Surficial geochemical signatures of tin and tungsten deposits north of the St. Austell Granite

G.S. Camm[1] and C.J. Moon[2]

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A large regional soil geochemical survey of the area north of the St. Austell Granite shows the distinct signatures of differing types of mineralisation. Breccia and stockwork Sn mineralisation in the Treliver area is generally unenriched in base metals and tungsten. In contrast main phase E-W veins are enriched in base metals as well as Sn. Tungsten enrichment is present in the Castle-an-Dinas area associated with As and the mined vein and a NW trending Fe vein. Arsenic is not evenly distributed through the metamorphic aureole and is concentrated around specific late granites (especially Castle-an-Dinas) and mineralised veins, both Sn and W bearing.

[1]Camborne School of Mines, University of Exeter, Redruth, Cornwall, TR15 3SE, U.K.
[2]Department of Geology, University of Leicester, University Road, Leicester, LE1 7RH, U.K. (E-mail cjm@le.ac.uk).

Introduction

Although there has been considerable discussion of surficial geochemistry and the signature of the different types of mineralisation in SW England (Hosking, 1959, 1971), there have been few published accounts of large scale soil geochemical surveys. This is regrettable as soil sampling is a more reliable indicator of primary mineralisation and elemental signatures than stream sediment sampling and soils are less contaminated by past mining activity.

This paper describes the results of a major (~ 10 000 samples), commercial soil sampling campaign in an area north of the St. Austell Granite, including some significant known mineralisation, such as the Castle-an-Dinas W deposit. Some of the more interesting anomalies were tested by diamond drilling in the early 1980s (Camm, 1983; Camm and Taylor, 1983) and led to the discovery of significant, previously unknown, mineralisation, which has been described by Camm and Dominy (1997).

Geology

The area sampled was in an arcuate grid, NE from the W end of the St. Austell Granite and including both the Castle-an-Dinas and Belowda Beacon granite outcrops (Figure 1). Quartz porphyry dykes, associated with granite intrusion, cross cut the area, notably at Royalton. Published geological mapping shows the aureole rocks to be composed of Meadfoot Group sediments on the southern limb of the Watergate Bay anticlinorium (Ussher *et al*., 1909). The Meadfoot Group consists mainly of siliciclastic metasediments but include calcareous beds that have been metamorphosed to calc silicate (calc flintas) within the aureole. The exact origin of these is unknown but they are either thin limestones or basic tuffs (Camm and Dominy, 1999).

The mineralisation known before the start of exploration in 1980, consists of a significant W deposit at Castle-an-Dinas mined from 1917 to 1957 (Brooks, 2001) and a number of Sn prospects detailed by Jenkin (1964a, b) and Dines (1956), shown on Figure 1. Historical records suggest that as well as simple veins and stockworks, bedded, replacement and breccia ores were also present (Henwood, 1843; Foster, 1876). The latter three types were described from the south of the area in the old Parka, Fatwork and Gaverigan mines. The old records comment on the lack of sulphides and hardness of ore in these mines. Alluvial and eluvial tin deposits have been worked both on the Goss Moor area and at Gaverigan (Camm and Hosking, 1985). Sampling was designed to avoid the main area of alluvial working, which had previously been evaluated. Iron-bearing veins were also known from the Ruthvoes and Toldish areas (NW strike between the T and G of Figure 1) and have been mined for ochre (Dines, 1956).

Element (all ppm)	X_{25}	X_{50}	X_{75}	Maximum	Mean	Standard deviation
Regional (n=2686)						
Sn	90	160	290	4700	238	293
Cu	110	140	180	670	147	76
As	15	40	80	1960	70	110
WO_3	<10	<10	<10	3720	14	105
Treliver (n=2630)						
Sn	150	240	400	27500	376	712
Cu	120	130	150	640	133	52
As	30	30	40	250	36	19
WO_3	<10	<10	<10	1050	7	23
Gaverigan (n=3088)						
Sn	290	380	530	17800	484	527
Cu	100	120	160	1280	120	88
As	10	25	70	1130	43	52
WO_3	<10	<10	<10	140	13	18
Parka (n=1854)						
Sn	240	330	450	5600	414	404
Cu	110	130	200	1280	146	102
As	15	30	90	1290	59	70
WO_3	<10	<10	<10	770	10	23
Royalton (n=858)						
Sn	210	290	420	5700	365	314
Cu	160	190	220	650	197	59
As	120	180	240	940	187	89
WO_3	<10	<10	30	360	18	24

Table 1. *Summary statistics for regional and detailed sampling. Calculated using 0.5 × detection limits for results < detection limit.* X_{25}, X_{50}, X_{75} *– 25th, 50th and 75th percentiles.*

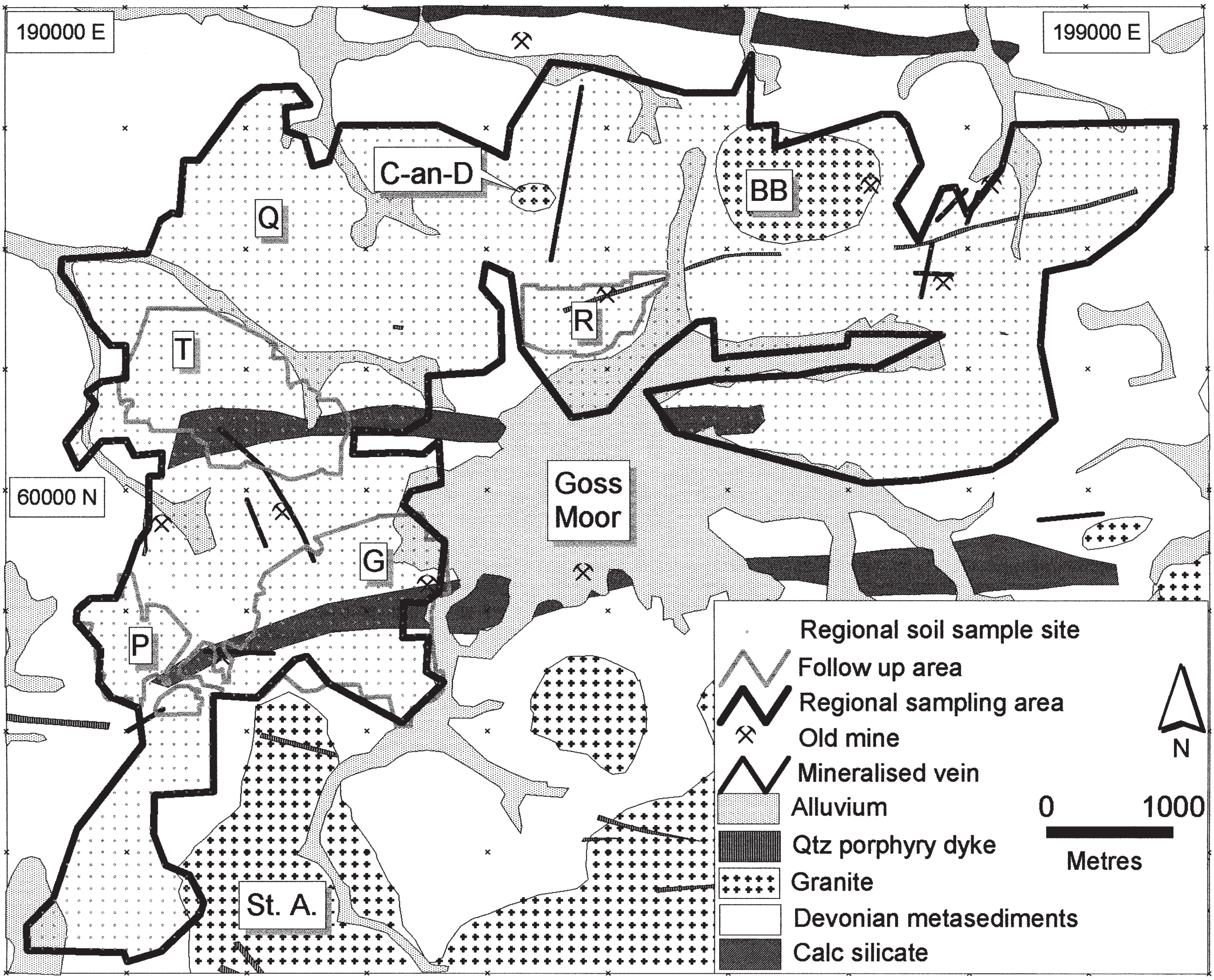

Figure 1. *Location of regional samples and follow-up areas. Geological data modified from BGS sheet 327. Mines from Jenkin (1964a, b). Follow-up areas: G - Gaverigan; P – Parka, R – Royalton, T – Treliver. Granites: BB – Belowda Beacon, C-an-D – Castle-an-Dinas, St. A. – St. Austell, Other areas: Q – Quoit. × indicates Ordnance Survey kilometre grid.*

Sampling, analytical and interpretational methods

Initial sampling of the area used a 100 × 100 m grid; samples (B Horizon, -1 mm) were analysed for Sn, tungsten (reported as WO_3), As and Cu by XRF, as well as low level As by AAS. Sampling methods and spacing were determined by an orientation study that showed slightly superior contrast for the whole sample rather than size fractions (Camm, 1983). Sampling was by hand auger, followed by crushing in a tema mill of the whole sample. In the original interpretation in the early 1980s data were plotted as grey scale maps on dot matrix printers (Camm, 1983). For the present study data were re-entered into Arcview 3.2 GIS and statistics were calculated using MINITAB 12.

Follow-up samples were collected at 25 × 25 m intervals to prove the continuity of anomalies and a number of sample lines at Treliver were further sampled on 5 m spacing. As a check on the multi-element nature of anomalies at one location (Treliver) samples were collected in 1999 at 200 × 25 m intervals and analysed by 25 element ICP-ES following aqua regia digestion and sieving to –190 μm.

Regional survey

Regional soil samples were collected on a 100 m grid over the target area with a total of 2686 samples. Contouring of the data (summarised in Table 1) highlights regional trends and subdued local variation, including in the tin data the nugget effect of sampling discrete cassiterite grains. Contour intervals were selected by examining percentile tables and log-probability plots (Figure 2) of regional and detailed sampling and common intervals were chosen to enable comparison between the different data sets. Examination of the contoured regional soil maps (Figure 3) shows the very different signatures of the tin and tungsten deposits.

The N-S trending 3 km long vein-like tungsten zone at Castle-an-Dinas is very clearly detected by high contrast WO_3 and As anomalies with a suggestion that As partly extends to encircle the granite outcrop. The data confirm the more limited soil sampling of Hosking and Curtis (1961) and Beer *et al*. (1986) who defined tungsten anomalies over the 2 km strike of the main 1-2 m wide vein, a sub-parallel extension, ~150 m to the west, and less discrete extensions to the N and S. Although Cu is known from the vein and Sn from the wallrocks (Beer *et al*., 1986) there is little evidence of Sn anomalies near the vein although Cu is slightly higher downslope from the vein, suggesting hydromorphic movement of Cu or a separate discrete source. The data provide conflicting evidence for the relationship of the granite and the tungsten vein. Both WO_3 and As have broad highs around the granite, although WO_3 seems to be concentrated in the vein, supporting the intrusive nature of the granite relative to the vein detailed by Beer *et al.* (1986).

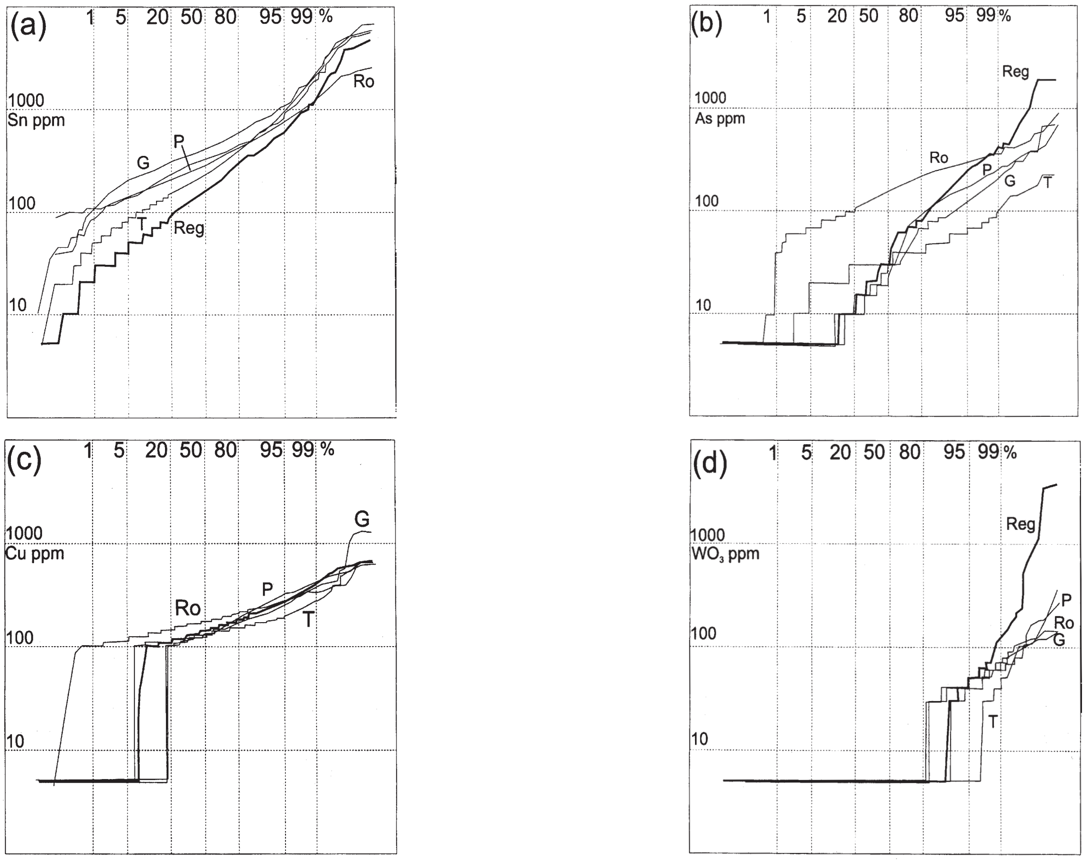

Figure 2. Log-probability plots of Regional (thick line, Reg), Gaverigan (G), Parka (P), Royalton (Ro) and Treliver (T) soil samples. (a) Sn ppm, (b) As ppm, (c) Cu ppm, (d) WO_3 ppm.

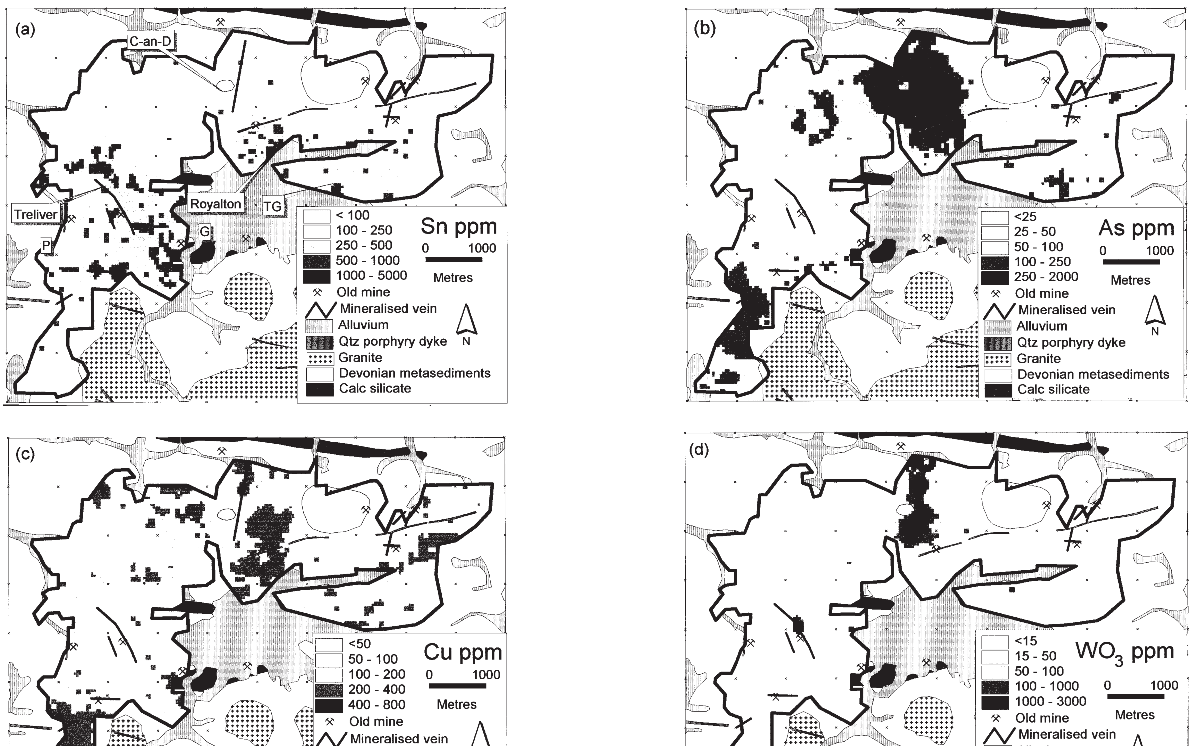

Figure 3. Regional soil sampling results from area within thick line superimposed on regional geology. Elemental contents generated from a 200 m window of nearest neighbours, inverse distance weighting based on 100 m grid sampling. Geological data modified from BGS sheet 327, granite outlines shown within sampled area. × indicates Ordnance Survey kilometre grid. Follow-up areas: G - Gaverigan; P – Parka, Royalton, Treliver. C-an-D – Castle-an-Dinas, TG – Tregoss. (a) Sn ppm, (b) As ppm, (c) Cu ppm, (d) WO_3 ppm.

If the distinctive geochemical features of tungsten mineralisation are accepted as both As and WO_3 anomalies then similar, but weaker anomalies, are present in the Quoit area, ~1 km WSW of Castle-an-Dinas. The association of this geochemical feature with a gravity anomaly (Tombs, 1977) and slight topographic high suggest the occurrence of a buried mineralised granite cusp, similar to Castle-an-Dinas, with tungsten mineralisation on its western flank. Another striking feature of the tungsten map is the anomaly associated with the known extent of Ruthvoes Fe lode, with a high near a small open pit. According to Dines (1956) the lode mainly produced ochre and some manganese but has not previously been reported to contain tungsten.

In contrast, regional Sn anomalies can be defined over the Parka, Gaverigan, Royalton and Treliver areas with lesser anomalies south of Belowda Beacon and at Tregoss (Figure 3a). The Gaverigan, Parka and Royalton anomalies could be anticipated from the descriptions of Dines (1956) but Treliver could not. Mineralisation in the Treliver area was described as an offshoot of the Ruthvoes Fe mines by Dines (1956), although Jenkin (1964a) describes that near Treliver farm, as a little known tin open cut mine. The overall control on tin distribution appears to be E-W trending, calc-silicate related, and N-S trending anomalies, as well as the spatial correlation of tin highs with alluvium. This can be notably seen in the NW trending valley N of Ruthvoes and also in the parallel valley to the west. The major ENE striking Royalton quartz-porphyry dyke is upslope of moderately high Sn concentrations. Arsenic anomalies are spatially correlated with Sn at the NW tip of the St. Austell Granite and with Sn and Cu at Parka.

Regional Cu signatures show strong depletion to the SW of the Ruthvoes Fe vein, west of Quoit and around Belowda Beacon. Known U mineralisation at Quoit and Trenowth (Ball *et al*., 1990) is not detectable in any of the elemental maps shown in Figure 3.

FOLLOW UP SURVEYS

Detailed soil sampling at a 25 × 25 m spacing was undertaken at 4 areas: Gaverigan, Treliver, Parka and Royalton, totalling ~8200 samples.

Treliver

Detailed sampling confirmed the strong N-S and less well defined E-W Sn trends seen in the regional data. Both the main N-S Sn anomaly (Anomaly 1, Figure 4a) and, to a lesser degree, Anomaly 2, are associated with a depletion in Cu and As. Trenching and drilling showed that these are underlain by tourmaline-rich breccia bodies and veins that cut the E-W trending calc-silicates expressed as Anomaly 4 (Camm and Dominy, 1999). Anomaly 3 also trends N-S but has no Cu or As expression. In contrast, lesser, E-W trending anomalies 6 and 7 show correlation of Cu and Sn, probably indicating main stage veins. Anomaly 5 correlates with the occurrence of alluvium north from Ruthvoes village.

The spatial association of WO_3 with the known location of the Ruthvoes Fe vein seen in the regional data, particularly the highest values near a small open pit, is confirmed. The probable subcrop of the vein can be mapped to the NW by weak highs (~20 ppm WO_3) relative to a very low background.

Follow-up samples were collected over Anomaly 1 of Figure 4a at 5 m intervals with 120 m between lines. These data (Figure 5)

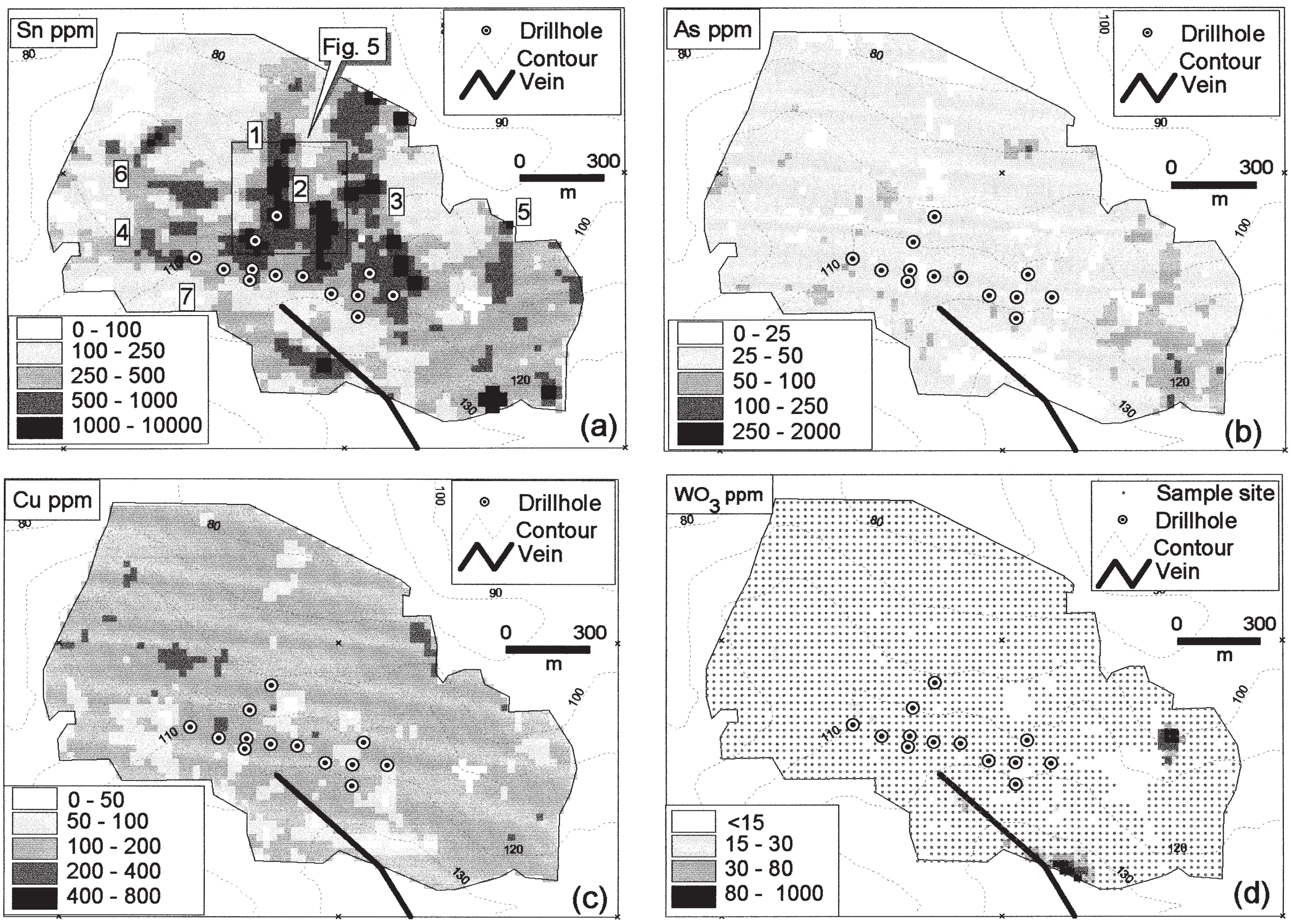

***Figure 4.** Detailed sampling: Treliver, 25 m spacing. Elemental contents generated from a 50 m window of nearest neighbours, inverse distance weighting. Contours from 50 m grid digital Ordnance Survey data. × indicates Ordnance Survey kilometre grid. Geological data modified from BGS sheet 327. (a) Sn ppm, (b) As ppm, (c) Cu ppm, (d) WO_3 ppm.*

confirmed the continuity of the anomaly at ~1000 ppm Sn, although sharp peaks due to the nugget effect of sampling discrete cassiterite grains can be seen. The southernmost line also shows that Anomaly 2 (eastern end of the line) is 20-30 m wide with Sn in excess of 1000 ppm.

Microscope examination of bulk panned concentrates from the soil confirmed the nature of the anomalies. A sample from Anomaly 1 contained 90% cassiterite with some spherules of wood tin. Other samples from the N-S trending anomalies contained cassiterite and tourmaline but no sulphides. Axinite was present in samples over the calc-silicates.

Multi-element aqua regia ICP-ES (1999, fine fraction) analysis showed that the N-S anomalies also have a weak B signature and also an acid leachable Sn anomaly, perhaps reflecting the presence of non-cassiterite tin bearing minerals but transition element depletions were not detectable. Arsenic and copper anomalies are present in the NE over the northern continuation of the anomalies in Figures 4(b) and (c). A strong Sb anomaly is present over the outcrop of the Routhvoes Fe vein correlating with the WO_3 anomaly in Figure 4(b).

Gaverigan/Parka

Soil samples in this area (Figure 6) are less easy to interpret as there has been been extensive small scale mining. The regional Sn anomalies at Parka, Fatwork and Gaverigan are delimited in detail. The anomaly immediately north of the exposed granite was drilled and found to consist of tourmaline-rich sheeted veins systems, paralleling a sub-outcropping granite ridge, as described by Bristow and Scott (1998). This mineralisation is accompanied by a strong As anomaly spatially associated with calc-silicates and a Cu anomaly to the SW of the known vein as seen in Figure 3. Drilling of the eastern (Gaverigan) Sn anomaly intersected breccias that become sheeted veins near the surface (Camm and Dominy, 1997).

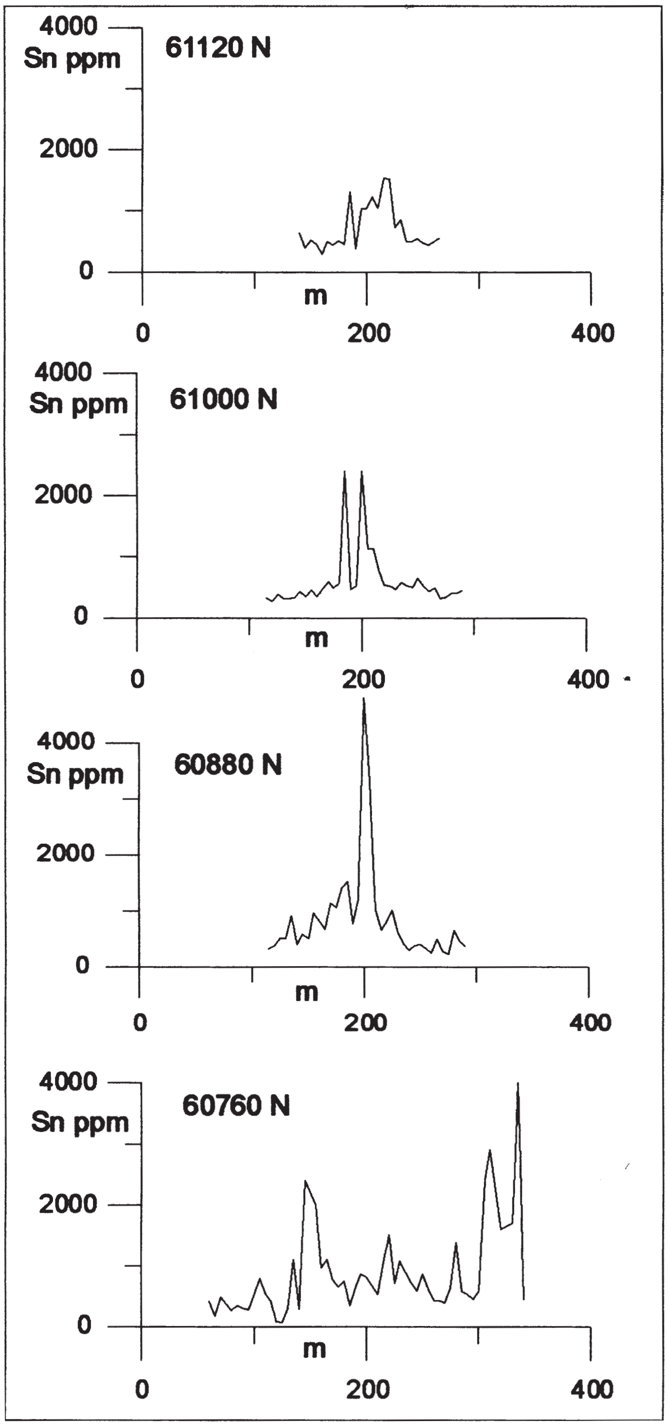

Figure 5. *Detailed 5 m spaced soil sampling results along selected lines at Treliver. Location of grid shown on Figure 4 (0 m- 191600 E).*

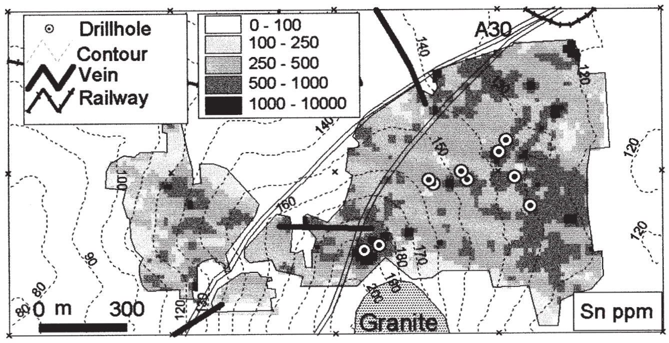

Figure 6. *Detailed sampling: Gaverigan/Parka, for Sn ppm. Elemental contents generated from a 50 m window of nearest neighbours, inverse distance weighting. Contours from 50 m grid digital Ordnance Survey data. Geological data modified from BGS sheet 327. × indicates Ordnance Survey kilometre grid.*

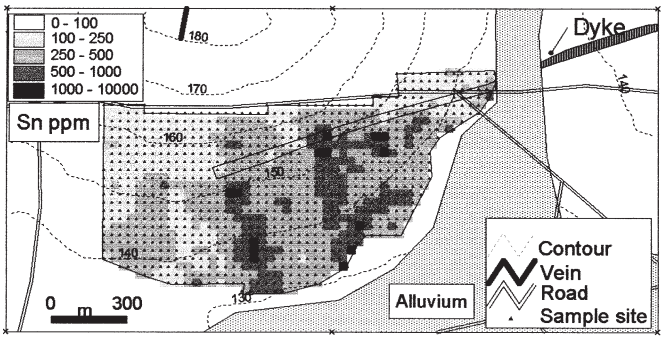

Figure 7. *Detailed sampling: Royalton, for Sn ppm. Elemental contents generated from a 50 m window of nearest neighbours, inverse distance weighting. Contours from 50 m grid digital Ordnance Survey data. Geological data modified from BGS sheet 327. × indicates Ordnance Survey kilometre grid.*

Royalton

Detailed sampling (Figure 7) shows that the control on Sn distribution is not the quartz-porphyry dyke as might be anticipated from Dines's (1956) description but a NNW trending linear feature that intersects the dyke. Their significance has not been tested by drilling.

Discussion

The four elements chosen for XRF and AAS analysis delineate well the different styles of mineralisation. Multielement analysis by ICP-ES added little to the detection of mineralisation at Treliver although it aided delineation of rock and soil types.

The regional data indicate the very different signatures of the Sn and W prospects and mines within the aureole of the St. Austell Granite. The Castle-an-Dinas cusp appears to be specialised in W and the associated vein mineralisation is enriched in As and Cu, similar to other discrete cusps, notably Hemerdon (Beer and Ball, 1987).

The signature of the Sn prospects appear to differ with type. The N-S trending breccia and stockwork zones are essentially mono-elemental Sn anomalies and depleted in base metals. In contrast the E-W vein anomalies are Cu and, sometimes, As rich. This contrast has not previously been recognised. During their investigation of the regional Sn anomalies Dunlop and Meyer (1978) suggested that base metals could be used to distinguish bedrock mineralisation from placers based on their work at Wheal Jane. This co-incident base metal and tin signature was confirmed by other surveys at Wheal Jane (Hosking, 1971; Moon *et al*., 1995). The present study suggests that single element Sn anomalies could be bedrock derived and should be treated with caution. Soil panned concentrates should be collected and the angularity of grains examined to see if cassiterite is locally derived. Nearby bedrock mineralisation will be expressed by angular cassiterite associated with tourmaline whereas placers will show more rounded cassiterite.

The spatial correlation of tungsten with the NW trending Ruthvoes vein is less easy to explain as mineralisation associated with this vein direction has been thought of as late stage (Dines, 1956) although Hosking (1964) regards it as re-activated. The association of Sb and W support Hosking's suggestion as W is generally considered to have been deposited at high temperature and Sb at much lower temperatures. The structure possibly acted as a conduit for epithermal fluids in the Mesozoic.

The distribution of As is not uniform within the aureole and high As concentrations result from the intrusion of the Castle-an-Dinas and part of the St. Austell Granite and their associated mineralisation, both W and Sn-Cu rich. However, other granite intrusions such as Belowda Beacon are not enriched.

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