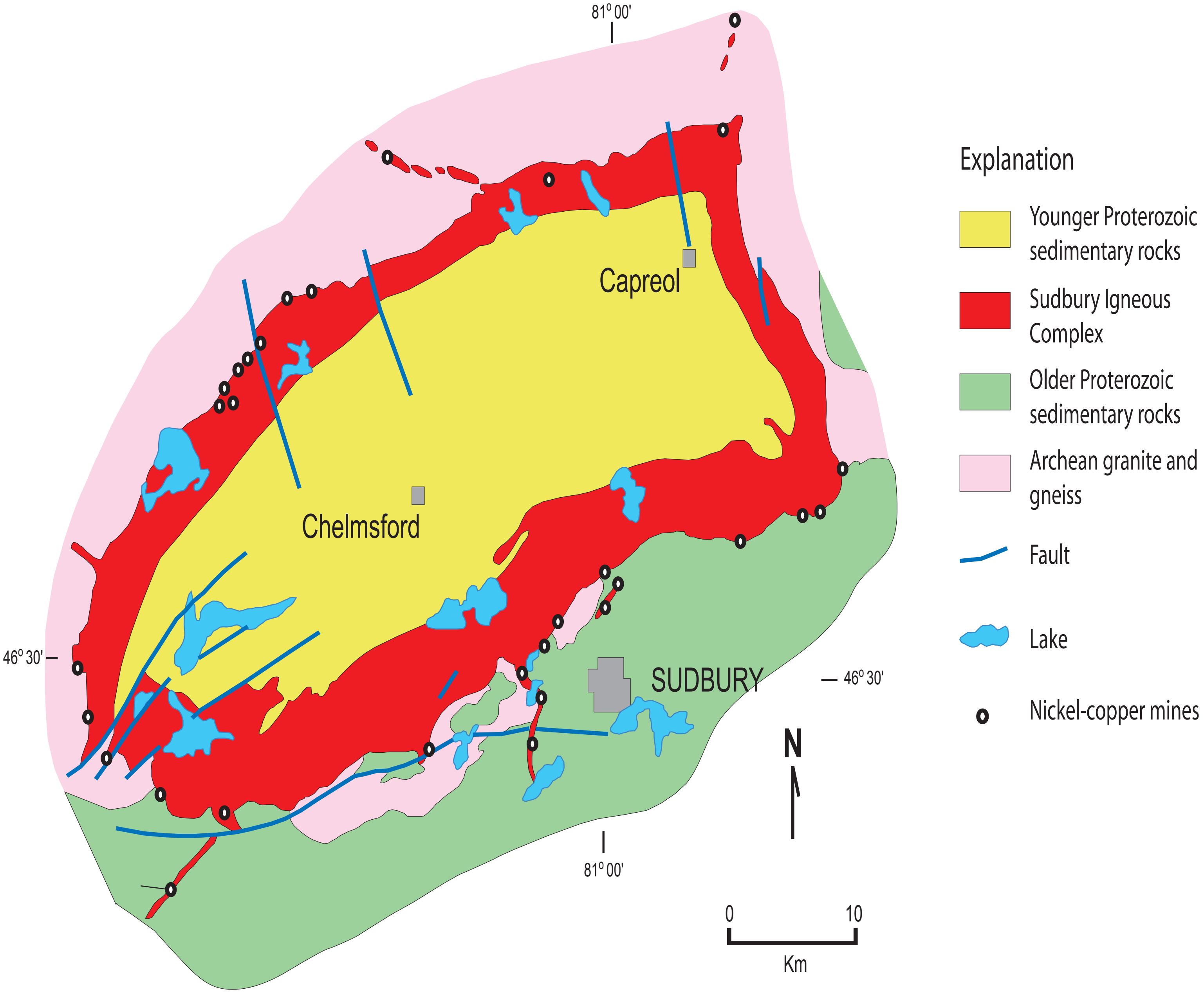

Figure 10i. Simplified geologic map of the Sudbury Igneous Complex, showing locations of some the more important nickel-copper mines. The Sudbury Igneous Complex formed in a meteor impact crater in Archean granite and gneiss and sedimentary rocks. Nickel-copper deposits occur near the contact of the Sudbury Igneous Complex with the Archean granite and gneiss and Proterozoic sedimentary rocks. The younger sedimentary rocks formed during and after the impact event, in part filling the crater. The elliptical shape of the Sudbury Igneous Complex is the result of deformation during the development of a younger orogen. Modified from Eckstrand (1996).

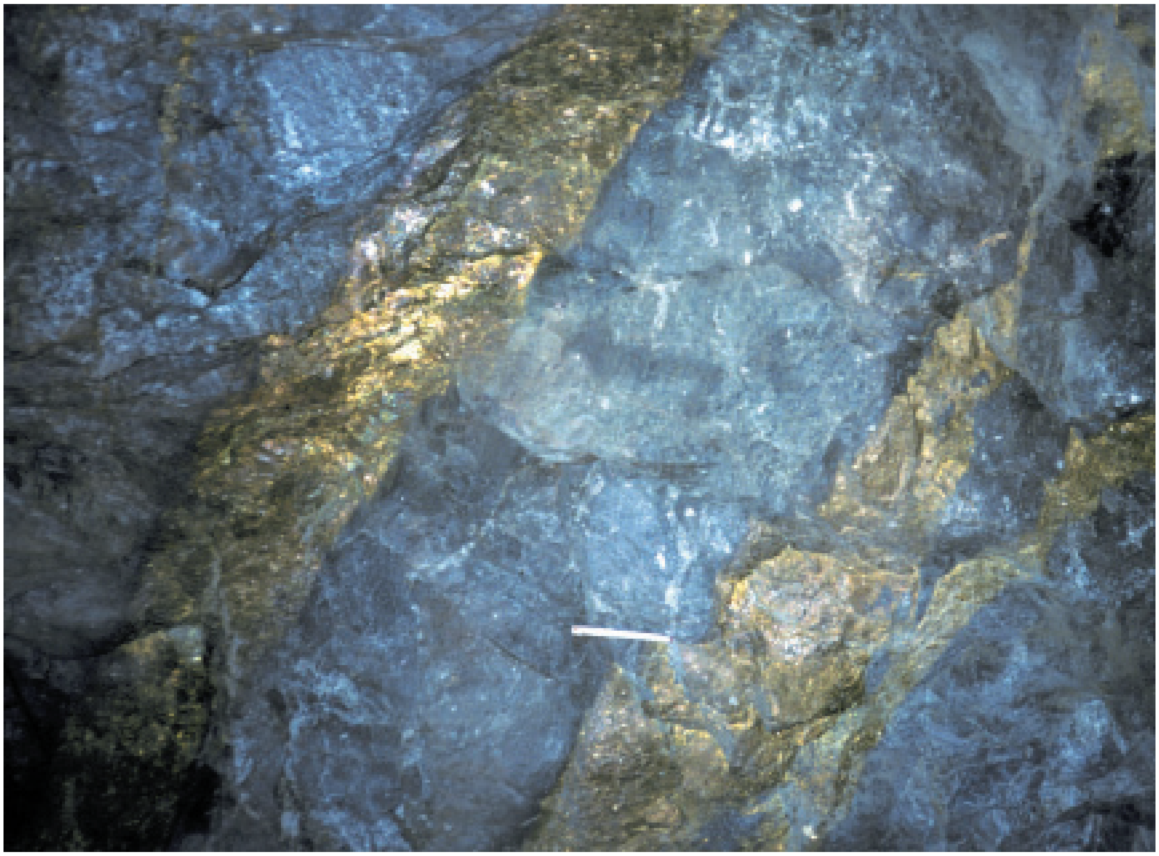

Figure 10j. Chalcopyrite-rich veins (yellow) cutting gneiss in the Sudbury Igneous Complex, Strathcona mine, Ontario. These veins formed as molten ore material enriched in sulfur, iron, copper, and platinum-group metals separated from the magmas that formed the Sudbury Igneous Complex and migrated into cracks in the rocks adjacent to magma intrusion. A pen (white object in lower center part of photo) provides a scale for the veins. [photo taken by Michael L. Zientek, July, 1985].

Figure 10k. Cerro Rico de Potosi, Bolivia, the world's biggest silver deposit. The extensive dumps of waste rock on the slopes of the volcanic dome are a result of mining silver and tin for more than 450 years.

Figure 10I. Purple amethyst quartz crystal from Brazil. Purple color results from traces of iron. Crystal grew as part of the lining of a large gas bubble inside of a lava flow. Crystal is 15 cm in diameter; a pen is shown for scale.

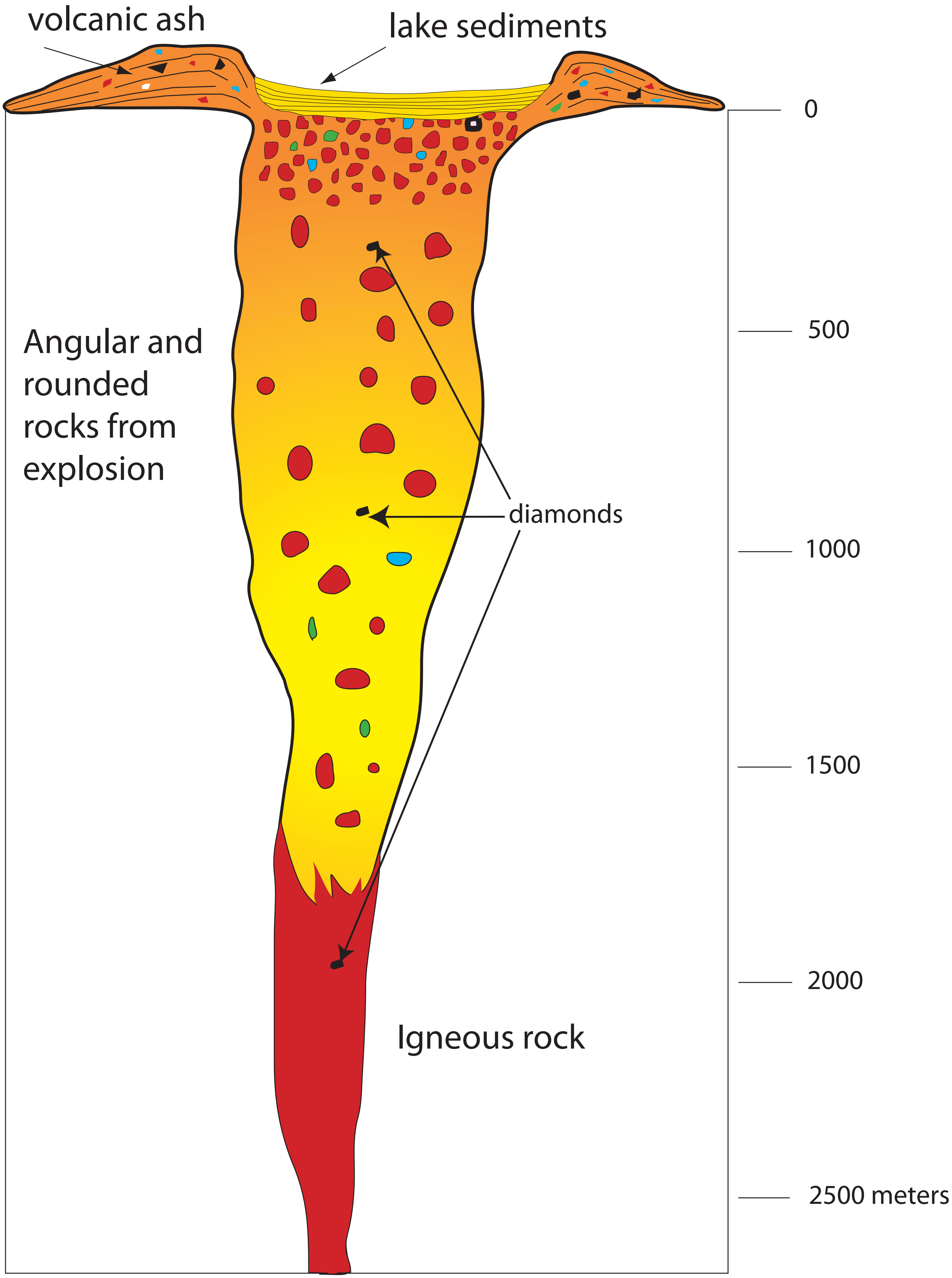

Figure 10m. Model of a diamond kimberlite pipe. These pipes form by explosive processes that originate in the Earth's mantle where pressures and temperatures are high enough to form diamonds. The diamonds are associated with a particular type of dark rock called a kimberlite.