The dressed ore from the concentrate bins is trucked in six to eight ton loads to the river port, where they discharge into a barge via chutes, or are conveyed on board by modern ship loaders incorporating slat conveyors or belt conveyors fitted with slewing mechanisms and hoist to discharge the concentrate directly above the barges' holds. Surplus ore is stock-piled on the adjoining plots. At one site the dressed ore from the plant is directly conveyed by aerial rope-way to the river port.

The steel barges, ranging from 150-600 tons capacity, transport the ore to Marmagoa harbour, about 20 miles distant, for transhipment to the sea-going vessels. The transhipment is done by boom cranes on the sea-going vessels.

The loading capacity of Marmagoa harbour is 650 tons per hour and can take vessels up to 20,000 tons.

The installation of a Pelletising plant in Goa with an annual capacity of half a million tons is under way and is expected to be ready this year for full capacity production.

The mines in Goa are privately owned and worked on one shift, six days a week. The labour force employed in the mining industry average about 20,000, including workers and monthly paid staff. At present, out of ten main mining sites, only at three sites are the mines fully mechanised. The daily production, mechanised as well as hand mining, is approximately 20,000 tons, but can be increased by installing more beneficiation plants and Pelletising plants and working in two shifts.

In conclusion, Goa's economy is mainly based on the mining industry and today Goan mines contribute substantial wealth for Goa and the remainder of India.

Acknowledgements.

The writer is indebted to M/s. V. M. Salgaocar & Brother Pvt. Ltd. for making it possible for him to study the formation of the laterite iron ore deposits and the mining systems laid down at the different sites in Goa while he was an employee.

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A Preliminary Study of the Distribution of certain Metals of Economic Interest in the Sediments and Waters of the Carrick Roads (West Cornwall) and of its "Feeder" Rivers

K. F. G. HOSKING AND R. OBIAL

SYNOPSIS

SAMPLES of active sediment were collected from the estuary known as the Carrick Roads and from its associated creeks and "feeder" rivers, all of which occur in the St. Day/Truro/Falmouth district of West Cornwall. The minus-80-mesh (B.S.S.) fraction of these samples was analyzed, by means of rapid semi-quantitative colorimetric methods, for copper, zinc, arsenic and tin. In addition, numerous water samples from the drainage systems were analyzed for their "total-heavy-metal" content.

The metal distribution patterns of the fluviatile tracts reflected all known mineralised areas and, in addition, revealed a hitherto unknown tin-high one which merits further investigation.

The metal distribution patterns of the waters and sediments of the estuarine tract indicate the river systems draining mineralised terrain and suggest that such studies in similar, but little investigated, areas with difficult hinterlands might facilitate the search for ore deposits by revealing, during the initial stages of exploration, which river systems should be given priority during the "follow up" programme.

INTRODUCTION.

Apart from giving final-year and research students of the Camborne School of Mines experience in the organisation, running, etc., of a sizeable geochemical exploration programme, the exercise, which occupied five days during Easter 1966, and provided the data for this paper, was designed to determine to what extent the distribution of certain metals in the waters and sediments of the streams feeding the Carrick Roads estuary of West Cornwall reflects the presence of known lodes, and indicates the possible presence of hitherto undiscovered mineral deposits. In addition, it included an investigation of the distribution patterns of the same elements in the estuarine waters and sediments in order to determine if such work might facilitate prospection, particularly of regions with difficult and little explored hinterlands, by indicating during the initial stages of the programme which, if any, of the "feeder" rivers drained mineralised terrain.

FIELD PROCEDURES AND ANALYSIS.

The finer fractions from, as near as possible, the centres of streams, and from the margins of the estuary, were collected in plastic scoops and transferred to appropriately labelled, resin-impregnated bags. In addition, at each sampling point, the pH of the water was measured by means of indicator papers and its " total-heavy-metal " content was determined by the usual dithizone method.

At several selected points along the estuary fringe the pH and " total-heavy-metal " content of the surface water were determined at intervals of 15 minutes in order to discover if these varied significantly with the state of the tide.

A 15-foot boat with an outboard motor was used to collect sediment and water samples along three traverse lines across the Carrick Roads. The sediment samples were collected by means of a Mud Snapper, a nickel spring-loaded grab (footnote) attached to a Nylon 'rope', which is cast overboard at the sampling point and whose jaws close just after striking the sediment, and by so doing collect a reasonable sample of the latter (provided the jaws are not prevented from closing completely by a comparatively large body, such as a pebble). In addition, the pH and " total-heavy metal " content of the surface water at each sampling point were determined by the methods noted above.

The location of each sampling point on the traverses was determined by resection which involved, in each case, the measurement of the bearings, by means of a prismatic compass, of at least three prominent, appropriately disposed, points which could be located on the map. Plotting was subsequently carried out at the base camp.

Finally, in order to investigate variations in the pH and " total-heavy-metal " content of the water with depth, samples were collected in polythene bottles at a number of points down to 90 feet by a skin-diver and subsequently analyzed in the laboratory.

For convenience, variations in the cold-extractable copper content of all sediment samples were determined at the base camp laboratory, rather than on-the-spot, which is the usual procedure. This determination involved shaking a measured volume of the wet sediment with a buffer, titrating, with controlled shaking, with a standard solution of dithizone in benzene until the organic phase was grey-blue, and recording the number of ml. dithizone added.

Footnote : This apparatus, costing, in 1962, 28 dollars, was obtained from the G.M. Manufacturing Company, 12 East 12th Street, New York 3, N.Y.

Tin, total copper, zinc and arsenic in the minus-80-mesh (B.S.S.) fractions of the dried sediments were determined in a laboratory established in a small marquee. Calor gas was used as the source of heat, and tin was determined by the gallein-methylene blue method, copper and zinc by bisulphate fusion-dithizone methods, and arsenic by a modified Gutzeit method.

The final plotting of the results was also carried out at the base camp.

GENERAL GEOLOGY. (Fig. 1.)

The study area consists essentially of Lower and Middle Devonian non-calcareous sediments and minor penecontemporaneous greenstones which were invaded in Permo-Carboniferous times by granitic magma, which locally thermally metamorphosed the invaded rocks and which consolidated as a batholith with a markedly irregular surface. This igneous mass has been in part uncovered by erosion, and exposed portions of it, which occur as relatively high moorland tracts, fringe the area of interest along the west and north-east.

Subsequent to the development of the batholith numerous elvan dykes were emplaced which, in the area under investigation, strike, with few exceptions, approximately N.E.-S.W., and these were followed by the genesis of similarly striking hypothermal lodes which have been worked primarily for tin (occurring as cassiterite) and copper (occurring as sulphides) but which also locally contain, in addition, considerable quantities of hypothermal arsenopyrite, sphalerite and pyrite (the last occurring in particular profusion, associated with cassiterite, in the lodes of Mount Wellington, Nangiles and the Janes Mines). (Footnote.) The wall-rock associated with such lodes may be tourmalinised, chloritised, haematitised, greisenised and silicified.

In Cornwall, generally, genesis of hypothermal lodes was followed by one, or possibly several, distinct periods of mesothermal mineralisation which resulted in part, in the deposition of siderite, galena, ' low-temperature ' sphalerite, etc., in late-reopened hypothermal lodes (as at Poldice, Wheal Hope, Wheal Jane and Wheal Badden in the study area), and in part in the development of essentially mesothermal lodes whose strikes are commonly about normal to those of their hypothermal neighbours. In the area under review there are few examples of the latter, but a lead-bearing example occurs at Wheal Daniell. Whilst most of the mesothermal mineralisation is probably little younger than the hypothermal, some may be of Jurassic or Tertiary age.

Footnote : For fairly comprehensive distribution details of the lodes and mines of the area see Dines (1956), Map VIB.

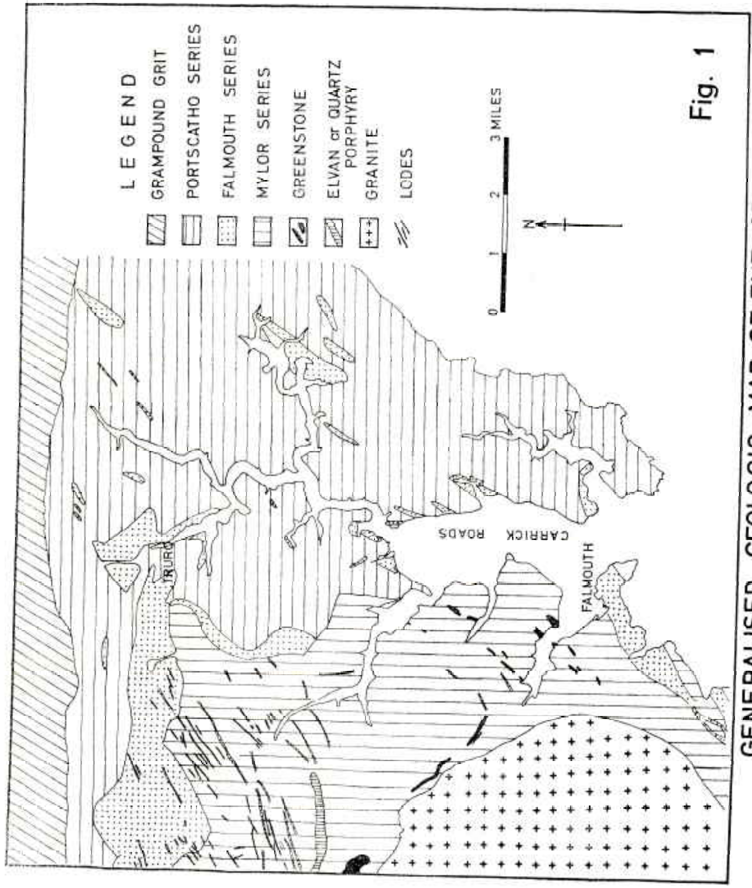


Fig. 1

GENERALISED GEOLOGIC MAP OF THE STUDY AREA

(AFTER THE GEOL. SURV. MAP)

Finally, the hypothermal lodes were faulted to varying degrees by numerous barren cross-courses whose strikes vary between N.-S. and N.N.W.-S.S.E.

The higher portions of the granite and some of the lodes were uncovered by sub-aerial erosion in Mesozoic times, but after the Alpine 'storm' the South-West was almost totally submerged and was represented by an archipelago of essentially granitic islands. This submergence was followed by emergence in stages during Pliocene times which resulted in the development of a number of marine platforms of which the one now standing at about the 400-foot contour is the most extensive.

Elevation continued into Pleistocene times, with the further development of several more platforms.

At this time an ice-sheet extended over the land as far south as a line joining Bristol with London, and possibly an off-shore tongue reached the Scilly Isles: Cornwall, therefore, was subject to permafrost conditions. At the end of Pleistocene times the climate became more temperate and the accompanying thaw caused a migration of rock debris, of all sizes, from high ground into valleys and on to the marine platforms: the resulting periglacial solifluction product is known as 'head-of-rubble'.

Elevation continued into Recent times, probably raising the land some 40 feet above its height in the Pleistocene. The wet climate of these times caused the rivers to be frequently swollen and consequently they were able to excavate their channels rapidly and so effect the concentration of dense resistates — particularly cassiterite. At the same time, torrents flowing from the high granite areas on to the 400-foot platform built up further local concentrations of cassiterite there. Both in the valleys and on the platforms the concentrating action of the flowing water was such that marked concentration of cassiterite occurred immediately above the hard-rock floor.

Elevation was finally followed by a depression of about 30 feet, and it was this which resulted in the development of the Carrick Roads and its associated estuarine creeks by a process of valley drowning, and which permitted these depressed zones to be in part infilled by estuarine sands and muds and peat beds. It also had the important economic effect in the Restronguet Creek (II in fig. 8) of making the recovery of the alluvial cassiterite there very difficult by allowing it to be covered not only by considerable thicknesses of barren sediment but also by considerable depths of tidal water. These problems were in part overcome in the seventies of the last century by the development of a submarine mine which involved, amongst other things, the sinking of two shafts, one on the beach just below high-water mark, and the other in the middle of the creek. (For details of this most interesting venture see Taylor, 1873.)

The following sections, after Henwood (1873, pp.204-205) indicate the character of the stanniferous alluvium where it was worked by submarine mining at Restronguet Creek, and in the upper extensions of the creek near the junction of the Perranwell and Carnon valleys :—

Restronguet Creek. (Submerged under 12 feet of water at high tide.)

SECTION A.	*Ft.*
River mud	6
Mud and coarse sand	8
Mud, compacted with abundant oyster shells 6 to 12 ft. from the top	49
Tin ground	½ to 6
Bedrock — Blue or buff clay slate.	

SECTION B.	*Ft.*
River mud	7 to 9
Mud and sand	9
Blue mud with oyster, cockle and other shells ...	9
Tin ground	½ to 6
Bedrock — Clay slate.	

The tin ground consists of subangular masses of granite, elvan, slate and quartz together with both large masses and small grains of tin ore.

Perranwell-Carnon Junction.	*Ft.*
Angular gravel, sand and silt, debris of various rocks and veinstones stamped at mines in the upper parts of the valley, passing down into rounded masses of granite and of slate in numerous thin bands. Remains of deer in the lower part, and, at the bottom oyster shells	12-15
Fine silt mixed with oyster shells, leaves, nuts and branches ; occasional wing cases of beetles ...	½ to 1½
Tin ground, of small more-or-less-rounded masses of tin ore interspersed with angular and sub-angular blocks of schorl rock, schorlaceous granite, quartz, quartzose slate and veinstones from both granite and killas country rock, the latter in great abundance. Occasional granules and flakes of gold	2-3
Bedrock — Thickly lamellar clayslate containing a N.-S. lead vein that was worked across the width of the alluvial workings and for depths of from 12 to 15 fms. below the tin ground.	

CONTAMINATION.

The various aspects of contamination which are particularly relevant when interpreting the results of applied geochemical surveys in the mineralised areas of Cornwall have been dealt with at some length in earlier papers (see particularly, Hosking *et al.*, 1965, pp.34-37) and need not be discussed again, in detail, here. Briefly, however, the 'normal' distribution patterns of elements in natural waters and sediments may be modified, sometimes markedly, by the addition of metals, etc., particularly from material in and around operating and abandoned mines, mills and smelters, and from domestic sources, and possibly from fertilizers used by farmers.

In the area under investigation, contamination, due to mining activity, is particularly marked in the valleys which intersect the mining districts of Gwennap, St. Day, Chacewater and Baldhu (rivers 4 and 5 in fig. 2). In particular, the Carnon River (no. 4, fig. 2) has received vast amounts of tailings from the St. Day, Baldhu and Chasewater mines, and in the Bissoe area further tailings were added to it from an arsenic recovery plant which treated 'imported' ore. At the present time Hydraulic Tin Limited is recovering cassiterite and a bulk sulphide product from the accumulated tailings and alluvium in the lower reaches of this valley, and, although their mill is a highly efficient one, it is, naturally, contributing geochemically significant concentrations of a number of metals to the superficial sediments below the site. Some idea of the character of the contributions of the mill to the active sediments may be deduced from the following analysis of a sample of the mill float collected in 1958 :—

Element (or oxide)	*Per Cent.*
Silver	0.00935
Gold	0.00005
Tin	1.19
Lead	0.72
Copper	12.90
Bismuth	0.094
Arsenic	9.30
Antimony	0.11
Selenium	0.020
Tellurium	Nil
Iron	35.66
Alumina	0.24
Titania	0.035
Manganese	0.01
Zinc	1.75
Nickel	0.02
Cobalt	0.015
Lime	0.02

Element (or oxide)	*Per Cent.*
Magnesia	0.08
WO_3	Nil
Silica	0.33
Sulphur	37.20
Chlorine	Tr.
P_2O_5	Tr.
Fluorine	Nil
Oxygen and combined water (by difference) ...	0.29
	100.00

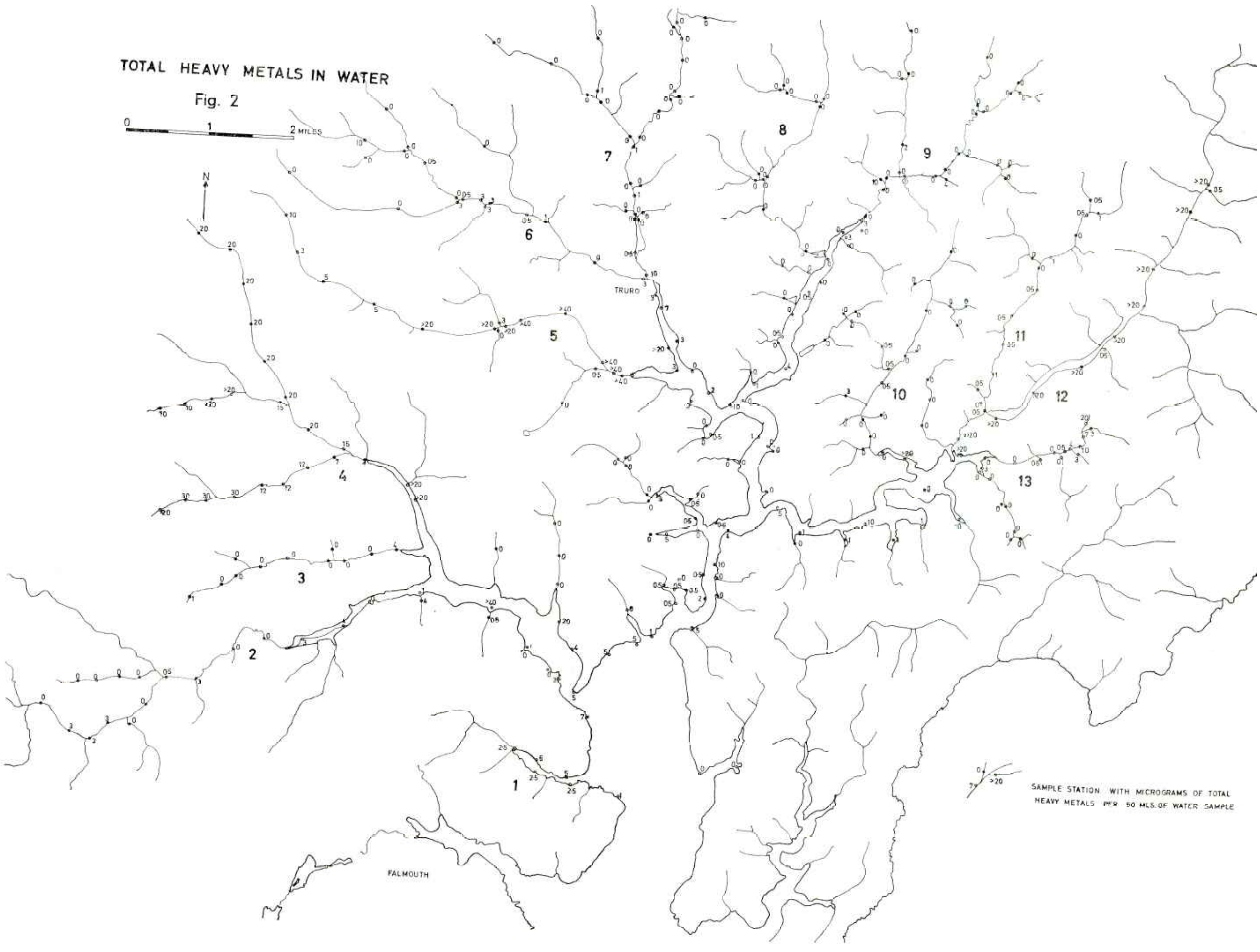
In addition, the waters of the Carnon River are heavily contaminated by copper-rich waters emerging from the now partly collapsed County Adit which drains the St. Day mining field. This adit, which commences at little to the north of Bissoe, is a very extensive underground drainage system whose branches, etc., total some 30 miles in length. In the past copper was recovered from its emerging waters by cementation (metallic copper, commonly seen under the microscope in briquetted samples of Hydraulic Tin float. doubtless derives from this site) whilst the suspended iron oxides were collected in settling pits and sold as ochre. At the present time the adit water, because of its high acidity (and possibly also because of its high metal content) is not acceptable to local cattle. Some idea of the extent to which this water contaminates the river is indicated by the marked differences (apparent in the following analyses, carried out by W. Brown, Esq., in September, 1959) in the 'metal' content of the latter when compared with that of a neighbouring stream at points not far removed from the mill of Hydraulic Tin Limited.

A. Carnon Stream.

Component	*Parts per thousand*
Copper sulphate	0.006027
Iron sulphate	0.007612
Aluminium sulphate	0.08041
Magnesium sulphate	0.03585
Calcium chloride	0.06073
Magnesium chloride	0.00140
Sodium and potassium chlorides	0.05462
Colloidal silica	0.004949
Stannic oxide	0.000051
pH	5.2

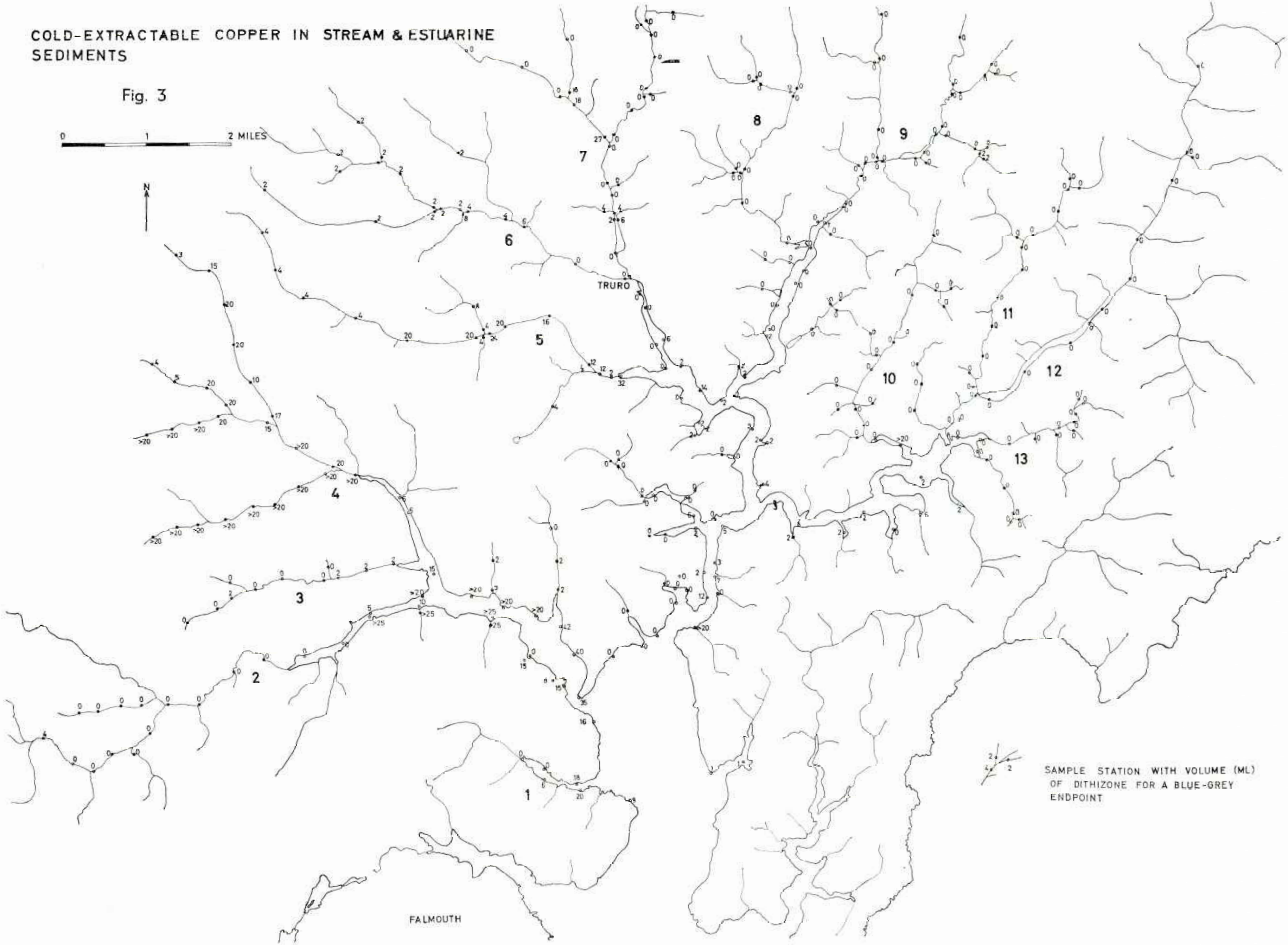
TOTAL HEAVY METALS IN WATER

Fig. 2



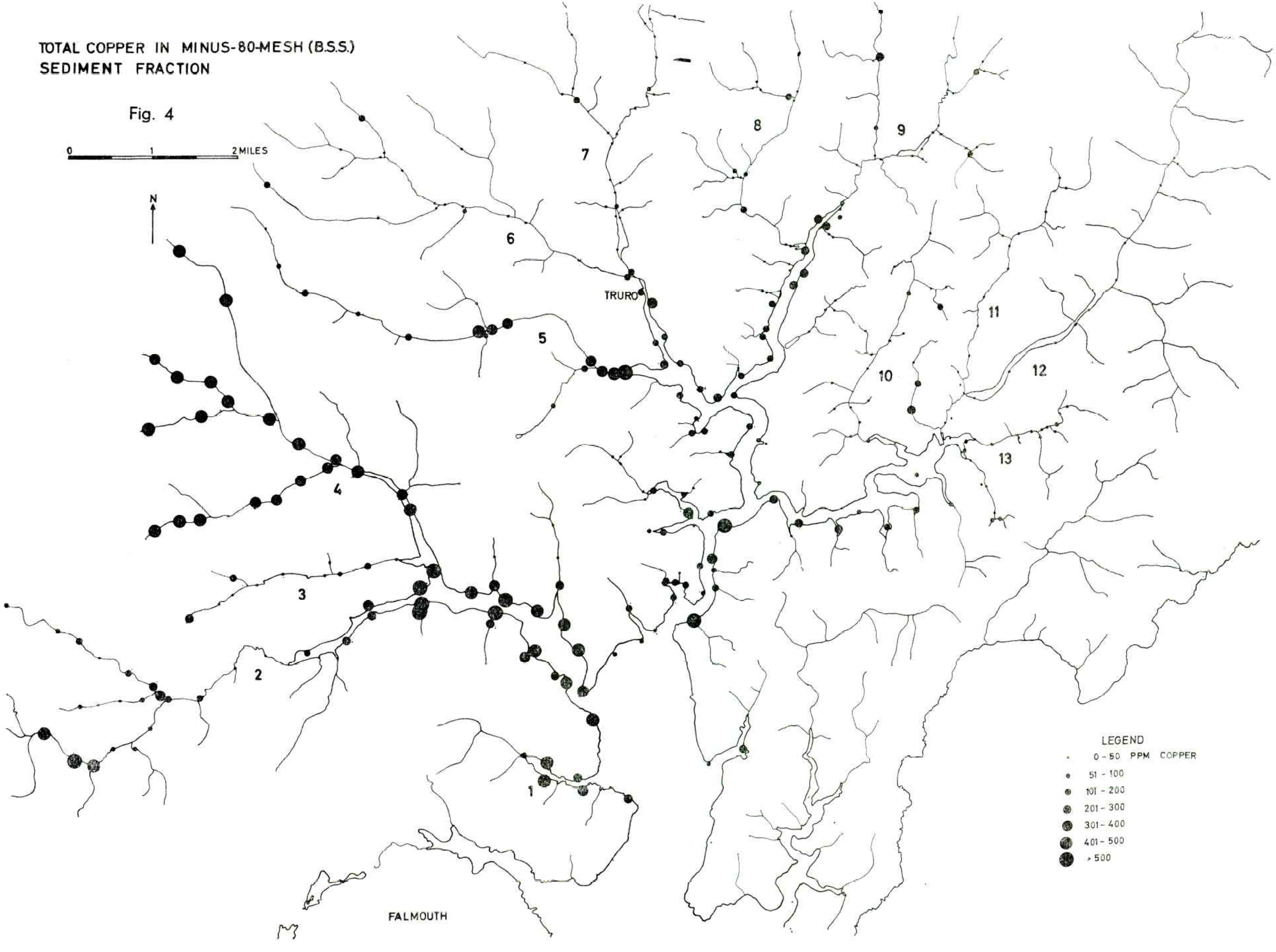
COLD-EXTRACTABLE COPPER IN STREAM & ESTUARINE SEDIMENTS

Fig. 3



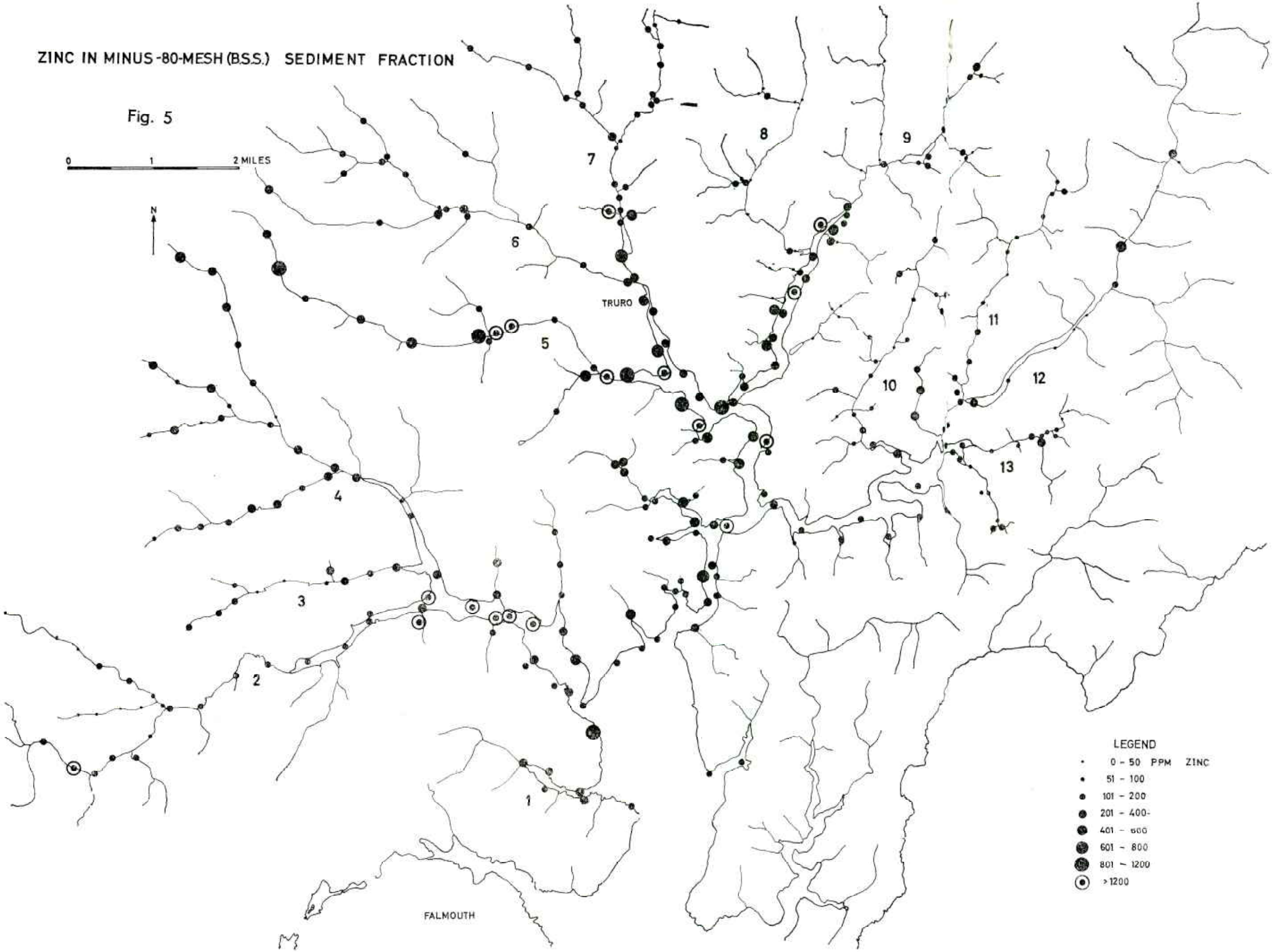
TOTAL COPPER IN MINUS-80-MESH (B.S.S.)
SEDIMENT FRACTION

Fig. 4



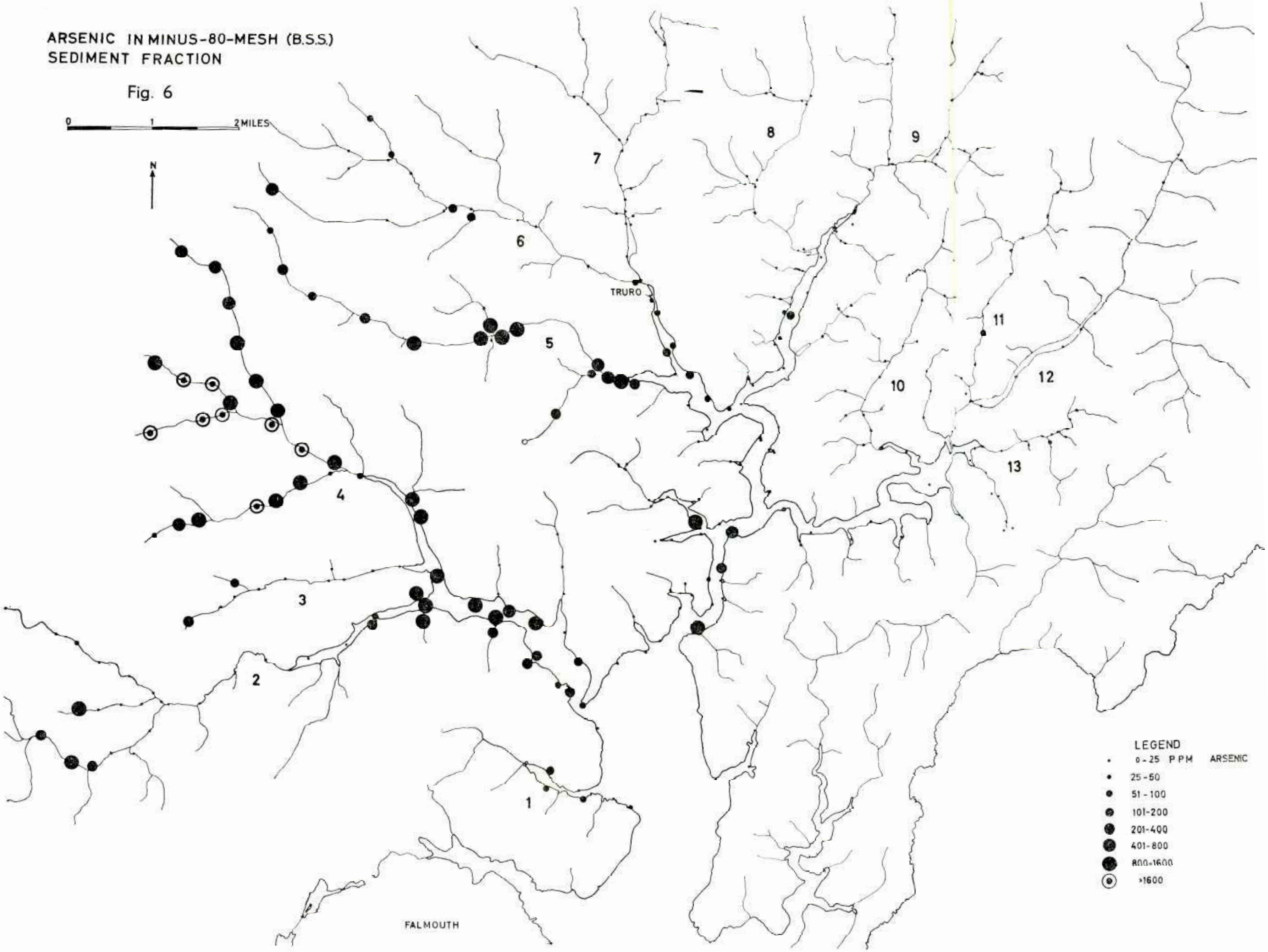
ZINC IN MINUS-80-MESH (B.S.S.) SEDIMENT FRACTION

Fig. 5



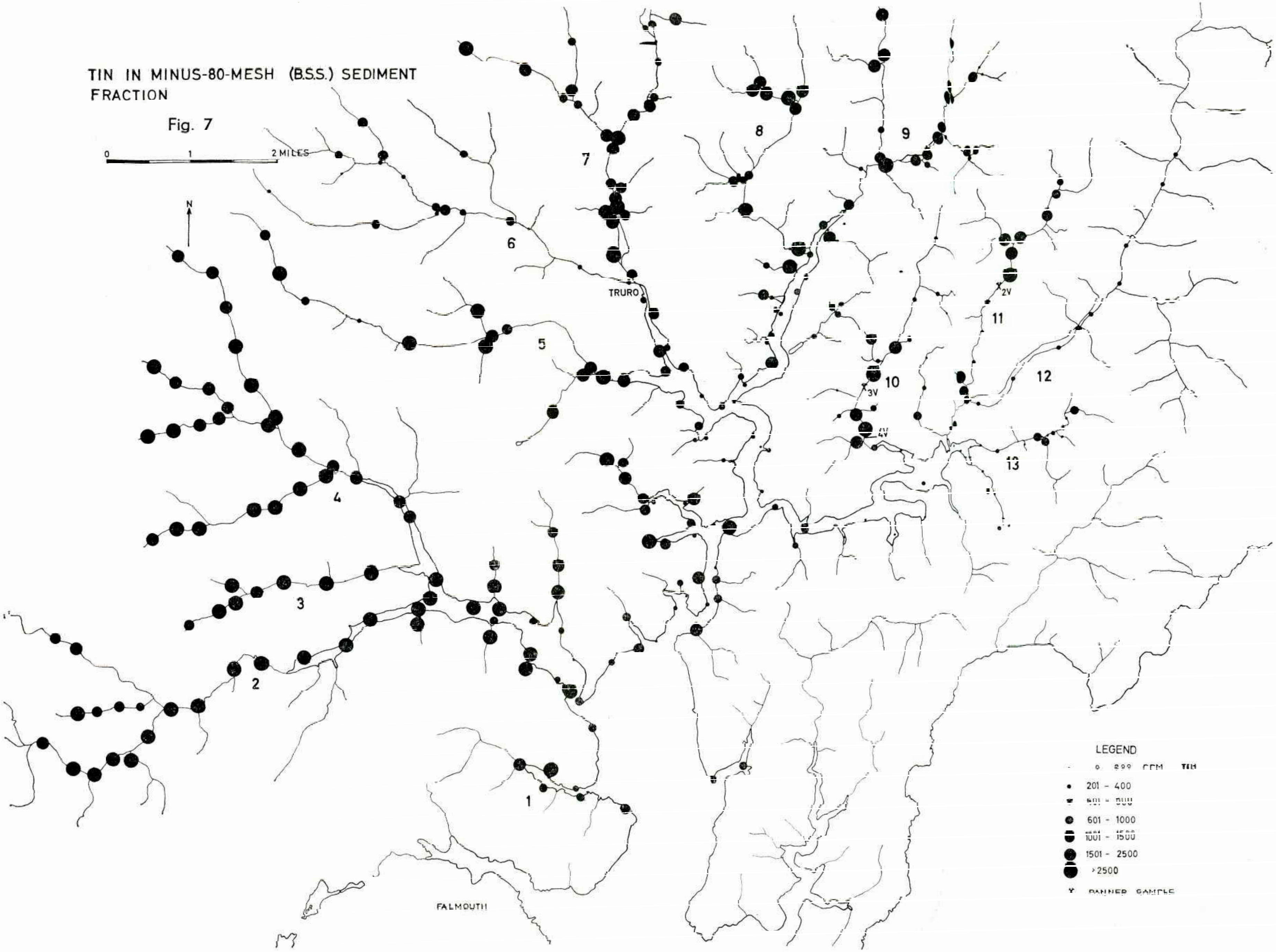
ARSENIC IN MINUS-80-MESH (B.S.S.) SEDIMENT FRACTION

Fig. 6



TIN IN MINUS-80-MESH (B.S.S.) SEDIMENT FRACTION

Fig. 7



B. Neighbouring stream.

Copper sulphate	Nil
Iron sulphate	Nil
Aluminium sulphate	Nil
Magnesium sulphate	0.00621
Calcium chloride	0.04835
Magnesium chloride	Nil
Sodium and potassium chlorides	0.0042
Colloidal silica	0.0218
Stannic oxide	0.0002
pH	6.4

The River Fal (river 12, fig. 2) has also been contaminated by tailings, etc., from mines on, and just to the south of, the St. Austell granite mass. Its waters are of particular interest because of their exceptionally high uranium content, which was first established by Ostle (1954), and which is due to the fact that the river is constantly receiving supplies of the element in question from the dumps and actively oxidising lode of the South Terras Mine at Grampound. In addition, the river transports considerable quantities of china clay which have been lost during the beneficiation of the material on, and just to the south of, the St. Austell granite mass. This clay is transported into the estuary, and near Ruan Lanihorne the vegetation of the saltings is coated with this white substance, a phenomenon which demonstrates in a most spectacular way how widespread is the distribution of the finer fluviatile fractions, at least, in the upper estuarine reaches. Further discussion of the Fal contamination problem is discussed by Hosking *et al.*, 1965, pp.34.37.

So far as is known all the other rivers which have not yet been discussed, and which flow into the northern and eastern parts of the estuary, drain areas devoid of mines, and any significant contamination of these is most likely to be due to effluents from domestic and industrial sources. Copper and zinc are the elements of particular interest to the applied geochemist most likely to be added in appreciable quantities from such sources (see Hosking *et al.*, 1965, pp.34-35) and, obviously, are likely to be most apparent below the largest river-bordering settlements: it is to be expected, therefore, that the sediments just below Truro will contain appreciable concentrations of the two elements in question.

DISCUSSION OF THE ANALYTICAL RESULTS.

For convenience, the significance, etc., of the metal distribution patterns of the fluviatile and estuarine tracts will be discussed separately.

A. Metal distribution patterns of the fluviatile tracts.

Rarely, if ever, is a sizeable geochemical survey carried out involving the distribution of metals in waters or sediments without anomalies being revealed whose causes are not immediately apparent and sometimes still obscure after a great deal of 'follow-up' work has been carried out. The results of the survey under review are no exception, but for the most part, as their following brief analysis will indicate, they are understandable.

Total-heavy-metals in water. (Fig. 2.)

The high concentrations, *in the fluviatile tracts,* are confined essentially to rivers, 4, 5 and 12. Those in rivers 4 and 5 are due to adit waters, etc., from the St. Day, Wheal Busy, and Wheal Jane and associated mines. Those in river 12 are due to zinc, etc., added to the system by adit waters from mines to the north of Grampound.

Cold-extractable copper. (Fig. 3.)

High concentrations of cold-extractable copper in the minus-80-mesh fraction of the river sediments are confined to rivers 4 and 5 and broadly indicate the location of the St. Day, Wheal Busy and Wheal Jane groups of mines.

Total copper. (Fig. 4.)

The high concentrations of 'total copper' are also essentially confined to rivers 4 and 5 and are due to the mines mentioned in the previous sections. Occasional samples, containing concentrations of copper in the range 101-300 p.p.m., were obtained from rivers, 8, 9, 10, and from the stream between rivers 10 and 11. They are of some importance as they suggest that these areas which were thought to be devoid of mineralisation, may not be barren. In an area such as this it is particularly important, during analysis of the results, to realise that the levels of concentration of 'lode metals' in sediments which have been developed entirely by natural causes may look rather indifferent when compared with those due to mining activity.

Finally, the copper-high points on river 2 reflect the presence of the somewhat 'diffuse' mineralisation on Carnmenellis, and that of lodes in the Ponsanooth area : lodes which were worked at Magdalen and Roskrow mines.

Zinc. (Fig. 5.)

It is difficult to make many pertinent comments re the distribution pattern of zinc in the fluviatile deposits. Most of the river sediments show appreciable concentrations of the element, a fact

which is probably due to the local presence of lodes to the occurrence of appreciable concentrations of zinc in the country rocks (footnote) and to contamination due to mining activity and settlement.

Considerable 'follow-up' work is needed in many parts of the study area before the local relative importance of the various zinc sources can be determined. Unlike the other metal patterns of the fluviatile tracts zinc does not clearly indicate, excepting in one instance, the distribution of known ore bodies : in part this may well be due to the fact that these bodies are not generally particularly rich in the element in question. River 5 sediments are the exception : locally they do contain high concentrations of zinc and these are so disposed that they indicate, what are broadly termed in this paper the Wheal Jane group of mines — mines in which some of the lodes do contain appreciable concentrations of sphalerite.

Arsenic. (Fig. 6.)

In marked contrast to the zinc pattern, the arsenic one clearly indicates the known lode areas which are concentrated in the area embracing rivers 2 to 5. The pattern does not, however, indicate the presence of lodes in the upper reaches of the Fal (river 12) although some of them (e.g., that at South Terras Uranium Mine) contain appreciable amounts of the element in question.

Tin. (Fig. 7.)

The sediments of many of the streams contain unexpectedly high concentrations of tin and the distribution pattern, as determined, does not permit differentiation to be made between areas containing known tin-bearing lodes and those which do not. Very probably such a differentiation would have been possible, however, were the absolute tin values of all the samples determined instead of recording that certain samples contained more than 2,500 p.p.m. of the element in question. Lack of time for analysis was the sole reason for this omission.

That high tin values do occur in the sediments of a number of rivers which drain what have always been regarded as barren areas is, of course, of great interest, and detailed 'follow-up' studies are warranted in such places. The source of the metal in these rivers can, at this time, only be speculated upon. The tin may, indeed, have been derived from hitherto unknown veins, and the fact that the tin-rich sediment samples in rivers 10 and 11 occupy a roughly N.E.-S.W. zone — one which corresponds in strike with that of the hypothermal lodes of the study area as a whole — lends some support to this suggestion. On the other hand the tin in the sediments

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Footnote : Unpublished studies of one of us (K.H.) have demonstrated that the Devonian slates are unusually rich in zinc and a number of other elements.

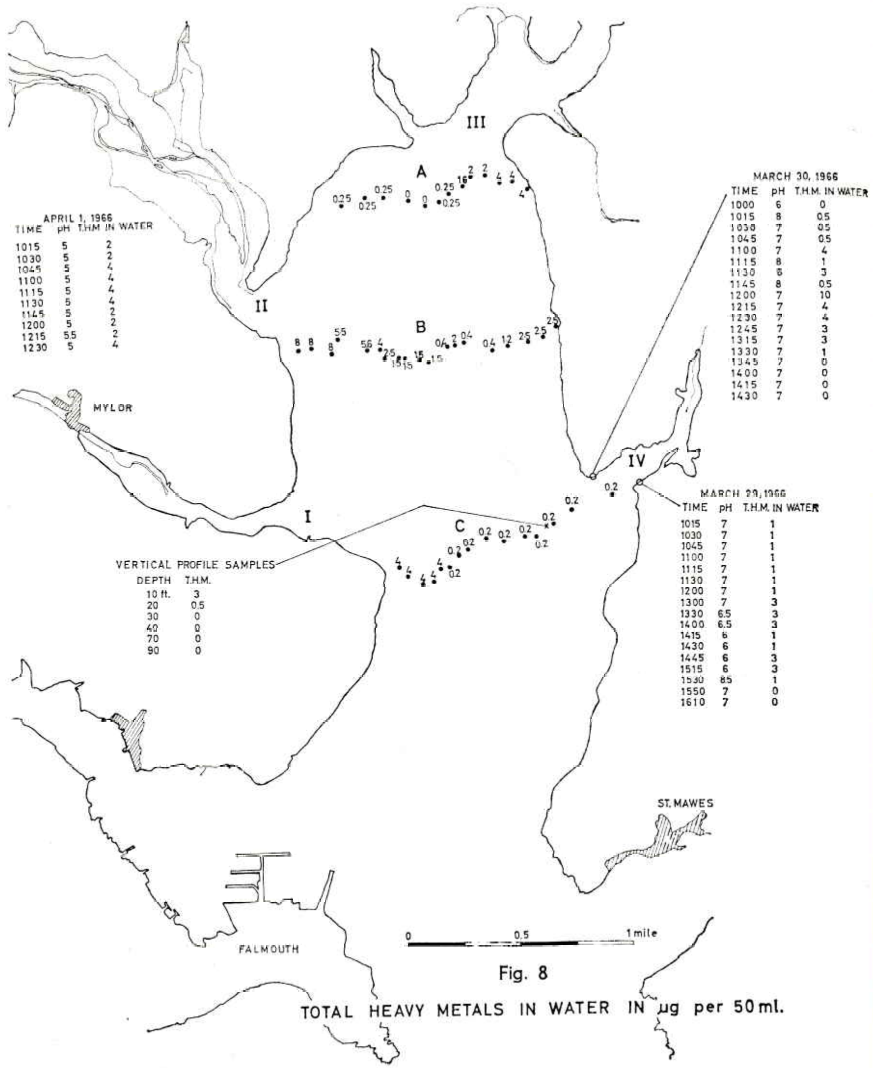

Fig. 8

TOTAL HEAVY METALS IN WATER IN µg per 50 ml.

in question could be a component of cassiterite which was locally concentrated on the marine platforms during the periods of emergence noted earlier and has, since that time, been transported into the river systems and concentrated somewhat there. Further unknown quantities may have been derived directly from the slates, which are certainly not devoid of the element, and possibly small, long abandoned, and now forgotten smelters and Customs mills may have locally contributed significantly, but these could not possibly solely account for the widespread distribution of high values.

In order to test the possibility that cassiterite is, indeed, responsible for these high values, samples were panned from rivers 10 and 11, and from site 2V (fig. 7) appreciable quantities of the mineral in question were recovered.

The manner of occurrence of the elements under review in the sediments.

It is important to realise that, particularly in those areas where mining has taken place, the elements in question are not limited to those minerals which are likely to occur in areas which have not been subject to such activity. The following table illustrates how the elements are likely to occur in areas affected by man's activities and in virgin ones.

Element	Virgin Areas	Other Areas
Tin	Cassiterite. (Varlamoffite derived from Stannite and other tin-bearing minerals.)	Cassiterite. Stannite.
Copper	Oxysalts. Adsorbate.	Oxysalts. Adsorbate. Sulphides.
Zinc	Largely as adsorbate.	Adsorbate. Oxysalts. Sphalerite.
Arsenic	Ferric arsenate. Other insoluble arsenates. Adsorbed arsenate ions.	Ferric arsenate. Other insoluble arsenates. Adsorbed arsenate ions. Arsenides, sulpharsenides (arsenopyrite), etc.

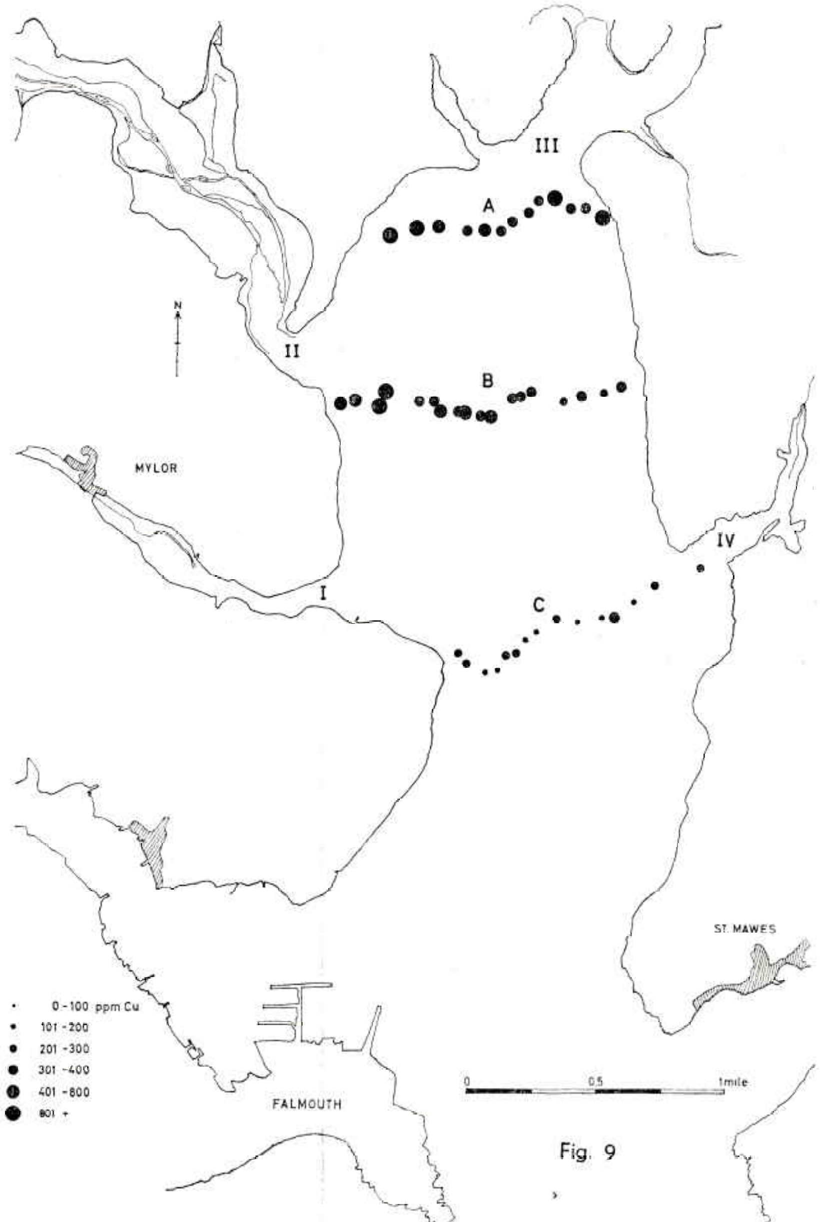

Fig. 9

COPPER IN THE MINUS-80-MESH FRACTION OF ESTUARINE SEDIMENTS

In the area under review, it is probable that where mining has occurred the high concentrations of the elements in question occurring in the sediments of both the fluviatile and estuarine tracts are due largely to the presence of cassiterite, copper-bearing sulphides, sphalerite and arsenopyrite.

B. Metal distribution patterns of the estuarine tracts.

The metal distribution patterns of the waters and sediments of the creeks are shown on figs. 2-7 whilst those of the Carrick Roads are indicated on figs. 8-12.

As, for the most part, these patterns have been largely determined by mining activity they are not difficult to interpret and need not, therefore, be subject to lengthy analysis at this stage : all that is necessary is to emphasise certain features which may also occur in other estuaries and which should be borne in mind during the planning of any exploration programme in which estuarine studies are to figure in the initial phases.

1. The total-heavy-metal content of the surface waters of the creeks and of the Carrick Roads (figs. 2 and 8) indicates very clearly the mining areas, including that which is situated in the vicinity of the upper reaches of the Fal. The picture is slightly complicated by the fact that a few moderately high values occur in the creek below Truro (river 7) : these are undoubtedly due to domestic and industrial effluent.

The tendency for a metal-high belt of water to persist in the Carrick Roads from Restronguet to south of Mylor Creek is of real interest in that it demonstrates how limited is the lateral migration of surface waters which occurs, and indicates that if the metal content of estuaries is to be used in order to facilitate the location of mineralised hinterlands, samples covering all the creek entrances must be taken : analysis of a few, or even a considerable number of samples taken at random from the body of the estuary, may well give quite misleading results.

As was anticipated, analysis of samples of waters from various depths below the surface demonstrated that metal ions derived from hinterland sources are essentially confined to the uppermost portion of the water.

Analysis of water samples taken at intervals of 15 minutes from a number of points only permits certain tentative conclusions to be drawn because, for reasons of time, at only one station were samples taken on either side of high tide. At this latter station the results suggest that the metal content of the waters is greatest a little after high tide : this is a result which might be anticipated, and suggests that when carrying out studies of the type under review as far as possible water samples should be taken from, say, one to two hours after high tide.

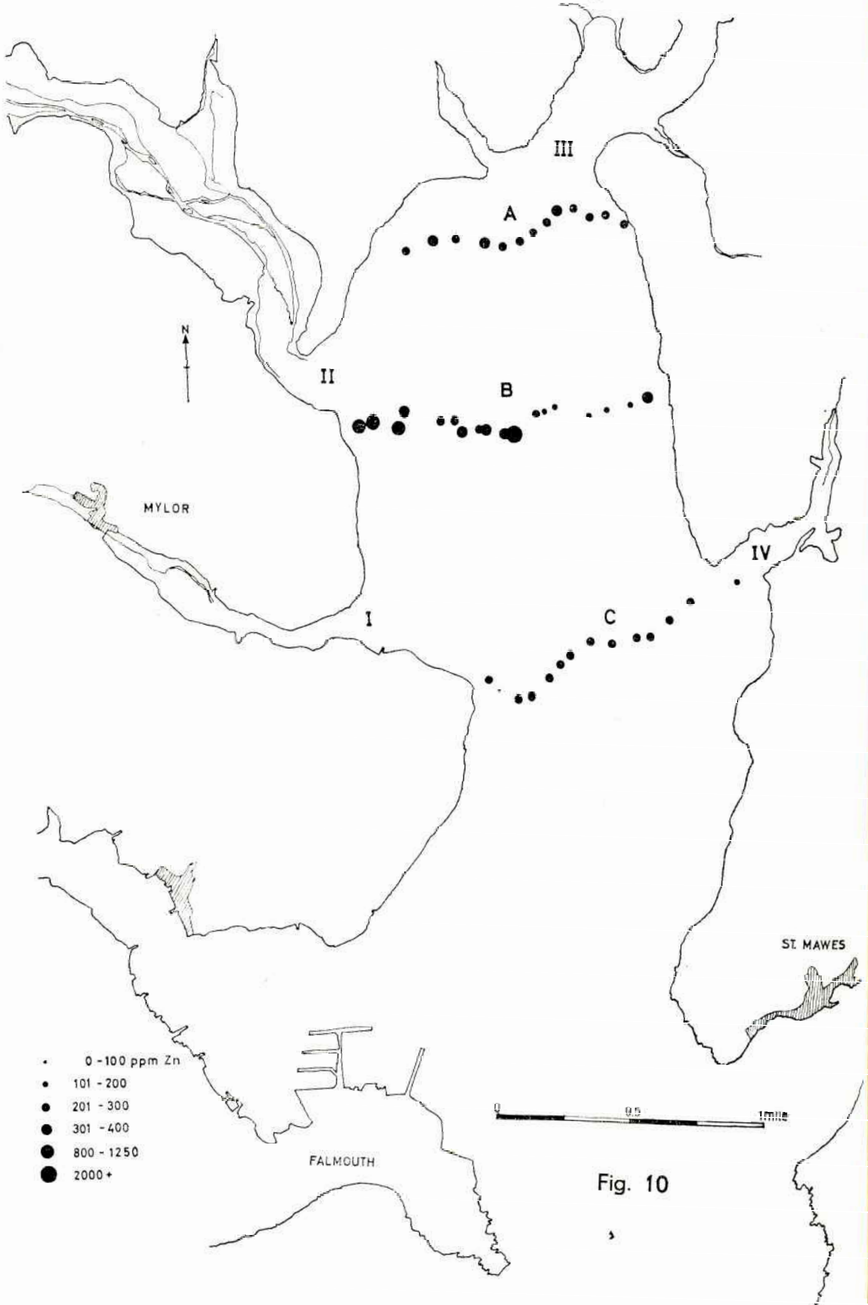

Fig. 10

ZINC IN THE MINUS-80-MESH FRACTION OF ESTUARINE SEDIMENTS

2. The cold-extractable copper ('on-the-spot' copper) content of the creeks is high in creeks I and II (fig. 8), that is the Mylor and the Restronguet Creeks. The high concentration in the former is probably related to a long-abandoned copper mine occurring there, whilst that of the latter is due to the St. Day and other mining fields which have been discussed earlier. Cold-extractable values of creek sediments give no indication of the presence of the Fal mines, whilst those of samples taken along the Carrick Roads traverses are all uniformly low, with the exception of the first and fourth sample (reading from west to east) on traverse B. (Because of the monotonous character of this pattern it has been omitted from this paper.)

It is necessary to be very cautious when drawing conclusions based on comparisons between the cold-extractable copper content of a wet unscreened sample and the total copper content of the minus-80-mesh fraction of the dried sample. Nevertheless, the comparatively high total copper in a number of the Carrick Road sediments (fig. 9) combined with their very low cold-extractable copper content gives strong reason for believing that the copper is present largely as comparatively dense sulphide and that colloids with adsorbed copper, on reaching the Roads, are rapidly dispersed.

3. Generally, the concentrations of 'total' copper, zinc and arsenic in the minus-80-mesh fraction of the creek sediments are appreciably higher than those of neighbouring fluviatile sediments of the 'feeder' rivers. There may well be a number of reasons for this, but in the region under review it is probably due primarily in the mining areas to gravity concentration of the type operating in sluice boxes. Briefly, fluviatile sediment is dumped at the head of a given creek as a result of deceleration and flocculation of colloids, and is reworked in such a way that the light components are preferentially transported down the creek and then dispersed in the Carrick Roads. That is to say the high concentration of the metals under review in the creeks is due essentially to reconcentration of mill tailings. The presence of fresh sulphides in the active sediments of Restronguet Creek has been confirmed by one of us (K.H.) by examination of samples under the microscope, and serves to confirm the foregoing observations.

It would, of course, be wrong to assume that the high concentration of copper and zinc in the creeks owes little or nothing to adsorption of these metals on to colloids: it may well be that appreciable adsorption does take place in the creeks, and in those which are not associated with mineralised zones it is probably the major cause of any marked concentrations which may occur.

4. There is little doubt that in the Carrick Roads sediments with high concentrations of the metals under review owe this characteristic to the fact that they contain components of mill tailings which have been flushed out of the creeks drainings the mining

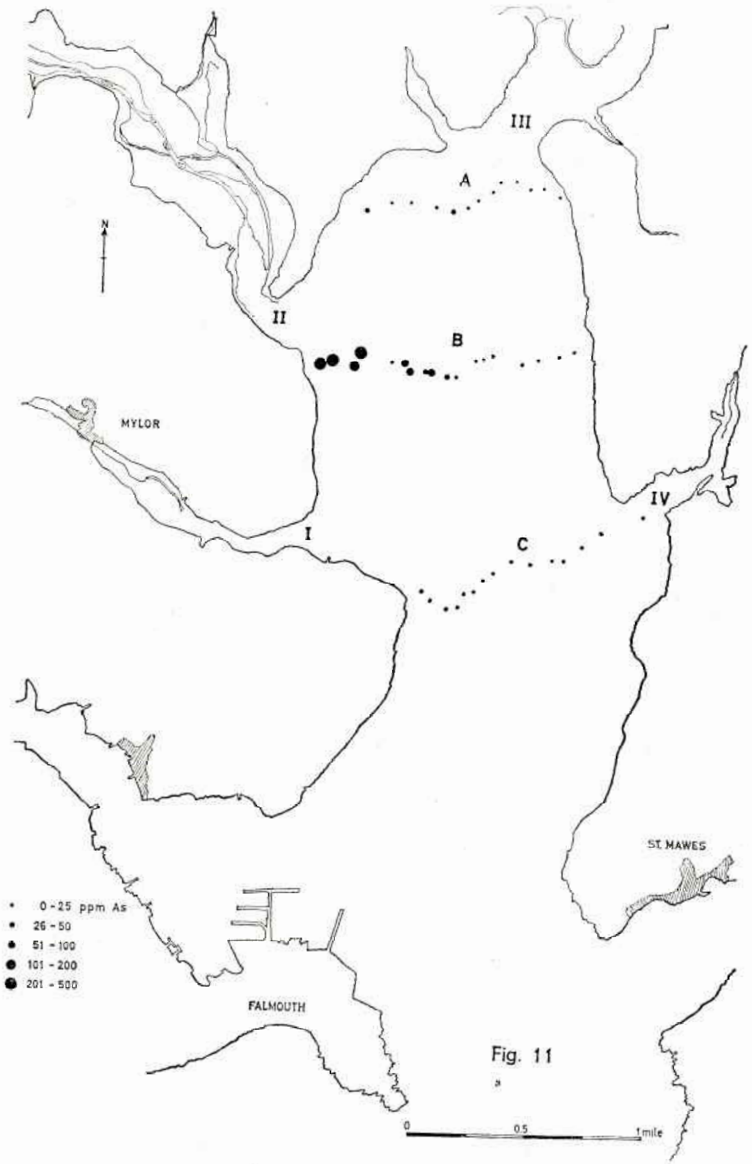

Fig. 11

ARSENIC IN THE MINUS-80-MESH FRACTION OF ESTUARINE SEDIMENTS

areas. Colloids with heavy metal ions adsorbed on them are rapidly dispersed in this particular environment. Concentrations of tin, etc., are most marked in the sediments immediately beyond the mouths of the creeks supplying these metals, and it is clear that during a reconnaissance geochemical exploration programme in which a study of the metal content of estuarine samples was to be employed in an endeavour to differentiate between rivers draining mineralised terrain and those flowing over barren ground, a minimum requirement would be the collection of samples across the mouths of all the creeks feeding the body of the estuary. This could be easily done from a boat and, indeed, if the latter were of reasonable size the analyses could also be carried out on board.

The metal distribution patterns of the Carrick Roads indicate very clearly the creeks draining mining areas, and the tin pattern, in particular, also gives reason for believing that sources of this metal occur in the east as well as in the west of the region.

CONCLUSION.

The study discussed in this paper has further demonstrated the difficulties of interpreting metal distribution patterns of fluviatile sediments in a much mined area with numerous settlements. Frequently high concentrations of metals occur in unexpected areas and the reasons for such concentrations cannot be determined with any degree of certainty without considerable follow-up studies which must include not only field work but researches into local industrial history. The importance of the latter is indicated by the following passage from Hamilton Jenkin's " The Cornish Miner " (1927, pp.177-178) :—" Truro had three (tin) smelting works, one near the railway viaduct . . . a much older one near Tregolls . . . and a third . . . near the present gasworks. To the west of Truro was Calenick Smelting-House, at the top of the Calenick estuary . . . Calenick itself had a rival in the Penpoll Works at Point, whilst in the Carnon Valley were two more smelters situated at Bissoe and Cons." All these smelters doubtless produced marked tin contamination which still persists !

However, despite problems of the type noted above, a new area worthy of further examination has been broadly delineated which *might* contain tin deposits of economic interest.

Despite the fact that the metal distribution patterns of the creeks and estuary proper owe much of their character to man's activities, their investigation suggests that in little explored areas with difficult hinterlands, and particularly where the river systems are short, studies of the metal content of samples of estuarine water and sediments which have been collected from appropriate points, which have been indicated earlier in the paper, might facilitate exploration by indicating which river systems should be given

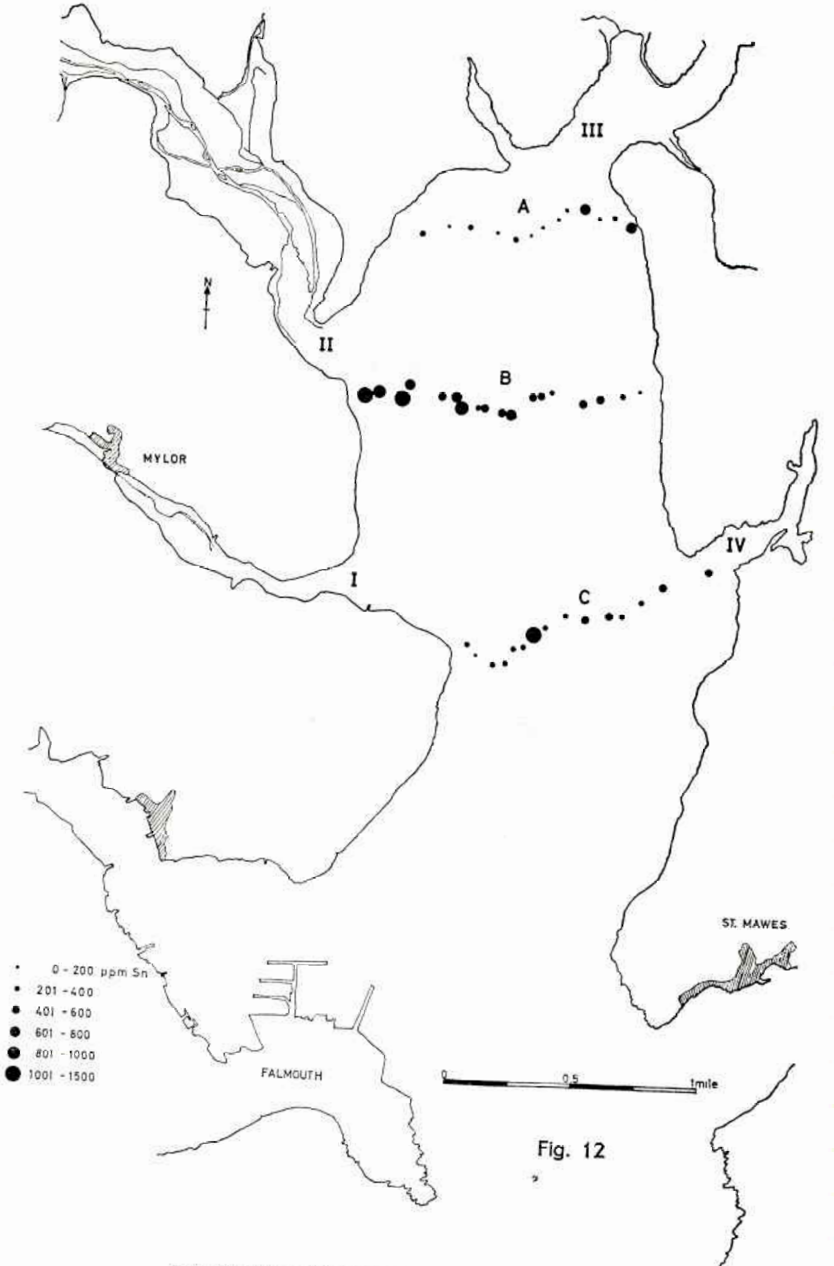

Fig. 12

TIN IN THE MINUS-80-MESH FRACTION OF ESTUARINE SEDIMENTS

priority during the subsequent stages of exploration. In this respect the work supports the findings of Webb *et al.* (1963) and Hosking *et al.* (1963).

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