VEIN AND GREISEN SN AND W DEPOSITS
(MODELS 15a-c; Cox and Bagby, 1986; Reed, 1986a,b)

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SUMMARY OF RELEVANT GEOLOGIC, GEOENVIRONMENTAL, AND GEOPHYSICAL INFORMATION

Deposit geology

Vein deposits consist of simple to complex fissure filling or replacement quartz veins, including discrete single veins, swarms or systems of veins, or vein stockworks, that contain mainly wolframite series minerals (huebnerite-ferberite) and (or) cassiterite as ore minerals (fig. 1). Other common minerals are scheelite, molybdenite, bismuthinite, base-etal sulfide minerals, tetrahedrite, pyrite, arsenopyrite, stannite, native bismuth, bismuthinite, fluorite, muscovite, biotite, feldspar, beryl, tourmaline, topaz, and chlorite (fig. 2). Complex uranium, thorium, rare earth element oxide minerals and phosphate minerals may be present in minor amounts. Greisen deposits consist of disseminated cassiterite and cassiterite-bearing veinlets, stockworks, lenses, pipes, and breccia (fig. 3) in gangue composed of quartz, mica, fluorite, and topaz. Veins and greisen deposits are found within or near highly evolved, rare-metal enriched plutonic rocks, especially near contacts with surrounding country rock; settings in or adjacent to cupolas of granitic batholiths are particularly favorable.

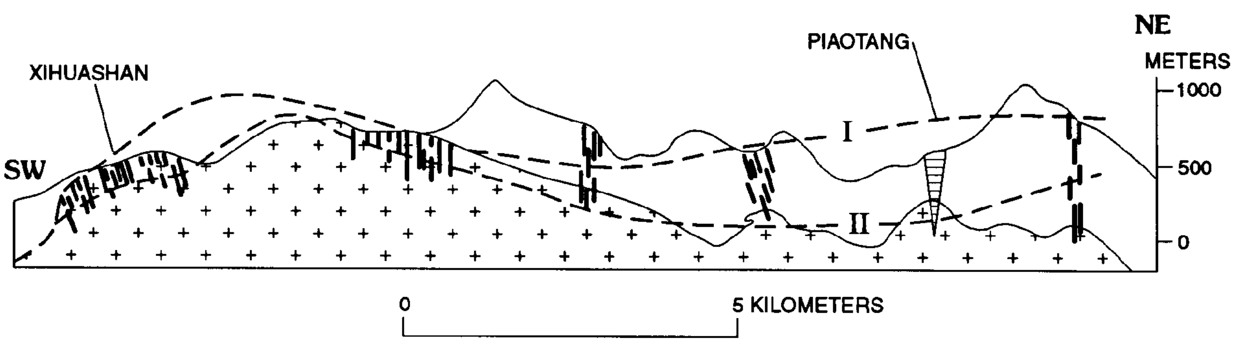

Figure 1. Generalized longitudinal section through the Xihuashan and Piaotang tungsten deposits in the Dayu district, China. Other vein systems are indicated by heavy lines. I, upper limits of ore zones; II, lower limits of ore zones. Patterned area is granite batholith. Unpatterned area is sedimentary and metamorphic rocks (from Elliott, 1992).

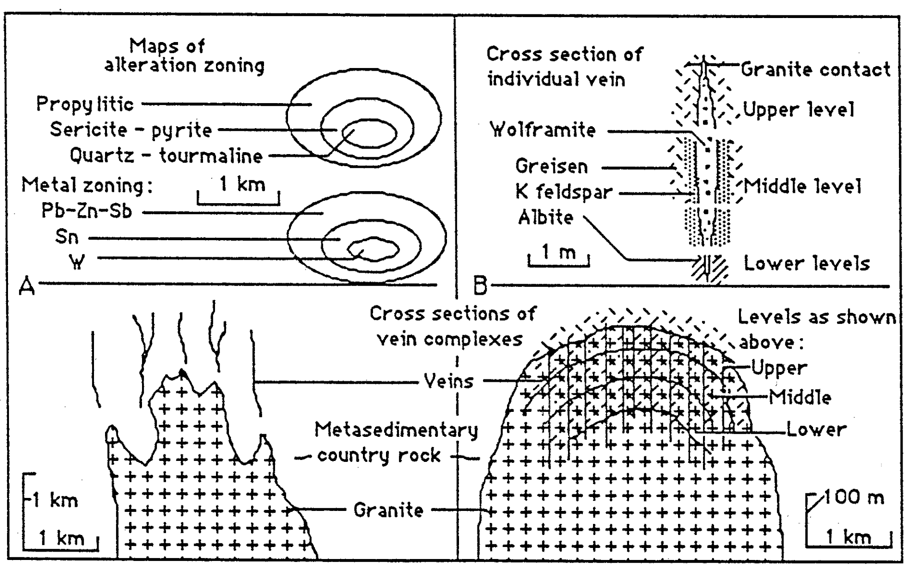

Figure 2. Maps and sections of tungsten vein deposits illustrating mineral and alteration zoning. *A*, Chicote Grande deposit, Bolivia; *B*, Xihuashan, China (from Cox and Bagby, 1986).

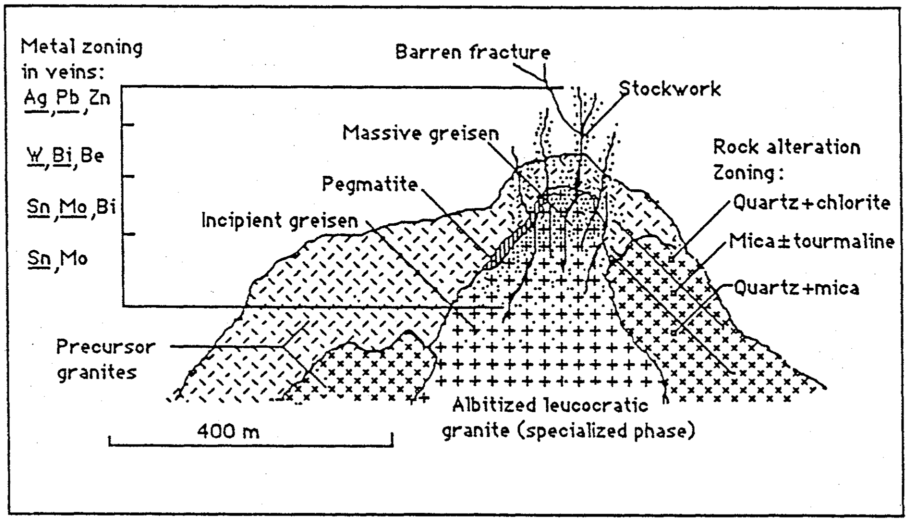

Figure 3. Diagrammatic cross section of a tin greisen (from Reed, 1986b).

Examples

Pasto Bueno, Peru (Landis and Rye, 1974); Panasqueira, Portugal (Kelly and Rye, 1979); Dayu, China (Tanelli, 1982; Elliott, 1992); Dajishan, China (Elliott, 1992); Cornwall, United Kingdom (Hosking, 1969); Herberton, Australia (Blake, 1972); Lost River, Alaska, United States (Sainsbury, 1964; Dobson, 1982); Erzgebirge, Czechoslovakia (Janecka and Stemprok, 1967); Baid al Jimalah and Silsilah, Saudi Arabia (du Bray and others, 1988; Kamilli and others, 1993).

Spatially and (or) genetically related deposit types

Associated deposit types (Cox and Singer, 1986) include tin skarn (Model 14b), tungsten skarn (Model 14a), tin replacement deposits (Model 14c), complex tin-silver-sulfide veins, Climax-type molybdenum deposits (Model 16), and molybdenum vein and greisen deposits (Model 16a, Kotlyar and others, 1995).

Potential environmental considerations

Both tin and tungsten are rare metals and have low abundances in the earth's crust. Consequently, the quantities of these metals that are mined are much smaller than other metals like copper, lead, and zinc. In addition, the United States is largely reliant on imports rather than domestic production. For example, in 1993, 81 percent of tin and 84 percent of tungsten consumed in the United States was imported (U.S. Bureau of Mines, 1994).

Potential for significant geoenvironmental impact is minor. Scarce data are available but the environmental impact is generally dependent on the sulfide mineral content of tungsten and tin ore. The principal ore minerals; wolframite series, scheelite, and cassiterite; are moderately to highly resistant to physical and (or) chemical weathering and tend to concentrate in eluvial or alluvial deposits. The mobility of tin in natural environments is low (Rose and others, 1979). Cassiterite, the principal tin ore mineral, is highly resistant to both chemical and physical weathering and can be transported long distances from source areas to be concentrated in stream, beach, or marine placers. The mobility of tungsten is intermediate to low in neutral pH water (Rose and others, 1979) but tungsten concentrations in alkaline water, including some hot springs and saline lakes (Krauskopf, 1969), may be elevated. Extraordinary concentrations of 40-64 mg/l tungsten have been reported for brines of Searles Lake, Calif.; hot springs feeding Searles Lake contain as much as 240 μg/l tungsten (Carpenter and Garrett, 1959). The principal ore minerals, wolframite and scheelite, are similar to cassiterite in resistance to chemical weathering but are somewhat less resistant than cassiterite to physical weathering. Tungsten ore minerals are brittle and readily break down into fine particles that disperse into fine-grained sediment. Therefore, tungsten placers are found only near lode sources.

The sulfide mineral content of tin and tungsten ore is generally low and seldom exceeds a few percent. In this ore, the principal sulfide minerals that have significant acid-generating capacity are pyrite, chalcopyrite, and arsenopyrite. Host rock and ore may be enriched in molybdenum, thorium, and uranium; these elements may be mobilized in highly acid environments.

The majority of deposits are in terrane consisting of plutonic granitic rocks and pre-intrusive clastic sedimentary or metasedimentary rocks that have low acid buffering capacity. A potential hazard in regions containing these types of deposits is the presence of high abundances of radon inside buildings because most of these deposits are hosted by rock with elevated uranium abundances. For example, in the United Kingdom, the highest abundances of radon are found in the counties of Cornwall and Devon (Scivyer and others, 1993), a region long famous for production of tin and tungsten from lode deposits associated with granitic plutons (Hosking, 1969). Radon is a health hazard in some underground Cornish mines (Dungey and others, 1979).

Mining, milling, and smelting have low to moderate environmental impact. Milling generally involves gravity, flotation, and magnetic separation; reagents used are generally benign. Concentrates are of high unit value and can be shipped long distances to processing plants and smelters. Smelters are not particularly harmful but may release sulfur dioxide.

Exploration geophysics

Magnetic, gravity, and radiometric surveys can be used to define areas in which prospective leucocratic granites may be present (Hoover and others, 1992). These granites tend to be associated with gravity and magnetic lows and have elevated radioelement (uranium, thorium, and potassium) abundances. Airborne radiometric surveys may identify exposed parts of prospective plutons. Remote sensing techniques may help define exposed leucocratic granites or detect altered areas. At the district or deposit scale and in the less common case of high sulfide ore, audio magnetotelluric techniques, induced polarization, and electric-field-ratio profiling can be used to map variations in rock resistivity due to sulfide mineral content.

References

Hosking (1969), Kelly and Rye (1979), Cox and Bagby (1986), Reed (1986a,b), du Bray and others (1988), and Elliott (1992).

GEOLOGIC FACTORS THAT INFLUENCE POTENTIAL ENVIRONMENTAL EFFECTS

Deposit size

The most common tungsten vein deposits are quartz-wolframite veins. These range from less than 0.1 to about 10 million metric tonnes of ore containing 0.4 to 1.6 percent WO_3; median size and grade is 680,000 metric tonnes and 0.81 percent WO_3 (Menzie and others, 1992). Tin vein deposits range from less than 0.01 to about 10 million metric tons of ore containing 0.5 to 2.5 percent tin; median size and grade is 240,000 metric tonnes and 1.3 percent tin (Menzie and Reed, 1986a). Tin greisen deposits are generally larger than tin or tungsten vein deposits and range from about 0.8 to 70 million metric tons containing 0.2 to 0.5 percent tin; median size and grade is 7.2 million metric tonnes and 0.28 percent tin (Menzie and Reed, 1986b).

Although the size of individual deposits may be small to moderate, the tendency of these deposits to cluster can profoundly affect the environment, economy, and culture of a region, as in Cornwall, U.K.; Dayu district, Jiangxi Province, China; and the Erzgebirge, Czechoslovakia and Germany.

Host rocks

Tin and tungsten deposits exhibit a close spatial association with granitic plutonic rocks, especially late-stage, highly evolved, specialized biotite and (or) muscovite (S-type or A-type) granites and leucogranites. Small to moderate-sized cupolas of larger subsurface plutons are especially favorable hosts; deposits may be endo- or exocontact. Exocontact deposits usually are in pelitic and arenaceous sedimentary or metamorphic rocks and within the contact metamorphic aureole of a pluton. Most endocontact deposits, including tin greisens, and many tin and tungsten veins, are in or near cupolas and ridges developed on the roof or along margins of granitoids.

Surrounding geologic terrane

Surrounding terrane is variable but generally dominated by felsic plutonic rocks and sequences of pelitic/arenaceous sedimentary or metamorphic rocks. Regions with tin and tungsten deposits, such as southeastern China, commonly have a geologic history of multiple orogenic and tectonic events. Genesis of highly-evolved specialized granites associated with tin-tungsten deposits often involves several stages of magmatism. Regional structures may localize emplacement of favorable granitoids, whereas local structures, including faults and breccia zones, may localize ore deposition.

Wall-rock alteration

Alteration directly associated with ore includes greisenization, albitization, and (or) tourmalinization. Greisen is a type of phyllic alteration (including sericitic) characterized by Li-F-bearing micas, topaz, tourmaline, fluorite, and quartz. Kaolinization, a type of argillic alteration, is widespread in parts of Cornwall, U.K. Silicification is also important, especially in the contact aureoles of granitic plutons and cupolas. Other alteration types include microclinization, chloritization, and hematization. Zoned alteration has been identified in some tungsten vein systems, including the Xihuashan mine, Dayu district, China, where upper parts of veins have well developed greisen zones; middle parts have quartz-rich greisen and silicification; and lower parts have K-feldspar-rich greisen. Higher tungsten grades are found in the upper and middle portions of veins (Wu and Mei, 1982).

Most alteration assemblages associated with tin and tungsten vein and greisen deposits have low acid buffering capacity. Zones of chloritic or feldspathic alteration, usually minor in extent, have low to moderate acid buffering capacity.

Nature of ore

Most vein deposits consist of individual veins or sets of veins that are individually minable. Some mines and districts contain hundreds of such veins. The mineralized zone at the Xihuashan mine in the Dayu district, China, consists of more than 650 veins arranged in three sets of steeply dipping parallel veins (Elliott, 1992). The veins have an average thickness of 0.4 m (maximum of 3.6 m), average length of 150 m (maximum of 1,075 m), and vertical extent of about 250 m. Other deposits consist of bulk-minable vein stockworks, as do some parts of the tungsten deposit at Baid al Jimalah in Saudi Arabia (Kamilli and others, 1993) and the Hemerdon deposit in U.K. (Mining Magazine, 1979). Some are truly disseminated in greisenized granite cupolas, such as Silsilah tin deposit in Saudi Arabia (du Bray and others, 1988). Less commonly, tin greisens may have the form of pipes, lenses, or irregular breccia zones.

Deposit trace element geochemistry

Most tin and tungsten vein and greisen deposits have a close spatial association with highly evolved peraluminous, S-type, A-type, ilmenite series, or metallogenically specialized granitic rocks. These granites have high contents of specific rare elements (F, Rb, Li, Sn, Be, W, and Mo) relative to normal granites. They may also have elevated concentrations of B, Nb, Ta, U, Th, and REE. Mineralized veins and greisens are usually extremely enriched in lithium, fluorine, rubidium, boron, and beryllium and also contain sulfide and sulfosalt minerals of Cu, Pb, Zn, Bi, Ag, As, and Sb. Their sulfur and heavy metal contents, however, are usually small.

Ore and gangue mineralogy and zonation

Minerals listed in decreasing order of abundance; potentially acid-generating minerals underlined.

Tungsten: Vein mineralogy varies from simple, consisting almost entirely of quartz and wolframite, to complex as at Pasto Bueno, Peru, and Panasqueira, Portugal. At Pasto Bueno, the principal vein minerals are wolframite, tetrahedrite-tennanite, sphalerite, galena, and pyrite in a gangue of quartz, fluorite, sericite, and carbonate. Minor amounts of molybdenite, chalcopyrite, bornite, arsenopyrite, enargite, stolzite, scheelite, zinnwaldite, topaz, tungstite, and native arsenic are present (Landis and Rye, 1974). At Panasqueira, more than 50 vein-forming minerals, including sulfide, sulfosalt, oxide, carbonate, silicate, phosphate, and tungstate minerals, have been identified (Kelly and Rye, 1979). In general, the most common minerals in tungsten vein deposits in addition to quartz are: wolframite, molybdenite, bismuthinite, pyrite, pyrrhotite, arsenopyrite, bornite, chalcopyrite, scheelite, cassiterite, beryl, mica, and fluorite.

Studies of zoning and paragenesis in many tungsten vein deposits (Landis and Rye, 1974; Kelly and Rye, 1979; Wu and Mei, 1982) indicate that, in general, tungsten minerals form earlier, at higher temperatures, and possibly closer to an igneous source than sulfide and carbonate minerals. A general mineral precipitation sequence from silicate to oxide, sulfide, and finally carbonate minerals is common to many deposits.

Tin: The mineralogy of tin vein deposits is extremely varied and complex, especially where sulfide and sulfosalt minerals are present. The most common minerals are cassiterite, wolframite, arsenopyrite, molybdenite, hematite, scheelite, beryl, galena, chalcopyrite, sphalerite, stannite, and bismuthinite in addition to ubiquitous quartz.

The Cornwall region (U.K.) is frequently cited as one of the classic areas of ore zoning, with Sn, Cu, Pb-Zn, Fe-(Mn, Sb) zones distributed sequentially around individual intrusive centers and arranged according to depth to granite contacts. The zones are roughly parallel to granite-metasediment contacts and may represent paleoisogeother mal surfaces (Guilbert and Park, 1986). The tin zone, the deepest zone, is generally found from depths of about

1,300 m within the granite to a short distance outside the granite contacts in metasedimentary rocks (Guilbert and Park, 1986).

In most greisen deposits, polyphase mineralization and multiple mineralizing centers control ore distribution and render identification of zoning patterns quite difficult. Nevertheless, the idealized disseminated greisen deposit associated with an individual cupola is zoned with respect to distributions of Sn, Mo, As, Bi, W, Be, Ag, Pb, and Zn (Hosking, 1969; Reed, 1986b). Abundances of elements toward the beginning of this list are greatest in hydrothermally altered rocks nearest mineralized cupolas, whereas abundances of elements toward the end of the list are greatest in distal parts of mineralized areas. Alteration zoning consists of albitization below the ore; pervasive greisenization with quartz-muscovite-topaz ± fluorite ± tourmaline; and chloritic alteration. Pyrite and arsenopyrite are common in the strongly greisenized zones. In addition to cassiterite and wolframite, other minerals include molybdenite, bismuthinite, native bismuth, pyrrhotite, bornite, chalcopyrite, scheelite, beryl, tetrahedrite-tennanite, sphalerite, galena, enargite, hematite, stannite, sulphostannates, siderite, and calcite. Complex uranium, thorium, rare earth element oxide and phosphate minerals are commonly present in minor amounts.

Mineral characteristics

Tin-tungsten veins are commonly coarse-grained; grain sizes as much as several cm are common and, in the Dajishan mine, China, wolframite crystals up to 1 m in length are found in quartz veins (Elliott, 1992). Very large wolframite crystals are also present at deposits in eastern Nevada. Ore and gangue minerals in tin greisens are finer-grained. Quartz is the most common gangue mineral in both veins and greisen and may account for 90 percent or more of vein fillings. Ore and gangue minerals other than quartz are commonly enclosed or capsulated by quartz thus protecting them from oxidation and weathering by surface and ground water. Post-mineralization faults, however, may expose ore and gangue, including sulfide minerals, to oxidation and solution in mine water.

Secondary mineralogy

Secondary tin and tungsten minerals are rare and, if present, have limited geoenvironmental impact. Varlamoffite ($(Sn,Fe)(O,OH)_2$), a complex oxidation product of stannite, has been reported from numerous localities. The oxidation and weathering of wolframite or scheelite deposits can produce small amounts of tungstite ($WO_3 \cdot H_2O$) and (or) ferritungstite ($(W,Fe)(O,OH)_3$). Where the sulfide and (or) sulfosalt mineral content is high oxidation and weathering may result in the formation of secondary and supergene minerals, some of which, including goethite, limonite, jarosite, chalcanthite, and others, are soluble (underlined).

Topography, physiography

Tin and tungsten vein and greisen deposits are found in areas of varied topography. Granitic plutonic rocks associated with these deposits tend to form positive areas of moderate to high relief. Silica-rich rocks such as greisens, stockwork vein zones, and quartz veins form knobs or linear ridges in areas of low relief.

Hydrology

Tin and tungsten veins and greisens are commonly vuggy and are zones of high permeability relative to surrounding granitic or metasedimentary rocks. In addition, post-mineralization faulting may follow veins and large, individual veins may contain major water courses, making control of mine drainage a potential problem.

Mining and milling methods

Mining: Tin and tungsten veins and greisens are mined by conventional underground and open-pit methods. Most production is probably from underground mines because of the relative small size, narrow widths, and depths of orebodies. Cut-and-fill stoping and open stoping are probably most common underground methods.

Ore dressing: Tungsten--Gravity and flotation, using organic compounds, methods are most commonly used. Xanthate collectors are used to float sulfide minerals from scheelite ore; subsequently, fatty acids and soaps are used to float scheelite. Fatty acids are also used to float wolframite. Magnetic and electrostatic methods are also used. Magnetic methods are used to separate wolframite and cassiterite. Tin--Gravity is only practical way of preparing cassiterite concentrates. Complex sulfide ore that contains a significant amount of tin in sulfide or sulfosalt minerals requires special treatment that may involve flotation.

Because of the friable nature of both tin and tungsten minerals, a significant amount of these minerals may be lost in finer grained material (slime) during milling. Care must be exercised in the initial crushing, grinding, and first-stage separation to prevent excessive sliming.

Metallurgy: Tungsten--Tungsten concentrates, containing approximately 60-65 percent WO_3 (scheelite), can be combined with coke and steel in an electric furnace and reduced to ferrotungsten; alternatively, concentrates can be treated chemically to produce intermediate products or tungsten metal (as powder). Because of tungsten's high melting temperature (3,400°C), chemical decomposition and purification are used, instead of pyrometallurgy, to produce tungsten metal. This process involves three steps: (1) decomposition of tungsten minerals, (2) purification of tungstic oxide, and (3) production of metal powder (Li and Wang, 1955). Most current production, trade, and consumption of tungsten, however, involves an intermediate product called ammonium paratungstate (APT). The preparation of APT is a chemical process involving calcination, pressure digestion, filtration and purification, solvent extraction, and crystallization (Lassner, 1982). Tin--Smelting tin from cassiterite concentrates generally involves either a (1) carbo-thermic process of heating tin concentrate with carbon or (2) fuming process in which tin concentrate is heated with sulfur or sulfide minerals to volatilize stannous sulfide. A chloride volatilization process is also used in tin smelting (Harris, 1979).

ENVIRONMENTAL SIGNATURES

Drainage signatures

Because of the low solubility of tin and tungsten minerals, high values in water are not expected. In the unusual case, in which the primary ore sulfide mineral content is high, highly acidic water with elevated abundances of iron, aluminum, fluorine, and variable copper and zinc may characterize drainage from mines or mine wastes. Highly acid water can also mobilize fluorine and uranium, whose abundances are commonly elevated in tin and tungsten ore.

Metal mobility from solid mine wastes

In general, metal mobilities from solid mine wastes are low. When the sulfide and (or) sulfosalt mineral content of ore is moderate to high, metal mobilities increase due to production of low pH water and formation of soluble secondary minerals.

Soil, sediment signatures prior to mining

Soil and stream sediment may have elevated tin and tungsten contents (tens to hundreds of ppm) and may contain anomalous abundances of elements characteristic of specialized granites (F, Rb, Be, Nb, Ta, Mo, U, Th, Li, and REE). Other possible pathfinder elements are As, Bi, B, Cu, Pb, and Zn.

Potential environmental concerns associated with mineral processing

Potential hazards include:
(1) High silica dust blowing from unstable mill tailings.
(2) Possible high concentrations of U, Th, Be, Mo, As, P, and REE in mill tailings and smelter waste due to primary enrichments of these elements in host rock and ore and the gravity and magnetic separation methods used in milling, which concentrate high specific gravity minerals.
(3) Waste from APT process includes alkaline effluents and residues containing Mo, P, As, U, Th, and REE (Raddatz and others, 1988).

Smelter signatures

Tin smelters may release sulfur dioxide and other volatile elements, including arsenic, fluorine, chlorine, and others, present in ore or used in smelting process.

Climate effects on environmental signatures

The effects of various climatic regimes on the geoenvironmental signature specific these deposits are not known. However, in most cases the intensity of environmental impact associated with sulfide-bearing mineral deposits is greater in wet climates than in dry climates. Acidity and total metal concentrations in mine drainage in arid environments are several orders of magnitude greater than in more temperate climates because of the concentrating effects of mine effluent evaporation and the resulting "storage" of metals and acidity in highly soluble metal-sulfate-salt minerals. However, minimal surface water flow in these areas inhibits generation of significant volumes of highly acidic, metal-enriched drainage. Concentrated release of these stored contaminants to local watersheds may be initiated by precipitation following a dry spell.

Geoenvironmental geophysics

Audio magnetotelluric techniques, induced polarization, and electric-field-ratio profiling can be used to detect hydrothermally altered areas and the presence of ground water. Gamma ray spectroscopy can be used to measure uranium and thorium abundances and radon can be determined by several special collectors used in conjunction with laboratory analysis.

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