Palaeozoic tin ± tungsten deposits in eastern Australia

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EXPLORATION MODEL

Examples
Greisen style, Collingwood (Queensland); Vein style, Aberfoyle (Tasmania); Breccia pipes, Ardlethan (New South Wales); Skarn, Mount Lindsay (Tasmania); Replacement, Renison (Tasmania)

Target
• Replacement deposits, massive greisens, porphyry-style stockworks (underexplored in Australia).
• Target 50–100 Mt @ >0.5% Sn. Replacement deposits have the highest grade; greisens and stockworks potentially offer the largest tonnages.
• Sn as cassiterite—mineralogically simple ores.
• Sn dominant metal, but possibly also W and Ag.

Mining and treatment
• Open cut or underground, depending on location, grade and tonnage.
• Cassiterite grain size and liberation characteristics significantly affect recovery (sliming).
• Sn in silicates, sulphides and oxides (Sn-bearing magnetite) irrecoverable.
• Arsenic causes smelter difficulties: Pb & WO3 undesirable concentrates.

Regional geological criteria
• Areas of known Sn mineralisation.
• Highly fractionated, felsic granites with intermediate to reduced oxidation states.
• Granites of Siluro-Devonian, Carboniferous, and Permo-Triassic age.
• Batholith only now being unroofed or still shallowly buried.

Local geological criteria
• Spatially associated with the apical portions of granites in the roof zones of batholiths.
• District-scale metal zoning.
• Contact metamorphism, alteration, structure, dykes and geophysics may assist in locating concealed granites.
• Alteration mapping to locate hydrothermal alteration zones.

Mineralisation features
• Greisen bodies in roof of granite or beneath internal contacts within granite; transgressive veins; stratabound replacements.
• Gangue: quartz, mica, feldspars, tourmaline, topaz.
• Metal zonation (down temperature) may be W–Sn–base metals.
• Cassiterite may occur as infill or replacement.

Alteration styles
• Greisenisation, feldspar addition (K and/or Na), tourmalisation, skarnification. Silicification, chloritisation and propylitisation in more distal portions.
• Width of alteration variable; may be absent or unnoticeable adjacent to some mineralised granites.
• Alteration most pronounced in granite and overlying zones; granite flanks may be unaltered.

Deposit geochemical criteria
• Related granites are felsic (SiO2 > 70%), highly fractionated and enriched in incompatible elements and volatiles (F, B).
• Alteration zones are also enriched in incompatible elements and volatiles.
• Ore elements include Sn, W, Ag.
• Trace elements in mineralisation may include F, B, Cs, Bi, In, Cd, Sb, As, Cu, Pb, Zn, Tl.
• O, S, C isotopes reflect magmatic sources and/or wallrock inputs. Nd, Sr, Pb isotopes, either juvenile or evolved, depending on nature of granite source.
Surficial geochemical criteria

- Chemical analysis of granites is a guide to Sn-mineralising potential.
- Rock chip sampling for Sn, W in alteration zones.
- Soil anomalies (5–20 ppm Sn typical soil content; >50 ppm Sn prospective), also As, Pb in soils.
- Stream sediment sampling for indicator minerals (cassiterite, Nb-rich ilmenite, tourmaline), and elements Sn, As, Pb, F, U, Th. Stream sediments typically have 5–20 ppm Sn (>20 ppm being prospective). Sn dispersal train in stream sediments may be up to 10 km long.
- Traditional methods (panning) useful if Sn is present in the coarser fraction.

Geophysical criteria

- Sn-mineralised granites have low magnetic susceptibility; alteration destroys magnetite except in chlorite–magnetite lodes and some skarns.
- Sn granites are radiogenic (high K & U) with high Th in I-types, low in S-types. Feldspathic and phyllic alteration high in K.
- Gravity lows indicate granite batholiths at depth.
- Sulphide-bearing lodes may be electrically conductive; pyrrhotite-bearing lodes may be magnetic.

Fluid chemistry and source

- High salinity: >5 wt% NaCl to saturated brine; fluid immiscibility may be present.
- Moderate to high temperature (250–400°C typical during Sn precipitation stage); decreasing T and salinity with time.
- CO₂ ± CH₄ typically present; CO₂/CH₄ variable.
- Fluid ΣS/Σ metal ratios are low.
- Fluids derived from volatile phase separation during magma crystallisation; possible role for meteoric and/or highly exchanged fluids.
- Sn precipitation driven by fluid–rock reactions, decreasing temperature and/or fluid oxidation.

Comments on genesis

- Sn deposits are sourced from magmatic aqueous fluids exsolved from crystallising granites; meteoric water may be involved.
- Mantle involvement in Sn-mineralising systems has been suggested by Nd isotopes, but direct involvement of mantle materials is not supported by other evidence. Exploration for Sn systems based on spatial relationships to felsic, strongly fractionated and reduced granites is clearly preferred.
Main features of Sn±W ore bodies

Types of Sn±W deposits in eastern Australia

Tin ± tungsten mineralisation in eastern Australia comprises a diverse range of deposit styles. All deposit styles, however, have a close spatial and genetic relationship to the apical regions of granitoid plutons. Deposit styles include pegmatite and magmatic segregations within granitoids and adjacent wallrocks, greisens, stockworks, skarns and replacement orebodies (both proximal and distal types), and (tourmaline-bearing) breccia pipes. Greisens tend to be contained within the roof zones of granitoids, either lying directly beneath the upper contact or beneath internal contact zones within the cupola. Breccia pipes, veins and stockworks are usually transgressive to the granitoid contact. Replacement and skarn deposits range from proximal (adjacent to the granitoid contact) to distal (up to 2–3 km) from the granitoid contact.

Other Sn-mineralising styles are under-represented; for example, granitoid-related Sn–Ta–Nb pegmatites (e.g. Walwa, Lachlan Fold Belt), which are well represented in the Western Australian Shield (Solomon & Groves 1994). Non-granitoid-related Sn–Ta–Li pegmatites are absent, but are widespread in the Western Australian Shield (Solomon & Groves 1994). Porphyry Sn systems of the Bolivian type (e.g. Sillitoe et al. 1975) are also under-represented, but provide a potential target. Tin also forms significant alluvial deposits, which in some provinces (New England Orogen and north Queensland) have been the main source of historical tin production.

Grade/tonnage considerations

Grade/tonnage relationships for economic Sn±W systems range from >1% Sn at 0.1–1 Mt ore for hydrothermal vein deposits to 0.8–1.0% Sn at >10 Mt ore in carbonate-replacement deposits and ~0.3% Sn at ~10 Mt ore in greisen-style deposits (Menzie et al. in Hutchison 1988; Taylor 1979). Greisens potentially provide the largest tonnage; however, their typical grade is low relative to carbonate-replacement bodies, which have the advantage of both tonnage and grade. Hydrothermal veins, though relatively small in terms of tonnage, may have very high grades.

The largest deposits in eastern Australia (Renison and Mt Bischoff, Tasmania) are of the carbonate-replacement type with total resources of around 450 kt and 1.2 Mt Sn, respectively (See Solomon & Groves 1994 for grade and tonnage data). Other significant hardrock producers have been Ardlethan (Lachlan Fold Belt, New South Wales, breccia pipe, ~50 kt Sn; Cleveland, 1975) which contain significant potential resources are present in several deposits that are not presently economic because of grade and/or metalurgical problems, e.g. Taronga (New England Orogen, New South Wales, stockwork, ~64 kt Sn), Sundown (New England Orogen, Queensland, stockwork, ~30 kt Sn), Doradilla (New South Wales, skarn, ~33 kt Sn), and Collingwood (north Queensland, greisen, ~28 kt Sn).

System zonation

Sn±W systems are usually part of larger district (kilometre) scale metal zoning, radially arranged around the highest temperature, most granitoid-proximal system cores. Zoning typically comprises W-dominated systems in the granitoid or adjacent overlying rocks, with zonation outwards, initially dominated by Sn, then Cu, Pb–Zn–Ag, then perhaps distal, low-temperature occurrences of F, and Hg (Taylor 1979 and references cited therein). The proximal (granitoid and pegmatic) portions of Sn systems may also contain Ta and Nb mineralisation as well as F; Be and Li. In detail, there is variation and in some tin provinces zoning appears to be absent (e.g. Wagga, New South Wales, and Cooktown, Queensland, tin provinces). In other places, metal zoning is well developed, as in the Herberton district of north Queensland (Blake & Smith 1970); around the Mole Granite in the southern New England Orogen; and in the Zeehan mineral field in western Tasmania, where rich Ag-bearing base-metal lodes have been mined in their own right (Solomon & Groves 1994). In the Cornish tin province of Britain substantial amounts of Cu, Pb, Zn and Ag have been mined from distal stockwork systems (Willis-Richards et al. 1989). Small, but potentially high-grade, Ag-rich polymetallic systems are a potential target in the periphery of zoned hydrothermal systems centred on Sn±W mineralisation.

The scale of Sn systems

The size of the alteration and mineralisation systems associated with Sn±W deposits is small relative to those of porphyry Cu deposits (Premoli in Hutchinson 1988). Greisens systems in the proximal portions of granitoid intrusives may have only 200–300 m vertical extent, with little obvious alteration in the overlying wallrocks. Thus, the degree of exhumation and preservation of the apical portions of granitoids is important. For stockwork systems such as Taronga (New South Wales) and Aberfoyle (Tasmania), and replacement deposits such as Renison (Tasmania), the exposure of the progenitor pluton would mean the loss of the deposits, and probably any evidence for them having existed.

Mineralogy and alteration

The mineralogy of Sn±W stockwork veins can be quite simple in the higher temperature parts of the deposits. Ore minerals principally consist of cassiterite ± wolframite in a gange, which may comprise quartz, muscovite, feldspar, tourmaline, topaz, fluorite and apatite. Sulphides are generally minor and may include pyrite, pyrrhotite and arsenopyrite. Stannite may also be present. The mineralogy of carbonate-replacement deposits can range from relatively easily mineable cassiterite in a silicate-carbonate gange: cassiterite–pyrrhotite ores (as at Renison), to metallurgically difficult ores (particularly in proximal skarns), where Sn is bound in silicate minerals such as malaivate and pyroxenes. Scheelite tends to occur instead of wolframite. Tourmaline is abundantly developed in some breccia pipes, and chlorite with base-metal sulphides (even magnetite) may occur with cassiterite in some lode and pipe deposits. The ratio of cassiterite to wolframite in veins may be a function of the differing precipitation mechanisms for Sn and W (Jaret, quoted in Solomon & Groves 1994).

High-temperature magmatic to subsolidus hydrothermal alteration of the associated granitoids is common, with higher temperature feldspathic alteration (K or Na dominated), greisenisation (quartz and muscovite ± topaz, fluorite), tourmalinisation (B) or even topazisation (F). Feldspathic alteration within granitoids can be texturally very subtle (Pollard et al. 1983). Chloritisation with base-metal sulphides can be present in lower temperature lodes. The mineralogy of Sn-mineralised skarns can be complex, with typical skarn minerals being augmented by the addition of F- and B-bearing phases (see Kwak 1987).

Mineralogical and metallurgical considerations are very important for the economic viability of Sn prospects. Difficulties include: 1) fine grain size of cassiterite, leading to 'slim' during crushing and flotation; 2) presence of Sn bound in silicate and sulphide phases; 3) presence of complex sulphide and sulphosalt minerals containing As, Sb, etc. and 4) unusual mineralogical properties, e.g. magnetic cassiterite. These factors should be assessed during the early stages of exploration of Sn±W prospects. At Doradilla (New South Wales), huge amounts of Sn in weathered fault and fracture zones (70 Mt at ~1 wt% Sn; Kwak 1987) are contained in secondary varlamoffite, rendering the Sn metallurgically irrecoverable and the deposit unviable.

Geological setting of Sn systems

Rock associations

Sn±W mineralisation is invariably associated with the upper parts of felsic and fractionated granitoid plutons and, in particular, with cupolas and ridges on the tops of batholiths, where
exsolved magmatic fluids have evolved, been focussed, and/or ponded. Deposits may be intimately associated with a specific phase or anhydride of a granitoid pluton. Carbonate-replacement and skarn-style deposits require reactive wall rocks, which may comprise Mg- or Ca-carbonates. Mafic and ultramafic rocks, including serpentinisated ultramafics, are also reactive to Sn+W mineralising fluids.

Granitoids associated with tin mineralisation tend to be chemically distinct from more typical felsic granites and, as such, are often referred to as 'specialised' or 'tin' granites. They are felsic (>70% SiO₂), enriched in incompatible elements, such as Rb, U, Nb, F, B, Li, Be and Cs (hence the term 'specialised') and depleted in compatible elements (Ba, Sr, Fe, Ti, Ca, Mg, Zn, Cu, Ni, etc). Peraluminous granitoids have elevated P and low Th and Y, while metaluminous granitoids have high Th and Y and low P. These chemical features are the result of extended fractional crystallisation mechanisms rather than unique or special source materials. Sn+W-mineralising granitoids comprise K-feldspar, quartz, sodic plagioclase, and minor modal amounts of biotite and or muscovite. They are poor in Fe–Ti oxide minerals. Accessory mineral phases may include topaz, fluorite, tourmaline, apatite, monazite and Li-micas. The granitoids may also be texturally variable, indicating that volatile build-up and exsolution occurred in a relatively shallow crustal environment (typical of tin granitoids in general).

An exploration strategy

1. Define Sn provinces, based on historical records.
2. Determine igneous association (suite/supersuite) related to Sn mineralisation. Determine the chemical and geophysical properties of the related granitoid suite/supersuite.
3. Establish the extent of this association locally and regionally. Does the distribution of related granitoids coincide with the known distribution of historical Sn production or are the related granitoids more extensively developed regionally?
4. Within the region of prospective granites so defined, locate areas that may indicate just unroofed or shallowly buried granitoid cupolas, using structure, gravity, contact aureole geometry, dyke swarms, presence of contemporaneous volcanics, hydrothermal alteration zones, and metal zoning. Cupolas and dykes may form linear belts where they have intruded along structural weaknesses to higher levels.
5. Interpret regional structure to identify potential fluid pathways that may have focussed magmatic fluids emanating from granitoid cupolas. The distribution and relationship of these structures relative to older reactive rocks should also be examined.
6. Consequent stream sampling for cassiterite and elements associated with specialised granitoids and related mineralisation (As, Ag, F, etc) may define alteration systems over buried cupolas. More detailed studies of metal zoning may also assist at this stage, as well as mapping of alteration at prospect scale. Metal zoning at all scales needs to be emphasised. For example, low Sn grades in stockworks carrying Zn, Pb and As may indicate the lower temperature distal end of an economic Sn system.

Acknowledgment

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Key references


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