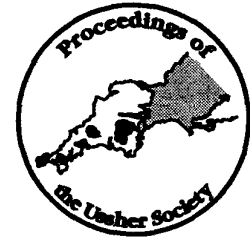


**METASEDIMENT-HOSTED TIN MINERALIZATION  
IN THE INDIAN QUEENS AREA, MID-CORNWALL**

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**INTRODUCTION**

Tin mining in the Indian Queens area was initially based on placer deposits around Goss Moor and Gaverigan and later from shallow underground workings (Figures 1 and 2: Dines, 1956; Camm and Hosking, 1985). Historical records (Boase, 1832; Henwood, 1843; LeNeve Foster, 1876) indicate that the metasediment-hosted hardrock deposits had an unusual character, not being of the classical vein-type. Geochemical soil sampling, float mapping and soil microscopy were undertaken in the 1980s and identified a number of Sn anomalies striking east-west and north-south (Camm, 1982-1984). The soil sampling was followed up by trenching and diamond drilling at Gaverigan [SW 930 590] and Treliver [SW 903 605]. Targets sought were those suitable for open pit mining with a potential of 4-7 million tonnes at 0.3-0.4 % Sn. The results of this activity demonstrated that the metasediment-hosted tin mineralization was unusual and probably associated with hydrothermal metatourmalinite breccia bodies and tourmaline sheeted vein systems. This contribution presents a preliminary report on these studies and describes the styles of tin mineralization encountered.

**GEOLOGICAL BACKGROUND**

The area of interest lies around the north-western part of the St. Austell mass where the granite lies at a high structural level. The granite hosts world-class china clay deposits which resulted from a protracted hydrothermal history. Emplacement is dated at about 277 Ma with mineralization within 4-5 Ma (Chen *et al.*, 1993). A number of small unexposed granite highs and ridges are connected to the main mass at depth. The gently-dipping contact aureole and geophysical data suggest an elliptical granite body some 20 km in diameter. Fine-grained rhyolite and porphyry dykes (elvans) cut across the district, intruded later and contemporaneously with the multi-stage granite intrusion (Hill and Manning, 1987). The granite and dyke rocks intruded politic, psammitic and calcareous sediments of Devonian age. Mineralization occurs both in the granite (endogranitic) and surrounding country rocks (exogranitic) in a variety of structural settings and styles (Bromley and Holl, 1986).

**HISTORICAL BACKGROUND**

Around Indian Queens there have been many small open pit and shallow underground mining operations for cassiterite. The principal mines (Figure 2) being Parka [SW 921 588], Indian Queens Consols [SW 917 586], Fatwork and Virtue [SW 922 584], Gaverigan [SW 934 593] and Treliver [SW 920 605], the last incorrectly assumed to be an iron mine (Dines, 1956). Previous workers' (Boase, 1832; Henwood, 1843; LeNeve Foster, 1876) descriptions of the mines report a compact rock containing many small irregular rock fragments (breccia) and of short veins often in layers or floors arranged one above another. They also describe veins traversing the rock in various directions and in some cases 'S'-shaped lenticular lenses of ore. A number of terms were used to describe the mineralization including *lodes*, *floors*, *stockworks* and *carbonas*, often imprecisely. Mention was also made of lodes striking east-west and north-south which had rich orezones at intersections.

**DETAIL OF TRELIVER AND GAVERIGAN DEPOSITS**

*Local structure and geology*

Both deposits lie within the Lower Devonian Meadfoot Group which has been modified structurally and mineralogically by the St. Austell granite and its satellites intruded during the Variscan Orogeny. Published map data (BGS sheet 3471973) show the area to lie just to the north of the exposed western lobe of the St. Austell granite where exposure is poor due to alluvial and colluvial cover. The major rock types in the area are Devonian metasediments, east-west striking calc-silicate beds (calc-flintas) and porphyry dykes. Few faults are shown, though examination of old mine data suggest the presence and trend of tectonic structures. Gravity data indicate that the roof of the granite lies less than 500 m below the surface and a positive gravity anomaly reflects changes in the underlying granite roof and lithological variations in country rocks (Tombs, 1977). On the basis of the geophysical data, aerial photographs and LANDSAT imagery,

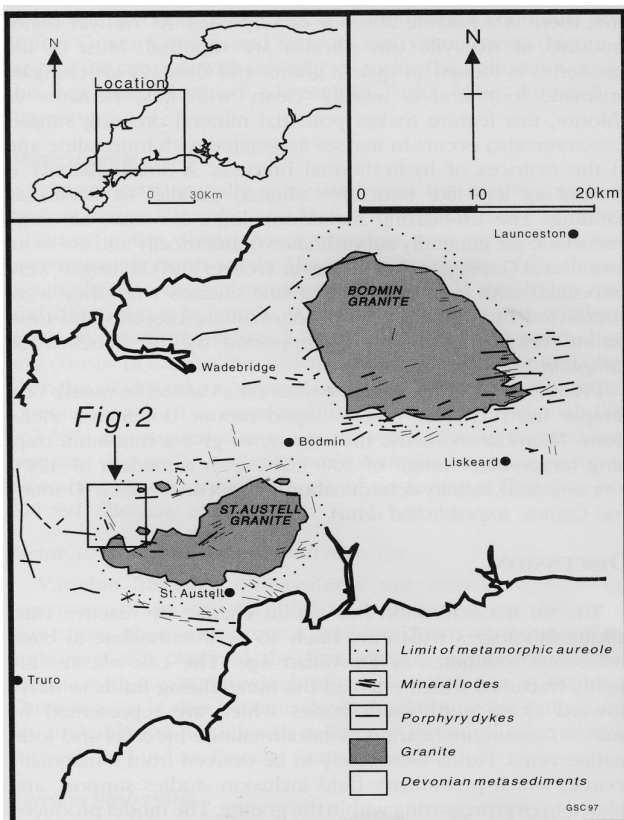


Figure 1. Map showing the location of the study area.

lineaments are indicated which trend north-south, north-west-south-east and east-north-east—west-south-west. These are dominated by a north-south complex sheeted and highly jointed disturbance zone. In the north-west of the St. Austell granite there are a series of north-north-west—south-south-east-trending hydrothermal breccia bodies, e.g. Wheal Remfry breccia (Allman Ward *et al.*, 1982). Float mapping during exploration demonstrated that other breccia bodies exist to the north of Remfry, these have been reported by Bromley and Holl (1986).

### Detailed Geology

#### Meadfoot Group

The Meadfoot Group is a series of dark blue-grey slates with thin beds of siltstone and limestone and intercalations of volcanic material. They strike east-west with local variations  $\pm 20^\circ$ , and dip southwards at Treliver (60-70°) and northwards at Gaverigan (sub-vertical). Microfolding, typically chevron and more open flexuring are both well-developed. Thermal spotting suggests the proximity of the granite.

#### Calc-silicates

These appear to have a lensoid geometry, varying from 50 cm to 50 m in thickness striking mainly east-west and dipping to the south at Treliver and north at Gaverigan. In the thicker sections intercalations of metapelite are common. In the more competent sections of the calc-silicates metasomatic and metamorphic minerals, predominantly chlorite, axinite, epidote and diopside are extensively developed obliterating any primary texture. A detailed structural analysis proved difficult due to the absence of marker beds in the calc-silicate succession. Furthermore, there was an absence of cleavage-bedding relation and an uncertainty of the possible existence of an early folding phase which may have produced an early sub-parallel bedding and cleavage. Irregular hairline fracturing is common and can be associated with shear zones. Relatively rarely they are infilled with quartz, chlorite, and/or hematite and are distinctively cross cutting and of 'late' appearance. The data at Treliver indicates that north-west-south-east and north-south, and a complex flat dipping westnorth-west—east-south-east fracture systems are in evidence with both brittle and semi-ductile fracturing occurred. Originally mapped as impure limestones, these may be of intermediate to basic pyroclastic origin (A.V. Bromley, *pers. comm.*). Bedding and compositional banding are less well defined, locally absent and elsewhere varied, another indication of a probable volcano-sedimentary origin. The calc-silicate rocks are generally better mineralized where they are severely metasomatised, coarse-grained and highly fractured. This lithology is a better host than the siltstones to tin mineralization due to its relative competency, allowing fracture development and thus fluid permeability and chemical reaction. In addition to cassiterite and rutile, hematite is present and loci for tin-rich zones appear to be concentrated in fold hinges. The mineralization corresponds to the east-west geochemical soil Sn anomalies.

#### Alteration phenomena

Boreholes show pervasive tourmalinization to increase with depth with a postulated front some 300-500 m from the granite/ country rock contact. The form of the tourmalinization is probably controlled by the subsurface granite/country rock contact which corresponds approximately to an arcuate ridge between Fraddon Down and Castle an Dinas. The tourmalinization has progressively pervaded and replaced the more argillaceous components, leaving the siliceous bands and producing the characteristic 'zebra' banded texture. In the calc-silicates tourmalinization is rarely developed with boron-rich fluids forming axinite in preference. Pervasive tourmalinization does not appear to be associated with any significant tin mineralization.

Argillization related to either hydrothermal fluids and/or deep weathering is widespread. Metapelite facies are the most prone to argillization although the calc-silicates are also weathered and

characterised by limonite staining. Argillic alteration has been identified to variable depths suggesting an uneven alteration profile and also, an interactive relationship with the pervasive tourmalinization front. In the Treliver area a 30 m wide north-south zone of argillized soil can be mapped and is coincident with a north-south tourmalinized zone and strong Sn anomaly. Details of the argillic alteration in the Fraddon Down area are reported by Bristow *et al.* (1997).

Hematization of 'late' origin is locally developed on a pervasive front and occurs as hematite with quartz as major fissure filling structures. The major fissure filling structures appear to have exploited a series of north-west-south-east strike-slip faults and accessory north-south horsetailing branch faults. These faults are likely to be of "crosscourse" origin and represent major channelways for fluid flow during kaolinization of the St. Austell granite (Dominy *et al.*, 1994).

#### Hydrothermal metatourmalinite breccias and sheeted veins

The sheeted veins are complex and multi-stage and range from 1-2 m in width to 1-2 mm stringers, trenching at Treliver indicated strike lengths up to several 100 m. The diatremic metatourmalinite breccia bodies appear to exploit north-south to north-northwest—south-south-east fractures developed during the emplacement of the granite. Narrow stringers of tourmaline veining occur at the top of the breccia bodies and along adjoining microfracture systems formed during hydraulic fracture (Dominy *et al.*, 1996). Tin mineralization is associated with both the breccias and veining, and is reflected by zones of north-south oriented Sn soil geochemistry anomalies.

#### Tin mineralization

The main tin mineralization is hosted by calc-silicates in veins (micro-sills) and bedded and replacement ore. At Gaverigan cassiterite is observed as single twinned crystals, radiating clusters of acicular crystals ('*dnepnoskite*' of Hosking *et al.*, 1987) and grain segments. Treliver shows two forms of cassiterite in quartzalbite-rich bands as either <50  $\mu\text{m}$  or up to 0.1 mm in size. In both localities cassiterite is associated with rutile, quartz and tourmaline, there is a notable absence of sulphides. At Treliver minor amounts of malayite (tin silicate) are reported. Most of the cassiterite is locked in quartz grains and displays an elongate prismatic form and is usually 'clean' with little hematite or chlorite, this feature makes potential mineral dressing simple. Cassiterite also occurs in masses associated with tourmaline and in the matrices of hydrothermal breccias. A small quantity is present as lens-like structures aligned parallel to hornfelsic banding. The tin-bearing metatourmalinite breccias, although important, are generally subordinate volumetrically and are more common at Gaverigan. Rich zones at Treliver and Gaverigan were associated with east-west striking calc-silicates were they were intersected by north-south metatourmalinite breccias and tourmaline veins, this pattern is supported by the geochemical sampling.

Preliminary fluid inclusion studies on a cassiterite-quartz vein sample from Treliver reveals liquid-vapour dominated inclusions. Microthermometric measurements give a minimum trapping temperature range of 200-350°C with a median of 325°C (uncorrected), salinity determination was not undertaken (Dominy and Camm, *unpublished data*).

## DISCUSSION

The tin mineralization lies within chemically reactive calc-silicate lithologies which are likely to be intermediate to basic tuffaceous sediments of Devonian age. The calc-silicates are highly fractured which enabled the mineralizing fluids to move upward along north-south zones which are represented by (minor?) cassiterite-bearing metatourmalinite breccias and tourmaline veins. Fluids were likely to be derived from a magmatic source, which preliminary fluid inclusion studies support, and related to overpressuring within the granite. The model produced by Allman-Ward *et al.* (1982) and modified by Bromley and Holl (1986) invokes the relief of magmatic overpressuring

by the propagation of vertical hydraulic fractures and concomitant boron metasomatism of wallrocks. Where  $\sigma_3$  equalled the lithostatic pressure micro-sill formation took place by the prising apart of sub-horizontal bedding and cleavage planes. This resulted in extensive wallrock boron metasomatism and cassiterite deposition, and the eventual sealing of the system. The process repeated cyclically allowing the development of further micro-sills at progressively higher levels until surface penetration occurred. Following this further magmatic overpressuring resulted in the formation of explosive hydrothermal breccias. The calc-silicate rocks show minimal tourmalinization and are dominated by wholesale replacement. The metamorphosed Meadfoot Beds are pervasively tourmalinized when in close proximity to vein and breccia systems and less pervasively above the granite contact.

Five main styles of tin mineralization may be recognised in the area:

#### Bedded ore

Lenses and disseminations parallel to metatourmalinite and calc-silicate banding principally observed at Indian Queens Consols, Fatwork, Parka and at Gaverigan. Cassiterite is primarily associated with tourmaline and minor quartz. Space for ore deposition was created by micro-sill development by the prising apart action of hydrothermal fluids on the metasediment cleavage and/or bedding (Bromley and Holl, 1986).

#### Replacement ore

Predominantly east-west striking calc-silicate hosted mineralization was observed at both Treliver and Gaverigan related to hydrothermal quartz-albite flooding of the calcareous horizons. Mineralization was controlled by the chemical composition (reactivity) of the rocks and structural connectivity of fractures leading to fluid flow. Cassiterite mineralization is predominantly associated with quartz and minor tourmaline. In some cases mineralization may have been referred to as the east-west 'lodes' in historic accounts of the area. It is interesting to note that both Indian Queen Consols and Fatwork and Virtue mines (Figure 2) lie near the contacts with calc-silicate rocks. Calc-silicates were for the first time observed adjacent to Parka Mine during float mapping.

#### Sheeted veins systems

These occur spatially associated with the metatourmalinite breccia bodies (Bromley and Holl, 1986). Each centre of mineralization in the district has tourmaline vein swarms oriented approximately north-south. The strong continuity of Sn anomalies implies that these structures are between 25 and 100 m wide and 200 to 600 m in length. At Treliver individual vein widths of up to 10 mm were observed. The veins merge into bedded ore and consist of tourmaline, quartz and minor cassiterite and often form the stockwork or 'stringer ore' noted at Fatwork and Indian Queen Consols. It is suspected that the Gaverigan eluvials [SW 932 585] are situated above a north-south striking sheeted vein complex (Figure 2). A sheeted vein complex has been observed recently in an exposure just north of Gaverigan at Highgate [SW 924 591] (Bristow *et al.*, 1997).

#### Metatourmalinite hydrothermal breccias

Variable amounts of cassiterite are associated with the metatourmalinite breccia bodies as revealed by drilling at Gaverigan. These also occur at Fraddon Down where one of the authors (GSC) obtained the first sample of metatourmalinite breccia with cassiterite which initiated exploration in the area. These breccia bodies become sheeted veins near the surface and are probably the north-south striking 'main lodes' referred to at Fatwork and Indian Queens Consols mines.

#### Tension gash veins

A description of Parka Mine by LeNeve Foster (1876) indicates

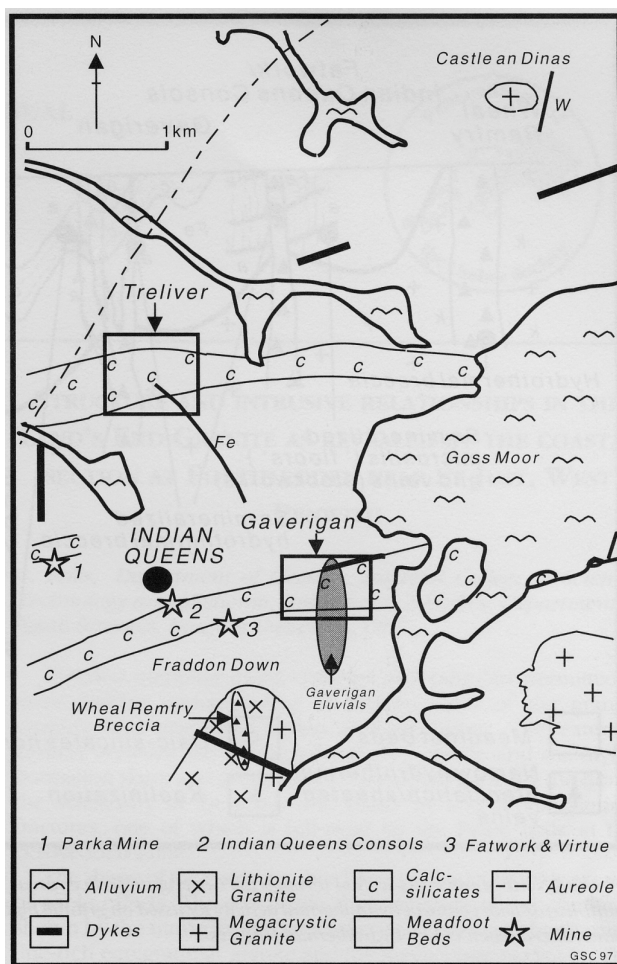


Figure 2. Geological map of the Indian Queens area showing the northern margin of the St. Austell granite and the Wheal Remfry breccia. The Treliver and Gaverigan deposits are centred on the east-west striking calc-silicate horizons.

high grade lens shaped orebodies suggesting a tension gash-type geometry (Figure 3). Low angle shearing was observed at Treliver and may also have occurred here. Individual veins may be up to 0.45 m thick and composed of nearly pure cassiterite with minor quartz. Tin-bearing metatourmalinite breccia veins found on the mine clump suggest that they may have acted as channelways for the mineralizing fluids. Any shear couple would need to have been active during or just prior to mineralization to account for the vein morphology. This style of mineralization reflects variations in the dominant controlling factors for ore deposition in the area, open spaces created by hydraulic jacking along bedding and cleavage planes.

The passage of ore fluids was controlled by the morphology of the granite roof at topographic highs and north-south striking metatourmalinite hydrothermal breccias and sheeted veins. Further mineralized structures occurred where fluid pathways were provided by strongly developed lithological contacts and over granite highs, together with the occurrence of lithologies prone to replacement. All deposits are characterised by a simple mineralogy of quartz, tourmaline and cassiterite with the absence of sulphides which is reflected in the geochemical soil anomalies. The absence of sulphides suggests the lack of reactivation of this early phase of mineralization and therefore no overprinting has occurred by later hydrothermal activity as seen in the Camborne-Redruth district.

In conclusion it is clear that this area bears a complex series of

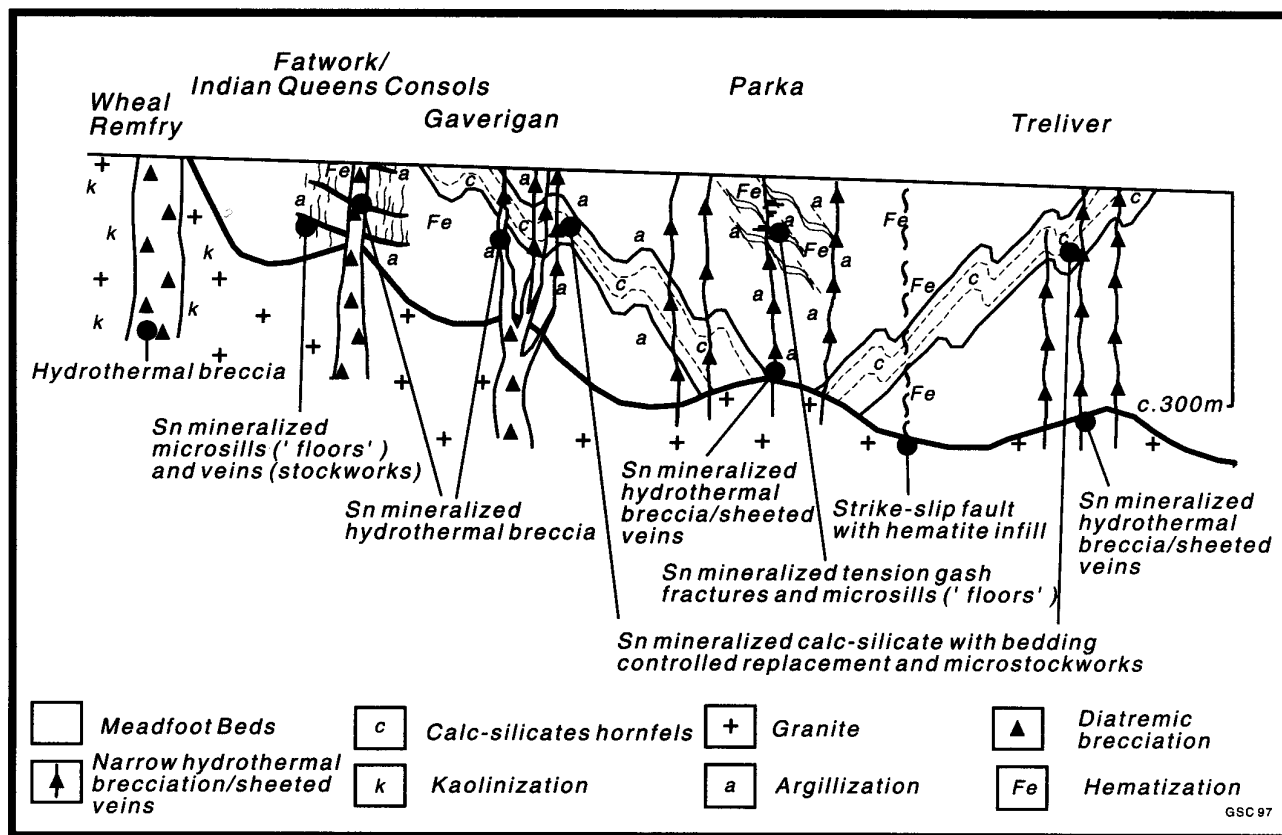


Figure 3. North-south cross-section through the Gaverigan-Treliver area. The St. Austell granite is exposed to the south in the Remfry pit and dips gently northwards with centre of hydrothermal activity focussed on granite highs. The calc-silicate horizon form a possible synclinal structure and is strongly mineralized when cut by hydrothermal features.

metasediment-hosted styles of mineralization which owe their existence to the close proximity of the St. Austell granite. Mineralizing fluids were almost certainly derived from the granite and flowed along hydraulic fractures hosting breccia and sheeted veins. Well developed mineralization is related to the presence of highly reactive calc-silicate horizons which are near surface in the Gaverigan and Treliver areas. It is considered that Treliver and Gaverigan are not unique and other deposits may lie within the area, should the tin price significantly improve further investigation would be warranted. The simple mineralogy of the deposits would facilitate a simple method for cassiterite concentration.

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