

normal idling periods. But it must be emphasised that this system does not **make** compressed air, but just makes more use of the services of the compressors installed.

Thus the high expense of new compressors was averted by the practical use of one D.D. drift which was no longer of any use and thus dispensable and which purely by coincidence happened to be the right vertical interval from the upper level for the required pressures. I.e. the cost of pipes, bulkhead, dam and water reservoir excavation, being involved against the cost of a new compressor.

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The Distribution of Tin, Copper, Zinc, Beryllium and Phosphorus in the Stream Sediments of the Land's End Peninsula, Cornwall

K. F. G. HOSKING, J. A. HOSKING, G. B. THOMAS,
USMAN AHMED, AND J. B. PISARSKI.

Synopsis

THE Land's End Peninsula consists of a little-investigated kidney-shaped mass of granite (coarse- and fine-grained) fringed by metamorphosed non-calcareous sedimentary rocks and intercalated 'greenstones'.

Numerous lodes, generally tin- and/or copper-bearing, which are genetically related to the granite, are known, and have been much exploited.

Many deposits of alluvial tin have been worked both in areas known to contain lodes and in ones in which no lodes have been discovered.

Samples of minus-80-mesh (B.S.S.) sediment from all the streams draining the Peninsula have been analyzed for Sn, Cu, Zn, Be and P by rapid colorimetric methods with a view to determining to what extent the distribution patterns of these elements reflect the presence of known ore deposits, suggest the existence of unworked lode extensions and hitherto unknown primary deposits, and reveal something more of the structure of the possibly polyphase granite mass.

The results reveal the regional zonary distribution of tin, copper and zinc, indicate the presence of all known primary ore- and alluvial-fields, and, in addition, certain areas in which unworked lode extensions, or possibly 'new' lodes, may occur. They also demonstrate that the fine-grained granite is distinctly poorer in P than the coarse-grained variety: however, they do not yield conclusive evidence that the coarse-grained granite consists of more than one phase, although the Be patterns suggests that either a distinct marginal phase exists or that marginal differentiation has occurred.

This paper deals essentially with the results of an applied geochemical survey of the Land's End Peninsula, in which Sn, Cu, Zn, Be and P were determined in the minus-80-mesh fraction of sediment samples collected from all the streams in the region. The work was carried out by post-graduate and final-year students of the Camborne School of Mines as part of their prospecting studies at their Easter (1964) camp. The collection of 352 samples from an area of c. 90 sq. miles, followed by their drying, screening and analysis in a temporary laboratory and the preparation of maps occupied five days.

Apart from giving students experience in the organisation and running, etc., of a sizeable applied geochemical survey, the object of the exercise was to determine to what extent the presence of known primary and alluvial ore-deposits was reflected in the distribution patterns of certain elements in the minus-80-mesh (B.S.S.) fraction of the stream sediments and to discover whether these patterns also indicated the presence of unworked lode extensions and hitherto undiscovered ore-bodies. In addition, it was hoped that the patterns might throw further light on the structure of the granite mass (which may well be a polyphase intrusive) as similar, as yet unpublished, studies had done so when carried out on the Carnmenellis mass.

General geology. (Map 1 and Figs. 1/1 to 1/5.)

The Land's End Peninsula consists essentially of an exposed portion of the Permo-Carboniferous granite batholith which extends from Dartmoor to the Scilly Isles. The granite is locally fringed by non-calcareous, essentially fine-grained sediments (killas) of Devonian age with which are interbedded intermediate basic intrusives and effusives (collectively termed 'greenstones'). These were folded before and during the emplacement of the granite and were thermally metamorphosed by the invading acid magma and locally chemically altered as a result of agents emanating from it.

Robson (1948, 447) records that the available analyses of greenstones from 12 localities within the Land's End Peninsula show the following characteristic percentage range and (the average):— SiO_2 , 36-50 (43.90); Al_2O_3 , 11-21 (17.37); Fe_2O_3 , 1-8 (4.53); FeO , 7-16 (11.23); MgO , 3-11 (6.00); CaO , 4-15 (10.46); Na_2O , 1.2-6.5 (2.57); K_2O , 0-3 (1.41); TiO_2 (0.61); P_2O_5 (0.83). The fairly wide range of chemical composition is a notable feature and in Robson's opinion is due to local differentiation, shearing, and initial variation in the nature of the magma from place to place. (For a comprehensive survey of the greenstones reference should be made to Robson, 1948 and 1954-54.)

Most of the granite of the Peninsula is coarse-grained, but a fine-grained variety, which has been emplaced within the coarse textured rock, occurs in the north-east and is described later.

The coarse-grained granite (as the analyses below indicate) is a potash type with minor, but very variable amounts of soda: it is comparatively poor in iron and magnesia. The minerals present include quartz; abundant orthoclase; albite-oligoclase (which is usually subsidiary, but abundant and Botallack and Providence); biotite (usually abundant, but subsidiary to muscovite in some of the lode areas); tourmaline (usually present, and abundant near the granite contact and in some of the mines where it may in part have been introduced during lode development); and the accessory minerals apatite, magnetite and zircon. The reaction minerals found are pinite, andalusite and topaz.

Robson (1948, 438-9) recognises two varieties of the coarse type and makes the following observations about them:—

"(i) The 'marginal' type is a coarse uniform grain, with finer varieties and few large phenocrysts: a fairly regular rate of cooling and possibly a more basic rock results: plagioclase, biotite and zircon are more abundant here.

(ii) The main 'porphyritic' type is very coarse and extremely large orthoclase crystals (1-7") are usual, . . . : they lie in all directions . . . and may be in fluxion along the cleavingway joints . . . : grey glassy quartz, mica, tourmaline, and widespread cordierite (pinite) are present: biotite, apatite and zircon may be included in later minerals."

In this coarse-grained granite cognate and accidental xenoliths are not uncommon.

The fine-grained granite, which occurs as two small intrusive masses within the coarse-granite at Castle-an-Dinas and at Knill's Steeple (near Carbis Bay) is composed in the former locality of orthoclase, much albite-oligoclase, quartz, biotite, pinite and a little topaz, and is there locally tourmalinised and kaolinised. In the latter locality the rock is a tourmaline-biotite variety, consisting of quartz, orthoclase, a little plagioclase, tourmaline, biotite, muscovite, and appreciable amounts of topaz and andalusite: cordierite is seen in a few sections.

Table 1 contains analyses, reported by Reid and Flett (1907, 59) of the coarse-grained granites of Lamorna, Gready and Botallack and of the fine-grained granite, which has been kaolinised by hypogene processes, from Georgia China Clay Works.

Granitic veins, largely contemporaneous with the main intrusion, are abundant in the invaded rocks near the granite contact. Pegmatites, however, are few, small, and mineralogically simple, consisting of quartz, feldspar, muscovite and black tourmaline. Most post-date the emplacement of the granite, but that occurring in a structural trap at Porthmeor (Zennor) developed during the early phases of granite invasion.

Locally, as at Pendour Cove (Daniell, 1925) and at Penlee Quarry (Hosking, K. Unpublished Studies) granitic components have invaded greenstones producing hybrid rocks.

Four granite dykes, all of which post-date the major granite, occur in the region. The one which is 30 ft. wide and extends from Ludgvan to Sancreed is a normal granite porphyry. The Wherry dyke, outcropping in the reefs off Penzance, is also a granite porphyry which, where intersected by a lode, was riddled with cassiterite. At Carn Barges (Lamorna) an 8-ft.-wide dyke of pink microgranite is exposed on a granite platform: it is locally highly tourmalinised and intersected by barren quartz veins and others containing, in addition to quartz, tourmaline, feldspar, chlorite and

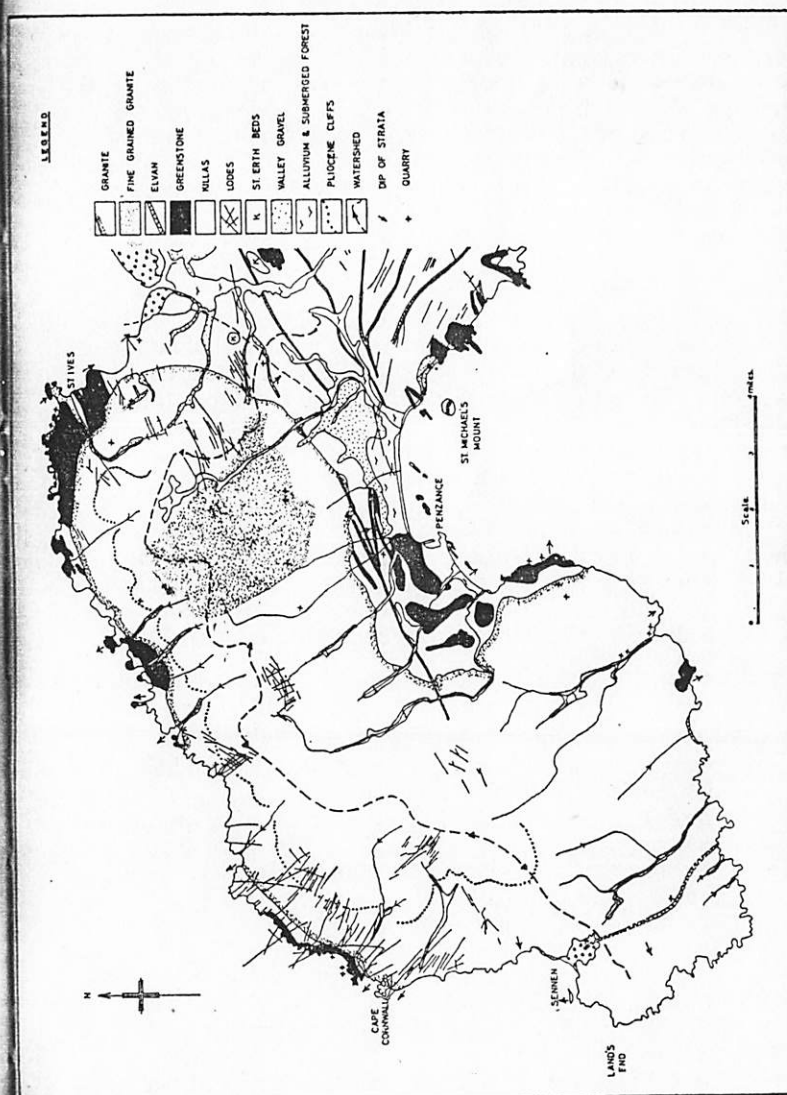
arsenopyrite (Robson, 1948, 441). The fourth dyke, which strikes N.N.W.-S.S.E., and is exposed at Sennen school quarry, consists of a fine aggregate of feldspar and quartz in which are included nests and rosettes of black tourmaline.

TABLE 1.
Chemical Analyses of Certain Land's End Granites

	Lamorna	Gready	Botallack	Georgia (Kaolinised)
SiO ₂	70.17	69.64	74.54	71.15
TiO ₂	0.41	—	—	0.16
Al ₂ O ₃	15.07	17.35	14.86	19.41
Fe ₂ O ₃	0.88	1.04	2.53	1.32
FeO	1.79	1.97	0.23	0.09
MnO	0.12	tr.	tr.	0.09
CaO	1.13	1.40	0.29	0.21
MgO	1.11	0.21	tr.	0.45
K ₂ O	5.73	4.08	3.73	1.44
Na ₂ O	2.69	3.51	3.49	0.05
Li ₂ O	0.11	tr.	tr.	0.03
H ₂ O (105° C.)	0.18	} 0.72	} 0.87	0.16
H ₂ O (above 105° C.)	0.70			5.09
P ₂ O ₅	0.34	tr.	—	0.07
Cl	0.06	—	—	tr.
F	0.15	—	—	0.11
S	0.04	—	—	—
B ₂ O ₃	strong tr.	—	—	0.33
Less O for F & Cl	100.68	99.92	100.54	100.16
	0.07	—	—	0.04
	100.61			100.12

A period of lode development followed those when the major and minor granitic bodies were emplaced. Most of the known lodes occur in the vicinity of the granite/invaded rock junction, though a few swarms, notably those at Balleswidden and Ding Dong, are near the centre of the granite mass, and, because of erosion possess comparatively limited extension in depth. Possibly, but by no means certainly, other lodes existed in the area but have been completely eliminated by erosion.

The lodes, which are narrow bodies with considerable strike and dip lengths, are commonly structurally and mineralogically complex due to repeated re-opening and to progressive changes in the nature of the ore-forming agents during their development.



MAP 1. A general geological map of the Land's End Peninsula. (Based on the Geol. Surv. Map.)

Well inside the granite contact tin mines are dominant, whilst near the contact both tin and copper mines are widespread, so that, in plan, the region displays clear evidence of primary zoning, a phenomenon due to the tendency for much of the cassiterite to be deposited at lower horizons in the lodes than the later-developed copper species. Furthermore, Dines (1956, 9) has traced the tin zone within certain of the lodes of the Geevor and Levant Mines (where, as is usual in Cornwall, it is in part overlapped by the copper zone) and has shown that it dips away from the granite but at a considerably smaller angle than that of the neighbouring granite/country-rock contact. However, lode development was much more complex than the broad distribution of tin and copper might suggest. Successive minerals were not necessarily deposited at successively higher horizons: indeed, at Geevor Mine both early and late minerals are commonly found in a given lode at the same horizon (Garnett, 1963) and one of us (Hosking, K. F. G., Unpublished Studies) has established that in the Land's End area lodes in many other mines (e.g., Wheal Edward, Wheal Cock, the Garth Mine, West Tolvadden, Trenwith Mine, etc.) exhibit the same phenomenon. In addition, though it is probable that most of the lode minerals were deposited soon after the emplacement of the granite, some of the uraninite and coffinite in the Geevor Mine was laid down in Jurassic and Tertiary times (Darnley et al., 1963). However, in view of the lack of strong igneous or volcanic activity of these ages in, or in the vicinity of, the region (the phonolite of the Wolf Rock — of Jurassic age possibly — is the only example) it is probable that these late deposited species have been derived from the products of remobilisation of early lode minerals.

Within the region, only the paragenesis of the lodes in the granite of Geevor Mine has been studied in detail. There Garnett (1963) recognises the following phases of mineralisation:—

1. Main wall-rock alteration. (Reddening of the feldspars of the granite. Greisenisation (K.H.).)
2. Impregnation of wall-rock by arsenopyrite, pyrite and chalcopyrite.
3. Development of cassiterite by replacement.
4. Infilling with tourmaline.
5. Deposition of feldspar and arsenopyrite.
6. Deposition of quartz and cassiterite.
7. Deposition of tourmaline and cassiterite.
8. Deposition of chlorite and cassiterite.
9. Deposition of cassiterite, chalcopyrite, pyrite and green fluorite.
10. Deposition of chalcopyrite, chalcocite, sphalerite (and early uranium species? (K.H.).)
11. Deposition of quartz and purple fluorite.
12. Deposition of calcite and siderite.
13. Deposition of quartz and jasper.

Kaolinisation is an early phenomenon, extending from phase 1 to c. 7 whilst quartz is deposited in greatest quantity during phases 5 to 10. Although not mentioned by Garnett, a great deal of earthy hematite was locally deposited, possibly during phase 8, in the lode zones. Garnett, however, notes that mineralisation phases 1 to 4, unlike those which followed, were not accompanied by movement of the lode fissure wall.

Although at Geevor both early and late — high and low temperature — species occur in the same lode, elsewhere in the region they may occupy different sets of fissures. In Penlee Quarry, for example, lodes with distinctly different mineral assemblages occur. Thus one contains quartz, chlorite and molybdenite, another quartz, cassiterite and pyrite, and a further one galena, quartz and chalcedony: still other types are found there.

The paragenesis established by Garnett at Geevor is broadly applicable to the region as a whole though it does not, of course, embrace all the mineral species found there. Wall-rock alteration associated with lodes in the killas also closely parallels that accompanying lodes in the granite: tourmalinisation, sericisation, chloritisation, hematitisation and silicification all occur. On the other hand greenstones near the lodes though often chloritised, are sometimes altered to skarns containing varying amounts of garnet, axinite, epidote, zoisite, calcite, etc.: typical examples occur at Carrick Dhu and in the Botallack-Pendeen cliffs.

Finally, well inside the granite perimeter, where erosion has left little more than the roots of lodes, the ore-bodies are both structurally and mineralogically simple as compared with the virtually intact lodes along the fringe zones of the region.

Between the Permian and Jurassic periods South-West England was land and then the higher parts of the granite batholith were uncovered; but in Upper Cretaceous times it was almost completely submerged, and some of its higher platforms may be of late Cretaceous or early Eocene age: on these the flint may have been deposited which now occurs in considerable amount on some of the present beaches.

Probably following the Alpine (Miocene) disturbances all the land below the present 400-ft. contour was submerged: then the Land's End was a granite island about 31 square miles in extent. This submergence was followed by emergence in stages during Pliocene times, a process which resulted in the formation of a series of marine platforms (Figs 1/1 and 1/5) of which the one now standing at about the 400 ft. contour is the most extensive.

Elevation continued into Pleistocene times, with the further development of three more platforms of which the most marked is the so-called 10 foot one, and upon which a well-preserved raised beach is often found.

At this time an ice sheet extended roughly as far south as a line from Bristol to London (off-shore, the sheet probably spread at least as far south as the Scilly Isles) so that Cornwall was subject to permafrost conditions. Temporarily during the Pliocene, and again towards the end of the period, the climate became more temperate, and the thawing of the snow and ice caused frost-shattered surface debris to migrate to lower levels. The result of this was that large quantities of angular boulders set in a matrix of sand and clay (and, beyond doubt, containing considerable quantities of cassiterite in the vicinity of tin-lode areas) were deposited in the valleys and on the 10-foot and higher platforms. This periglacial solifluction product is termed "head of rubble" or "head".

Elevation continued into Recent times, probably elevating the land a further 30 feet above the height it had attained during the Pleistocene. During this time the climate was of a very rainy type and consequently the rejuvenated rivers carried large volumes of water which enabled them to deepen their channels rapidly and at the same time to wash and sort the debris in their valleys so that the dense cassiterite tended to be concentrated immediately above the rocky floors. At the same time, torrents flowing on to the various platforms also effected local concentration of cassiterite there.

Following this stage was one in which forests flourished and the debris from these accumulated on the low level gravels. This was succeeded by a period of depression which lowered the beds of the rivers at their mouths to as much as 40 ft. below the present O.D. At the same time the low-level gravels, already covered with forest bed and peat, were further buried beneath estuarine and marine deposits, and low-lying forests were submerged. An excellent example of a submerged forest and of a low-level alluvial tin deposit occurs in the vicinity of Marazion.

Finally, sand-dunes were developed where the cliffs were low, the beach gently shelving and rich in sand, and the shore was exposed to strong on-shore winds. In the Land's End Peninsula these conditions occurred at Sennen.

Topography and drainage.

For the purpose of the present study the only topographical features requiring comment are the elevated marine platforms. (See Figs. 1/1 and 1/5.)

The higher platforms, which are all on granite, occur between 600 and 750 feet, and from these carns arise along the watershed which trends approximately parallel to the north coast and is, on an average, about $1\frac{1}{2}$ miles inland.

The 250-400 ft. Pliocene platform is the major physiographic unit of the Peninsula and is particularly well preserved between St. Just and St. Ives where it terminates against the cliff-like edge

of the higher ground. On the platform both granite and invaded rocks are planed off uniformly.

Locally, as at Ayr-Clodgy (St. Ives), a marked 180-ft. platform is seen, and later post-Pliocene platforms occur at the 65-foot level (e.g., at Penlee, where it is partly covered by 'old' beach deposits) and at the 10-foot level (e.g., at Porth Nanven, where it is covered largely by granite boulders).

Concerning the characteristics of the drainage one cannot do better than quote Robson's concise summary (1948, 431):—

"Drainage is determined and directed by the elongated granite dome and its early Tertiary uplift; the cleavingway (N.N.W.-S.S.E.) joint system, and to a less extent, the strikes of the contact rocks. The net result is a N.E.-S.W. watershed with post-Cretaceous consequent streams trending mainly S.S.E., common to the Cornish region; and implying an initial tilt in this direction? This stream pattern is perfectly shown on the uniform jointed granite mass and any deviation from the normal S.E. or N.W. trend is due to jointing, or to local differential erosion on reaching the contact rocks, e.g., the N.W. streams at Tregeseal and Halsetown, turn S.W. and N.E. at Kenidjack and Stennack respectively due to selective erosion of slate. (Streams 23 and 37 respectively on the geochemical maps of the present paper.) Repeated direction changes by the Newlyn stream (no. 6 on the geochemical maps) are due to this and here is a clear case of its capture of the east Lamorna stream near Lower Drift. The south flowing streams channel directly across the platforms and buffs and form steep gullies in the 430 ft. level, . . . and have a gradient of about 100 ft. per mile. The north flowing streams are restricted and grade steeply at 300-500 ft. per mile through swampy head-filled valleys. The pre-Pliocene drainage courses, rejuvenated by the post-Pliocene uplifts, were maintained independent of the structure of the border rocks: the streams are thus antecedent. Though at one time torrential, the present flow is very small, and the large initial valleys disproportionate. Most drainage is subterranean via joints, and wells yield an abundant water supply."

The influence of mining on the metal content of the stream sediments.

In the Land's End Peninsula the natural metal distribution patterns in the superficial active portions of the sediments of many of the streams have been grossly altered as a direct or indirect result of hard-rock and alluvial mining.

Sheet-wash has, doubtless, been responsible for the transference of appreciable quantities of fine cassiterite and other heavy-metal species from mine dumps situated in valleys to the sediments of the adjacent streams: it has also, probably, transported considerable quantities of metals in solution into the stream environment where

a proportion was almost certainly incorporated into the sediments by adsorption, direct precipitation, or co-precipitation. The Tregeseal Valley (stream 23) is an area in which the above probably took place.

The tailings from mills effected gross contamination of stream sediments. The high metal values in stream 22 are due to losses from the Balleswidden mill, and the exceedingly high tin, copper and zinc values recorded in the sediments of stream 24 are due to the fact that this stream has received tailings from Geevor Mine.

In the past small mills were erected in certain valleys to treat ore acquired from other areas: the tailings from these also materially increased the tin and copper content of the sediments further down-stream. The high metal content in the middle reaches of stream 23 is due to this.

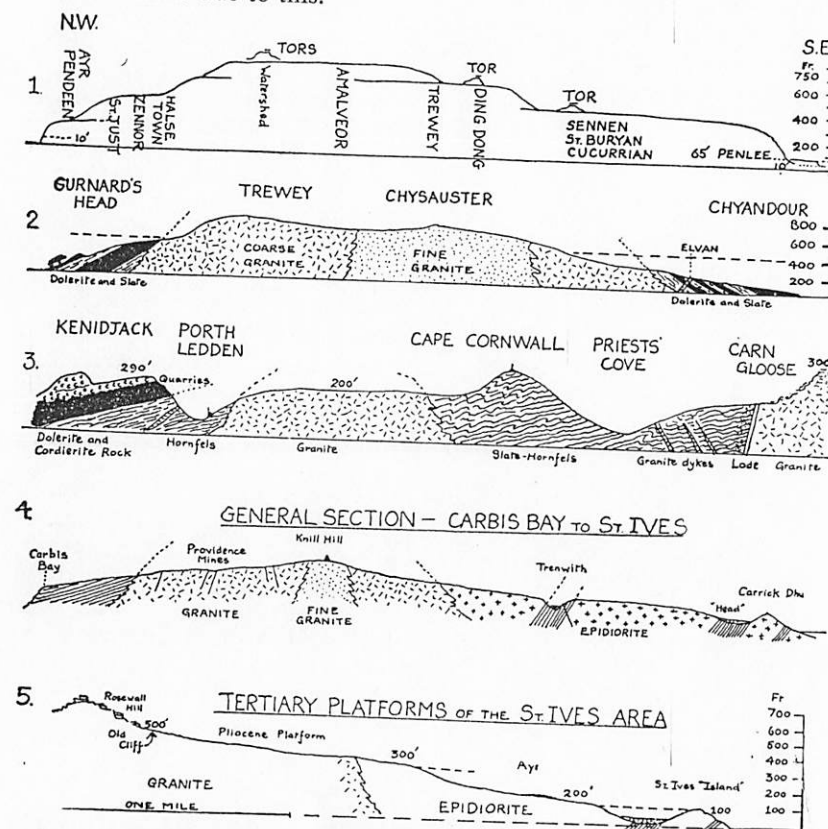


FIG. 1. Sectional diagrams illustrating various features of the Land's End Mass. Fig. 1/1 and 1/5, platforms: figs. 1/2, 1/3 and 1/4, rock relationships. (Figs. 1/1 to 1/3 after Robson, 1948, 436, and figs. 1/4 and 1/5 after Robson, 1945, 281.)

Many of the streams were worked for alluvial cassiterite. This operation entailed the removal of the superficial sediments in order to reveal the pay-dirt just above the bedrock. Consequently, the normal sediment sequence has been completely disturbed, and in Map 1, in accordance with the nomenclature used by members of the Geological Survey, such disturbed deposits are recorded as alluvium, not as river gravel. Furthermore, considerable tin losses were sustained during the beneficiation of the alluvial ore by comparatively primitive methods, and it is probable that the richer the deposit the greater the losses. It is of further interest to note that cassiterite was won from many valley alluvials where no lodes have ever been reported. Henwood (1874, 195-7) refers to such deposits in the valleys of the streams that drain the area between the southernmost part of the Peninsula and Mousehole, and he notes, for example, that near Bojewans, $1\frac{1}{2}$ miles S. by E. of Sancreed, at a confluence in the valley that reaches the coast at Lamorna Cove there were 6-12 ft. of granitic sand and gravel covering 2 to 8 ft. of peat which, in turn, rested upon 2 to 9 ft. of pay-dirt consisting of rounded masses of granite and lode material containing wood-tin which commonly coated quartz crystals. Have the parent lodes been completely destroyed by erosion or are they still in part intact beneath the superficial cover? It is of interest to note that just above the confluence noted above, at Bojewans, the minus-80-mesh (B.S.S.) fraction contains more than 5,000 p.p.m. tin! (See Map 2.)

Analytical methods employed in the present study.

Sediment samples, having been collected in resin-impregnated envelopes, were dried, screened through an 80-mesh Nylon screen, and portions of the undersize were analyzed by the following colorimetric methods in a temporary laboratory which was established in one of the buildings of Geevor Mine:—

1. Tin. The modified gallein method. (Stanton and McDonald, 1961-62, 27-29.)
2. Total and acid-extractable copper. 2,2'-biquinoline method. (Ward, Lakin and Canney, 1963, 19-27.)
3. Zinc. Dithizone method with hot HNO_3 digestion. (Stanton and Gilbert, 1956, 7-9.)
4. Beryllium. Beryllon II method. (Debnam and Webb, 1959-60, 343-344.)
5. Phosphorus. Vanadate/molybdate method. (Ward, Lakin and Canney, 1963, 66-68.)

Discussion of the results. (See Maps 2-6.)

Tin. (Map 2.)

Although the distribution of tin in the various size-fractions of representative samples of active stream sediment has not been determined during this study, such work on samples from similar Cornish areas has demonstrated that most of the metal occurs in

the finer fractions, and that analysis of the minus-80-mesh (B.S.S.) fraction will yield perfectly satisfactory results when the object is to locate sub-outcropping lodes. (This also holds for the other elements of particular interest to this investigation.)

Distinctly anomalous concentrations of tin in sediments are due essentially to lode-derived cassiterite (SnO_2): in barren Cornish sediments the tin present occurs largely in biotite, in which it proxies for iron and magnesium: locally, where appreciable muscovite or secondary micas exist these species may hold a considerable quantity of tin in the form of minute crystals of cassiterite which lie along cleavage planes.

Unlike copper and zinc, appreciable concentrations of tin occur in the sediments over the heart of the Land's End granite as well as in those near the contact and on the pre-granite rocks. This is due largely to the fact that the tin zone underlies the copper/zinc and so has been less affected by erosion than the latter. The presence of primary zoned deposits and the effects of erosion must not be forgotten during the search for economically important primary tin deposits in the region, as a copper lode near the contact may be tin-bearing in depth, and a tin lode well inside the contact may be of limited economic importance as it is likely to possess only a modest dip length.

The vast majority of the lodes indicated on the accompanying maps are tin-bearing (though not necessarily at, or near, the surface), and have been worked: consequently, as noted earlier, the sediments of the streams in the vicinities of these bodies are generally heavily contaminated by tin-bearing tailings. (This is not surprising when it is realised that in the past little more than 50 per cent of the cassiterite mined was recovered.) Similarly, as mentioned in an earlier section, a number of other streams, in areas not known to contain lodes, are, nevertheless, contaminated as a result of alluvial tin mining: a typical example is stream 17. The sources of this alluvial tin are uncertain: perhaps they were small, but possibly numerous, cassiterite-bearing stringers: perhaps they were well-defined lodes, the remains of which still await discovery and lie beneath the alluvium and thin superficial cover of the adjacent ground. On the other hand it is possible that the parent deposits, whatever their nature, have been completely destroyed by erosive processes. In addition, the fact that particularly along the south coast tin-rich valleys are, on occasion, closely associated with parallel, tin-poor ones which trend across the probable strike of any lodes in the area, suggests that the bodies from which the alluvial cassiterite was derived were of modest dimensions and so even if what remained of them were discovered it might be only of slight economic interest.

There are, however, a number of streams whose sediments contain distinctly anomalous concentrations of tin (i.e., greater than 1,500 p.p.m.) which may be due essentially, or entirely, to natural

causes, and which, therefore, point to areas worthy of further examination. The chief amongst these are in the vicinity of stream 9 and in the tract embracing the upper reaches of streams 3 and 4, though possibly the high concentrations in the latter may be due, at least in part, to tailings from Ding Dong Mine.

The high concentrations of tin in stream 6 are also interesting as only one lode, that of the small Garth Mine, is indicated in the vicinity of this drainage system on the one-inch Geological Survey Map, and as it consists essentially of copper/siderite ore with only minor amounts of cassiterite (the 'wood-tin' variety) it is unlikely that tailings from the beneficiation of this material were the major contributors of the tin in the sediments. However, mining operations not known to the writers may have taken place in the vicinity of this stream, so it is premature to conclude that probably unworked lodes occur there. Clearly, further field — and historical — studies are needed to settle such matters.

Copper. (Map 3.)

Copper occurs in the stream sediments of the Peninsula as a component of sulphides, oxy-salts, biotite mica, and organic complexes, and adsorbed on colloidal, particularly organic, material.

Most of the lodes along the northern and eastern portions of the granite contact are copper-bearing and consequently streams bearing the tailings from mines in these areas are characterised by sediments which are often rich in both total- and cold-extractable-copper. Not surprisingly, sediments of stream 24 (which is in the vicinity of the operating Geevor Mine) are the richest in the element in question. There much of the total-copper is incorporated in sulphides (which are much more persistent in a stream environment than is generally believed): the cold-extractable-copper probably largely represents copper, leached from ore oxidising underground, in the mill, and in neighbouring dumps, which has been subsequently removed from solution by colloidal material.

Throughout the study it has been noticeable that a high cold-extractable to total copper ratio most commonly occurs when the sample is rich in organic matter, and on occasion the ratio is c. 1 to 1, indicating that virtually all the copper present is adsorbed on colloids or a component of organic complexes from which it is liberated by a comparatively mild attacking reagent. The high cold-extractable copper content of the sediments of stream 1 is due to the fact that the stream is receiving copper-rich waters from Wheal Darlington and neighbouring mines and that the waters are being stripped of their copper by organic matter as they flow through the Marazion marshes.

The present study indicates that in this area a high cold-extractable to total copper ratio only points to the presence of ore (either in situ, or transported by man to the site) when the concentra-

tions of both cold-extractable and total copper are high: the writers have, therefore, recorded the product of these concentrations on Map 3.

The magnitude of the copper concentration and the copper concentration patterns of the sediments of several streams (particularly when they are considered in conjunction with the concentration patterns of the other elements which have been studied, and with available geological and historical data) suggest areas which may contain mineral deposits and which are, therefore, worthy of further examination. Streams 3, 4, 6 and 7 all locally contain sediments with appreciable concentrations of cold-extractable and total copper which cannot at present be ascribed entirely, if at all, to the work of man: obviously further study of the area over which these streams flow is merited.

The sediments of stream 7 (which reaches the sea at Mousehole) may owe their appreciable copper content to the erosion of members of the series of lodes which have been revealed in Penlee Quarry and which have been mined in West Tolvaddon: however, the possibility that the high copper content of these sediments is due largely, or entirely, to mining operations has not yet been eliminated.

Zinc. (Map 4.)

The region is not one which is zinc-rich although there is probably considerable more zinc in many of the lodes than the literature suggests: this distorted view is due to the fact that the metal was never sufficiently abundant in the Land's End lodes to be worth recovering, and so sphalerite, the species in which the zinc occurs in the unoxidised portions of the ore-bodies, received little or no more than the scant mention given to the other gangue minerals.

All the sphalerite from the Peninsula yet examined by one of us (K.H.) is of the high-temperature type: that is to say, it is iron-rich and contains ex-solution bodies, generally of chalcopyrite. This sulphide was deposited with, or immediately after, the primary copper minerals and so it is not surprising that the zinc distribution patterns in the stream sediments are broadly the same as those of copper. The fact that commonly the concentration of zinc in the sediments does not differ greatly from that of total copper is of considerable interest, but why this similarity exists is not clear as the sediments both from streams which have been contaminated by tailings, such as nos. 1, 37 and 38, and from those which are apparently uncontaminated, such as no. 3, exhibit this characteristic.

Zinc may occur in the sediments as sphalerite, as a component of oxy-salts and organic complexes, in biotite mica, and adsorbed on colloids, particularly those which are organic. The background zinc concentrations which, in common with those of copper, are characteristic of the sediments of the upper reaches of streams 9 to

13, are due largely to biotite-held metal. (Hosking, K. F. G. Unpublished Studies.) The high zinc content of the sediments of streams which have been polluted by tailings from mines near the granite contact is largely due to the presence of sphalerite, but should the stream contain much organic matter, as stream 1 does, a considerable proportion of the zinc in the sediments may be organically held.

The zinc content of some of the sediments of certain streams, for example, no. 7 and no. 9 (the eastern tributaries) which do not appear to have been contaminated by mining operations, is sufficiently high to suggest the presence of unknown primary deposits. On occasion, as in stream 7, these high values are associated with comparatively high copper values. (In both the copper and zinc sections expressions such as "high copper values" and "high zinc content" mean high by comparison with values commonly found on the Peninsula: only a very few samples contain sufficient zinc and copper for them to be considered to have high concentrations of these metals when the metal content of sediments from zinc and copperfields generally is being discussed.)

Beryllium. (Map 5.)

Beryllium and phosphorous were determined because it was felt (in view of the results of certain unpublished studies, carried out by certain of the writers, on the distribution patterns of these elements in the stream sediments of the Carnmenellis granite mass) that should the Land's End granite be made up of a number of phases each might be characterised by distinct beryllium and phosphorous concentration ranges which would be reflected by the Be and P content of the sediments: thus it might be possible to broadly delineate each phase.

Interpretation of the beryllium distribution pattern is complicated by the fact that not only is the element a constituent of the granite but it also occurs as a dominant component of certain lode minerals.

In the granite (judging by the results of some of the writers' unpublished studies on the distribution of beryllium in certain horizons at Geevor Mine) most of the element occurs in biotite mica. Lode beryllium has only been recorded from the mines between Levant and Carn Kenidjack. At Wheal Edward acicular phenakite occurs in veinlets together with adularia, quartz, chalcopyrite and cassiterite: at Levant it is found in skarn-type ore in greenstone as danalite, and at Wheal Cock in a similar environment as helvite, phenakite, bertrandite and herderite (Kingsbury, 1961). It is not surprising that the sediments of streams draining this area locally contain some of the highest concentrations of beryllium recorded during the present study. However, after making allowances for the fact that material derived from the lodes by natural

causes or the activities of man is probably largely responsible for the local comparatively high concentrations of beryllium encountered in the sediments, there is still a strong indication that sediments overlying the marginal portions of the granite are distinctly richer in the element in question than those occurring over the core. This suggests that there may be present either a marginal intrusive phase (on which the minus-80-mesh fractions of stream sediment samples contain 2, or more, p.p.m. Be) or the granite mass possesses a beryllium-enriched marginal differentiated zone. The latter is the more probable as at Carnmenellis, where three distinct granite phases occur, their boundaries coincide remarkably closely with changes, not only in the Be and P content of the minus-80-mesh stream sediment fractions, but also, in the lode-free areas, with changes in their zinc, tin and copper content.

The beryllium content of the sediments over the fine-grained granite is somewhat higher than that of those over the adjacent coarse-grained variety, but this does not serve to delineate the former and, in any case, the observed concentrations may be due largely to natural and man-made contributions from the lodes there.

Phosphorus (recorded as P_2O_5). (Map 6.)

Most of the phosphorus occurs in the granites and fringing rocks as apatite but a minor amount is present in the granites as monazite (and xenotime?). In the lodes the dominant phosphorus-bearing species is fluor-apatite (it is comparatively common on the Wheal Edward dumps) but at Wheal Cock both francolite and herderite have been recorded. On the dumps of Wheal Margery (Carbis Bay) the secondary copper uranyl phosphate, torbernite, is to be found.

In the stream sediments phosphorus is largely present as apatite, though in organic-rich sediments there may be an appreciable quantity of organically-bound phosphorus and, in addition, it is conceivable that in the marshy area near Marazion a considerable amount of vivianite may also be present — the phosphate fraction of the species having been derived from organic sources. A little phosphorus may also locally occur in the sediments in bone and shell fragments. Monazite, though occurring only in very small amounts in the granite may be locally appreciably concentrated in the drainage systems, because of its toughness, inertness and moderate density, though it has yet to be demonstrated that this has happened in the West of England.

The P_2O_5 content of the minus-80-mesh fractions of the sediments over the fine-grained granite is distinctly lower (generally below 1,500 p.p.m.) than that of those over the coarse-grained variety (often 2,000, or more, p.p.m.). This permits the plan of the fine-grained granite to be drawn with considerable confidence.

Indeed, the P_2O_5 concentration pattern suggests that the boundary of this granite, as shown on the one-inch Geological Survey Map, is probably in need of some modification.

The P_2O_5 content of the sediment samples collected over the coarse-grained granite give no reason for believing that it consists of more than one phase.

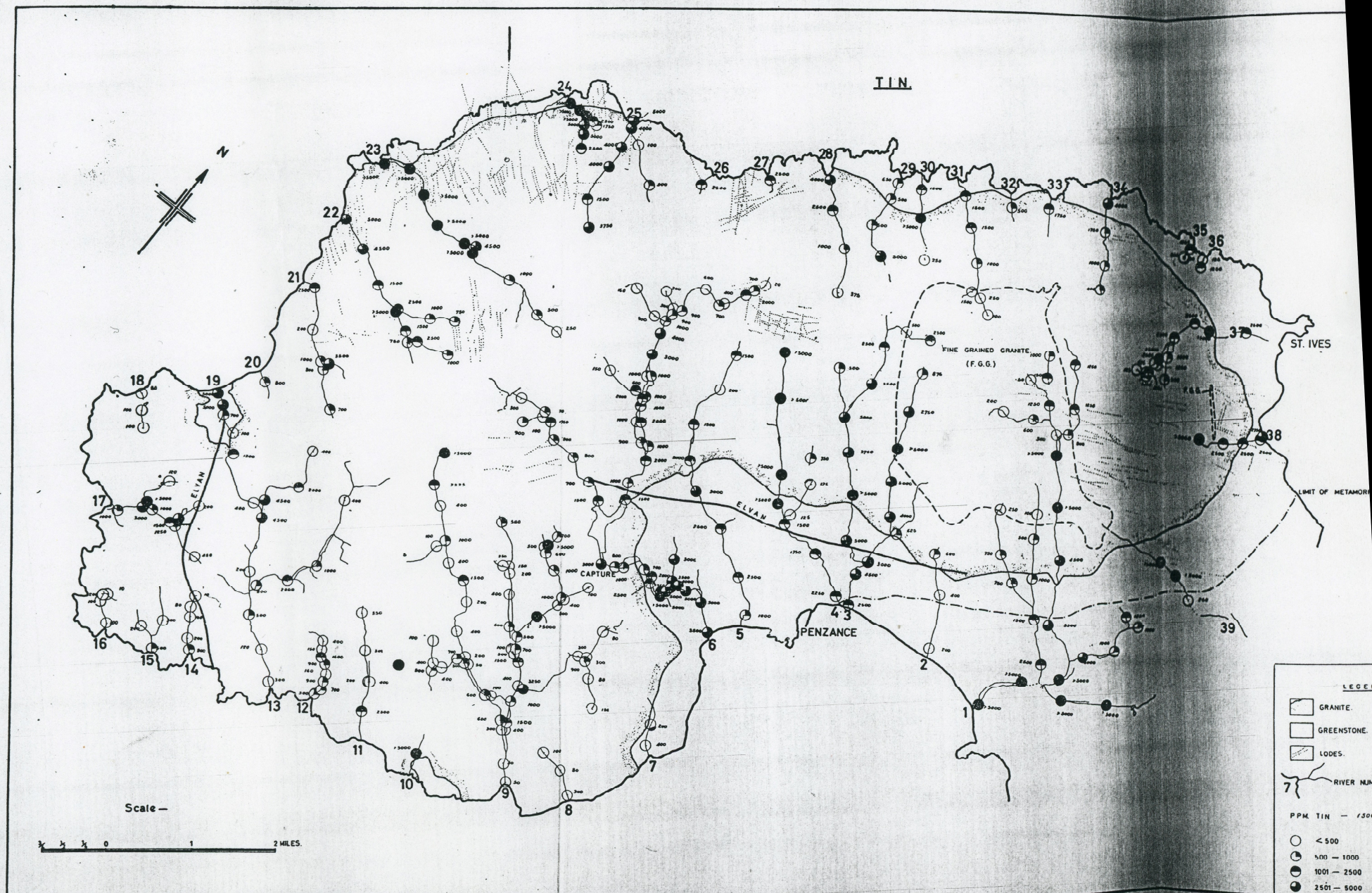
The high concentrations recorded in the samples from stream 12 prompt the writers to consider the possibility that they might be due to fertiliser washed, or blown into the stream from adjacent fields. However, as some of the sediment samples also contain distinctly anomalous tin and copper values it is probable that the high P_2O_5 content is due, essentially, to lode-derived apatite.

Acknowledgements.

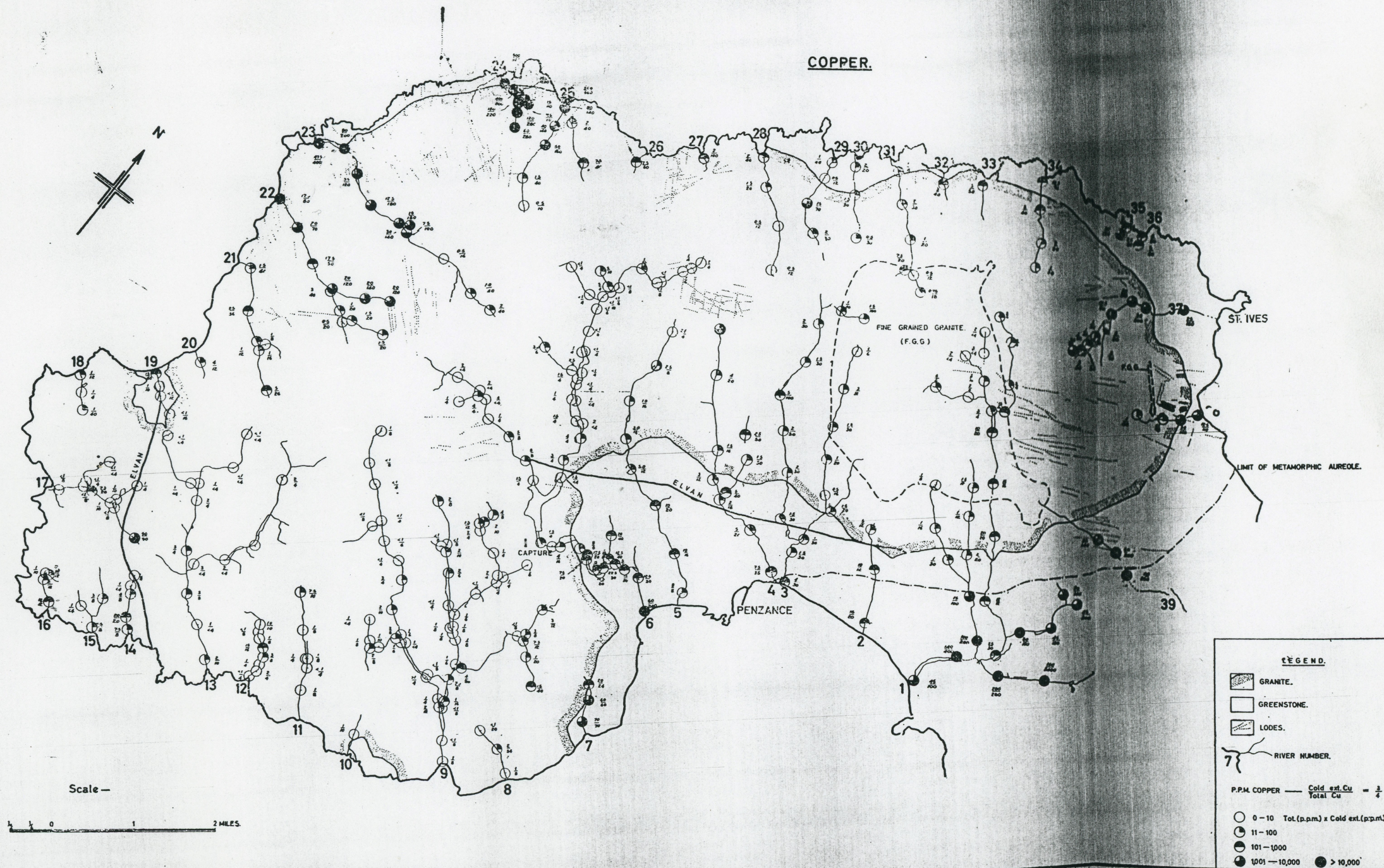
The writers are greatly indebted to Mr. Batchelor, Managing-Director of Geevor Mines Ltd., for making available buildings for living-quarters, temporary laboratories, etc., and for all the other help he so generously gave during the period when the above study was carried out. They are also very grateful to all those students who assisted in the collection and subsequent analysis of the samples. Finally they wish to acknowledge the great assistance given by Mr. Boles who was largely responsible for the production of the maps.

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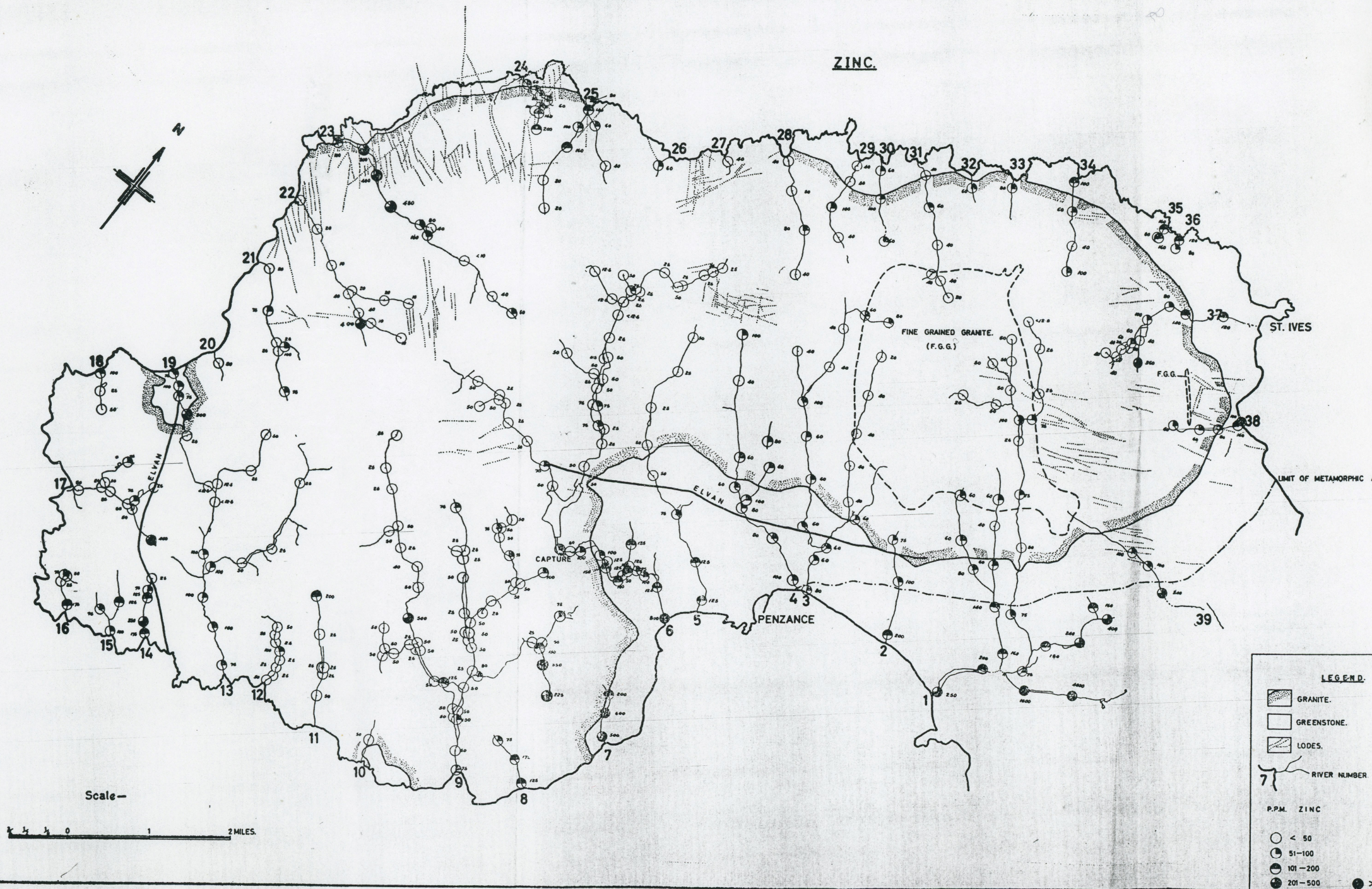
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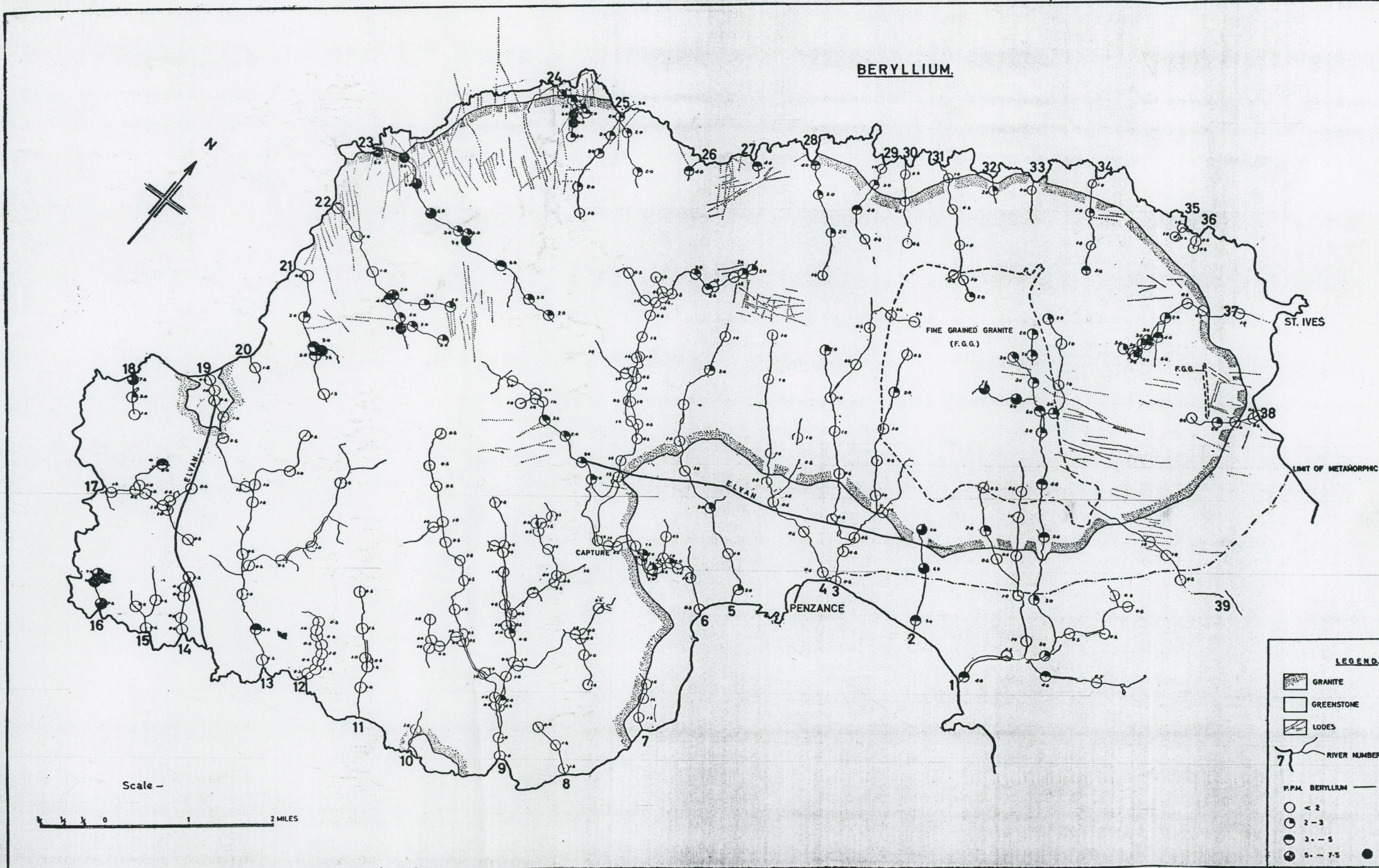
MAP 2. Distribution of tin in the minus-80-mesh (B.S.S.) fractions of sediments from the streams of the Land's End Peninsula.



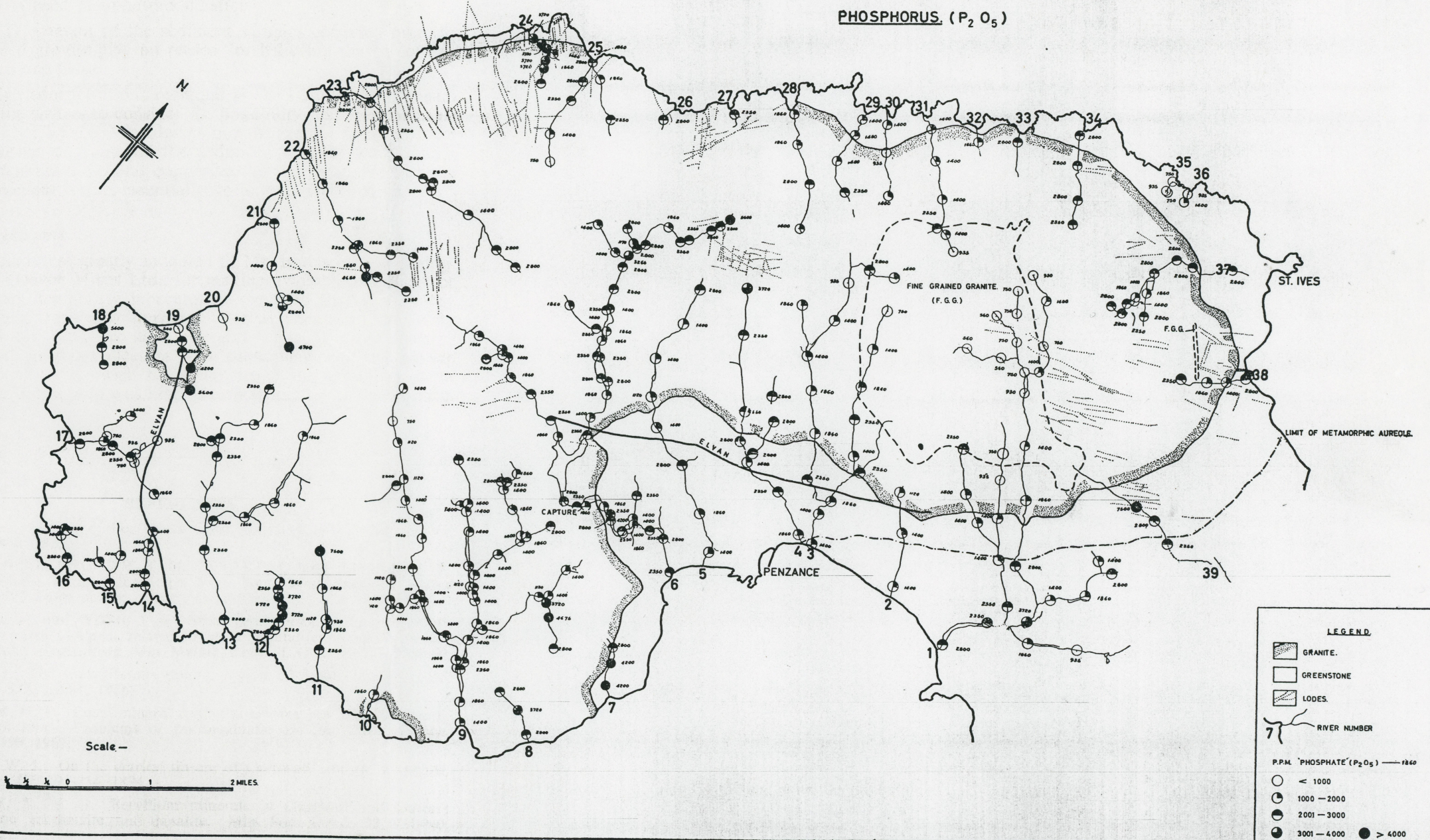
MAP 3. Distribution of total and acid-extractable copper in the minus-80-mesh (B.S.S.) fractions of sediments from the streams of the Land's End Peninsula.



MAP 4. Distribution of zinc in the minus-80-mesh (B.S.S.) fractions of sediments from the streams of the Land's End Peninsula.



MAP 5. Distribution of beryllium in the minus-80-mesh (B.S.S.) fractions of sediments from the streams of the Land's End Peninsula.



MAP 6. Distribution of phosphorus (as P_2O_5) in the minus-80-mesh (B.S.S.) fractions of sediments from the streams of the Land's End Peninsula.