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Tin, tungsten, and tantalum mineralization – more than just the result of magmatic fractionation

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Primary Sn, W, and/or Ta mineralization is closely related to highly evolved granitic rocks. Not all highly evolved granitic rocks show associated mineralization, which implies that magmatic processes (e.g., fractionation, phase separation) certainly are necessary, but not sufficient. Instead, the potential of highly evolved granites to form Sn, W, and/or Ta mineralization may be primarily related to their source rocks and the melting of these source rocks.

The formation of Sn, W, and/or Ta mineralization involves a sequence of processes that operate in different tectonic settings and that may be widely separated in time, i.e., (i) source enrichment, (ii) source accumulation, and (iii) metal mobilization from the source. The sequence of these processes controls the distribution of mineralization in belts (and gaps within these belts). Magmatic processes and interaction of the melts and fluids with the wall rocks at emplacement level, however, control size, grade, shape, and kind (vein, greisen, skarn) of mineralization.

(i) Intense chemical alteration of silicate rocks at the surface results in the preferential loss of most feldspar-bound elements (e.g., Na, Ca, Sr, and Pb) and in the residual enrichment of elements incorporated in or adsorbed on clay minerals (e.g., Li, K, Rb, Cs, Sn, and W). Thus, exogenic processes produce some of the hallmark geochemical signatures of tin granites that are also obtained by extreme magmatic fractionation of granitic melts. Intense chemical alteration occurs in tectonically stable areas with limited topography, as for instance in the interior of large continental masses.

(ii) Source accumulation involves two separate processes, i.e., sedimentary and tectonic accumulation. Sedimentary accumulation occurs when these blankets of chemically intensely altered sediments are redistributed from the “top” of the continent to the margins of the continent during supercontinent fragmentation. Tectonic accumulation may occur when passive-margin sedimentary packages are reworked in an active margin setting. Source accumulation may be particularly important when delta deposits become tectonically stacked.

(iii) The nature of heat source controls the type of melting of the crustal source rocks and the partitioning of metals between melt and restite. Sn and W are preferably bound to biotite and are distributed into the melt during biotite consumption at high melting temperature. Ta is enriched in muscovite that melts at lower temperature. High melting temperatures are only possible by heat input from the mantle by (a) mantle-derived melts in subduction settings, (b) emplacement of ultrahigh-temperature metamorphic rocks that had been subducted to mantle depth during continental collision, and (c) mantle-derived melts in extensional settings. Internal heating in orogenically thickened crust only generates minimum-temperature melts. The age of mineralization reflects the event of heat input.

The superposition of source enrichment (on supercontinent), source accumulation (at continent margin), and heat input (at plate boundary) explains both (i) the distribution of Phanerozoic primary tin, tungsten, and tantalum mineralization and (ii) their irregular distribution along these belts, (iii) their contrasting age within a particular belt, (iv) their relation to contrasting tectonic settings within a single belt, and (v) their presence on both sides of major sutures.