WHEAL JANE: SOIL GEOCHEMISTRY REVISITED

CHARLES J. MOON

Moon, C.J. 2002. Wheal Jane: soil geochemistry revisited.
Geoscience in south-west England, **10**, 336-342.

The Nangiles area provides a small, relatively undisturbed, window over the B Lode subcrop of the Wheal Jane deposit. Sampling replicated the previously described positive Sn, As and Cu anomalies and showed negative anomalies for Fe, Mn and Mg to the south of B Lode. ICP-MS analysis detected strong Bi, In, acid soluble Sn and W anomalies as well as weaker Sb and Hg highs. A broad Pb high may reflect cross-cutting late Bi sulphosalt mineralisation. Soil Zn and Cd anomalies are lacking, possibly because of leaching. Regional soil geochemical data for a 6 × 5 km block collected in 1973 have been digitised. The data set comprises ~3600 samples collected at ~16 m spacing along lines with ~ 300 m between lines. The Carnon Valley and the area around Chacewater are strongly anomalous as a result of both Sn and Cu contamination and Sn placer deposits. The other major feature is an anomaly parallel, and to the south of, Wheal Jane at Cusgarne. Part of this is probably alluvial but distinct Cu-Sn anomalies are present up slope from the alluvium and relate to previously undocumented Sn-Cu-Pb-As mineralisation.

Department of Geology, University Road, University of Leicester, Leicester, LE1 7RH, U.K.
(E-mail: cjm@le.ac.uk).

INTRODUCTION

The area surrounding the Carnmenellis and Carn Marth granites is the most productive part of the Cornubian orefield, including the major producers of the 1980s at South Crofty and Wheal Jane. Although soil geochemistry has been widely used as an exploration tool in uncontaminated areas, few data have been published. This study details the multi-element geochemical signature over an undisturbed part of the Wheal Jane orebody, the Cu and Sn geochemistry of the region around Wheal Jane and multi-element follow-up of one of the more significant anomalies to the south of Wheal Jane around the hamlet of Cusgarne (Figure 1).

BACKGROUND GEOLOGY

The main lithologies in the area are slates of upper Devonian age, divided between the northern Porthtowan Formation and the southern Mylor Slate Formation (Leveridge *et al.*, 1990). These sediments have been intruded by the Carn Marth and Carnmenellis granites, which crop out to the west and south of the area of interest. Their metamorphic aureoles strike approximately N-S through the western most kilometre of Figure 1. The area is cut by a number of quartz-feldspar porphyry - rhyolite (elvan) dykes shown on Figure 1, which are broadly synchronous with the late stages of granite intrusion (Leveridge *et al.*, 1990).

The major mineral deposit in the area is Wheal Jane, which was mined between 1971 and 1991 (Moon *et al.*, 1995), although there was extensive smaller scale mining in the eighteenth and nineteenth centuries elsewhere in the study area (Dines, 1956; Jenkin, 1962, 1963). Mineralisation within the Wheal Jane lease area (Figure 2) consists of a number of distinct styles (Rayment *et al.*, 1971; Kettaneh and Badham, 1978): (1) Mineralisation spatially (although not genetically) associated with the footwall and hanging wall contacts of quartz–porphyry dykes, such as B Lode. (2) Tin mineralisation in steeper fractures such as M Lode. (3) Massive sulphides in restricted areas of B Lode. (4) Narrow chalcopyrite-sphalerite veins (caunter lodes) dipping 50 –70° south and of different strike to the dykes. (5) Late pyrite and galena fillings in N–S trending faults, termed cross courses.

A simplified model of the main mineralising episodes is (Holl and Bromley, 1988): (1) Greisenisation with a wolframite, cassiterite, löllingite, native bismuth and quartz assemblage (greisen phase). (2) Tourmalinisation of shear zones with deposition of quartz and cassiterite in a very fine-grained assemblage as a result of rapid deposition and shearing (tourmaline phase). (3) Extensive chloritisation of shear zones and/or wall rocks with further introduction and remobilisation of quartz, cassiterite and sulphides (arsenopyrite, stannite, chalcopyrite, sphalerite, pyrite and quartz), (chlorite phase). (4) Sulphide mineralisation as veining of earlier ore and as massive banded pyrite, sphalerite and chalcopyrite (replacement veins). (5) Vuggy quartz and barren sulphide veins cross-cutting the original fabric.

Outside the Wheal Jane lease area, the main target of mining has been thin copper and tin veins that have mainly been mined by hand stoping (Dines, 1956; Jenkin 1962, 1963). Soils in the upland areas are generally brown earths with little zonation in the B horizon.

Figure 1. *Index map of survey areas. Geology after BGS Sheet 352, Falmouth (British Geological Survey, 1990). Ordnance Survey from Digimap (2001).*

NANGILES AREA: WHEAL JANE B LODE

The Nangiles area has been used as an orientation area in three studies (Hosking, 1971; Rayment, 1973; Dunlop and Meyer, 1978). Hosking (1971) discussed the geology of the area in detail and, based on a map of approximately 1810, argued that although the area had been trenched any disturbance was very localised as the trenches were backfilled with their own debris. Longitudinal sections (Rayment *et al.*, 1971; Davis and Battersby, 1985) show that the part of the structure sampled is mineralised although sub-economic.

Samples were collected during November 2000 as part of a student exercise along 4 NW-SE linear traverses at 100 m intervals, 10 m along lines and at approximately 40 cm depth. Location was controlled by pacing and controlled by field boundaries on Ordnance Survey 1:2500 maps. The samples were dried and sieved at the University of Leicester. Samples from all 4 traverses were analysed by Inductively Coupled Plasma Emission Spectrometry (ICP-ES) following an aqua regia attack and, subsequently, a subset from line B over the interpreted subcrop of B Lode was analysed by ICP-ES and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at Chemex Labs in Vancouver, also following an aqua regia digestion. The ICP-MS data provided high quality data for additional elements such as Bi, Cd, Cs, Ga, Ge, Hf, In, Nb, Sb, Ta, Tl, Th and W. Quality was controlled by the insertion of duplicates and in-house reference materials and precision was generally better than 10%. There was an excellent correlation between the Leicester and Vancouver ICP-ES data.

All four lines (from east to west, A-D) cross B Lode (Figures 2 and 3 a-d), as determined from mine plans. Lines A and B showing no obvious contamination from mining or other human activity, although line A is about 150 m west of the edge of the tailings dam. Key samples are missing from Line C around the house on the centre of the line, which was also the location of a shaft shown on the 1890 Ordnance Survey map of the area. Line D appears to have significant contamination as discussed below. The area slopes from NNE to SSW with all lines sloping from NW (0 m) to SE.

B Lode and the spatially associated quartz porphyry dyke form the major geochemical feature in the survey. Both copper and arsenic (Figures 3a and b) give distinct anomalies immediately down slope from the subcrop of B lode. The As data however, become less clear downslope and Line D has high As concentrations throughout, probably reflecting airborne contamination from the Bissoe As refinery, 800 m to the SE, as well as mine spoil, as indicated by hummocky ground. The Cu and As results correlate well with those of Hosking (1971) who also determined total Sn, which gives a peak of 250-300 ppm relative to a background of <20 ppm Sn (Figure 3 a-d). Lead (Figure 3c) has a broad (>300 m) high, with maximum enrichment over a probable cross cutting vein, shown on the BGS map and in the section of Nangiles in Hill and MacAlister (1906). These lead data contrast with those of Dunlop and Meyer (1978) who described Pb values as low. One notable feature of the lines is the sharp decrease in Fe, Al and Mn immediately over, and to the south of, the subcrop of the B lode dyke and vein. These data confirm the findings of Dunlop and Meyer (1978) who suggest that the sharp decrease reflects the hanging-wall of the dyke. The low, however, appears to extend throughout the southern part of lines A and B. Other elements that show a similar pattern are Co, Cr, Mg, Mn, Ni and V. Another feature of the ICP-ES data is the lack of a Zn anomaly over B Lode. This is somewhat surprising as Wheal Jane was a significant Zn producer.

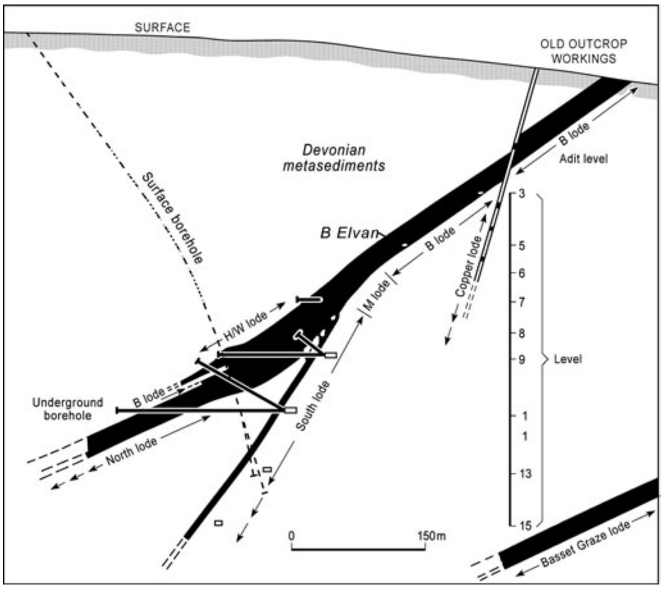

Figure 2. *Section through Wheal Jane, looking east (after Davis and Battersby, 1985).*

Line B appeared to have the least contamination and was chosen for analysis by ICP-MS to test the signal of the subcrop of B Lode, which is clearly visible in the ICP-ES data for Cu and As (Figure 4a). The SE end of the line does shows an erratic increase in As probably reflecting either dust from the tailings pond or airborne contamination from the Bissoe stack. The distinct change in the Fe data over B Lode can be seen in Figure 4b.

The ICP-MS data (Figures 4c and d) show high contrast Bi and In anomalies and weaker Hg and Sb anomalies, over and downslope from the B Lode subcrop, although the peak In values are displaced 20 m N from the others. The Hg, Bi and Sb peaks correlate well with acid soluble W and Sn peaks determined by ICP-MS. Cadmium, like Zn, shows no anomaly, although there is a broad Ag high. Lithium and Be show weak highs over the subcrop of B Elvan, as do La, Ce, Hf and Zr although the ICP-MS data do not completely cover the dyke subcrop.

REGIONAL GEOCHEMISTRY: WHEAL JANE REGION

Using sample parameters derived from his orientation study over the the Nangiles section, Rayment (1973) conducted a soil survey over available ground in a 6 × 5 km area to locate extensions to the Wheal Jane mineralisation or other previously unknown anomalies (Figure 5). Based on the orientation study, samples were collected at 16 × ~300 m on NNW-SSE oriented lines. In order to minimise the impact of mine waste and tailings, no samples were collected from around obvious dumps. In total, including some follow-up lines, 3613 samples were analysed: colorimetrically for Sn and by AAS for Cu. Tin was determined to indicate tin mineralisation, potentially both bedrock and placer, and Cu to discriminate between the two types (Dunlop and Meyer, 1978). Sample locations were plotted on 1:2500 map sheets and have subsequently been digitised for this study using Ordnance Survey Landline data (Digimap, 2001).

The data, plotted by percentile (Table 1), show the obvious enrichment in Sn in the Carnon Valley, particularly south of Chacewater (Figure 1) and around known mineralised veins (Figure 5a). The alluvial enrichment is well known and the Carnon Valley, south of Wheal Jane, has been mined in the twentieth century (Camm *et al.*, 1981). Other alluvial highs are south of Threemilestone (177600 E, 44200 N) and along the Hick's Mill Stream, near the village of Cusgarne (175500 E, 40700 N). The Cu data (Figure 5b) show a general enrichment in the west, particularly around Chacewater and both to the south and north of Cusgarne, often closely correlating with areas of known mineralisation.

In order to identify areas for follow-up and to remove the affects of alluvial concentration and known mineralisation, buffers (corridors) were constructed around the veins and alluvium mapped on the published geological map. The major anomalies (Figures 6 a and b) of the remaining 1899 samples are in the Cusgarne area, to the south of Chacewater and to the south of Threemilestone. The first two have associated Cu anomalies and can be interpreted as bedrock mineralisation whereas the last may be mainly a high level placer. The quartz-porphyry dykes

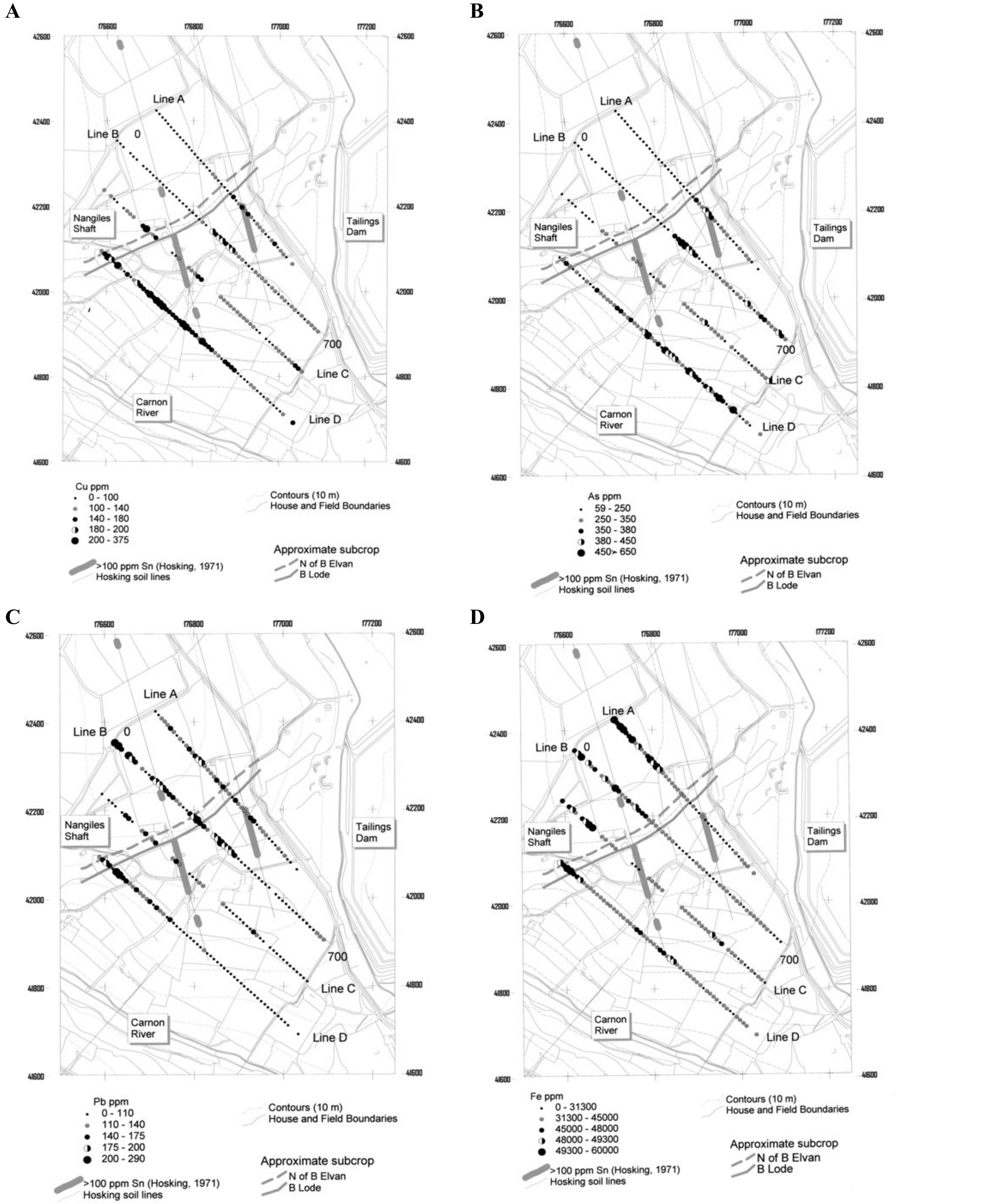

Figure 3. *Soil sampling at Nangiles over B Lode, Wheal Jane. University of Leicester data. Hosking (1971) Sn data shown for comparison. Geology after BGS Sheet 352 (British Geological Survey, 1990). Ordnance Survey data from Digimap (2001). Location of area shown in Figure 1. Lines are A-D from east to west. (a) Copper. (b) Arsenic. (c) Lead. (d) Iron.*

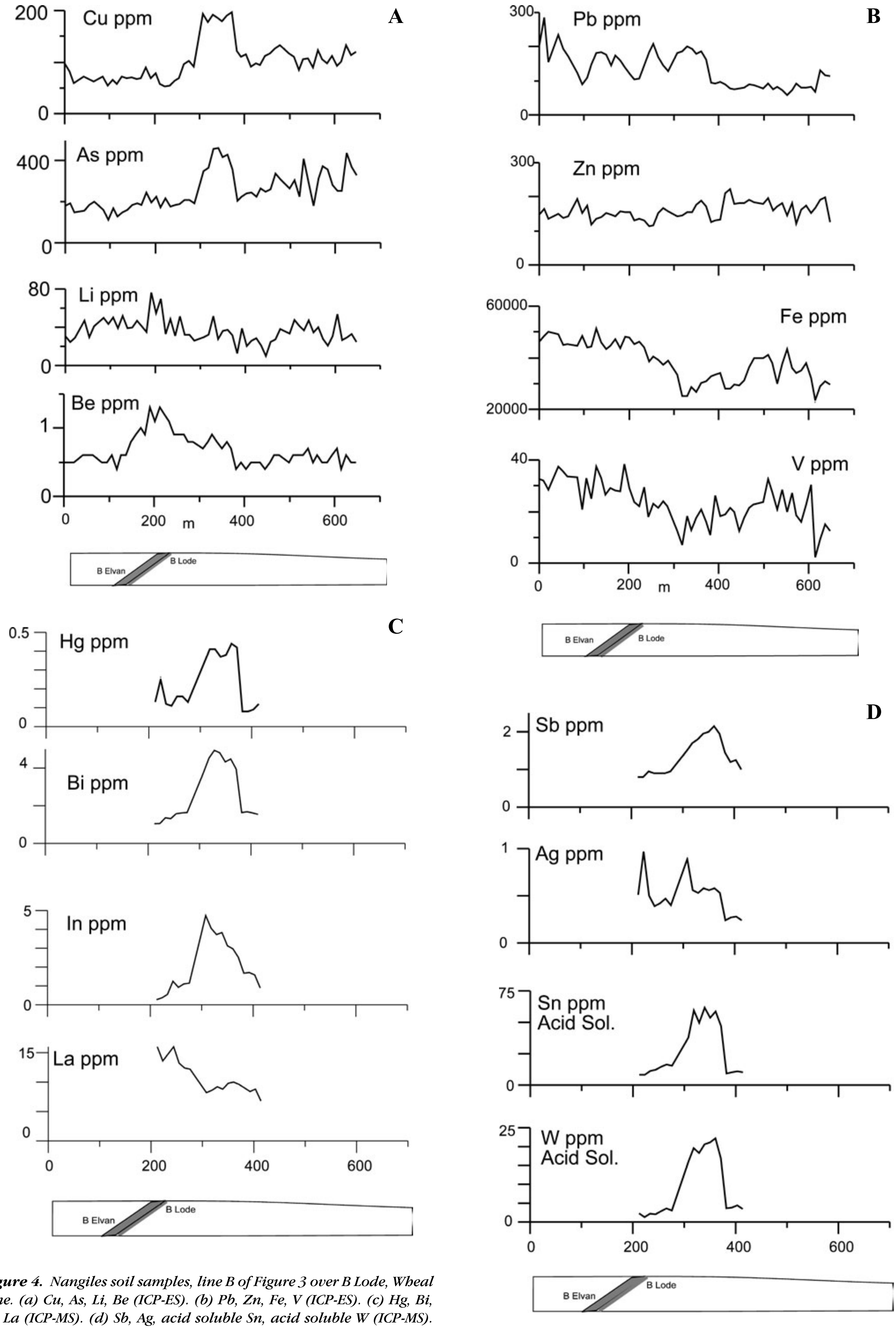

Figure 4. *Nangiles soil samples, line B of Figure 3 over B Lode, Wheal Jane. (a) Cu, As, Li, Be (ICP-ES). (b) Pb, Zn, Fe, V (ICP-ES). (c) Hg, Bi, In, La (ICP-MS). (d) Sb, Ag, acid soluble Sn, acid soluble W (ICP-MS).*

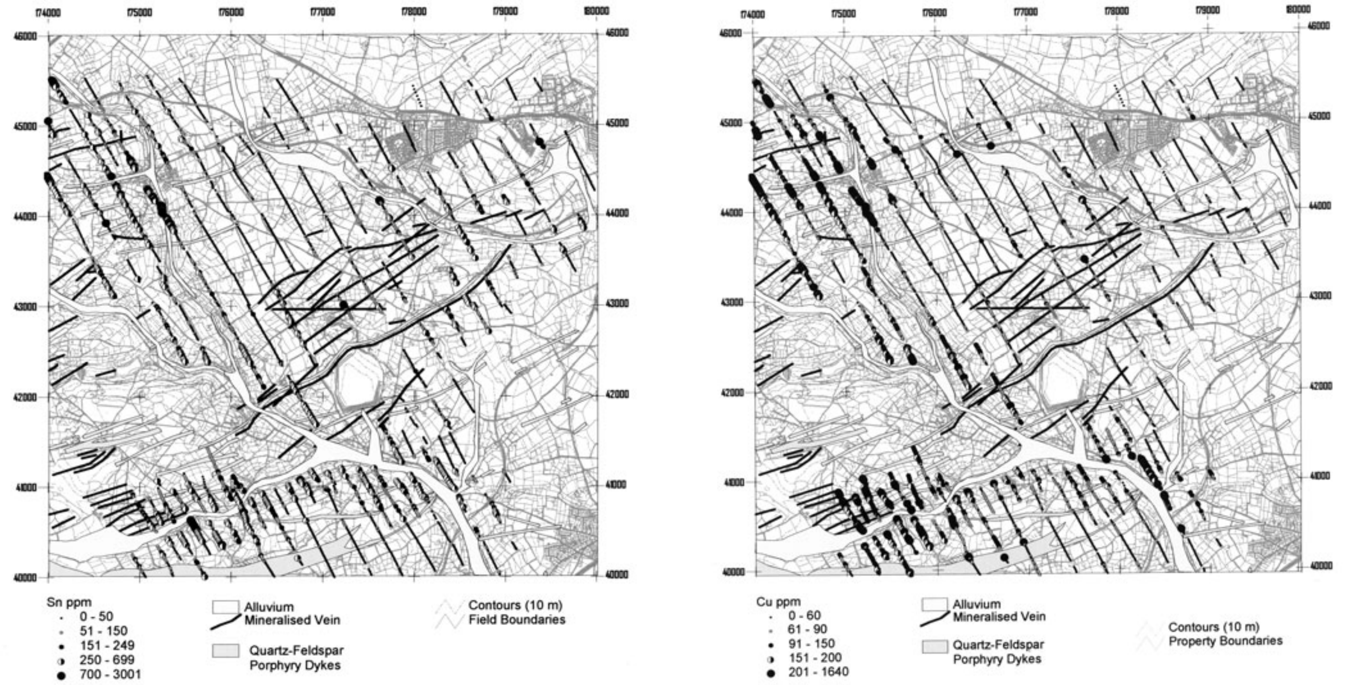

Figure 5. *Regional soil samples (Rayment, 1973). Geology after BGS Sheet 352, Falmouth (British Geological Survey, 1990). Ordnance Survey data from Digimap (2001). Named locations shown on Figure 1. (a) Sn ppm. (b) Cu ppm.*

	n	Min.	Max.	50	75	90	95	99
Total Data								
Sn	3565	<25	3000	50	150	250	350	700
Cu	3553	12	1640	59	90	150	208	371
Buffered Data								
Sn	1899	<25	1000	50	100	150	250	400
Cu	1895	14	411	52	74	108	150	250

Table 1. *Descriptive statistics for the CGF regional data and buffered version after removing sites within 200 m of alluvium and 100 m of mapped veins.*

have been classified into those associated with geochemical anomalies or known mineralisation and those which appear unmineralised (Figures 6a and b). The most promising target is in a linear anomaly parallel and to the south of the Hick's Mill stream from 175000 E, 40000 N to 177500 E, 41000 N, discussed in detail below. A further target is associated with the dyke to the north of Cusgarne. The area around Chacewater has been investigated in detail by soil profiling and anomalies around the village appear to be related to contamination as they decrease in metal content with depth (Jones, 1974).

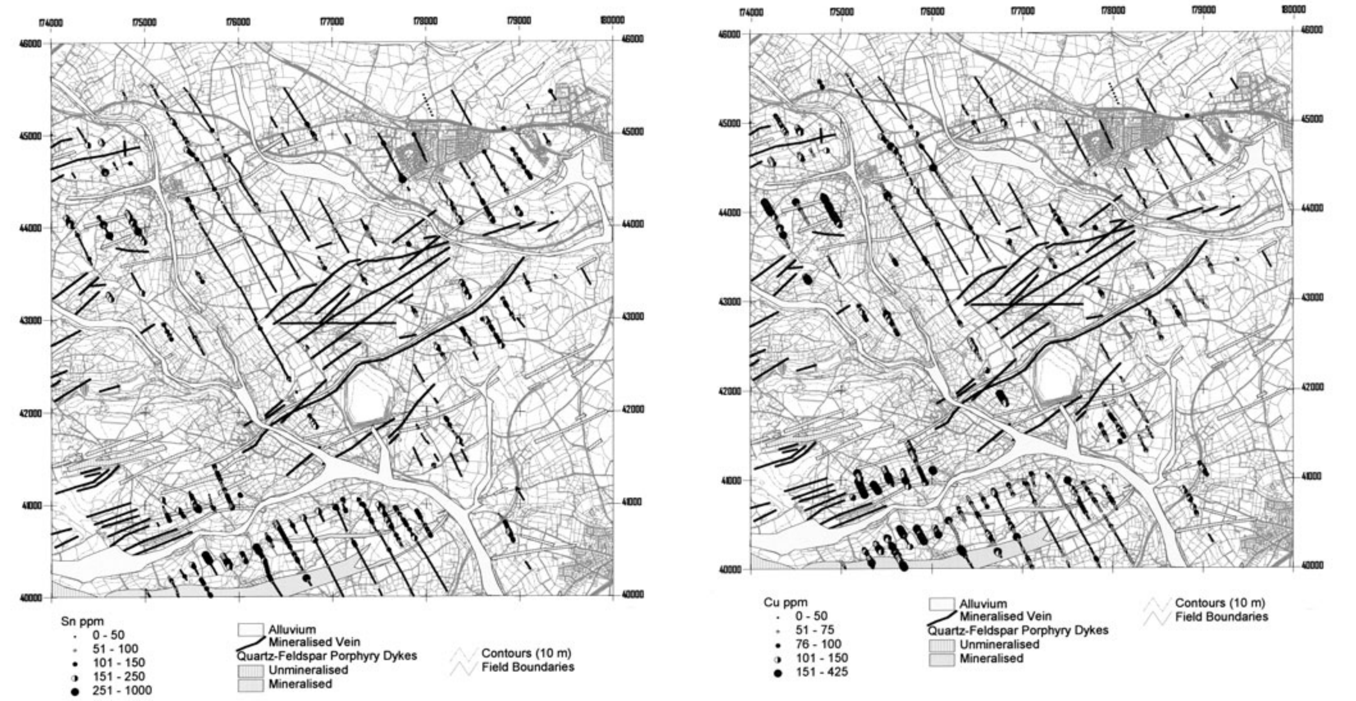

Figure 6. *Regional soil samples (Rayment, 1973). Geology after BGS Sheet 352, Falmouth (British Geological Survey, 1990). Ordnance Survey data from Digimap (2001). Named locations shown on Figure 1. Samples within 200 m of mapped alluvium and 100 m of mapped veins removed. (a) Sn ppm. (b) Cu ppm.*

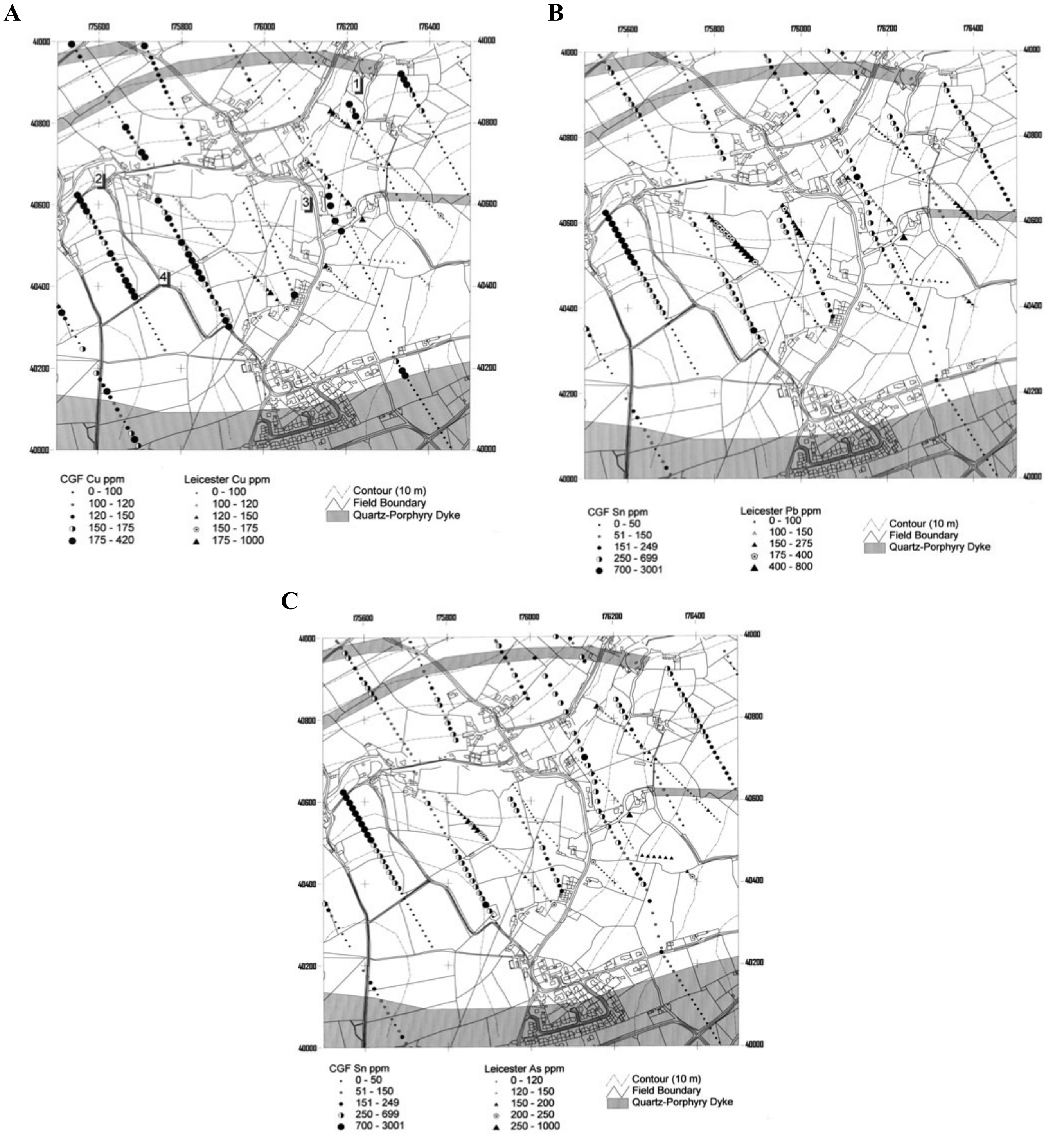

Figure 7. *Regional and follow-up samples, Cusgarne area. Geology after BGS Sheet 352, Falmouth (British Geological Survey, 1990). Ordnance Survey data from Digimap (2001). Named locations shown on Figure 1. (a) Regional Consolidated Gold Fields Cu data, Leicester Cu data. Numbers refer to anomalies discussed in text. (b) Regional Consolidated Gold Fields Sn data, Leicester Pb data (50, 75, 90, 95 percentiles). (c) Regional Consolidated Gold Fields Sn data, Leicester As data (50, 75, 90, 95 percentiles).*

CUSGARNE

The regional anomaly has been followed up by detailed sampling and profiling by Consolidated Gold Fields (Rayment, 1973) and multi-element geochemistry by the University of Leicester in 2001.

Both Sn and Cu have strong anomalies along the Hick's Mill Stream (Figure 7), which can be discounted as contamination from the stream and placer occurrence. The strongest Cu anomaly is around the school at Cusgarne (Figure 7) and appears to be partly a base of slope anomaly in marshy ground. However, recent (2001) building work at the school disclosed an old shaft, suggesting that bedrock mineralisation exists. The other prominent Pb and As anomaly (Figure 7) is a linear SW-NE feature with a sharp upslope cut off, indicating a previously unknown base metal Sn vein. This feature appears to be a strike extension of mineralisation at Pulla, which according to Jenkin (1963) was worked as South Clifford United, an unimportant copper mine. The overall Pb-Sn-Cu-As association is very similar to Wheal Jane but as far as is known the anomaly has not been drill tested. The mineralisation could be associated with the extension of the dyke to the east of the school, which has a Pb anomaly spatially associated with it.

Discussion

Multi-element signature of B Lode

The geochemical signal of the subcrop of B lode is multi-elemental. In addition to the Sn, As and Cu anomalies described by Hosking (1971), there are strong Bi, In, acid soluble W and lesser Sb and Hg anomalies. Although W and Bi might be expected as greisenisation is a feature at Wheal Jane, both W and Bi are widely associated with this style of mineralisation (Ball *et al.*, 1982; Beer and Ball, 1987) and Sb forms late stage Pb-Sb-Bi sulphosalts (Kettaneh and Badham, 1978), In and Hg were not anticipated. No indium minerals have been reported from Wheal Jane and, in SW England, roquesite has only been reported from Geevor (Criddle and Stanley, 1993). Indium is known to substitute in both tin sulphosalts and sphalerite (Schwarz-Schampera and Herzig, 1999) and concentrations of 300 ppm have been reported from Tresavean, 4 km SW of Wheal Jane (El Shazly *et al.*, 1956). However, this requires further investigation. The mineralogical location of Hg is also not known and requires investigation as do the regional distribution of Bi, In and Hg.

The broad Pb anomalies are not definitive of B Lode itself and may be associated with late cross cutting veins rich in galena and sulphosalts as suggested by Kettaneh and Badham (1978). The lack of Zn and Cd anomalies could be due to leaching of these very mobile elements (Rose *et al.*, 1979) and this leaching could explain the sharp change in Fe concentration across the subcrop of the dyke. The subcrop of the quartz-porphyry dykes appear to be detectable in soils using the rare earth elements, Be, Hf, Li and Zr even in aqua regia leaches.

Regional sampling

Bedrock mineralisation is detectable using a combination of -180 μm soil sampling and multi-element geochemistry, although there are many difficulties in interpreting the data due to placer deposits and mine waste. However, the 16 × 300 m sampling grid was effective in detecting B lode size targets. Elimination of alluvium and contamination, coupled with field checking, highlighted areas for follow-up, including the previously unknown Cusgarne area and the contaminated area surrounding Chacewater. It may, however, be that the coarse (-2 mm + 0.425 mm, cassiterite specific digestion) sampling technique recommended by Fletcher (1987) will give better results. Sampling at Cusgarne showed a similar anomaly signature to that at Nangiles, suggesting that other mineralised systems may be discovered using this multi-element approach.

Acknowledgments

Students at the University of Leicester collected, prepared and analysed the samples at Wheal Jane and Cusgarne and are thanked, as are analysts Emma Mansley and Kevin Sharkey. The original samples were collected under the supervision of Barry Rayment and Mike Hopley, who are thanked. BGS open file section kindly made the open file reports available. Landowners in the areas are thanked for access to their land. The Digimap project is thanked for the copyright Ordnance Survey data.

References

BALL, T.K., BASHAM, I.R., BLANK, D. and SMITH, T.K. 1982. Aspects of the geochemistry of bismuth in S.W. England. *Proceedings of the Ussher Society*, **5**, 376-382.

BEER, K. and BALL, T.K. 1987. Tungsten mineralisation and magmatism in S.W. England. *Chroniques de la Recherche Miniere*, **487**, 53-62.

BRITISH GEOLOGICAL SURVEY. 1990. Falmouth, 1: 50,000 sheet 352. HMSO, London.

CAMM, G.S., TAYLOR, I., HARTWELL, P. and SCARBOROUGH, B. 1981. Carnon valley, Cornwall, a placer tin deposit. *British Geologist,* 7, 65-71.

CRIDDLE, A.J and STANLEY, C.J. 1993. *Quantitative Data File for Ore Minerals.* Kluwer Academic, Dordrecht.

DAVIS, C.J. and BATTERSBY, G.W. 1985. Reopening of Wheal Jane mine. *Transactions of the Institution of Mining and Metallurgy*, **94**, A135 - A147.

DIGIMAP, 2001. Digital Ordnance Survey data. University of Edinburgh.

DINES H.G., 1956. *The Metalliferous Mining Region of South- west England*. HMSO, London.

DUNLOP, A.C. and MEYER, W.T. 1978. Detrital tin patterns in stream sediments and soils in mid-Cornwall. *Journal of Geochemical Exploration,* **10**, 259-276.

EL SHAZLY, E.M., WEBB, J.S. and WILLIAMS, D. 1956-57. Trace elements in sphalerite, galena and associated minerals from the British Isles. *Transactions of the Institution of Mining and Metallurgy*, **64**, 241-271.

FLETCHER, W.K. 1978. Analysis of soil samples. In: FLETCHER, W.K, HOFFMAN, S.J., MEHRTENS, M.B., SINCLAIR, A.J. and THOMSON, I. (eds), *Exploration Geochemistry: Design and Interpretation of Soils* Surveys. Reviews in Economic Geology, Volume **3**, 79-96.

HILL, J.B. and MACALISTER, D.A. 1906. *The Geology of Falmouth and Camborne and the Mining Districts of Camborne and Redruth*. Memoir of the Geological Survey of Great Britain.

HOLL, C.J. and BROMLEY, A.V. 1988. Application of mineralogy to the beneficiation of a tin-sulphide ore. *Minerals Engineering,* **1**, 19-30.

HOSKING, K. F. G. 1971. Problems associated with the application of geochemical methods of exploration in Cornwall, England. In: BOYLE, R.W. (Ed.), *Geochemical Exploration '71*. Canadian Institute of Mining and Metallurgy, special volume 11, Toronto, Canada, 176-189.

JENKIN, A.K.H. 1962. *Mines and Miners of Cornwall. Volume III, Around Redruth.* Truro Bookshop, Truro.

JENKIN, A.K.H. 1963. *Mines and Miners of Cornwall. Volume VI, Around Gwennap.* Truro Bookshop, Truro.

JONES, E. 1974. *Consolidated Gold Fields Limited: Geological report: Chacewater Project 1 August 1973-30 June 1974.* BGS open file report.

KETTANEH Y.A. and BADHAM J.P.N. 1978. Mineralisation and paragenesis at Mount Wellington Mine, Cornwall. *Economic Geology,* 73, 486-495.

LEVERIDGE, B.E., HOLDER, M.T. and GOODE, A.J.J. 1990. *Geology of the Country around Falmouth.* British Geological Survey Memoir, Sheet 352. HMSO, London.

MOON, C.J., WHATELEY, M.K.G. and EVANS, A.M. 1995. Narrow vein deposits – Wheal Jane, Cornwall. In: EVANS, A.M. (Ed.), *Introduction to Mineral Exploration*. Blackwell Science, Oxford, 344-367.

RAYMENT, B.D. 1973. *Consolidated Gold Fields Limited: Geological report: Chacewater Project 19 January-31 July 1973.* BGS open file report.

RAYMENT, B. D., DAVIS, G.R. and WILLSON, J. 1971. Controls to the mineralisation at Wheal Jane, Cornwall. *Transactions of the Institution of Mining and Metallurgy,* **80**, B224-237.

ROSE, A.W., HAWKES, H.E. and WEBB, J.S. 1979. *Geochemistry in Mineral Exploration (2nd edition.)*. Academic Press, London.

SCHWARZ-SCHAMPERA, U. and HERZIG, P. 1999. Indium: geology, mineralogy and economics- a review. *Zeitschrift fur Angewandte Geologie*, **45**, 164-169.