RHYOLITE-HOSTED SN DEPOSITS
(MODEL 25h; Reed and others, 1986)

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SUMMARY OF RELEVANT GEOLOGIC, GEOENVIRONMENTAL, AND GEOPHYSICAL INFORMATION

Deposit geology

Rhyolite-hosted tin deposits are in some multiple, overlapping, Tertiary-age flow domes (fig. 1). These deposits include cassiterite (SnO_2) and can be divided into four types: (1) sparse amounts of cassiterite in lithophysae, miarolitic cavities, and tiny gash veins, (2) in argillized zones and well-defined gash veins and anastomosing veinlets that vary widely in orientation and size, (3) in veins and stockwork-like areas of reticulate veinlets in the distal edges of rhyolite flow domes and in the underlying tuffs and ash-flow tuffs, and finally as (4) placer accumulations of "wood-tin" and crystalline cassiterite. Cassiterite was deposited in a near-surface environment characterized by extreme temperature and pr essure gradients. Conditions of tin deposition vary among localities, ranging from high-temperature vapor-dominated systems to low temperature and low pressure fluid-dominated systems. The largest of these deposits are in Mexico; in the United States no deposit of this type is currently in production nor have any produced a significant quantity of ore.

Examples

"Mexican-type tin deposits", for example, those in the states of Durango and Zacatecas; Black Range tin district, Sierra and Catron Counties, N. Mex.; one locality in Thomas Range, Juab County, Utah.

Spatially and (or) genetically related deposit types

No associated deposit types (Cox and Singer, 1986) are known, but geochemistry suggests that rhyolite hosting these deposits may be the extrusive equivalent of igneous rocks that host Climax-molybdenum type deposits (Model 16).

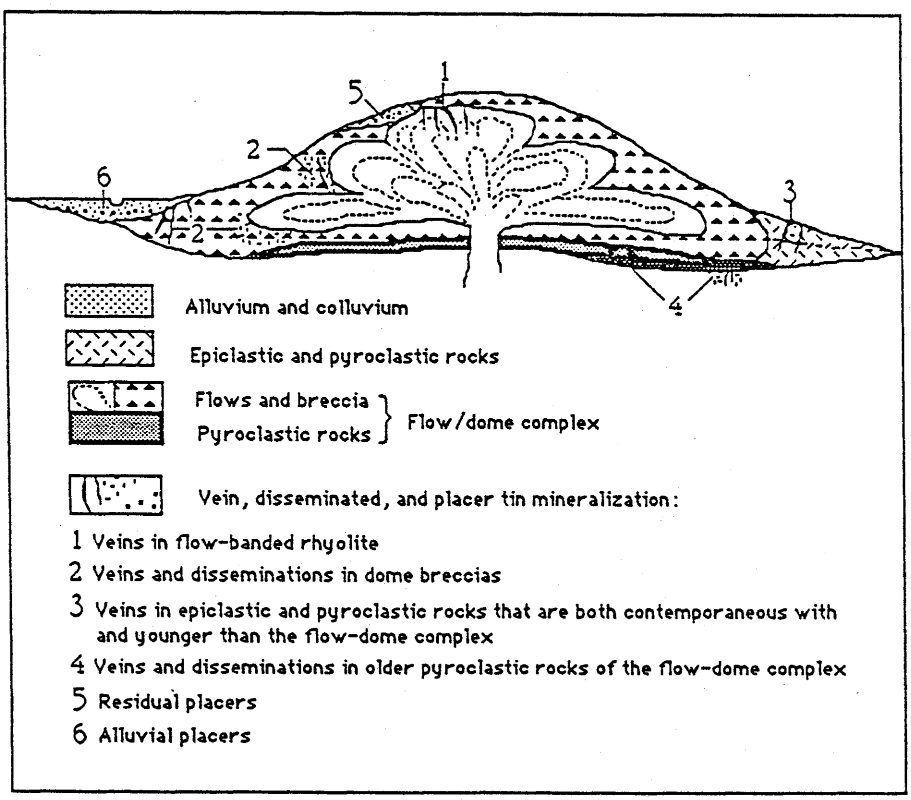

Figure 1. Diagrammatic cross section of rhyolite-hosted Sn deposit showing relationship of cassiterite concentrations to rhyolite dome (from Reed and others, 1986).

Potential environmental considerations
(1) Placer mining of known natural cassiterite concentrations in the United States and Mexico is essentially complete. Known deposits are not economically viable at the present time; in addition, small tonnages of these deposits probably preclude future economic viability. Similarly, associated low tonnage lode deposits are even less likely to be exploited. Environmental impact associated with past mining activities in the United States is limited. Acid-mine-drainage-generation potential associated with these deposits is minimal.
(2) Most old placer workings have generally been stabilized following mining activities; these present little or no environmental concern.
(3) The solubility of tin in surface water is very low; consequently it has virtually no impact on the environment.
(4) Arsenic-bearing minerals (for instance, durangite, beudandtite, and hidalgoite) associated with lode, rhyolite-hosted tin deposits are rare and volumetrically minor; incorporated arsenic is present in relatively insoluble mineral phases. Thus, arsenic associated with these deposits is of limited environmental concern.

Exploration geophysics
The high radioelement content of most host rhyolites can be identified using gamma-ray methods; similarly low thermal inertia related to elevated glass content can be used to identify these rhyolites. Resistivity studies can be used to identify argillic alteration zones. Most alteration zones associated with tin-bearing rhyolite are areas of intense vapor-phase activity. Vapor-phase altered rocks have local argillic alteration overprints. Multispectral remote sensing techniques can identify mineralized or altered areas.

References
Geology: Maxwell and others (1986), Duffield and others (1990), and Rye and others (1990).
Mineralogy: Foord and others (1985), Foord and others (1989), and Foord and others (1991).

GEOLOGIC FACTORS THAT INFLUENCE POTENTIAL ENVIRONMENTAL EFFECTS
Deposit size
Tin-placer deposits associated with rhyolite lava domes are very small (less than 100 tons). Associated vein-type deposits are also small; some veins may be as much as 30 to 40 cm wide and extend 100 m or more. Zones of reticulate veinlets may be several thousand square meters in size. In these zones, veinlets may be spaced every few tens of centimeters to several meters and much of the intervening rock is altered and mineralized.

Host rocks
These deposits are in high-silica, metaluminous to peraluminous, rhyolite flow domes and associated pyroclastic rocks.

Surrounding geologic terrane
Rhyolite lava domes with associated tin deposits are present in large volcanic fields, as much as several thousand km^2, within stable, intraplate continental crust.

Wall-rock alteration
Host rocks to rhyolite-hosted tin deposits experience vapor-phase alteration that locally results in argillic assemblages; mineralized vein rock is argillically altered.

Nature of ore
Cassiterite is present as well-formed crystals in high-temperature lithophysal and miarolitic cavities, and in some small veinlets. This type of cassiterite, deposited by vapor phase processes, is characterized by anomalous contents of iron, antimony, and titanium. Low temperature, fluid-dominated, veins and veinlets contain microcrystalline cassiterite that pseudomorphs hematite. Cassiterite deposited at low temperatures and under fluid-dominated conditions is wood tin that contains minor to major amounts of indium, arsenic, zinc, silicon, and lead as well as some antimony and iron.

Deposit trace element geochemistry
Rhyolite-hosted tin deposits contain elevated abundances of Nb, Th, U, Sb, Li, As, Zn, Pb, and rare earth elements (fig. 2).

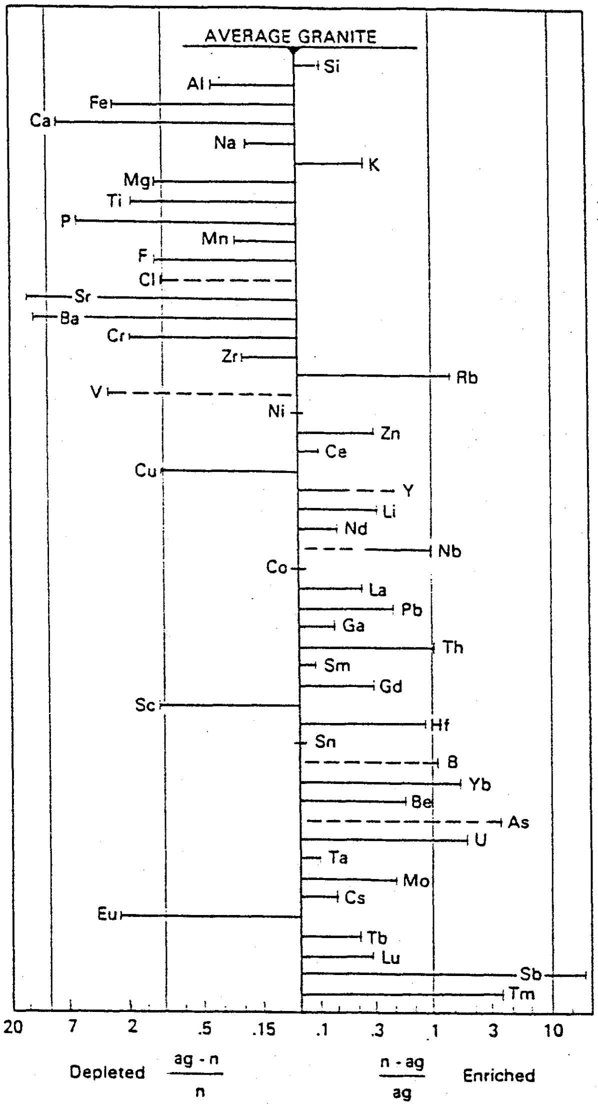

Figure 2. Diagram showing relative ratios of depletion or enrichment of elements in Taylor Creek Rhyolite compared to concentration in an average granite (Krauskopf, 1979). ag=average granite, n=average amount in Oligocene Taylor Creek Rhyolite.

Ore and gangue mineralogy and zonation

Potentially acid-generating minerals are underlined.

Type 1 deposits: cassiterite, hematite, pseudobrookite, bixbyite, braunite, topaz, quartz, cristobalite, tridymite and sanidine.

Type 2 deposits: hematite, cassiterite, quartz, fluorite, sanidine, heulandite, stilbite, chabazite, maxwellite, squawcreekite, tilasite, gasparite-(Ce), chernovite-(Y), calcite, beryl, "chernovite-(Ce)", cerianite, and others.

Type 3 deposits: quartz, hematite, sanidine, cristobalite, tridymite, cassiterite (crystalline and wood tin), durangite, beudantite, vanadinite, stolzite, calcite, hidalgoite, jarosite , alunite, opal, fluorite, smectite, cryptomelane, and todorokite.

Type 4 deposits: wood tin, varlamoffite, clay minerals.

Mineral characteristics

Cassiterite forms individual and intergrown euhedral crystals to several mm across. It is also intergrown with hematite, which it sometimes replaces. Wood tin is present in masses, as large as 4 kg, characterized by a banded and colloform layered structure.

Secondary mineralogy
Only secondary arsenate and arsenate-phosphate minerals have potentially deleterious environmental effects. Because sulfide minerals are very scarce in rhyolite-hosted tin deposits, secondary iron and manganese oxide minerals, usually produced by weathering and alteration of sulfide minerals, are also sparse.

Topography, physiography
All known rhyolite-hosted tin deposits lie in mountainous terrane with as much as several hundred meters of relief. Placer deposits are located on relatively gently sloping rhyolite domes and associated ash-flow tuff deposits. In a tropical climate, rhyolite-hosted tin deposits may have negative relief because of the rapid decomposition of rhyolite to bauxite and aluminum-rich soil.

Hydrology
Known deposits are located in a desert environment, where rainfall and consequent surface water runoff are limited. The rhyolites are very porous, permeable, and well drained.

Mining and milling methods
Cassiterite-bearing placers associated with tin-bearing rhyolite have been mined by hand. Primitive gravity separation techniques have been used to beneficiate some ore.

ENVIRONMENTAL SIGNATURES
Virtually nil. Low abundances of arsenic have been detected in water draining type 3 deposits. The climate in all known areas that contain rhyolite-hosted tin deposits is arid. Thus, potentially hazardous elements are little mobilized. Flash floods capable of significant placer deposit redistribution and widespread detrital cassiterite dissemination are rare.

Drainage signatures
Drainage basins in the principal United States and Mexican areas that contain rhyolite-hosted tin deposits contain sediment enriched in hematite, bixbyite, pseudobrookite, and cassiterite. Although specific data are lacking, rhyolite that hosts tin deposits contains elevated fluorine contents; accessory fluorite and topaz are the principal residences of fluorine in these rocks. Under some conditions, fluorine may be leached from these minerals leading to elevated concentrations in associated ground water.

Metal mobility from solid mine wastes
Metal mobility from these deposits is limited because they contain very minor quantities of sulfide minerals whose oxidation generates acid, metal-charged drainage.

Soil, sediment signatures prior to mining
Because cassiterite is resistant to mechanical and chemical degradation, soil and sediment associated with rhyolite-hosted tin deposits contains elevated tin abundances. Stream sediment collected from drainages in the Black Range, N. Mex., contain elevated abundances of Sn, B, Be, La, Pb, Y, and Zr (Steven Smith, unpub. data, 1995). Nonmagnetic heavy-mineral concentrates derived from these sediments contain elevated abundances of these elements plus Bi, Mo, Sb, W, Ti, and occasionally As. Stream sediment associated with rhyolite-hosted tin deposits in the Wah Wah Mountains, Utah, contains elevated abundances of a number of metals, including tens of ppm beryllium, tens of ppm niobium, and tens to hundreds of ppm tin; nonmagnetic heavy-mineral concentrates derived from these sediments also contain elevated abundances of some metals, including thousands of ppm tin, hundreds of ppm niobium, tens of ppm molybdenum, and, in addition, may contain thousands of ppm thorium (Detra and others, 1986; Duttweiler and Griffits, 1989).

Potential environmental concerns associated with mineral processing
No data.

Smelter signatures
Smelting tin ore derived from rhyolite-hosted deposits could produce anomalous amounts of indium, arsenic, antimony, and possibly other metals.

Climate effects on environmental signatures
No data; however, because cassiterite is resistant to mechanical and chemical degradation and because the sulfide mineral content of rhyolite-hosted tin deposits is low, deposits of this type located in different climate regimes probably have similar, minimal environmental signatures.

Geoenvironmental geophysics
Acid water related to jarosite- or alunite-enriched areas that may be associated with rhyolite-hosted tin deposits can be identified by ground or airborne geophysical surveys. Surficial acid water produces color anomalies on airborne or satellite imagery. Subsurface acid water can produce low resistivity anomalies identifiable from resistivity surveys. Surfaces characterized by enhanced radioactivity, such as might be present in waste piles associated with rhyolite-hosted tin deposits, can be identified by gamma ray spectrometry.

Acknowledgments.--Steven M. Smith and Karen D. Kelley provided information concerning the geochemistry of stream sediment associated with rhyolite-hosted tin deposits in the Black Range, N. Mex., and Wah Wah Mountains, Utah, respectively.

REFERENCES CITED

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

Detra, D.E., Arbogast, B.F., and Duttweiler, K.A., 1986, Analytical results and sample locality map of stream-sediment, heavy-mineral-concentrate, and rock samples from the southern Wah Wah Mountains, Utah: U.S. Geological Survey Open-File Report 86-161, 60 p.

Duffield, W.A., Reed, B.L, and Richter, D.R., 1990, Origin of rhyolite-hosted tin-mineralization: evidence from the Taylor Creek rhyolite, New Mexico; Economic Geology, v. 85, p. 392-398.

Duttweiler, K.A., and Griffits, W.R., 1989, Geology and geochemistry of the Broken Ridge area, southern Wah Wah Mountains, Iron County, Utah: U.S. Geological Survey Bulletin 1843, 32 p.

Foord, E.E., Hlava, P.F., Fitzpatrick, J.J., Erd, R.C., and Hinton, R.W., 1991, Maxwellite and squawcreekite, two new minerals from the Black Range Tin District, Catron County, New Mexico, U.S.A., Neues Jahrbuch Miner. Mh., H.8, p. 363-384.

Foord, E.E., Maxwell, C.H., and Hlava, P.F., 1989, Mineralogy of the Black Range Tin District, Sierra and Catron Counties, New Mexico (abs.): New Mexico Geology, v. 11, no. 2, 39-40.

Foord, E.E., Oakman, M.R., and Maxwell, C.H., 1985, Durangite from the Black Range, New Mexico, and new data for durangite from Durango, and Cornwall: Canadian Mineralogist, v. 23, p. 241-246.

Krauskopf, K.B., 1979, Introduction to Geochemistry (2nd edition): New York, McGraw-Hill, 721 p.

Maxwell, C.H., Foord, E.E., Oakman, M.R., and Harvey, D.B., 1986, Tin deposits in the Black Range Tin District; New Mexico Geological Society Guidebook, 37th Field Conference, Truth or Consequences, p. 273-281.

Reed, B.L., Duffield, Wendell, Ludington, S.D., Maxwell, C.H., and Richter, D.H., 1986, Descriptive model of rhyolite-hosted Sn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 168.

Rye, R.O., Lufkin, J.L., and Wasserman, M.D., 1990, Genesis of the rhyolite-hosted tin occurrences in the Black Range, New Mexico, as indicated by stable isotope studies; Geological Society of America Special Paper 246, p. 233-250.