Natural Environment Research Council

BRITISH GEOLOGICAL SURVEY

Mineral Reconnaissance Programme Report

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Investigations for tin around Wheal Reeth, Godolphin, Cornwall

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Mineral Reconnaissance Programme Reports

On 1 January 1984 the Institute of Geological Sciences was renamed the British Geological Survey. It continues to carry out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects; it also undertakes programmes of British technical aid in geology in developing countries as arranged by the Overseas Development Administration.

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Bibliographic reference

Beer, K. E., and **others**. 1986. Mineral Investigations near Bodmin, Cornwall. Part 5—The Castle-an-Dinas wolfram lode. *Mineral Reconnaissance Programme Rep. Br. Geol. Surv.*, No. 83.

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SUMMARY

Recognition of greisenisation closely associated with worked tin lodes near Wheal Reeth suggested the possibility of unrecorded or undiscovered mineralisation of stockwork or vein-sheet type. Geophysical methods were unable to define either greisenised or mineralised ground and a line of shallow percussive boreholes was drilled to examine the distribution of tin, associated base metals and fluorine in solid rock below surface soils which were potentially highly contaminated by former mining.

No economic mineralisation was revealed by the investigation nor was any broadly disseminated metallisation indicated. Not all of the worked tin-bearing structures could be identified from vertical percussion holes but one new vein was located by a combination of vertical and inclined drilling followed by shallow trenching. Results from inclined drillholes outline at least four more stanniferous veins or vein zones to the south of the Lady Gwendolen workings. The depth persistence of mineralisation in nearby Great Work Mine (c.365 m) suggests that some of the Wheal Reeth/Lady Gwendolen veins might repay deeper investigation.

Hand-panned heavy mineral concentrates from the drilling samples confirm the presence of only trace quantities of wolframite. They also reveal the ubiquitous enrichment of cassiterite at the base of the regolith cover, a feature which may explain in part the disappointing results obtained by commercial exploration groups when drilling below geochemical tin anomalies located by soil sampling.

The distribution of fluorine shows little correlation with that of tin and it is obvious that the Wheal Reeth area does not bear any swarms of greisen veins similar to those seen at Cligga Head. Indeed, it would appear that greisenisation may be only patchily developed along the vein walls.

INTRODUCTION

During detailed six-inch geological resurvey of the Land's End Sheet (One-inch Sheet 351/8), Dr. R T Taylor noted a widespread scatter of stanniferous greisen debris in waste dumps, hedges and field float around the site of Lady Gwendolen Mine [SW 588 301]*. This material is concentrated in a broadly east-west zone some 650 m wide covering the lower northern slopes of Tregonning Hill and part of the col between Tregonning and Godolphin Hills. Within this same zone course several tin veins formerly explored or exploited by Great Work Mine [c.595 306], Wheal Reeth (later Lady Gwendolen Mine) and Balwest Mine [c.595 298]. The major accumulations of greisen in the study area are shown in Figure 3.

The occurrence of abundant greisen in association with tin lodes presents distinct possibilities of localised sheeted or stockwork mineralisation developed adjacent to, or between, the wider vein structures. Indeed, in Dines' description of the Morris Lodes of Wheal Reeth (1956, pp. 234-5) there is a suggestion of vein sheeting. To test this possibility geophysical and geochemical traverses, approximately normal to the regional strike of the lodes, were planned to cross the full width of the greisen-bearing zone.

*National Grid 100 km square reference letters SW apply to all localities in this report

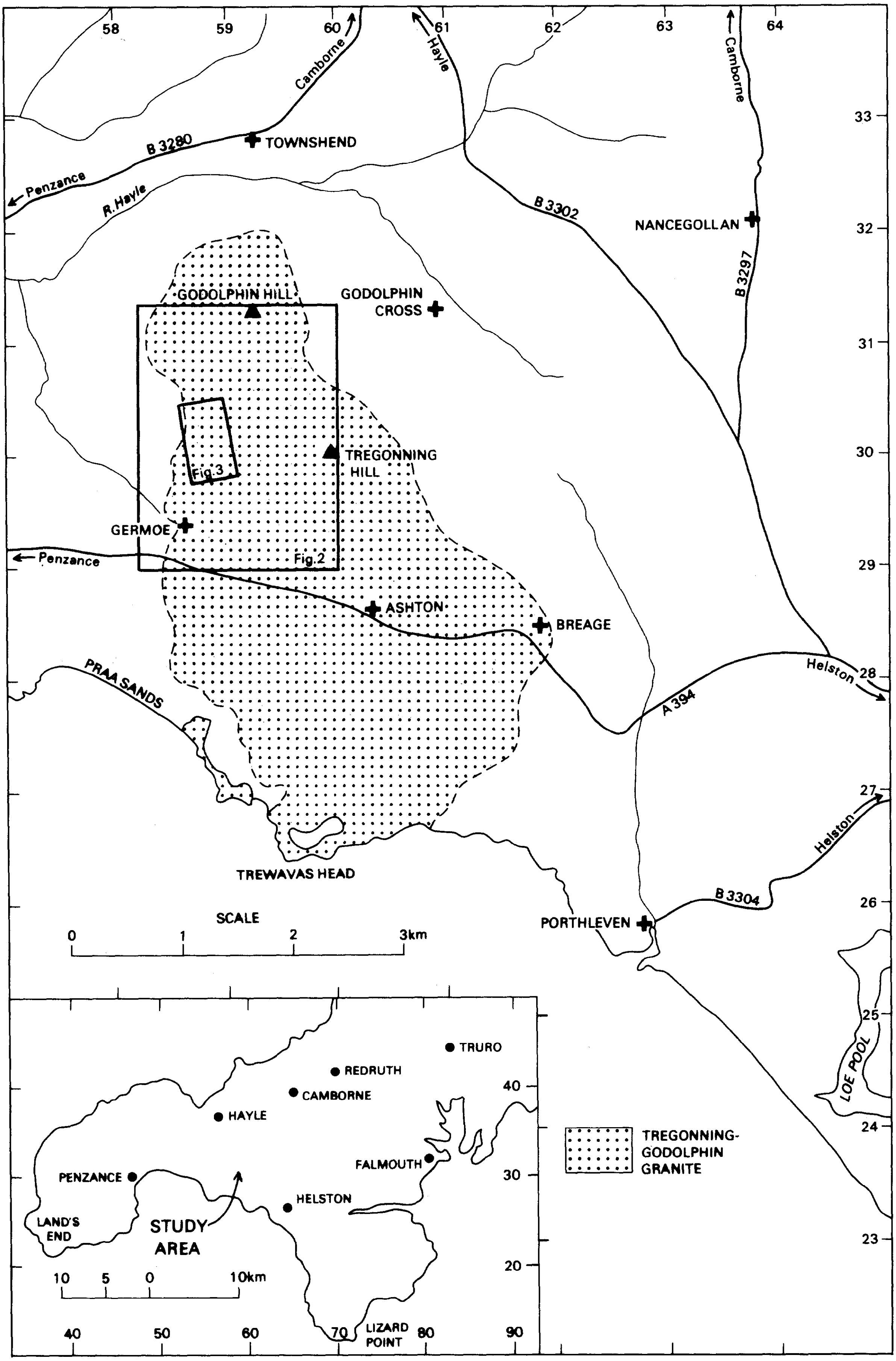

Fig.1. Location map.

Former mining activity has severely contaminated this area, which abounds in small waste dumps and trial pits, and much of the mined part is now uncultivated, often impenetrable, waste land; the remainder consists of small walled fields. As a result, traverse lines were difficult to site and only one continuous geochemical traverse, albeit sinuous, could be aligned across the zone. Even this was required to traverse two waste dumps.

Owing to the abundance of scattered coarse mine debris electrical geophysical surveys were completed only with difficulty and augering for soil samples was locally impossible. Local farmers intimated that finer mine waste was commonly used to infill field hollows during agricultural reinstatement of poor land. To avoid these problems a programme of deeper sampling, into the bedrock, was attempted with a Voltrac air-flush percussive drill.

LOCATION AND GEOGRAPHICAL SETTING

Wheal Reeth lies about 0.5 km west of the hamlet of Balwest and some 3.5 km north-west of Breage village on the Penzance to Helston main road (A394). It is situated in the col which separates Tregonning and Godolphin Hills, at an elevation of about 110m above sea level. The mine area is served only by a network of minor roads and tracks, all rather narrow and bedevilled by sharp bends. Penzance (14 km) and Camborne (16 km) are the closest rail heads.

Land usage is wholly agricultural, mainly grazing with some root, brassica and occasional grain crops. For the main part the soil is a sandy loam which drains well. The stream headwaters rise near the mine but their flow is generally small and during the period of mining industrial water had to be stored in tanks. Apart from agriculture, the area is dedicated to the tourist trade; there is no extractive mineral industry now operating although reclamation of sharp sand from the dumps of Wheal Grey China Clay Pit [594 291] was practised only a few years ago.

GENERAL GEOLOGY

The Tregonning-Godolphin granite mass (Figure 1) forms a small elongate outcrop extending some 5.5 km north from the coast and with a maximum width of about 3 km. South of the Helston-Penzance road the granite has little topographic expression, but to the north the summits of Tregonning Hill [599 300], 193.5 m high, and Godolphin Hill [592 312], 162.2 m, are landmarks in an otherwise subdued terrain. The granite is fully exposed along the coast and its relationship to the enclosing slates is particularly well displayed. Roof pendants of Mylor Slates and the presence of a banded pegmatite-aplite-leucogranite roof complex (Stone, 1975) indicate that the cupola has not been deeply eroded. Stone (1975) and Taylor and Wilson (1975) recognise two main granite facies: a biotite-granite with small feldspar megacrysts (Godolphin Granite of M.Stone) which may be later than, and intrude, a lithium-mica granite (Tregonning Granite) which forms the greater part of the outcrop. In these two accounts the authors disagree upon the distribution of the two facies and the mapping of Taylor is used in Figure 2.

Granite contacts are seen only in coastal sections where they are additionally complicated by the intrusion of apron-like sheets of roof complex facies into the contact hornfelses. At the eastern end of Praa Sands [586 275] the contact appears to be gently inclined but farther east, at Trequean Cliff [605 266] and Legereath Zawn [608 267], it is near vertical. The common occurrence of hornfelsed slate on the dumps (now largely removed) of Wheal Trewavas [600 265], derived from undersea workings, indicates a

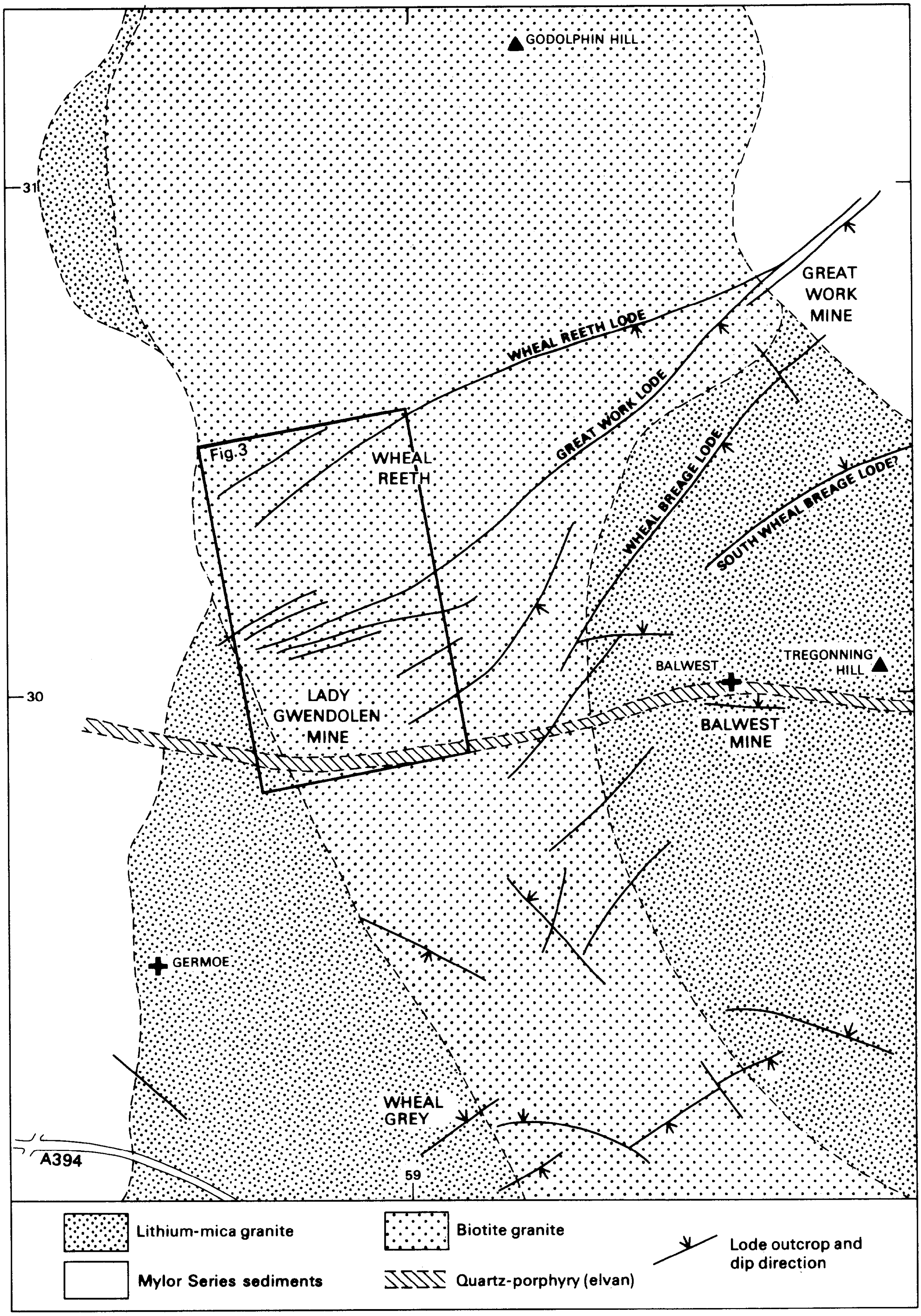

Fig.2. Geology around Wheal Reeth.

granite contact closely off-shore and implies that this contact must also be steep. Mining evidence (Dines, 1956, p225) and recent commercial exploration drilling (unpublished) at Carleen Mine [c.615 299] shows the contact here to dip gently eastwards; a similar attitude is reported from Great Work Mine (Dines, 1956, p.233). Although the western contact must pass through the workings of West Godolphin Mine [c.584 316], West Great Work Mine [c.578 313] and Leeds and St. Aubyn Mine [c.583 293] there is no record of its attitude. However, the breadth of the thermal aureole (Taylor and Wilson, 1975) and the Bouguer gravity anomaly plot of Tombs (1977) suggest a concealed prolongation of the granite westwards. The unusual northerly trend of this cupola is maintained at shallow depth to the north of Godolphin Hill and gravity surveys suggest that it is linked to a south-westerly trending subterranean granite ridge which is the extension of the Carn Brea-Carn Arthen-Pendarves outcrop (Beer, Burley and Tombs, 1975).

The granite is intruded into unfossiliferous dark grey and bluish grey Mylor Slates, a sequence which also includes intercalations of silty slates, sandstones, slumped beds and volcanic lava and ash. The Mylor Slates were regarded by Wilson and Taylor (1976) as Lower to Middle Devonian in age but this dating is brought into question by more recent microfloral studies at Mount Wellington Mine near Truro (Turner and others, 1979), which demonstrate the presence of Upper Devonian acritarchs.

An east-west porphyry dyke (locally termed elvan) crosses both the granite and the enclosing slates and can be traced along a strike length of 2 km. It was formerly quarried on Tregonning Hill.

Mineral veins in the Germoe area follow two main trends. The more continuous veins, and the more important producers, have an east-north-easterly strike and generally dip steeply north. A north-westerly trending set is less well represented, is usually less continuous and more poorly mineralised, and can be seen to intersect and heave the other set. Many of the veins cross the granite-slate contact and tradition suggests that viable mineralisation in either host did not persist into the other. The main product was cassiterite with lesser quantities of copper ores and token amounts of arsenic. Fluorite, usually colourless but sometimes green and rarely purple, together with traces of wolframite, can be found on the waste dumps but no production is recorded for these minerals.

Alteration of the granite is most pronounced around the mineral veins and the elvan dyke. Greisenised granite is reported as the wallrock to several lodes (Dines, 1956) and field mapping shows this form of metasomatism widely represented in the vein swarm zone between Balwest Mine and Wheal Reeth (Figure 2). Kaolinisation is less common around Great Work Mine and Wheal Reeth but is well developed close to the elvan on Tregonning Hill and at Wheal Grey, where it was formerly worked. It was at Wheal Grey in 1745 that William Cookworthy first recognised china clay in Cornwall. At both localities the alteration appears to have been localised, patchy and impersistent; production was both small and short-lived.

FORMER MINING

In the immediate vicinity of the study area tin ore was worked in Great Work Mine, Wheal Reeth, Wheal Breage, Balwest Mine and Lady Gwendolen Mine. Definition of each mine and an understanding of its record is confused by a history of periodic working and closure, sale and resale, changes of title and brief amalgamations, combined with a marked paucity of written records.

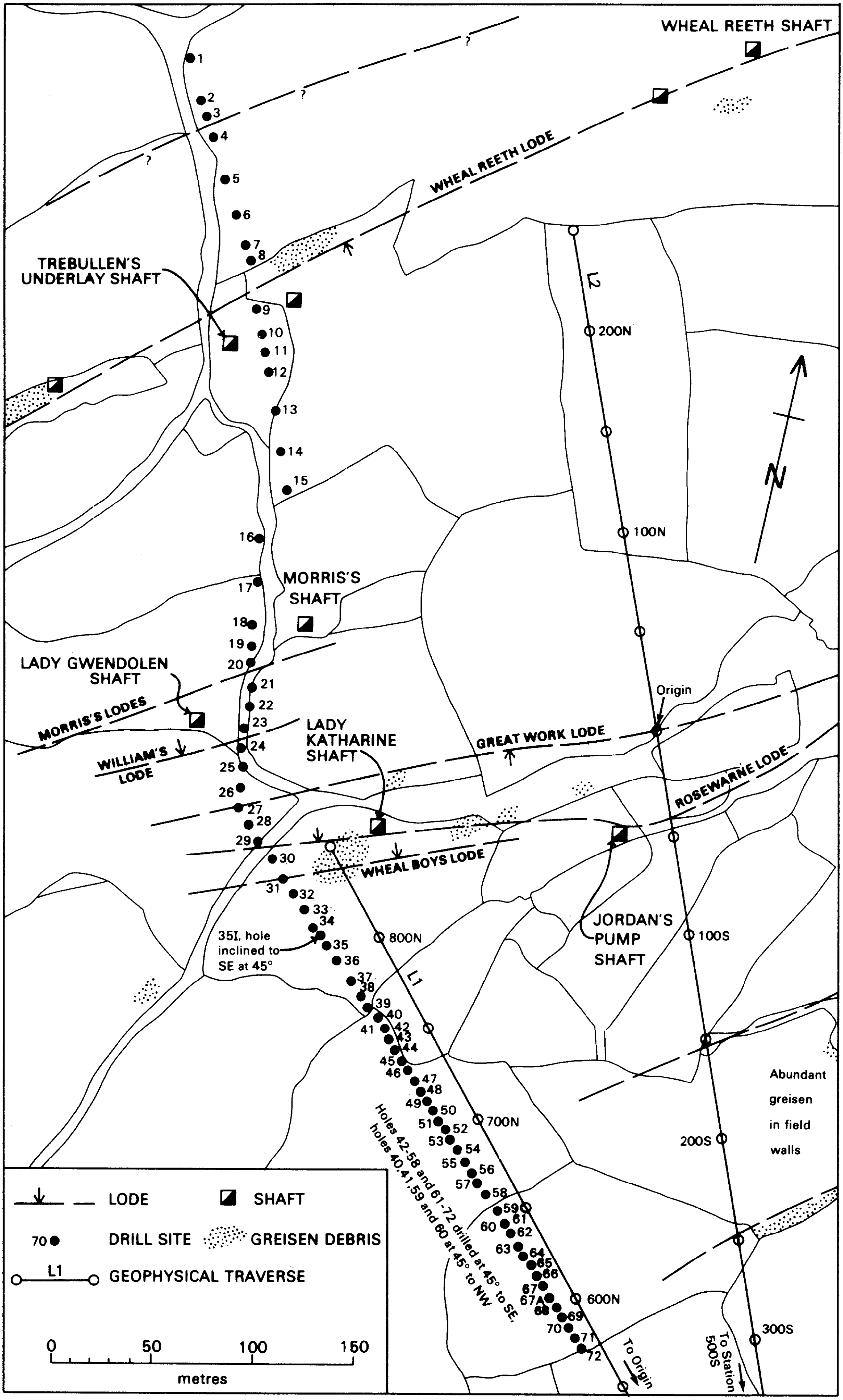

Fig.3. Traverse locations.

Great Work Mine is known to have been active before 1540, Wheal Reeth was mining in 1736 at 50 fathoms (91 m) below adit level and Wheal Breage was working in 1795 (Jenkin, 1965). By 1843 Wheal Breage had been incorporated into Great Work Mine (Henwood, 1843, Table 43). The history of Balwest Mine is not recorded but it is presumed to have become a part of Wheal Breage at an early date. The early years of Lady Gwendolen Mine are shrouded in some mystery but it appears that this title was being used in 1898 for workings on the western extensions of the Great Work veins.

In 1906 Lady Gwendolen was being actively prospected below adit level (about 80 ft. below surface) with two shafts down to a 100-ft. level, one of these presumably Lady Gwendolen Shaft [5874 3012]. This operation closed due to a coal strike but the mine was active again in 1919, probably through to 1923. In 1927 it was acquired by Wheal Reeth Tin Mines Ltd., who worked it until January 1930 and again from 1933 to final closure in 1938. Working of the waste dumps continued until 1943.

Wheal Breage Lode and South Wheal Breage Lode were retried from New Barkers Shaft [5944 3030] between 1934 and 1936 and Great Work Mine was reopened from 1934 to 1938, producing a little tin ore in that period. The Breage lodes were said to be too low-grade to pay when stoped at the 34-fathom level. At Great Work the lodes were more favourably regarded.

During the final working of Lady Gwendolen Mine, which reverted to the title of Wheal Reeth after 1934, six lodes were developed from four shafts (Figure 3). Of these, Wheal Reeth Lode, in the north, seems to have been somewhat isolated and was worked from the Wheal Reeth Engine Shaft [5896 3053] and Trebullen's Underlay Shaft [5873 3034]. There is a record of the adit level being cleared but no indication of the depth to which workings were taken, though it is believed they were shallow. The other five lodes - Morris, Williams, Great Work, Rosewarne and Wheal Boys were worked from Lady Gwendolen Shaft and Lady Katherine Shaft [5885 3011], the former sunk to the 160-ft. level and the latter, previously known as Rosewarne Pump Shaft, reopened to the 310-ft. level.

Relatively little is known about individual lodes and there are discrepancies between reports in the Mining Journal and information from J.Herbert Bennetts, the last mine manager, and from James Polglase, underground manager in 1934.

Morris Lode (also known as Morris's Lodes) was apparently a zone of narrow ferruginous quartz-cassiterite veinlets encased in greisen and separated by white kaolinised granite; occasionally they join to form a single vein. Dines (1956) quotes four major veins in the zone, which locally reaches a width of 40m, but only one vein (the southernmost) appears to have been developed, and this over a strike length of only 122m. Some rich tin values (up to 5% Sn) were patchily encountered but the milling returns give an average value of 0.71% Sn. The vein is reported as 0.6 to 0.7m wide with up to 0.7m of greisen on each side.

Williams Lode is probably the same structure as has been mentioned under the title of South Lode (Mining World, April 1928). Over a strike development of only 90 m the lode averaged 0.75 m wide with patchy mineralisation assaying at best only 0.72% Sn. The distribution of tin seems to have been too erratic to encourage stoping trials.

Great Work Lode in Lady Gwendolen Mine is presumably so named because it was believed to equate with the Main Lode (=Great Work Lode) in Great Work Mine. This is the relationship shown in Figures 2 and 3, but most authorities now quote Rosewarne Lode as the true western continuation of Great Work Main Lode. In Lady Gwendolen Mine the Great Work Lode has a very steep northerly

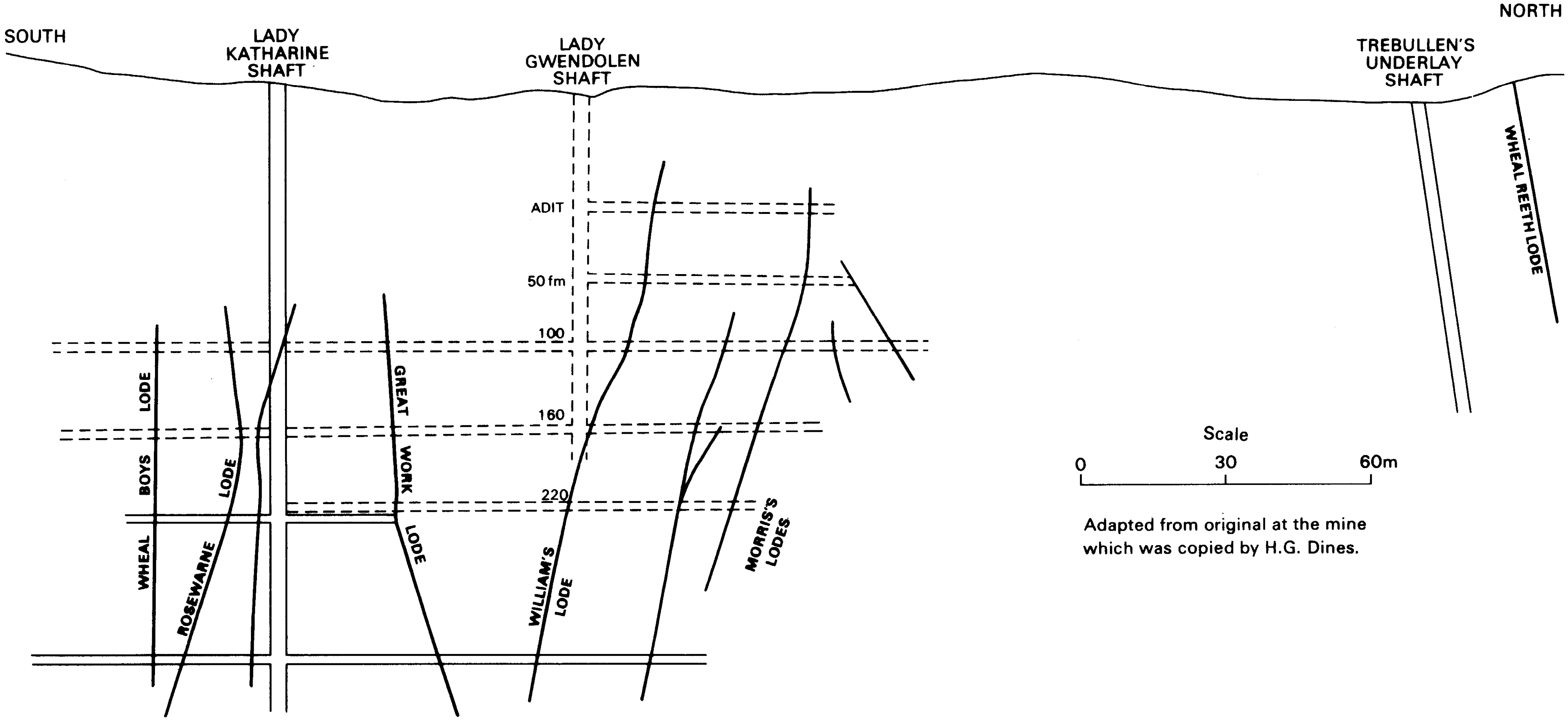

Fig. 4. Transverse section, Lady Gwendolen Mine.

dip, averages about 0.75 m in width and is reasonably uniformly mineralised with a mean grade of about 1.16% Sn. Copper staining is common but the tenor of copper is not known. The footwall consists entirely of soft, altered, buff-coloured granite but the hangingwall is mainly of greisenised granite up to 0.6 m wide. James Polglase, in a company report, mentions three further narrow lodes parallel to and within 20 m of Great Work Lode, all of these being in the hanging wall. The country rock appears to have been highly kaolinised granite and the tin mineralisation rather patchily developed.

Rosewarne Lode lies about 24 m south of Great Work Lode and these two structures, developed respectively over 360 m and 244 m, were regarded as the potential main producers in the expanded new mine. Rosewarne Lode is a strong structure differing from the other lodes in having a very hard granite wallrock, apparently not greisenised, and in places being split by a horse of granite (Figure 4). Its general dip is southwards at about 75 degrees. The lode was rather narrow, averaging only 0.69 m wide, but was of good grade and gave mill returns of 1.06% Sn.

Wheal Boys Lode seems to have been very variable in both grade and width but was sufficiently promising to have been developed over a strike length of 260m and to have supported a limited amount of stoping. One rich batch of ore totalling 255 tonnes gave an average grade of 3.28% Sn over 0.75 m but the lode was usually thinner than this (about 0.4 m) with only patchy distribution of payable ore.

Throughout the mine the cassiterite was coarse grained but it was erratically distributed, with some extremely rich pockets being reported. The only production figures available for Lady Gwendolen Mine are those for the last period of activity; they are given in Table 1. It was reported that flotation removed one-fifth of the tabled concentrate as sulphide and that this fraction contained 23% Cu. Records of copper sales exist only for 1937 and 1938, however. The tin concentrates were said to be free of arsenopyrite and wolframite, though both minerals are reported from the lodes and can be found on the waste dumps. Colourless and green fluorite are also common on the dumps but no attempt at production seems to have been made.

Estimated ore reserves in 1934 were 111,900 tonnes at 1.13% Sn. Production from 1934 to 1938 totalled 68,105 tonnes at 0.63% Sn, apparently about half the reserve tonnage. A significant proportion of the production, however, came from development ore and in consequence the depletion of tin reserves was less drastic than the figures depict. It also follows that the "run of mine" grade should exceed the rather low figures returned for 1934-8.

Table 1 Lady Gwendolen Mine output

Year	Tonnes ore crushed	Tonnes concentrate (70% Sn)	Grade of ore Sn
1928	2,282	37.25	1.14%
1934	11,687	123.99	0.74%
1935	16,359	142.90	0.61%
1936	18,920	149.40	0.55%
1937	12,539	98.18	0.55%
1938	8,600	96.09	0.78%

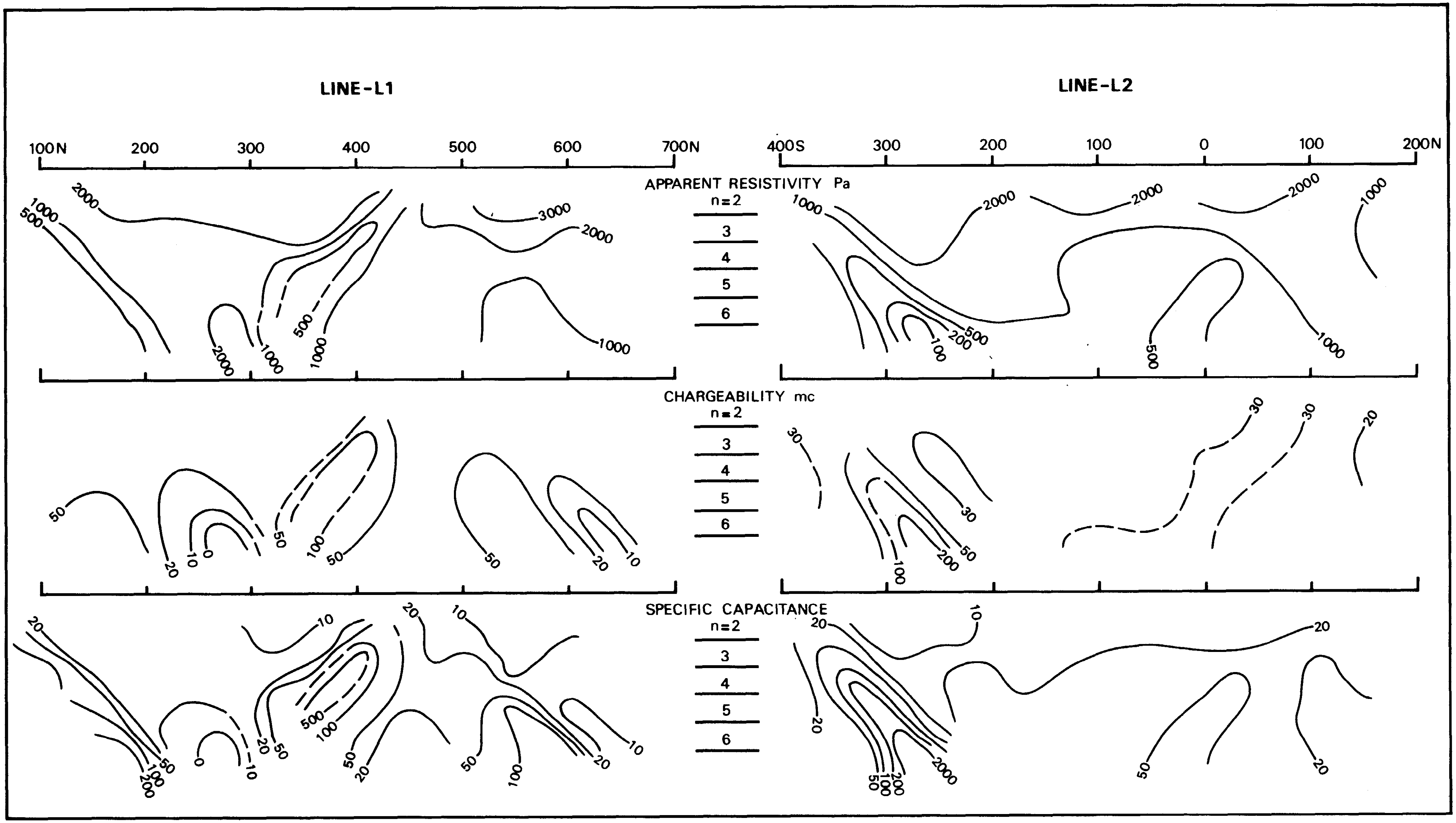

Fig.5. Induced polarisation pseudosections.

Available notes do not reveal the reasons for closure of the mine in 1938. Development in all directions was not pursued as actively as might have been expected, though whether this is wholly ascribable to financial policy or reflects some disappointment at the mineralisation being found is a matter for speculation. Certainly some of the lodes had proved to be very patchy and unable to support stoping, whilst in developing eastwards unexpected old men's workings had been encountered. There is no record of ore grades at depth but the limited amount of stoping on the 310-ft. level may reflect poor values at this horizon. It also seems evident from the available information that the mine suffered latterly from a lack of capital with which to fund sorely needed development and exploration; company shares steadily declined in value from 1934 to 1939.

No plans of Lady Gwendolen Mine, or of the earlier Wheal Reeth, have been deposited with the Mining Records office. Indeed, the working plans and sections seen at the mine by the late H.G.Dines - Figure 4 is a sketch from this source - seem to have been spirited away.

FIELD SURVEY

The major geological features of the area - distribution of the granite types and trace of the elvan dyke - are derived from Dr Taylor's recent remapping. Detailed field examination confirmed his observations on the widespread occurrence of greisen debris, the larger surface accumulations of which are shown in Figure 3. Most of this material has been derived from mine workings and, in an area such as this, it can be reasonably assumed that its present position closely reflects the location of its underground source. It may be deduced, therefore, that Wheal Reeth Lode and the two unnamed lodes south-east of Lady Gwendolen Mine are also associated with greisen. The source of two greisen-rich dumps south of Lady Gwendolen Shaft is uncertain - there are no obvious shaft sites nearby - but it is assumed that a greisen-walled quartz vein has been tried in this vicinity.

Surface depressions and small waste dumps mark the crop of some of the lodes but only Wheal Reeth Lode can be traced with certainty for any distance (Figure 3). To the north of the Wheal Reeth Lode there are vague surface indications suggestive of another parallel lode and along this line there was in the 1960s a small collapse of old, unrecorded, shallow mine workings. It is probable that a lode was explored here during early working at Wheal Reeth; presumably it did not prove promising.

Most of the shaft sites are still recognisable; the majority are blocked by refuse, partially to completely filled or collapsed. In Lady Katherine Shaft the timbering is intact and the shaft seems to be unblocked, though flooded. Lady Gwendolen Shaft has been capped with a concrete sollar.

Since the abandonment of underground mining considerable quantities of mine waste have been removed and parts of some dumps have been levelled out for reinstatement as pasture. Some of this waste has been spread across adjacent fields, used to infill collapsed shafts and levels or employed as metalling for gateways and tracks; sand tailings have been used to infill wet hollows and to make cement. In consequence of this activity there is widespread but indeterminable surface contamination by mineralised rock fragments and powder.

Mineralised specimens are still available on most waste dumps despite periodic retreatment and the frequent attentions of mineral collectors. These show isolated crystals, narrow stringers and occasional larger patches of cassiterite, usually in a quartz-tourmaline-chlorite vein rock. Associated

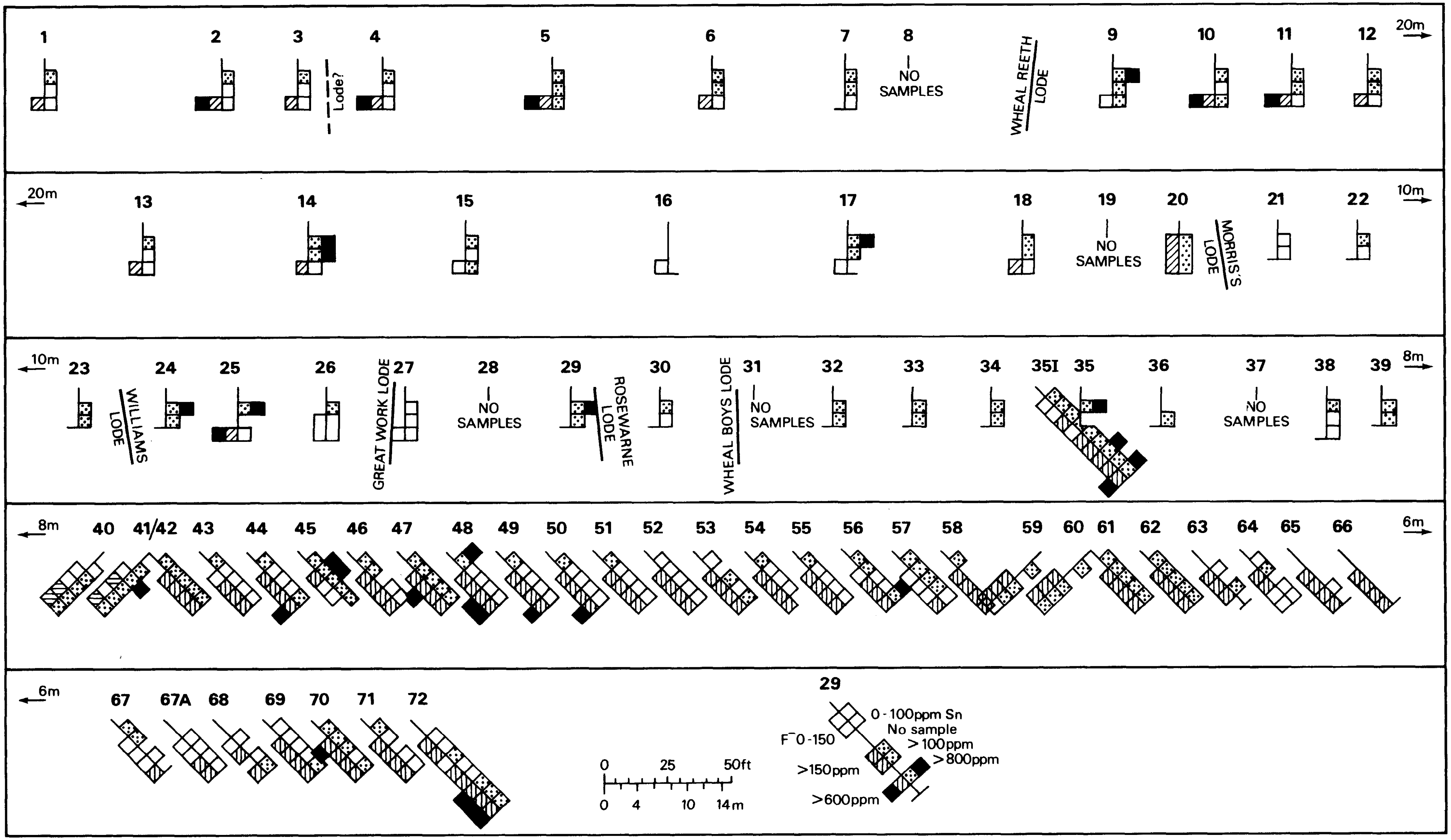

Fig.6. Drill-hole sections showing Sn and F values.

minerals include chalcopyrite, chalcocite, pyrite, rare arsenopyrite and wolframite and abundant colourless or green fluorite but only very rare purple fluorite. Not infrequently the stanniferous vein stuff shows irregular developments or narrow sinuous veinlets of pink coloured feldspar, some of which can be seen to post-date the ore minerals. From this feldspar Halliday (1980) derived a mineralisation age of 278 +/- 4 Ma.

GROUND GEOPHYSICS

Consideration of the known geology suggests that the only geophysical technique likely to provide any meaningful measurements from this area is that of induced polarisation. Because of the paucity of conductive ore minerals this method was not expected to identify the metalliferous veins but there remained a slight possiblity that granite, kaolinised granite and greisen might be distinguishable because of their differing porosities. Unfortunately the trial results were disappointing.

Two lines, L1 and L2, were measured, these lines mainly passing to the east of the later drilling traverse. Measurement stations were 50 m apart (Figure 3).

Apparent resistivity pseudosections for L1 (Figure 5) indicate an anomalous zone at station 450 m N suggestive of an artificial source. This was confirmed by traverses carried out with an EM15 gun and the source proved to be an iron water pipe. At the southern end of L1 the coincident increase in chargeability and decrease in apparent resistivity might indicate anomalous ground conditions, perhaps related to nearby mining. Similar effects at station 550 m N probably reflect the proximity of the Tregonning elvan dyke.

In the L2 pseudosections (Figure 5) the effects from this elvan are masked by those from the water pipe which passes below the traverse around 400-450 m south of origin. At this origin a slight decrease in apparent resistivity and increase in chargeability may be a single dipole effect (100-150 m W).

None of the known veins crossed by these traverses is reflected in the pseudoplots nor is there any indication of variations which relate to zones of greisenisation or kaolinisation. Because of this lack of signature no further geophysical work was attempted.

PERCUSSIVE DRILLING

No hand augered soil geochemical sampling was carried out around Wheal Reeth because of the expectation of widespread contamination. Instead, a sinuous traverse of shallow percussion drillholes was sunk to sample the undisturbed basal regolith and underlying solid granite.

As this was the first use of percussive drilling for deep geochemical sampling the programme was developed somewhat tentatively. The first 39 holes (Figure 6) were drilled vertically to depths of 20 ft and holes G1 - G17 were more widely spaced than the succeeding ones. The intersection of visible cassiterite in the lowest part of G35 emphasised the low probability of locating narrow sub-vertical mineralised veins in short vertical holes and encouraged experiments with angled holes. So successful was the inclined drilling technique that it was employed thereafter to ensure a full cross-section of the ground being sampled.

Rock dust and chippings were collected over drilling lengths of 5 ft (1.5 m), the uppermost sample being discarded as probably contaminated. The retained samples were split to provide a sub-sample for laboratory analysis and some 2 kg of the remainder was hand-panned to produce a heavy mineral concentrate which was field assayed by portable X-ray fluorescence meter to control selection for laboratory analysis.

GEOCHEMICAL ANALYSES

Field analysis of the heavy mineral concentrates was carried out on the wet sample taken directly from the pan. No account was taken of particle size, interelement effects, moisture content or sample weight; unrefined results were used solely to assess the presence of signficant mineralisation. The concentrates were later dried and homogenised prior to more careful analysis by portable equipment. Calculated crude tin contents of the bulk sample were used to select those samples submitted for more detailed analysis. The concentrates were later examined for sulphide minerals and wolframite associated with the cassiterite.

Only poor agreement was obtained between laboratory analyses for tin and the values derived from portable XRF assay of the wet concentrates. The product moment correlation coefficient between these two tin determinations is only 0.423, a value which proved barely adequate for the discriminative selection desired. This indifferent agreement is thought to be due mainly to two causes, the loss of fine or unreleased cassiterite during hand-panning and the wide variation in X-ray absorption arising from major differences in concentrate mineralogy.

Fluorine appears in the Wheal Reeth area in two roles. Within the greisenised zones around several veins it is locked mainly in gilbertitic mica and topaz and in this environment it is of early date, either pre- or syn-mineralisation. As fluorite it features in the lode material, always as a late introduction (after the tin and sulphides) and commonly infilling irregular voids in the vein. Fluorine determinations were carried out to check whether there was any clear-cut relationship to the tin content and to see whether the occurrences of greisen could be defined geochemically.

The method used was based upon one described by Pluger and Friedrich (1973). The sample was leached by a mixture of 25% perchloric and 75% nitric acids and extracted by stirring for 30 minutes. After addition of a buffer the fluoride activity of the supernate was determined using an Orion specific ion electrode connected to a suitable millivoltmeter. Not all samples could be analysed for fluorine in the time available; the results are included in Appendices 1 and 3.

Ninety seven samples, selected to represent a broad range of tin contents, were analysed for 12 elements by automatic X-ray fluorescence spectrometry. Elements determined were Ce, Ba, Sb, Sn, Pb, Zn, Ca, Ni, Fe, Mn and Ti and the results are given in Appendix 1. A further 138 samples were analysed only for tin using a manual XRF machine. Only 35 samples have not been analysed in the laboratory for tin content. In all but three of these samples the tin value as recalculated from assays of concentrates is lower than the average.

A summary of statistics and a correlation matrix for the 97 multielement analyses are given in Appendix 2. Combining the tin and fluorine analyses of both Appendices 1 and 3 gives the following statistical information.

For the 164 fluorine analyses the range is 20 to 2000+ ppm. The arithmetic mean is 353.8 and the standard deviation is 317.1. A total of 235 tin determinations (excluding repeat analyses) ranged from 27 to 4872 ppm with an arithmetic mean of 262.1 and standard deviation of 411.9. Somewhat surprisingly a very low negative correlation coefficient was obtained for these elements; for 142 samples analysed for Sn and F this was 0.032. Such poor correlation would indicate that there is no generic association between fluorine and tin and, therefore, that any cassiterite in the greisens is related to the later quartz veining and not to the greisenisation phase.

GEOCHEMICAL RESULTS

With the exception of holes 64, 65, 66, 67 and 67a which were drilled into the Tregonning elvan, all the drillholes were sunk into a variably kaolinised granite. The overlying soil is sometimes deep and perceptible reddening of the granite was noted to vertical depths of 15 ft. In essence the soil is a weathering regolith formed in situ, there having been little or no movement on these gentle slopes, and the clayey subsoil grades downwards into granite.

The uppermost few feet of soil were regarded as potentially contaminated and so were not collected. Between 5 ft and 10 ft in vertical holes and 5 ft and 15 ft in the inclined holes recoveries were usually of mineralic soils and below this of stained, weathered granite. The basic statistics for each element have been calculated for granite and elvan and their respective soil covers, these being quoted in Appendix 4.

In the XRF analytical method high Sn interferes with Pb, rendering statistical treatment for the latter element unreliable. All Sb results are close to detection level masking any systematic differences between contents in rock and soils. Because of their small numbers the elvan and elvan soil figures are statistically meaningless but they are separated for ease of comparison.

Relative to the granite the granitic soils are obviously enriched in Ni, Fe, Ti and Sn and probably slightly so in Zn and Cu. This pattern of distribution is also reflected in the elvan and elvan soil samples. No clear pattern emerges from Ce, Ba and Mn for either granite or elvan but Ca levels, which are closely similar in granite and granite soils, are markedly lower in the elvan soils. Only F is significantly depleted in the granite soils; it is also markedly lower in elvan than granite but does not seem to be depleted in the elvan soils. Individual elemental distributions are discussed below.

Cerium is one of the more abundant rare earth elements found in granites, with a range of 45 - 430 ppm (Hermann, 1970). The elvan content lies near the bottom end of this range and the granite mean below it, though this agrees with the conclusion of Burkov and Podporina (1967) who found that rare earths were depleted in kaolinised granitic rocks. They suggested that the lighter rare earths, being more mobile in an acid environment, would be preferentially leached during pervasive kaolinisation. Alderton and others (1980) recorded 47-100 ppm Ce in granites from SW England and showed that tourmalinisation frequently resulted in lower values of rare earth elements (REE), but greisening affected only the Eu concentration.

Recent studies have shown that monazite is commonly present in the Cornubian granites and that it can account for a large proportion of the total REE budget (Ball and Basham, 1979; Ball and others, 1982). This resistant mineral survives most alteration processes, including greisenisation and kaolinisation, and would be predisposed to give higher concentrations in soils than in the parent rock, in a manner similar to cassiterite (see later).

Moderate correlation with Ni and Fe (Appendix 2) suggests that Ce may be mobile under weathering conditions but there is no significant difference between soil and rock levels of Ce (Appendix 4). Better correlation with Ba and Ti would seem to indicate that such mobility is very limited and that much of the Ce in these soils is present in mineralic form.

Barium contents in granites are largely dependent upon calcium levels according to Fischer and Puchelt (1971), this in spite of the fact that Ba substitutes for K in most rock-forming minerals. The same authors quote an average value of 730 ppm in low calcium granites, a value very much higher than any in this survey (Appendix 1). Our low levels, however, accord with the determinations quoted by Exley and Stone (1964) from the Tregonning and other Cornish granites. The Ba content of the Tregonning elvan is markedly higher than that of the granite, probably reflecting its higher K and Ca levels (Exley and Stone, 1964). Barium is not enriched in the soils compared to the substrates though, paradoxically, it correlates best with Ti which is so enriched.

Antimony levels are low in both rocks and soils and are so close to the detection limit as to yield unreliable statistical correlations. Nor is there an adequate spread of values to indicate any distributional variation between rocks and soils.

Zinc in granite is quoted by Brehler and Wedepohl (1975) as an arithmetic mean of 51 ppm from 1106 samples; the mean of 58.23 from the present study is in good agreement with this value. Only slight enrichment of zinc in the Wheal Reeth granite soils is suggested by the figures of Appendix 4 but it is clear that there are markedly lower levels of zinc in the Tregonning elvan and its soils.

White (1957) showed that in loam soils from Tennessee some 45% of Zn is fixed in ferric oxides. In the current work correlation between Zn and Fe is only modest and it is proposed that Zn, although in part held in the iron sesquioxides, more commonly forms organic metallic complexes in the soils. In this respect it probably mirrors the accepted behaviour of copper, with which it correlates best.

Copper values at Wheal Reeth are considerably higher than those quoted for granites by Zeeman and Wedepohl (1974) which range up to 70 ppm with a modal value below 20 ppm. It seems probable that this difference reflects the degree to which copper ore minerals are disseminated through the greisens.

The same authors point out that a positive correlation of Cu with iron oxides in soils is commonly found, the absorption of Cu on oxide coatings being controlled by Cu concentration, pH and the strength of available chelates. The Wheal Reeth samples, however, show poor correlation between Cu and Fe and it is assumed that Cu in the soils is fixed as organo-metallic complexes. Copper correlates significantly only with Zn (Appendix 2) and, like that metal, shows only slight enrichment in the granite soils (Appendix 4). In parallel with Zn the Cu levels in elvan are appreciably lower than those in granite.

Even the highest calcium content in the analysed samples is much lower than the 11,300 ppm granite average quoted by Taylor (1964), and all but three samples are lower than the 4000 ppm Ca average reported from the biotite-granite by Stone (1982). Although removal of calcium frequently accompanies greisenisation and kaolinisation, the effect is not so severe as our analyses would require. It may be assumed, therefore, that calcium values are generally low in this study area but there is also a strong possibility of analytical bias further reducing the indicated Ca contents. There is no significant difference in Ca contents of granite soils and rock but there is a markedly lower Ca content in the elvan soils. Calcium correlates well with manganese but with no other element.

Manganese behaves similarly to calcium, reflecting that positive correlation. It too is lower than the granite average of 400 ppm given by Taylor (1964), by a factor of about 2, though the range of analytical results spans Taylor's figures and the average is only slightly lower than Stone's (1982) value. As with Ca there is no significant difference in the average contents of soil and rock but the elvan soils and the one elvan sample show markedly lower Mn values. Manganese correlates only with calcium and surprisingly, by Cornish standards, not with iron (Appendix 2).

Iron in the rock samples exhibits a restricted range of values, the upper limit of which is close to the 2.7% granite average given by Taylor (1964). They also accord well with values found by Exley and Stone (1964) in greisenised and kaolinised granites. In the granite soils the range is wider, this extension being wholly at the higher end (Appendix 4). There is a marked enrichment of Fe in the soils with the highest values concentrated in the uppermost sampled horizon where, presumably, enhancement is largely effected by adsorption of iron oxides on clay minerals formed by weathering processes. Iron correlates well with nickel and titanium and moderately with cerium and barium.

Nickel values in soils and granite are not well documented but Taylor (1964) gives an average of 0.5 ppm which is very considerably lower than the Wheal Reeth values. Ni is significantly enhanced in the soils where it is presumed to accompany Fe. Indeed, considerations of chemical properties, electronegativity, ionic radius, etc. suggest that Ni should behave similarly to Fe under weathering conditions and this close compatibility of behaviour is borne out by a strong, positive correlation coefficient (Appendix 2). Ni also correlates well with Ti.

The weathering cycle of titanium is poorly understood but it would seem from the Wheal Reeth results that it can be significantly enhanced in granite and elvan soils (Appendix 4). The mean rock value is somewhat lower than the 2300 ppm given by Taylor (1964) but only slightly lower than greisenised and kaolinised granite values quoted by Exley and Stone (1964), and in good accord with the biotite-granite of Stone (1982). Titanium in granites is held in the biotites as well as in discrete trace minerals such as sphene, leucoxene and rutile. It is probably the weathering of biotite which gives the strong positive correlation between Ti and Fe (and Ni?). It seems reasonable to suppose that Ti is fixed on the iron sesquioxides. Ti also correlates well with Ce, another element distributed in minor accessory mineral phases.

Tin geochemistry has been widely studied abroad but little has been published on British examples despite the economic importance of this metal. There is reasonable agreement by several authors of a world average granite tin content of about 3.6 ppm. Granites from Cornubia are all richer than this, according to the scattered published data. From Cligga Head, Hall (1969) quotes tin-in-granite values of 30 and 50 ppm rising to 700 and 270 ppm in stanniferous greisens. Alderton and Moore (1981) present tin analyses for a range of granitic rocks from SW England. From the Cligga Head and St. Michael's Mount cusps they record 34 and 32 ppm Sn but from the Birch Tor area of Dartmoor, where there is a local concentration of minor tin veins, the granite contained 54 ppm Sn. The normal coarsely porphyritic granites varied from 13 to 20 ppm Sn, a range in accord with that of 9-32 ppm quoted by Al Turki (1972) for Carnmenellis. From the Godolphin-Tregonning cupola Stone (1982) records only 9 ppm Sn in the biotite-granite but from 19 to 46 ppm in the lithium-mica variants. Levels of Sn ranging from 39 to 1770 ppm, increasing with the degree of greisenisation, were recorded from an Institute borehole at Bosworgey, some 3.5 km NNW of the study area (Ball and Basham, 1984). In the current work elvan was drilled in holes 64 to 67A inclusive and XRF analyses show a range from 43 to 80 ppm Sn in the unweathered rock.

An enrichment of Sn in the soil layer is clearly demonstrated in Appendix 4, and hand panning shows that almost all of that Sn content is referable to cassiterite. Being strongly resistant to weathering cassiterite is concentrated in the soil profile, particularly in the basal layers, during the chemical breakdown and dissolution of the commoner rock forming minerals. Appendices 1 and 3 and Figure 6 demonstrate that most boreholes show Sn enhancement in the soils even where there is no obvious mineralisation in the rock below. Bergerhoff and others (1967) suggest that on weathering any Sn released from the biotites would not be concentrated with Fe since Sn goes into solution with Fe only to a limited extent. In the present work the correlation between Sn and Fe is poor.

Fluorine usually appears as a late stage feature in granitic evolution, concentrating in the residual magmas, metasomatic fluids and hydrothermal solutions from which it crystallises in lithionite, zinnwaldite, topaz, tourmaline and fluorite. The fluorine contents of Cornish granites, therefore, are highly variable but are usually unaffected by kaolinisation. Results from the specific ion electrode analyses (Appendices 1 and 3) appear to be somewhat low for kaolinised granites and markedly low for greisens. Only a few repeat analyses were performed and these confirmed the general order of contents. The reason for these low results is unclear but, if attributable to incomplete acid leaching it raises doubts about the validity of any comparisons or calculations made.

Koritnig (1951) investigated granite weathering specifically and found that F decreased from the rock to the soil surface, a pattern which several authors have recorded for other rock types. The Wheal Reeth samples also show this general trend (Appendix 4) but when examined more closely some individual profiles are less simple.

Originally F determinations were intended only as a guide to the recognition of greisen zones with which might be associated some quartz-cassiterite veining. But overall the correlation between F and Sn is poor, presumably partly a function of the presence of barren greisen veins, tin in quartz veins, fluorite as a late vein infilling and the different behaviour of F and Sn in the weathering regime.

ASSESSMENT

It is apparent from Figure 6 that the recognition of mineralised vein structures and greisen zones from vertical drillholes is a "hit or miss" affair. According to Wilson (1972), who was working in the well-mineralised St Just area, significant geochemical dispersion of the commoner elements does not extend more than about 2m into the vein wall-rocks and not beyond the limits of visible alteration. On this evidence, therefore, important tin-bearing veins could pass undetected when sampling from drill holes up to 20 m apart, and especially so when analysed for only a limited range of elements.

Failure to recognise major mineralised structures in short vertical percussion holes is amply demonstrated in Figure 6; none of the worked veins of Lady Gwendolen Mine or Wheal Reeth gives rise to significant tin or fluorine anomalies in the adjacent drillholes.

To the south of Wheal Boys Lode a shallow sample (5-10 ft) from drillhole 35 gave high tin values on the portable fluorescence analyser but its significance was in some doubt due to the presence of abundant mine waste. An inclined hole, 35I, was drilled beneath the site and it returned anomalous tin values over its whole length (Appendices 1 and 3). A small trench cut through the dump material revealed quartz-chlorite veining in the granite in which there were discontinuous narrow veinlets of coarse brown cassiterite. One sample channelled across six inches of mineralised vein assayed at 4.6% Sn. It appears that at this site there is a stanniferous structure which has not been worked during former mining.

By using drillholes inclined at 45 degrees and spaced so as to give full lateral cover (holes 40-72) it was expected that any further sub-vertical mineralised structures would be intersected by at least one drillhole. The disposition of surface dumps and old shafts would suggest that evidence of tin mineralisation might be found around stations 54 and 70. The more northerly of these veins may be represented in the basal sample (25-30 ft) from hole 53 which assayed at 509 ppm Sn. If so, the vein here is both thin and unpayable. There is no equivalent indication of the southern vein.

From the drillhole results it is possible to suggest the presence of at least four other tin-bearing structures none of which seems to have been worked. A moderately high value (0.03% Sn) at the bottom of hole 39 when correlated with an average of 0.06% Sn over 2m near the bottom of hole 40 indicates a reasonably wide structure, albeit of poor grade. Associated with this, perhaps as a branch, is a probable richer but narrower vein found at 10-15 ft in hole 41. When panned the samples from holes 40 and 41 yielded a heavy mineral fraction containing some brown cassiterite in abundant tourmaline. The uppermost samples from holes 43, 51 and 55, all in the 0.04 - 0.05% Sn range, should be composed of in-situ granite, perhaps well weathered. There is, however, a distinct risk that they are contaminated by residual cassiterite from the weathering profile. From 10 ft depth to the base of hole 45 four samples range from 492 to 1211 ppm Sn, indicating a broad zone of tin mineralisation (c. 4m) which averages about 0.08%. The lack of equally high values in the adjoining holes suggests that the structure dips steeply, probably southerly. In hole 48 the uppermost sample assays 0.08%; it seems likely that this may be caused by in-situ mineralisation but clearly any causative vein must be both narrow and steep. The final example is seen at the base of hole 56 where an assay of 0.11% Sn presumably indicates some introduced tin mineralisation. Presumably here the vein is also narrow and steep. Panning the sample residue yields abundant brown cassiterite in a tourmaline-rich product.

Fluorine values in excess of 150 ppm are quite common to the south of the Lady Gwendolen workings; those in excess of 600 ppm are more infrequent but tend to be most commonly developed at the bottoms of some boreholes. It seems improbable that this feature is introduced by the percussive form of drilling and, therefore, must be assumed to be genuine, though there seems no logical explanation for such a distribution. Whilst a tenuous association with stanniferous veining may be claimed for the fluorine-rich samples in holes 44 and 47-50 no such association is apparent for the three samples at the bottom of hole 72.

CONCLUSIONS

This investigation has amply demonstrated the value of percussive drilling as an exploration method in areas of widespread superficial contamination and, particularly, has emphasised the advantages of inclined drillholes spaced so as to achieve full lateral cover. Fears of down-hole contamination from the sinking of heavy mineral dust, mainly cassiterite and wolframite, have proved to be groundless and by taking normal, reasonable precautions meaningful lithogeochemical samples can readily be collected.

The drilling provided no new information about the veins which had been worked in Wheal Reeth and Lady Gwendolen Mine. To the south of Lady Gwendolen, however, several additional structures have been indicated, none of which is known to have been explored underground. Presumed westerly extensions of two lodes in the Wheal Breage sett, marked by linear arrangements of dumps and shafts, were sought in this southern area. Only the northernmost lode seems to have any representation in the drillholes.

Correlation between tin and the other elements analysed is poor and there is no geochemical support for a concept of widely developed greisen veining associated with the tin mineralisation in this area. It must be presumed, therefore, that greisening of the lode walls is a patchy phenomenon and that the degree of greisenisation provides no guide to the location of payable tin grades.

In only one of the "new" veins, that at station 35, does the ore attain a commercial grade, here 4.6% Sn over 6 inches, equivalent to 0.98% SnO_2 over 1 metre (22 lbs/ton, in traditional mining units). This vein, however, has been seen and sampled at only one point. The other structures are all much poorer in tin - none better than 0.2% Sn over a metre. Together with the Lady Gwendolen veins, however, they do constitute a reasonably compact package with at least ten veins over a cross-sectional distance of 270 m. Such a package would seem to offer a temptingly easy and relatively inexpensive exploration target which, to judge from the conditions in Great Work Mine, should improve eastwards, especially in the exocontact zone. Thus both laterally and in depth there is ample scope for exploration eastwards; westwards the situation is less encouraging. Most of the veins just within the western contact of the Tregonning Granite seem to have been poorly productive, though they improve if traced out into the thermal aureole.

No metal resource remains within the sand tailings which are so prominently stacked near the buildings of the former Treweeth farm [5855 3009]. Samples from the higher dump assayed only 0.003% Sn and from the lower dump 0.015% Sn. Both dumps yielded large crops of heavy minerals consisting predominantly of black tourmaline with some zircon and topaz and only traces of cassiterite, some of which is in composite grains.

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APPENDIX 1

Multi-element analyses of selected samples (in ppm)

Hole No	Depth (ft)	Ce	Ba	Sb	Sn	Pb	Zn	Cu	Ca	Ni	Fe	Mn	Ti	F
1	5-10	28	90	1	468	54	101	259	1400	17	34000	220	2090	
2	5-10	19	46	2	132	31	82	135	1300	14	24000	190	1160	
3	5-10	32	105	2	727	88	88	150	1300	15	28000	200	2190	
5	5-10	28	102	1	585	52	75	148	1100	16	23000	200	1210	
	10-15	28	101	1	172	30	63	77	1400	8	18000	200	740	
	15-20	33	158	2	250	31	46	89	1200	5	20460	210	690	760
6	10-15	28	244	3	216	35	53	57	600	8	21100	180	910	
	15-20	26	360	2	80	23	43	46	1040	5	18760	180	750	560
7	5-10	30	118	0	535	61	79	133	260	12	21000	200	740	
	10-15	30	99	1	487	62	85	252	180	17	21000	190	790	
9	5-10	33	171	0	1654	141	65	153	2340	11	32700	260	2470	
	10-15	24	196	2	649	59	73	107	130	8	22900	330	750	
	15-20	34	257	1	365	44	46	80	210	8	17930	260	790	20
10	5-10	34	109	4	177	32	80	86	1690	23	26590	200	1790	
11	5-10	23	80	3	186	22	70	69	2160	13	22050	270	1030	
12	5-10	29	104	2	404	71	98	110	3740	16	33080	240	1920	
	10-15	26	70	0	255	182	100	59	1700	8	20700	230	880	
13	5-10	27	87	2	257	29	65	56	1920	15	23300	200	1290	
14	5-10	32	119	2	824	74	78	68	1000	18	28700	240	1980	
	10-15	29	86	2	4872	326	50	66	1400	6	14900	170	760	
	15-20	30	66	0	42	22	40	67	1730	4	13680	170	640	200
17	5-10	30	93	3	1026	88	75	101	500	18	27600	200	1710	
	10-15	12	115	0	161	14	105	249	500	15	20700	210	690	
18	5-15	23	102	1	258	47	77	94	2100	8	17900	200	800	
21	5-10	17	22	1	74	14	109	209	1200	16	22300	280	640	
	10-15	10	16	3	37	14	121	262	900	17	20300	190	550	
22	5-10	36	60	1	526	75	163	288	1210	25	30060	200	980	
23	5-10	66	71	0	761	73	85	126	300	17	20100	120	740	
	10-15	36	81	2	497	70	93	97	600	9	20800	140	700	

Hole No	Depth (ft)	Ce	Ba	Sb	Sn	Pb	Zn	Cu	Ca	Ni	Fe	Mn	Ti	F
24	5-10	29	213	1	1101	92	58	91	490	12	22740	190	1480	
24A	5-10	39	306	4	1449	169	179	347	5250	27	47630	380	1940	
25	5-10	37	176	1	835	77	68	57	770	19	33830	260	3020	
26	5-10	31	138	3	337	46	77	130	1780	24	32780	170	1600	
27	5-10	28	125	1	92	22	68	98	300	17	18900	110	920	
29	5-10	38	194	0	802	86	121	112	4580	14	38780	350	3020	
30	5-10	31	130	1	282	40	75	109	1100	20	30330	200	2000	
32	10-15	28	66	1	468	49	95	100	1400	9	23300	230	770	
33	5-10	41	146	1	249	41	65	60	1170	14	29740	240	2190	
	10-15	24	99	0	408	56	51	59	1200	8	17900	190	1080	
34	5-10	36	150	3	358	44	67	62	1250	19	30260	240	2310	
35I	5-10	42	192	2	554	60	64	45	650	25	39130	240	3810	66
	10-15	43	187	0	669	62	68	57	730	25	38420	240	3610	140
	15-20	28	112	3	274	36	37	55	1300	6	17190	190	850	200
	25-30	29	116	1	236	50	47	50	1200	4	14990	190	800	560
	30-35	28	106	4	162	47	44	47	1460	4	14710	170	880	560
	35-40	27	92	0	944	77	71	55	2230	4	21010	320	910	200
	40-45	28	99	1	617	60	69	73	2140	6	22300	360	770	280
	45-50	32	131	0	1250	107	67	37	1360	4	21360	350	890	1020
35A	5-10	34	135	0	300	33	59	26	700	14	24800	210	1950	
35B	5-10	33	139	1	845	83	64	47	700	14	27900	220	2180	
36	10-15	28	133	1	267	34	71	81	500	10	21000	240	850	
38	5-10	29	128	2	224	55	48	62	1510	15	26220	230	1670	
	10-15	32	122	0	82	34	53	79	1100	11	20800	160	1090	
39	5-10	32	123	2	589	69	59	27	750	14	24210	240	1790	
	10-15	41	172	0	324	85	59	62	1100	10	23400	340	1180	
40	10-15	34	121	5	111	35	60	76	1160	16	24480	190	1860	102
	20-25	24	152	1	690	53	41	57	1500	6	20220	240	760	280
	25-30	26	101	1	335	36	36	35	1470	4	17220	190	700	200
41	5-10	36	132	0	135	30	54	28	1100	12	23900	190	1890	
	10-15	28	117	0	1659	119	44	101	1660	10	26670	240	1230	140
42	15-20	26	149	1	147	16	50	34	1910	7	17430	290	590	300

Hole No	Depth (ft)	Ce	Ba	Sb	Sn	Pb	Zn	Cu	Ca	Ni	Fe	Mn	Ti	F
43	5-10	42	153	0	474	50	51	28	700	14	30200	160	3480	
44	5-10	28	106	0	220	30	61	39	1300	14	24700	240	1700	
	25-30	24	98	1	230	31	28	22	2670	2	13350	140	700	920
45	5-10	44	145	2	203	34	52	22	800	16	28700	240	2890	
	10-15	24	119	1	835	61	61	38	2220	9	23140	320	1070	300
	15-20	26	117	2	1211	89	88	124	540	10	26270	280	540	56
	20-25	26	104	1	492	47	70	75	400	8	24200	270	490	102
	25-30	23	148	0	631	51	73	56	1100	7	21100	280	470	
47	5-10	37	140	3	386	56	54	27	900	15	28000	200	2650	
	20-25	16	126	2	259	21	35	36	3000	4	15230	300	410	480
48	5-10	33	106	0	847	78	58	32	1000	15	24400	200	1920	
49	5-10	33	130	1	179	72	63	29	800	19	30100	200	2570	
	15-20	22	80	2	84	15	39	31	2270	3	13630	240	510	480
50	5-10	38	114	0	308	47	56	29	1000	16	26900	190	2410	
	10-15	27	62	1	84	23	51	24	1700	7	16500	220	870	300
51	15-20	24	80	3	27	21	38	45	1920	4	13940	200	610	300
53	25-30	29	91	3	509	44	35	27	2360	2	13290	240	530	560
54	5-10	44	186	2	169	37	58	33	800	25	40540	200	3990	
	10-15	28	82	2	56	24	36	30	1800	5	16740	170	1040	200
55	5-10	35	117	2	413	57	65	51	1330	20	30400	230	2200	
56	5-10	38	151	2	336	53	59	37	1190	21	35920	220	3120	
	10-15	22	137	3	283	69	73	107	750	10	28530	240	630	102
57	5-10	25	102	3	133	26	44	37	2480	10	22880	300	1120	
58	5-10	32	126	1	262	45	62	53	1150	21	32970	230	2470	
59	5-10	39	189	4	242	54	54	43	1070	21	41600	200	3750	
60	20-25	23	101	2	110	13	47	41	2430	3	15260	320	410	300
	25-30	26	124	1	115	17	43	56	2850	4	15530	310	360	440
61	5-10	36	167	2	216	55	58	37	700	19	35100	170	3080	
63	10-15	25	83	3	50	9	55	37	2030	5	18060	260	430	280
	20-25	29	118	2	143	24	52	56	1790	4	16920	210	670	280

Hole No	Depth (ft)	Ce	Ba	Sb	Sn	Pb	Zn	Cu	Ca	Ni	Fe	Mn	Ti	F
64	10-15	59	349	1	141	146	38	36	720	15	30130	180	2840	380
65	20-25	59	399	1	43	3	12	30	1360	4	19370	120	1710	520
67	10-15	66	289	0	137	34	43	34	700	21	29890	130	3300	78
67A	10-15	61	342	1	68	17	31	34	1190	14	29290	150	2900	78
72	20-25	24	160	3	209	40	25	42	1250	5	16520	130	810	78
	35-40	26	14	1	355	26	47	21	5430	2	24190	540	410	2000

All analyses were by XRF except for fluorine which was determined by specific ion electrode analysis.

APPENDIX 2

Multi-element statistics

	Element	Range (ppm)	Arithmetic Mean	Standard Deviation
n=97	Ce	10-66	31.423	9.617
	Ba	14-399	133.866	68.299
	Sb	0-5	1.474	1.167
	Sn	27-4872	452.907	569.938
	Pb	3-326	54.495	42.558
	Zn	12-179	64.041	25.529
	Cu	21-347	77.845	62.692
	Ca	130-5430	1406.598	939.983
	Ni	2-27	12.062	6.436
	Fe	13290-47630	24254.123	7103.160
	Mn	110-540	225.876	64.116
	Ti	360-3990	1464.227	940.255
n=38	F	20-2000	363.737	356.171

Correlation Matrix

Negative factors in bold type

Ce	1.000											
Ba	0.589	1.000										
Sb	**0.162**	**0.016**	1.000									
Sn	0.013	**0.025**	**0.086**	1.000								
Pb	0.144	0.074	**0.088**	0.851	1.000							
Zn	**0.118**	**0.210**	0.009	0.162	0.276	1.000						
Cu	**0.191**	**0.132**	0.048	0.156	0.183	0.815	1.000					
Ca	**0.197**	**0.126**	0.126	0.053	0.042	0.120	0.042	1.000				
Ni	0.397	0.152	0.087	0.010	0.126	0.515	0.370	**0.237**	1.000			
Fe	0.444	0.311	0.068	0.103	0.243	0.441	0.234	0.023	0.825	1.000		
Mn	**0.275**	**0.137**	**0.048**	0.130	0.082	0.214	0.043	0.573	**0.163**	0.133	1.000	
Ti	0.629	0.423	**0.012**	0.007	0.130	0.023	**0.200**	**0.158**	0.718	0.824	**0.166**	1.000
	Ce	Ba	Sb	Sn	Pb	Zn	Cu	Ca	Ni	Fe	Mn	Ti

APPENDIX 3

Additional tin and fluorine analyses (in ppm)

Hole No	Depth (ft)	Sn	F
1	10-15	90	
	15-20	60	560
2	10-15	80	
	15-20	50	760
3	10-15	80	
	15-20	80	280
4	5-10	120	
	10-15	60	
	15-20	60	760
6	5-10	250	
7	15-20	80	
10	10-15	80	
	15-20	150	780
11	10-15	300	
	15-20	80	1420
12	15-20	80	280
13	10-15	60	
	15-20	40	200
15	5-10	290	
	10-15	70	
	15-20	330	140
16	15-20		72
17	15-20		48
18	15-20	70	400
20	5-20	110	200
22	10-15	70	
24	10-15	320	
25	15-20	40	780
26	10-20	100	32
27	10-15	50	
	15-20	100	32
29	10-15	130	
30	10-15	60	
32	5-10	550	
34	10-15	580	
35I	20-25	140	98
38	15-20	50	
40	5-10	80	
	15-20	590	140
41	15-20	260	300
	20-25	120	142
	25-30	120	200
42	5-10	130	
	10-15	240	200
	20-25	190	300
	25-30	200	280
43	10-15	80	142
	15-20	80	200
	20-25	80	200
	25-30	60	200
44	10-15	80	480
	15-20	80	480
	20-25	70	300
46	5-10	210	
	10-15	180	200
	15-20		300
	20-25	70	480
	25-30	70	300
47	10-15	140	300
	15-20	120	920
	25-30	190	480
48	10-15	60	300
	15-20	50	480
	20-25	80	2000
	25-30	70	620
49	10-15	80	200
	20-25	50	480
	25-30	50	920
50	15-20	60	300
	20-25	70	200
	25-30	50	1240
51	5-10	450	
	10-15	80	300
	20-25	40	280
	25-30	40	200
52	5-10	100	
	10-15	100	520
	15-20	50	280
	20-25	60	520
	25-30	60	280
53	5-10	60	
	10-15		380
	15-20	150	280
	20-25	60	280
54	15-20	50	200
	20-25	50	400
	25-30		400
55	10-15	40	200
	15-20	60	280
	20-25	40	280
	25-30	60	280
56	15-20	90	400
	20-25	60	400
	25-30	1110	400

Hole No	Depth (ft)	Sn	F
57	10-15	180	76
	15-20	110	76
	20-25	110	102
	25-30	40	200
58	10-15		200
	15-20		280
	20-25		280
	25-30		400
59	15-20	190	300
	20-25	160	440
	25-30	80	440
60	5-10	150	
	15-20	130	300
61	10-15	140	200
	15-20	210	200
	20-25	330	300
	25-30	190	300
62	5-10	160	
	10-15	320	300
	15-20	160	300
	20-25	240	200
	25-30	150	300
63	15-20		200
64	5-10	100	
	15-20		380
	20-25	80	142
	25-30	80	142

Hole No	Depth (ft)	Sn	F
65	10-15		380
	15-20		380
	25-30		380
66	10-15		200
	15-20		200
	20-25		200
	25-30		200
67A	15-20	60	104
	20-25	60	200
	25-30	50	156
67	5-10	110	
	15-20		108
	20-25	50	54
	25-30		200
68	10-15	50	140
	15-20		280
	20-25	50	
	25-30	240	200
69	5-10	100	
	10-15	90	200
	15-20	40	600
	20-25	90	200
	25-30	150	440
70	5-10	120	
	10-15	120	800
	15-20	120	200
	20-25	70	440
	25-30	170	300

Hole No	Depth (ft)	Sn	F
71	5-10	140	
	10-15	90	440
	15-20		200
	20-25	50	200
	25-30	40	540
72	10-15	60	156
	15-20	40	156
	25-30	40	156
	30-35	60	280
	40-45	200	760
	45-50	160	2000+

Repeat analyses:

41	10-15	1490
43	5-10	130
53	25-30	440
56	5-10	310
70	5-10	100

APPENDIX 4

Elemental statistics for soils and rocks

	Ce	Ba	Zn	Cu	Ca	Ni
GRANITE SOILS						
No. of analyses	53	53	53	53	53	53
Maximum value	66	306	179	347	5250	27
Minimum value	17	22	36	22	260	5
Mean value	32.79	127.28	70.92	84.02	1375.3	15.98
Standard devn.	7.72	46.09	25.40	67.91	946.73	5.09
GRANITE						
No. of analyses	40	40	40	40	40	40
Maximum value	41	360	121	262	5430	17
Minimum value	10	14	25	21	140	2
Mean value	26.63	121.50	58.23	74.10	1486.8	6.73
Standard devn.	5.48	60.73	22.49	56.20	962.44	3.65
ELVAN SOILS						
No. of analyses	3	3	3	3	3	3
Maximum value	66	349	43	36	1190	21
Minimum value	59	289	31	34	700	14
Mean value	62.00	326.67	37.33	34.67	870.00	16.67
Standard devn.	2.94	26.79	4.92	0.94	226.42	3.09
ELVAN						
No. of analyses	1	1	1	1	1	1
Maximum value	59	399	12	30	1360	4

	Fe	Mn	Ti	Sn	F
GRANITE SOILS					
No. of analyses	53	53	53	87	31
Maximum value	47630	380	3990	1659	800
Minimum value	16500	100	430	40	32
Mean value	28122.3	221.70	1935.9	345.18	245.03
Standard devn.	6639.8	47.13	899.00	343.98	153.58
GRANITE					
No. of analyses	40	40	40	136	113
Maximum value	26270	540	1180	4872	2000+
Minimum value	13290	130	360	27	32
Mean value	18837.3	239.50	717.00	224.87	406.53
Standard devn.	3447.2	78.16	188.03	456.87	357.16
ELVAN SOILS					
No. of analyses	3	3	3	5	5
Maximum value	30130	180	3300	141	380
Minimum value	29290	130	2840	68	78
Mean value	29770.0	153.33	3013.3	111.20	223.20
Standard devn.	353.27	20.55	204.18	26.63	135.56

	Fe	Mn	Ti	Sn	F
ELVAN					
No. of analyses	1	1	1	7	15
Maximum value	19370	120	1710	80	520
Minimum value				43	54
Mean value				60.43	224.40
Standard devn.				13.56	126.05