

A  
T H E S I S  
entitled

GEOCHEMICAL INVESTIGATION IN MOUNT'S BAY, CORNWALL

Submitted for the  
degree of  
DOCTOR OF PHILOSOPHY  
in the

FACULTY OF SCIENCE OF THE UNIVERSITY OF LONDON

by  
PABLITO MOSLARES ONG

Royal School of Mines,  
Imperial College

July, 1966

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## ABSTRACT

A co-ordinated geochemical and geophysical investigation was undertaken in Mount's Bay. Echometer-sparker survey was carried out to determine the limits and thicknesses of the unconsolidated sediments. The offshore sediments and rocks were sampled, and their tin contents analysed.

The submarine rocks are similar to those found along the coast; the most common is slate. Dolerite occurs sporadically, possibly as dykes in slate. St. Michael's and Godolphin granites have limited seaward extensions. Spotted slate, normally associated with the contact zone, outcrops for more than one and a half miles south of Godolphin; this suggests a gently dipping granite-slate contact under the sea.

There are several sand formations in Mount's Bay. The thickest and largest is Penzance deposit, followed by Porthleven, Trewavas-Rinsey, Praa Sands, Perranuthnoe and Marazion formations.

Sediments of fluvial origin constitute the bulk of the marine sands; and the coastal and submarine rocks contribute only a small portion.

The stream and marine sediments have bi-modal size distribution; fine to medium (100 to 400 microns) grained detritus preponderate, and silt-clay (< 50 microns) fractions comprise the secondary maximum. The proportion of medium to coarse particles is higher in the streams than in the bay. On the whole, the marine sediments become finer seawards.

In the dry-sieved size fractions, the silt-clay particles contain the maximum tin-tenor. By contrast, in elutriation, the very fine to fine (50 to 150 microns) sand fractions have the highest tin contents.

Praa Sands, Trewavas-Rinsey, Perranuthnoe and Marazion sediments have higher tin-tenor than Penzance and Porthleven. By and large, the inshore sands, especially near the river outlets, are richer in tin than the offshore sediments.

Maxima in the tin content of the coarser (> 197 mesh) heavy minerals, particularly at Trewavas, coincide with the seaward projections of the lodes along the coast.

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## INTRODUCTION

Exploitable mineral deposits occur not only on the land but also under the sea. This phenomenon is exemplified by, for example: (a) the working of offshore lodes in Geevor Mine, Cornwall, (b) the undersea coal mines in Japan, and (c) the exploitation of submarine oil fields in various parts of the world. Similarly, underwater placer deposits are found in several localities; typical examples are the tin-bearing marine sands in St. Ives Bay, Cornwall and in Indonesia, and the diamonds off the coast of South Africa.

The primary object of this study is to gain an understanding of the sources, movements, and deposition of the tin-rich marine sediments, and their significance with respect to terrestrial and submarine geology. Furthermore, this research aims to ascertain the applicability of geochemical techniques to locate placer and/or bedrock mineralisations under the sea, and to the exploration of such deposits. This is immensely important from the point of view of economics because as civilisation advances, more and more minerals will be required to feed the expanding industries of the developed and developing nations. Time will come, perhaps in the not too distant future, that the mineral deposits in the land will not be enough to sustain the world demand. Indeed, man has already started to explore the sea and the areas underneath it for minerals. Thus, now is the time to discover or rather develop new geological

techniques for the utilisation of the marine and submarine mineral resources.

Mount's Bay was chosen as the study area because of the widespread occurrence of tin and other base metal mineralisations in the catchment areas of the rivers draining into the bay, and near the coast. So that there is the likelihood of offshore mineralisation which could help the purpose of this study.

The field work was carried out with the full cooperation of the Imperial College Geophysics Section. Certain established sampling techniques of submarine geology were freely utilised; some of which were modified to suit local conditions. Likewise, new procedures were developed for the collection of rocks and detailed samples of inshore sediments.

On account of an unsettled prevailing weather, a flexible program of work was instituted with the view to minimise, if not avoid, unnecessary loss of working-hours. When it was too rough to go out to sea, beach sampling, or analysis of samples was undertaken.

The earlier stages of the field work were devoted to collecting reconnaissance samples from the marine sediments, and these samples were analysed for tin at the Camborne School of Mines, Cornwall. Using the analytical data from the reconnaissance samples as guide, detailed sampling of the inshore sediments was subsequently undertaken. This was followed by sampling of submarine rocks. During the later stages, samples were collected from the

various rock types on the coast, beach sands and stream sediments. In addition, samples were taken from the economically promising portions of the unconsolidated sand formation in St. Ives Bay, which served as basis for comparison with the Mount's Bay sediments. Finally, the detailed studies of the samples were carried out at the Imperial College Applied Geochemistry Laboratory.

This thesis is subdivided into four main parts dealing with techniques, general description of the coastal and submarine geology, geochemical results, and summary of conclusions and recommendations for future investigations. Contrary to the usual style of most theses in Applied Geochemistry of describing the study area prior to the techniques, in this thesis, the former is discussed after the latter in order to achieve coherence of the text because the discussions in Part III (Geochemical Results) are essentially related to Part II (General Description of the Study Area).

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suggestions during the course of the work, and to Dr. I. Nichol who supervised the field operation. Likewise, sincere gratitude is extended to Dr. J.S. Tooms who did the final supervision of this study --- his advice and assistance were indeed invaluable.

Thanks are due to the Union Corporation which provided the barge, and to the crew members (1964) of the "Shamrock". Further acknowledgements are given to Holman Bros. Ltd. of Camborne for lending the compressed air operated percussion hammer.

To Mr. R.A. Gorges and Dr. K.F.G. Hosking, the writer is thankful for making available to him the facilities of the Camborne School of Mines Geochemistry Laboratory.

Also, the writer expresses his gratefulness to the Imperial College 1964 Geophysics Group in Cornwall, to Mr. N. Kelland for his splendid co-operation as leader of the divers, and to all the members of the Imperial College Underwater Club who participated in the sampling operation. Without their help, this work would have been seriously handicapped.

Finally, the writer extends his gratitude to his wife.

### Previous Work

Certain aspects of the geology of Cornwall received attention as early as the 18th Century. In 1758 Borlase described a few geological observations in his "Natural History of Cornwall". Sixty years later, the Royal Geological Society of Cornwall was founded which gave impetus for the detailed geological studies in

the county. Among the 19th Century leading students of Cornish geology were Carne, Davy and Boose whose works appear in the journals of the society. These pioneer-geologists were succeeded by several geologists of the Geological Survey of England and Wales whose well-documented works are in the Geological Survey Memoirs.

In recent years, a number of investigators undertook geological studies in Cornwall which have vital bearing on the present project. Webb (1947) studied the origin of the tin lodes, Bagchi (1947) examined the geology and petrology of the Land's End granite, and its metamorphic aureole, Hosking (1950-66) undertook geochemical surveys in most of the mineralised areas, and Garnett (1960) mapped the offshore geology between St. Agnes and Cligga Head.

Similarly, several books and papers about the geology of the sea and its shores, and sedimentary processes have appeared in the last few years. The ones which have significant bearing on the present work are: King's "Beaches and Coasts" (1961), Shepard's "Submarine Geology" (1963), and Mero's "The Mineral Resources of the Sea" (1965). In addition, Bagnold (1963) made an investigation on the mechanics of marine sedimentation, particularly the origin of sediments and their movements close to the shore. Reference will be made to their works where appropriate in the text.

Despite the numerous publications on various aspects of submarine geology, and nearshore sedimentation, none has been published yet about offshore geochemical studies in other areas.

Union Corporation investigated the surface and subsurface distribution of tin in the inshore sediments of St. Ives Bay, Cornwall during the summers of 1963 and 1964. Also, the writer (1962) studied the surficial distribution of tin and some commonly associated elements on Gwithian Beach (St. Ives Bay), and Krishnan (1963) examined the subsurface distribution of the same elements in the same locality.

## PART I: TECHNIQUES

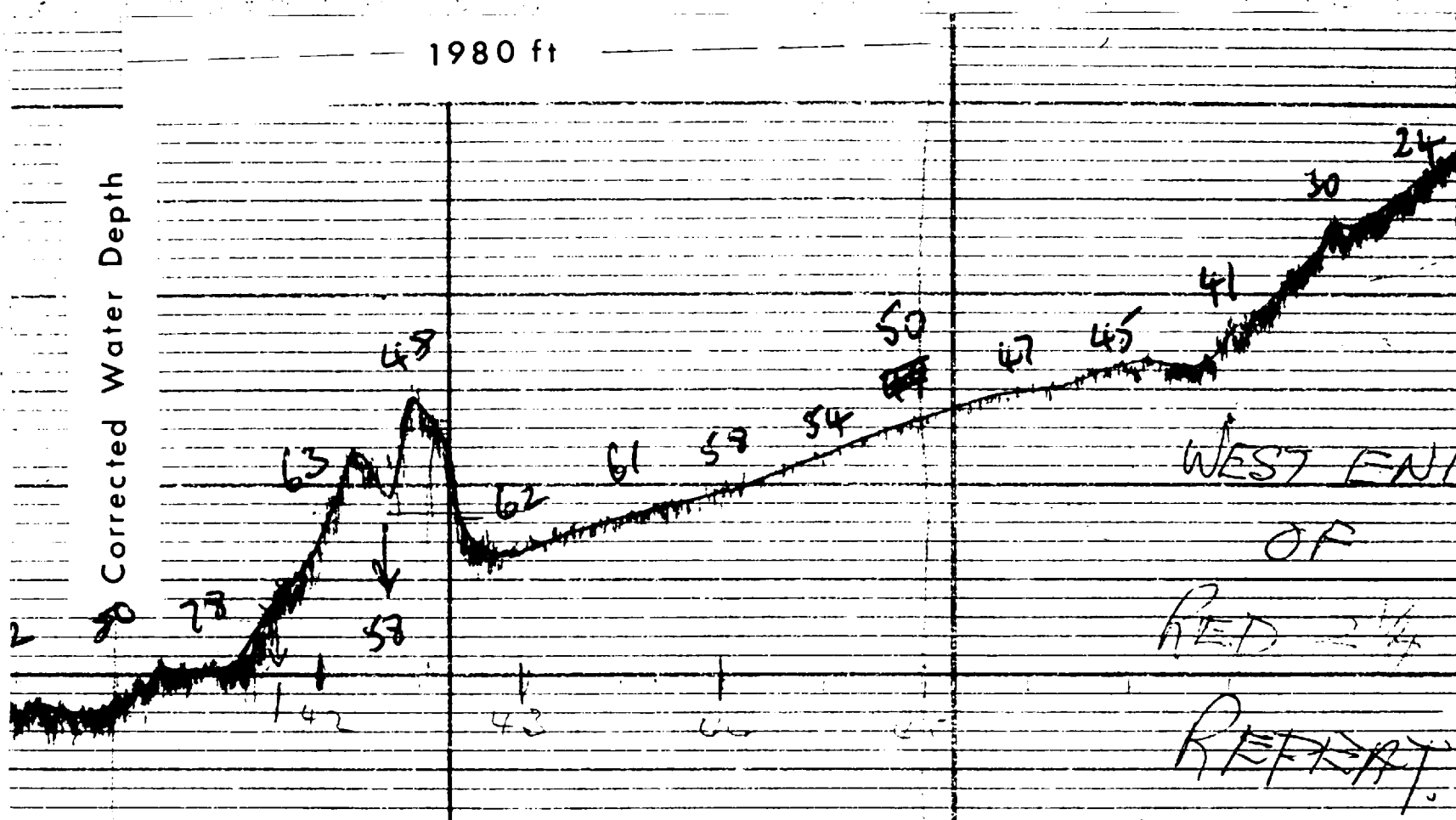
### SECTION A: BATHYMETRY AND CONTINUOUS STRATIGRAPHIC (SPARKER) PROFILER SURVEY

The bathymetric-sparker survey was undertaken by the Geophysics Section (Imperial College) prior to the geochemical sampling. The echo-sounder and sparker were operated simultaneously from a boat with a constant speed of about 5 knots. A total of 200 profile-miles were recorded giving an intersecting pattern throughout the study area.

The Decca Navigator was utilised in locating the various echo-sounding and sparker observation lines. Its accuracy was rather variable; it was least effective near the coastline. Hence, nearshore positioning was supplemented by land fixes, that is to say, the Decca-guided traverses were adjusted with the aid of sextant and/or compass.

#### Bathymetry

Bathymetric mapping was done with the Marconi Graphette echo-sounder which operates at 24 kilocycles per second and with a stylus speed of 92.3 inches per second on 6-inch recording paper. It gives an echo-gram readability of depths  $\pm 0.5$  foot at its calibrated value (the sound velocity in sea water is 4.92 feet per millisecond). The accuracy of the depth-



measurements depends upon several factors, such as (a) the state of the sea, (b) the nature of the sea bottom, (c) the configuration of the sea floor, and (d) the velocity of sound which is affected by temperature, pressure and salinity.

Correction due to the tidal changes, bottom slope distortions, and variance between the velocity of sound and calibration velocity were carried out on every echo-gram (Figure 1). The sound velocity was calculated by using Little's Table of the velocity of sound in sea water (1961). Bar checks were also done at least twice a day.

#### Continuous Stratigraphic Profiler or Sparker

The sparker was used in ascertaining the distributions and thicknesses of the offshore sediments, as well as prominent structures in the submarine rocks (see Beckman, Roberts and Luskin, 1959, and Beckman, 1960). It must be noted, however, that it was also possible to differentiate sand bottom from the consolidated rocks by means of the Marconi Graphette echosounder.

The instrument employed consisted of a 100-joule acoustic source, reactivated four times per second, and a hydrophone detector. Both were towed 200 feet behind the vessel.

An Alden dual-channel recorder was used. One channel printed the full spectrum of the acoustic signal, and the other

sorted out most of the low-frequency components. With this procedure, it was, by and large, possible to determine the interfaces (Figure 2) between the unconsolidated marine sediments and solid rocks (Bruckshaw and Taylor-Smith, 1963).

The original uncorrected Sparker record did not reflect the true picture of the submarine geological pattern. This was rectified by taking into consideration the velocities of sound in the offshore sediments and bedrock determined by the Sparker, employing standard seismic reflection techniques, and the sound velocity in sea water obtained from the echo-gram calculations. The average velocities of sound in sea water and in the marine sediments were 4.9 and 5 feet per millisecond, respectively. In the solid rocks, the velocity varied appreciably according to rock type. For the purposes of preliminary interpretations (by Geophysics Group), the sound velocities in Table 1, observed from the rocks on land, were utilised.

| Rock Types            | Velocity - Feet per millisecond |
|-----------------------|---------------------------------|
| Slates                | 10 - 14                         |
| Granite               | 11 - 17                         |
| Greenstone (Dolerite) | 12                              |

Table 1. Sound velocity in rock types present on the coast, which are also common in Mount's Bay.

The train of waves set up by the spark-discharge builds up to a maximum and dissipates in about 5 milliseconds. Consequently, with a velocity of about 5 feet per millisecond, it was generally not possible to discriminate reflections if the distance between the top of the unconsolidated sediments layer and the bed-rock was less than 12 feet. So far the best accuracy achieved, when all variables were considered, including the exaggerated vertical scale of the record, was about 1 millisecond which is equivalent to  $\pm 2.5$  feet for water and sediments, and  $\pm 5$  feet for consolidated rocks. The penetration-capacity of the instrument was primarily dependent on the character of the sea floor. In the solid rocks, the range was in the order of 200 to 300 feet.

Any accumulation of sand whose thickness could not be precisely defined by the sparker, but whose presence could be deduced by careful interpretation of the reflected energy level of the echo-gram, was recorded as having a thickness of less than 15 feet (Tooms, et al, 1965).

#### SECTION B: COLLECTION OF OFFSHORE SAMPLES

The program of the collection of samples from under the sea was divided into three major phases, namely, reconnaissance and detailed sampling of marine sediments, and rock sampling.

### Reconnaissance Sampling of Marine Sediments

An 18-foot motorised gig, rigged with a small winch, was used during the beginning of the sampling operation. At that stage, there were only two aqualung divers. When one was in the water, the other acted as stand-by diver, and he was ready to extend assistance at any time the first diver needed it. In addition, he served as the diver's attendant and "surface control". Communication with the diver was done by means of rope signals; the rope was also utilised as a safety line.

It was extremely difficult for the divers to operate from the gig, inasmuch as there was hardly any space for diving equipments, and no room for dressing and shelter. The latter problem was particularly inconvenient during cold and rainy days. Moreover, owing to the absence of a suitable ladder on either side of the boat, it was practically impossible for the divers to re-enter the gig when the sea was choppy.

Grab sampling was also carried out from the gig. Ideally, three people were required, one to navigate and locate the sampling points, another to operate the winch, and the third to attend to the grab sampler.

On account of the numerous limitations of the gig, it was soon discarded; the sampling operation was subsequently undertaken from "Shamrock", a 60-foot barge (Figure 3). The barge was exceptionally suited for the work because it had ample room



Figure 3. The "Shamrock".

for diving equipments, and hull-space suitable as a dressing room and shelter for the divers -- especially important during bad weather.

Another tremendous advantage of the barge was the availability of a steel ladder on its port side (Figure 4). It greatly helped the movement of the diver, thus it was much easier for him to get outboard and onboard. At this time, a 15-man diving team was at hand, but not all of them were employed in any one working day. Usually, only a 5 or 6-man combination was utilised in the daily sampling.



Figure 4. The steel ladder at the port side of "Shamrock".

Unlike during the start of the field work when the 18-foot gig was in use, air cylinders were sparingly utilised; only the stand-by divers used them. Air was mainly supplied to the divers through an air-line hose by a diesel low-pressure compressor aboard the barge. The compressor was capable of pumping 16 cubic feet per minute at a pressure up to 120 pounds per square inch (see Figure 5).

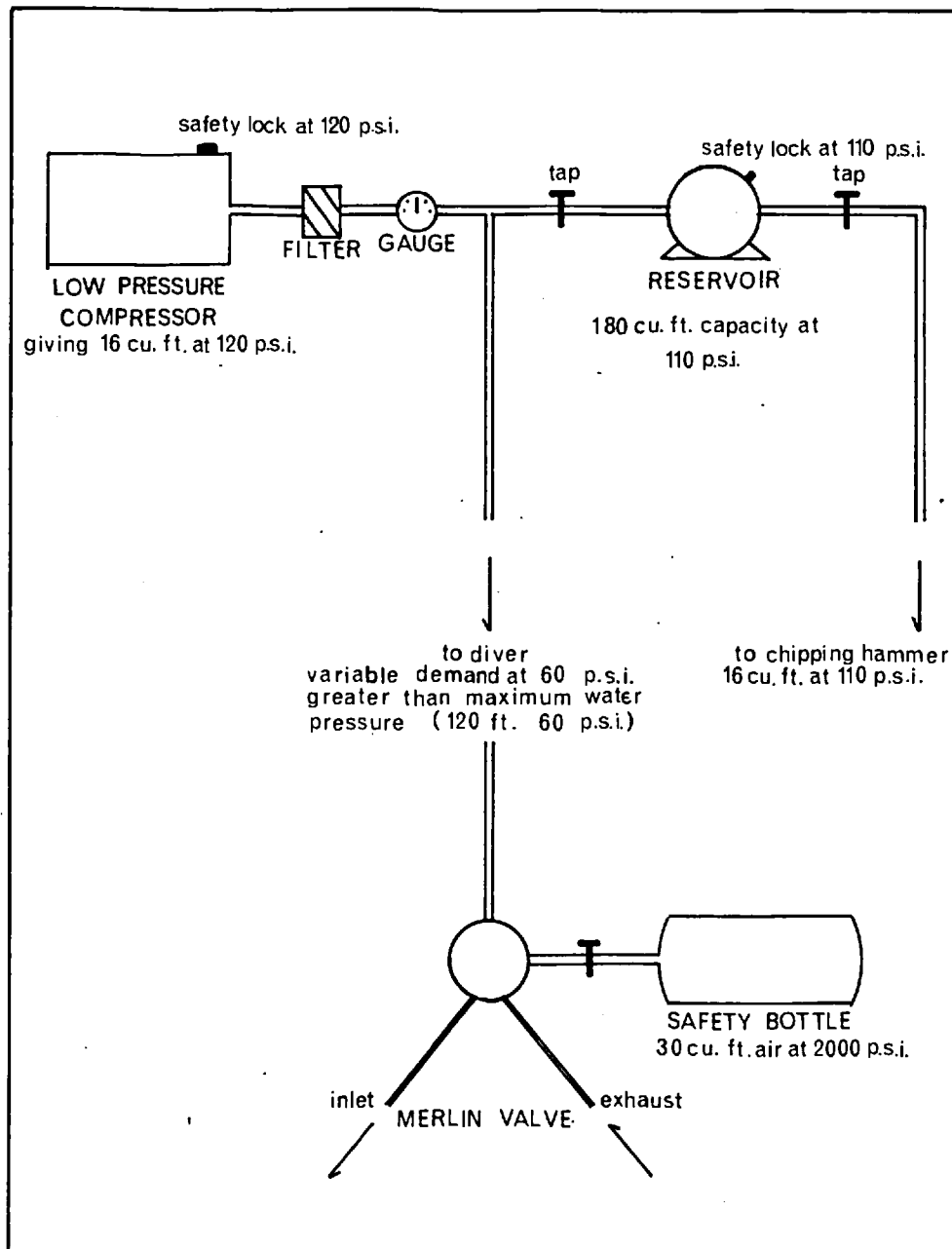


Figure 5. Low pressure air system on "Shamrock"  
(based on Kelland, 1964).

Aside from the stand-by diver, there was the "surface control" who served as the diver's attendant as well. He recorded the depth, length and number of dives, and also maintained communication with the diver via an underwater telephone (Figure 6).



Figure 6. The "surface control" using underwater telephone.

The diver used a stainless steel trowel, tied to his wrist, to scoop the sand into a polythene bag tied to the other wrist.

A sand or peat auger was tried as well; the divers reported a penetration of approximately 2 feet, but the spiral-end of the auger is nearly 10 inches, so that the effective penetration was only a little over 1 foot. The sand sample was transferred from the auger barrel (or polythene bag) into numbered kraft paper sample packets aboard the boat. The auger was seldom used because it required much effort to penetrate into the sand -- this was too much for the divers. The tool constantly



Figure 7. The grab sampler

used in the reconnaissance sampling was the grab sampler (see Figure 7). Before it was lowered to the sea floor, usually from the bow of the vessel, the spring-operated clamps were opened and locked in place with the safety catch. When the "grab" hit the sand bottom at a vertical or nearly vertical position, the lock released the clamps which in turn grabbed the sediments. The "grab" was pulled into the boat with a winch. It was, usually, necessary to have three or four grabs to obtain sufficient amount of sample. It should be noted that, even in the absence of a winch, it was still possible to do grab sampling.

Prior to the actual large-scale reconnaissance sampling of sand, a series of test were made on several groups of specimens from different parts of the bay. The three specimens of each group were taken from one particular locality with a scoop, auger, and grab sampler respectively. It was observed, as shown

| Sample No.                                       | Scoop    | Auger    | Grab     |
|--------------------------------------------------|----------|----------|----------|
| T <sub>1</sub> , T <sub>2</sub> , T <sub>3</sub> | 1300 ppm | 1000 ppm | 1000 ppm |
| T <sub>4</sub> , T <sub>5</sub> , T <sub>6</sub> | 1500     | 2000     | 1500     |
| T <sub>7</sub> , T <sub>8</sub>                  | 100      | 110      | ---      |
| T <sub>9</sub> , T <sub>10</sub>                 | 130      | ---      | 130      |
| T <sub>11</sub> , T <sub>12</sub>                | 170      | ---      | 160      |
| T <sub>13</sub> , T <sub>14</sub>                | 180      | ---      | 170      |

Table 2. Comparison of different methods of sampling in Mount's Bay.

in Table 2, that there was no appreciable variation of the tin distribution in the various samples of each group. Hence, the "grab" was most often employed inasmuch as it was easier and cheaper to operate than the rest.

To a very limited extent, a dredge, piston corer, and gravity corer (Figure 8) were also tried. The corers proved to be



Figure 8. The gravity corer.

ineffective because satisfactory penetration could not be attained owing to the well-compact nature of the marine sands.

Unlike the bathymetric-sparker survey, Decca Navigator was not employed during the geochemical sampling. Serious attempts were made to locate the samples at a half-mile grid interval but this was found to be impractical. Firstly, it was difficult and time-consuming to position the boat in a predetermined spot with the aid of a compass and/or sextant only. Secondly, with the aim of speeding up the work, it was decided not to drop the anchor while grab sampling; consequently, drifting could not be completely avoided. Hence, "spot sampling" was resorted to; this was done by getting the sample first, and then quickly followed by sighting coastal survey stations. The two methods employed in fixing the locations of the reconnaissance samples were by means of compass and sextant.

#### Compass.

This system involved sighting two or more prominent reference points on the coast. The intersection of the lines defined the position of the samples. In cases, where three or more stations were sighted, and the lines did not intersect at a common point, an average location was established in the centre of the figure described by the intersecting lines. The drawbacks of this method were the errors due to (a) magnetic attractions in the barge, and (b) the absence of any exact record of the sample

positions during the operations, the sample locations being plotted in the evenings. However, the compass was much easier to handle than the sextant during rough weather.

#### Sextant and Sextant Chart

From each position of the boat, the horizontal angles of at least two pairs of pre-determined coastal survey stations were measured with a sextant. The readings were then checked on the sextant chart. This chart is based on the principle that any point of a circle passing through other points (in this work, the coastal survey stations) subtends a constant angle  $\underline{x}$  with the latter points (Dr. T.L. Thomas of RSM, personal communication, and Garnett, 1960). A series of circles with varying diameters representing different values of  $\underline{x}$  were constructed between two survey stations. From the vessel (see Figure 9), the angle  $\underline{x}$  between two stations (a pair) was determined by a sextant. Likewise, the angle  $\underline{z}$  between another pair of stations, one of which may be common with the first pair, was measured. The intersection of the circles described by the measured horizontal angles determined the locations of sampling point. In instances where the sextant readings differed from any of the circles drawn between the survey stations concerned, the position was interpolated. A third angle from another set of stations was, on occasion, measured as a check. The sextant chart of Mount's Bay was drawn on 12 pairs of

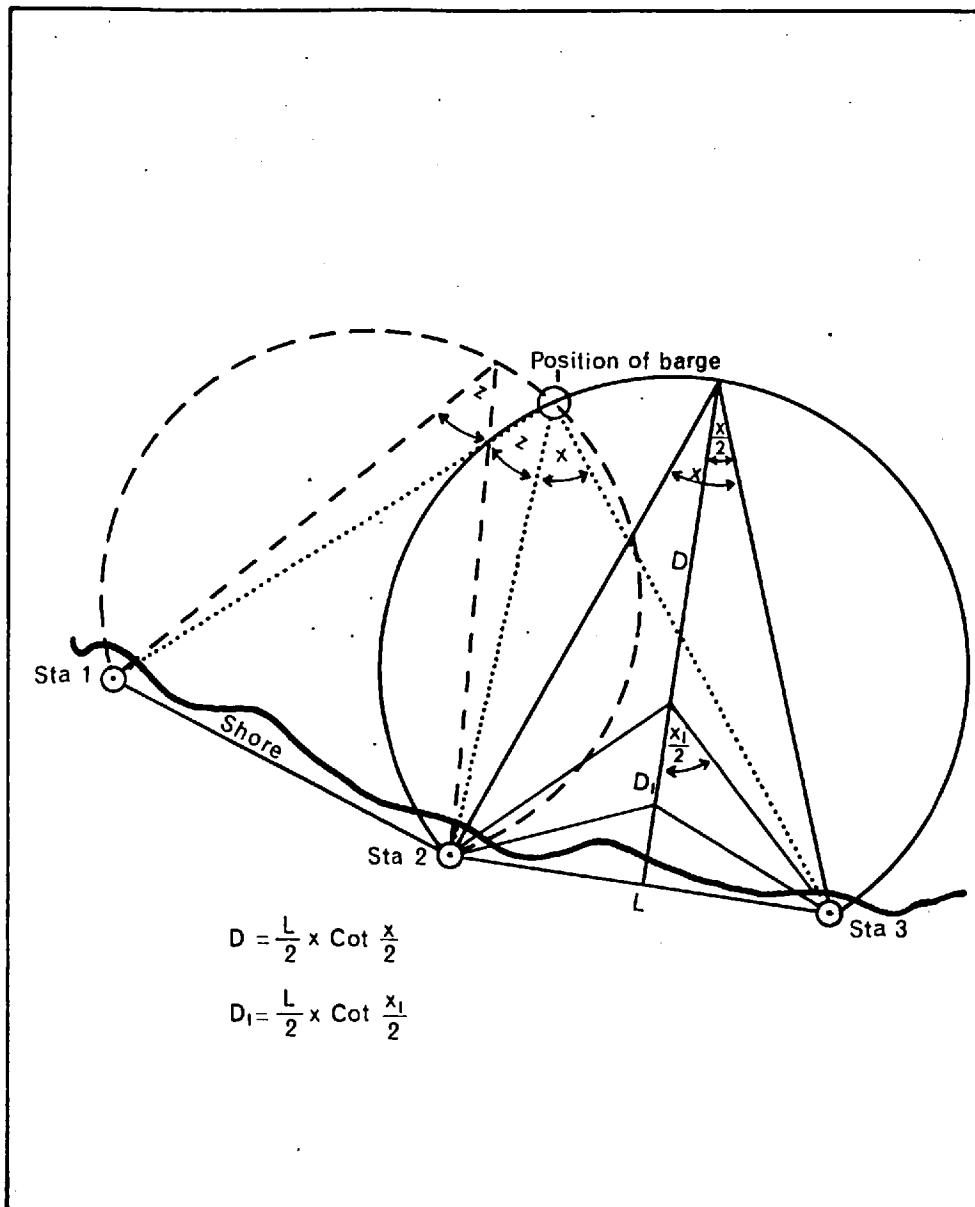


Figure 9. The principle of the sextant chart.

stations from nine reference points on the coast.

The advantages of sextant over the compass are (a) no plotting was needed during and after the sampling, (b) up to date record of sample locations was maintained during the operation, and (c) complete freedom from local magnetic interference; hence more accurate positioning was achieved.

The number of samples collected by the divers, or "grab" during a normal working day varied from 10 to 15, and 15 to 30, respectively; depending upon the depth and state of the sea, distance between samples, and speed of the boat. The density of reconnaissance sampling was 13 specimens per square mile.

#### Detailed Sampling of Marine Sediments

This phase of the sampling program was undertaken exclusively by divers using air cylinders, and operating from the 25-foot motorised gig equipped with a small winch (Figure 10). The samples were collected at 100-foot interval along the 13 traverse (submarine) lines indicated in Figure 22. The location of these traverses were based on the analytical data of the reconnaissance sand samples.

At the beginning of the sampling, two 700-foot quarter inch manila (hemp) ropes were used as traverse-guides. One pound lead weights were attached to each rope at an interval of 100 feet, and 14-inch plastic buoys with anchors were tied to the ends.

The ropes were coiled in a 2-foot diameter "fisherman's basket" so as to facilitate orderly handling.



Figure 10. The 25-foot motorised gig with a small winch.

At the seaward end of the traverse, the anchor of No. 1 buoy, with a polythene bag tied to it, was dropped into position. Then the boat was steered towards a prominent reference point on the coast, or along a pre-determined compass bearing; a straight course was maintained as far as possible. While the boat was moving slowly, "shooting of the line" was done, and consecutively numbered polythene bags were quickly tied close to the lead marker-weights (Figure 11).



Figure 11. "Shooting the line", and polythene bags being tied close to the lead marker-weights.

After the second buoy (No. 2) was dropped, the gig was coned along the specified course, and at about 100 feet from No. 2 buoy, the first buoy (No. 3) of the second 700-foot line was lowered into position. The techniques employed in the first 700-foot string of "shooting the line" and attaching the polythene bags were duplicated. After the last buoy (No. 4) was anchored, the first diver went down. He followed the line seawards and scooped sand into all the polythene sample bags, using a stainless steel trowel tied to his wrist. By noting the position of the bubbles, it was relatively easy for the gig to stay close to the diver. Constant communication with

him was maintained through the underwater telephone (Figure 6). The depth of every sampling point was determined with a depth gauge, and the readings were relayed to the "surface control". When the second line was completed, the diver came up near No. 3 buoy. Another diver went down close to No. 2 buoy; he followed the first line and filled all the rest of the sample bags. After the second diver had re-entered the boat, the ropes, with the specimens, were winched into the gig. The former were coiled again in the basket, and the sediment samples were subsequently transferred into kraft paper sample packets. The foregoing procedure were repeated until the whole length of the desired traverse line was covered.

As the work progressed, it was discovered that most of the divers could finish the two 700-foot lines in a single dive, so that the two ropes were joined. The 1,400-foot line was much less complicated to handle. Only two 14-inch plastic buoys were needed; at the 700-foot mark, a 4-inch buoy was attached--this served as a guide for the succeeding diver in the event that the first diver could not cover the whole line. The techniques of laying down the traverse lines, and collecting the samples were basically the same to those employed in the 700 feet lines. If the length of the traverse was greater than 1,400 feet, the forward buoy (No. 2) was left in place. The rest of the line was pulled into the boat; after the samples were recovered (except the one tied to No. 2 buoy), and using

No. 2 buoy as a pivot, the "shooting of the line" was resumed. In the event that the traverse line was longer than two lengths (2,800 feet) of the rope, the afore-mentioned process was repeated until the whole length of the intended traverse was completed.

Two to three traverse lines could be finished during a regular working day, depending upon the depth, length of traverses and weather condition. The number of samples varied from 30 to 50.

#### Sampling of Submarine Rock Outcrops

All the rock specimens from the bottom of the bay were gathered by divers operating from the barge; they employed hammer and chisel, and a pistol-like compressed air operated percussion hammer (Figure 12).

In the first method, the cold chisel and polythene bag were tied together to one hand of the diver, and the hammer to the other wrist. This technique was effective in the killas or slates but was less serviceable in the harder rocks (granite and dolerite). In the second procedure, the diver, with a polythene bag tied to one hand, went down to the sea bottom first; then the percussion hammer was slowly lowered to him. Compressed air was pumped from the deisel compressor, through a 100 cubic feet reservoir, aboard the barge (see Figure 5) --- this is the

same compressor which supplied air to the divers. The latter method proved to be quite adequate in sampling the underwater outcrops of granite and dolerite.



Figure 12. The compressed air operated percussion hammer.

In places where it was necessary to get more than one specimen, the writer, using the compass on the bridge, instructed the diver (equipped with underwater compass) through the telephone operator to move to the desired sampling point. It was

fairly easy to ascertain the relative position of the diver from the air bubbles coming to the surface.

The daily accomplishment varied from 12 to 20 samples depending chiefly on depth and state of the sea, distances between samples, speed of the boat, and hardness of the rocks. The sample density was about 13 per square mile.

As in the case of the reconnaissance sampling of the offshore sediments, compass and sextant were employed in locating the site of the rock specimens.

#### SECTION C: COLLECTION OF SAMPLES FROM THE COAST

This aspect of the sampling operation was grouped into three: rock sampling, beach sampling, and stream sediments sampling.

##### Rocks (including peat and head) Sampling

Most of the rock specimens were taken with a geological hammer, if the rock was very hard, a cold chisel was utilised. A stainless steel trowel, on the other hand, was used in getting samples from the soft rocks -- peat and head (periglacial solifluction product composed of angular rocks in a sand-clay matrix).

With the excellent details of the Ordnance Survey 6-inch maps, it was reasonably easy to locate the sampling points by visual observation.

### Beach Sampling

The bulk of the sand samples were taken, with the stainless steel trowel, from traverse lines across the major beaches. A number of these traverses were the onshore extensions of some of the submarine traverse lines shown in Figure 22. Two or more surficial samples were taken from every principal subdivision (backshore and foreshore) of the beaches, but no uniform interval of sampling was followed. In places, the different layers of beach sands were independently sampled. The depth of sampling varied from an inch to 24 inches. From the narrow beaches in the coves, samples were collected without maintaining a definite pattern.

The sand or peat auger was also employed in the sampling. However, this was sparingly utilised because it was found impossible to attain any reasonable depth of penetration. This was due to the fact that the beaches were not hard enough to enable the spiral-end of the auger to "bite". The auger was ineffective in the pebbly portions and coarse laminae of the beaches. Furthermore, unlike the trowel, it was not possible with the auger to obtain separate samples from the various thin sand layers.

The location and direction of the traverse lines were established with a prismatic compass. The lines were plotted immediately in the field on the Ordnance Survey 6-inch maps,

so that it was possible to check the reference points.

### Stream Sediments Sampling

The sediments were collected, with the stainless steel trowel, from the mouths and upstream portions of the rivers draining into Mount's Bay. The sample taken farthest inland was about a mile north of Marazion. The technique of establishing the location of samples was similar to that employed in the beach sampling.

## SECTION D: LABORATORY TECHNIQUES

### Sample Preparation

All the sand specimens were dried under a battery of electric lamps at the Camborne School of Mines. The reconnaissance sand samples were sieved through 80 mesh nylon (or bolting cloth) screen in Camborne, and then analysed for tin.

On the other hand, the preparation of the rock specimens was done in London. They were cleaned first with a stiff bristle brush; then crushed (in a small jaw crusher) to finer than 1/4 inch diameter, and were subsequently pulverised to minus 80 mesh in a ceramic ball mill.

### Representivity Test of the Fraction of Sample Analysed

Prior to the large-scale analyses, the representivity of the fraction actually analysed, in relation to the whole of each sample, was investigated on various samples from different parts of Mount's Bay. A broad summary of the test procedure is as follows:

- (a) Each sample was mixed thoroughly.
- (b) Three different portions, taken at random, from each sample were sieved through 20, 38, and 80 mesh, respectively. Half of the -20+38 mesh fraction was pulverised to minus 80 mesh.
- (c) The rest of the unsieved sample was divided into six equal parts by the electric sample splitter (Figure 13). Each portion was screened through 80 mesh nylon (or bolting cloth) sieve.
- (d) All the fractions and their pulverised equivalents from (b) and (c) were colorimetrically analysed for tin (see Stanton and McDonald, revised April, 1964).

The analytical data presented in Table 3 indicate that, by and large, there is no considerable difference between the tin contents of the minus 80 mesh fractions from (b) and (c), respectively. Hence, the minus 80 mesh constituents from (b) could be considered as fairly representative. In the preparation of the samples for large-scale analyses, therefore, the samples were neither coned and quartered, nor split with a sample



Figure 13. The electric sample splitter.

(electric) splitter. A portion of each well-mixed sample was simply sieved through an 80 mesh nylon screen. The minus 80 mesh fraction was then analysed for tin.

| Sample No. | Random Fractions  |                    |                   |                   | Electric Sample Splitter Fractions |                   |                   |                   |                   |                   |
|------------|-------------------|--------------------|-------------------|-------------------|------------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|            | Mesh              |                    |                   |                   | Mesh                               |                   |                   |                   |                   |                   |
|            | -20<br>(b)<br>ppm | -20<br>(bl)<br>ppm | -38<br>(b)<br>ppm | -80<br>(b)<br>ppm | -80<br>(c)<br>ppm                  | -80<br>(c)<br>ppm | -80<br>(c)<br>ppm | -80<br>(c)<br>ppm | -80<br>(c)<br>ppm | -80<br>(c)<br>ppm |
| 17         | 250               | 300                | 1600              | 12500             | 12500                              | 12500             | 12500             | 12500             | 12500             | 12500             |
| 66         | 30                | 40                 | 40                | 70                | ---                                | ---               | ---               | ---               | ---               | ---               |
| 331        | 50                | --                 | 390               | 8750              | 7500                               | 7250              | 7500              | 7500              | 7500              | 7000              |
| 660        | 100               | --                 | 110               | 290               | 270                                | 280               | 260               | 260               | 240               | 250               |
| 735        | 240               | --                 | 400               | 1800              | 1900                               | 2200              | 2250              | 2250              | 2200              | 2250              |
| 850        | 50                | --                 | 50                | 300               | 450                                | 350               | 290               | 350               | 330               | 340               |

Note: (bl) is pulverised minus 20 mesh fraction, and see page 32 for letter symbols.

Table 3. The distribution of tin in the various fractions of samples from different parts of Mount's Bay.

#### Efficiency Test of the Colorimetric Analysis for Tin

This examination was carried out to ascertain the capacity of ammonium iodide attack to liberate tin from various size particles of sand.

The -20+38, -38+80, and -80 mesh fractions of a number of samples were analysed colorimetrically and spectrographically. In addition, the insoluble residues from the ammonium iodide attack utilised in the colorimetric procedure was also analysed for tin in the spectrograph. The specimens tested, included some which have been used in the representivity determination.

| Sample<br>No. |          | -20+38 |            | -38+80 |            | -80   |                   |
|---------------|----------|--------|------------|--------|------------|-------|-------------------|
|               |          | Color  | Mesh Spect | Color  | Mesh Spect | Color | Mesh Spect        |
|               |          | ppm    | ppm        | ppm    | ppm        | ppm   | ppm               |
| 17            | Original | 250    | 400        | 1600   | 3000       | 12500 | >10000            |
| 17            | Residue  | ---    | 80         | ---    | 500        | ---   | 1500              |
| 192           | Original | ---    | ---        | ---    | ---        | 6000  | 7000              |
| 192           | Residue  | ---    | ---        | ---    | ---        | ---   | 3000 <sup>x</sup> |
| 331           | Original | ---    | ---        | 400    | 900        | 3000  | 4000              |
| 331           | Residue  | ---    | ---        | ---    | 70         | ---   | 150               |
| 735           | Original | ---    | ---        | 400    | 300        | 1000  | 700               |
| 735           | Residue  | ---    | ---        | ---    | 80         | ---   | 150               |
| 1108          | Original | 30     | 60         | ---    | ---        | ---   | ---               |
| 1108          | Residue  | ---    | 10         | ---    | ---        | ---   | ---               |

Notes: Samples 17, 331, and 735 were included in the test for representivity.

x Unchecked because of limited material available.

Table 4. Comparison of tin values obtained by colorimetric and spectrographic analyses of the various size fractions of samples, and also the tin contents of sand residues from the colorimetric determination.

The analytical results, some of which are tabulated in the above table (4), indicate that there is a bias between the spectrographic and colorimetric methods; the spectrographic results tending to be the higher. However, it is also apparent from the spectrographic data on the residues from the colorimetric analysis that ammonium iodide attack did not give a complete

extraction of tin from the samples, particularly in the coarser fractions. For example, the pulverised portions of the minus 20 mesh fractions yielded somewhat higher tin values than the unpulverised components (see Table 3).

On the other hand, although ammonium iodide attack did not always liberate all the tin from the fine sand, it was reasonably efficient with this material. This is signified by the lesser degree of differences between the analytical results obtained respectively by colorimetric and spectrographic analyses of the minus 80 mesh size particles (Table 4), as compared to those of the coarser fractions.

#### Mechanical Size-Analysis

Dry-sieving and elutriation were employed in the mechanical size-analyses. This particular investigation was undertaken with the view of gaining knowledge on the size distribution of tin, and its behaviour relative to quartz grains in suspension.

#### Dry-sieving

This made possible the separation of selected sand samples into different size-fractions.

Two sets of nylon screens were used. The first series consisted of 20, 38, 80, 125, and 197 mesh. To the second, 140 and

185 mesh were inserted between the last two screens (125 and 197 mesh). Fifty grams of each sample was passed through the series of screens. If the samples was too coarse, or pebbly, it was sieved through 20 mesh screen before the size analysis. The amount of sand retained in every screen was recorded.

The coarser fractions, +20, -20+38, and -38+80 mesh, were ground to pass 80 mesh. The tin was determined colorimetrically on all the size fractions.

#### Elutriation

The Blyth Elutriator (Pryor, et al, 1953) was used. It consisted principally of six vertical glass tubes of increasing diameters, and through them water was siphoned at a constant rate (Figure 14). This apparatus was designed originally to have a set of tubes with diameters that will vary with the square root of two; thus the ratio of water velocities in the different tubes would be 32, 16, 8, 4, 2, and 1. However, due to breakage, and replacement with similar but not identical tubes, the diameters of the first set (Table 5) did not conform with the ideal.

The average rate of water flow in the elutriation of the first batch of samples was 260 ml per minute, and the velocities inside the tubes varied from 5 to 0.15 cm per second (see Table 5). A 50-gram "feed" was utilised; the sizing was controlled by the diminishing water velocities in the tubes. The

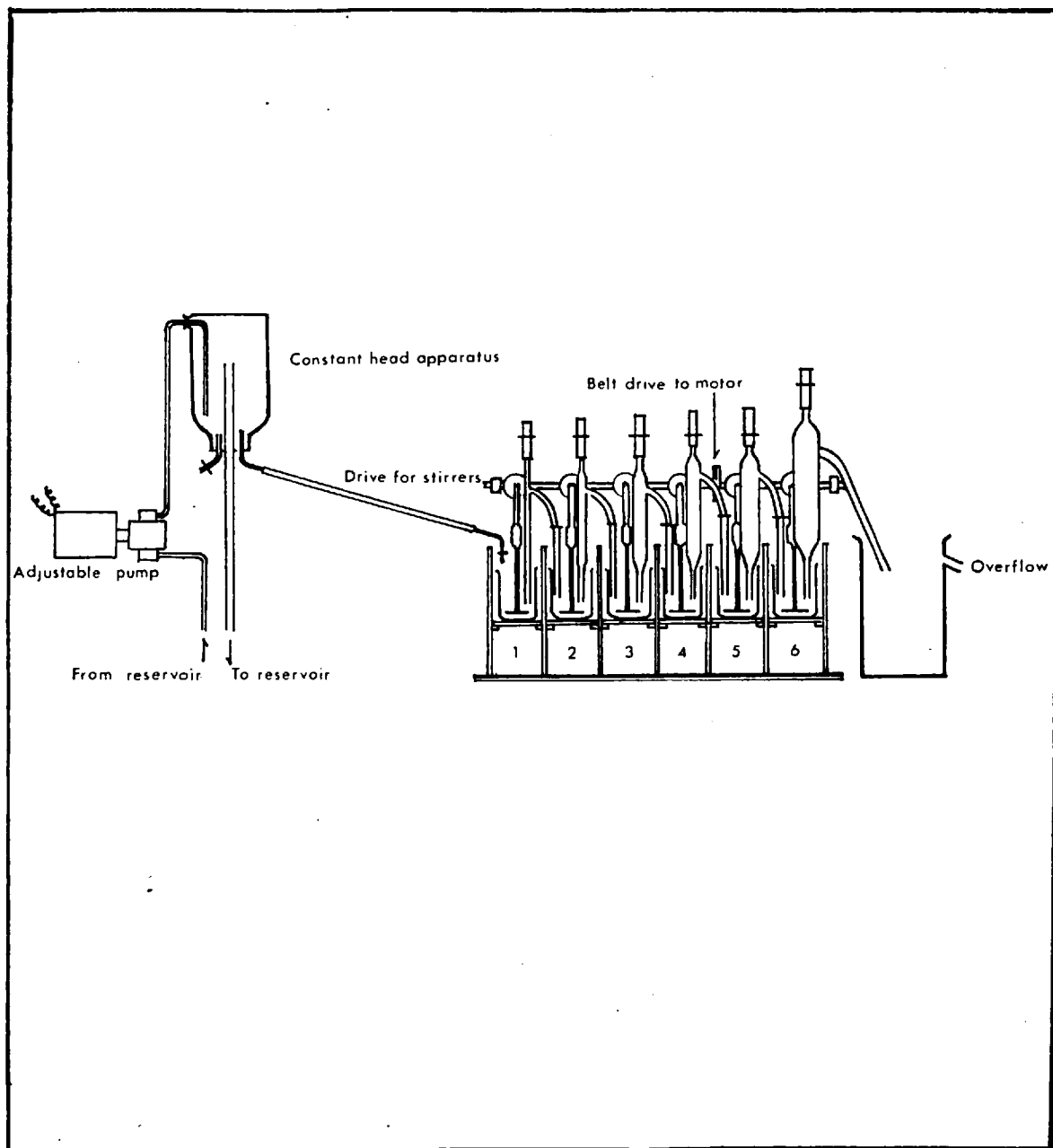


Figure 14. The Blyth Elutriator.

first tube, with the least diameter, had the highest velocity so that the fine and medium grained sediments were transported (in suspension) through it. The velocity in each succeeding tube gradually decreased, consequently the particles of sand moved through each tube became generally finer.

Periodic checking during the actual elutriation revealed that the rate of flow did not always remain constant. This was attributed to the accumulation of suspended sands (teeter column), which were too heavy to be shifted to the next beaker, but could not fall through the constricted lower portion of the tube. The narrow diameter entries, where the water velocities were much faster as compared to the main bodies of the elutriation tubes, considerably enhanced the formation of the teeter column. This phenomenon increased the effective weight of the water-sediment column in some tubes, particularly in Nos. 3, 4, and 5, resulting in diminished velocities which subsequently reduced the overall rate of flow. The undesirable effect of the teeter column was partially remedied by temporarily decreasing the rate of flow, at frequent intervals, until the sandloads settled out of the tubes.

The elutriation-time was directly related to the predominance of "fines" in the sample, that is to say, the very fine required much longer time for sizing. By and large, the treatment of individual samples varied from three to five hours.

| Tube No. | Maximum Diameter - cm | Velocity - cm/sec |
|----------|-----------------------|-------------------|
| 1        | 1.06                  | 5                 |
| 2        | 1.39                  | 2.9               |
| 3        | 1.92                  | 1.52              |
| 4        | 2.95                  | 0.67              |
| 5        | 3.32                  | 0.52              |
| 6        | 6.18                  | 0.15              |

Table 5. Maximum diameters of the first set of elutriation tubes, and maximum velocities observed in the widest part of each tube during the experiment.

The elutriator was latter modified. The old set of tubes with narrow diameter-entries were replaced with new ones without constriction at the lower ends (Figure 15). The sizes of the new tubes (Table 6) closely resemble to those originally envisaged by Blyth, that is, the tube diameters vary with the square root of two. Although the teeter columns were not entirely eliminated, their effect was notably minimised. Thus, the change of the rate of flow was negligible; as a result, the efficiency of the instrument improved remarkably. The sizing became more uniform, and elutriation time reduced to three to four hours.

The average rate of flow was 200 ml per minute, and the water velocities in the elutriation tubes, which varied from 6.4 to 0.09 cm per second, are tabulated in Table 6, as are the tube diameters.

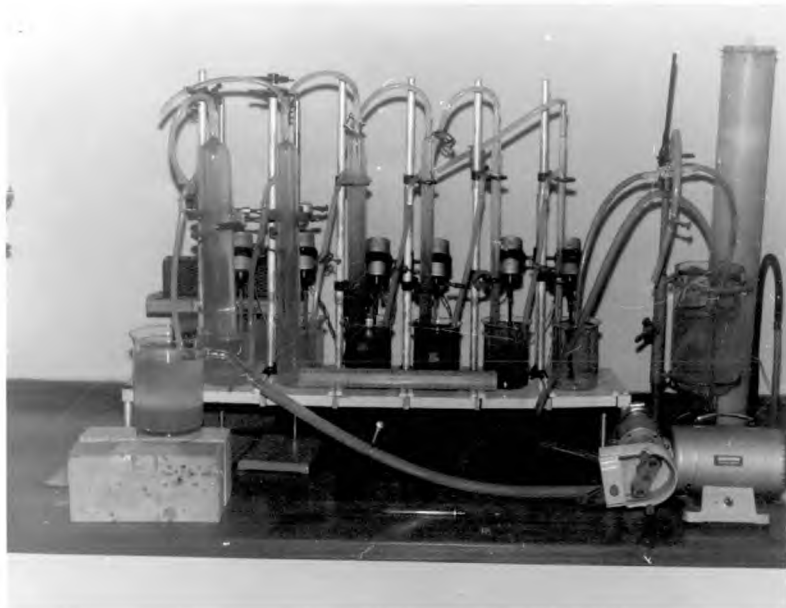


Figure 15. The modified Blyth Elutriator, with the resin column in the background, and the peristaltic pump in the right foreground.

| Tube No. | Maximum Diameter - cm | Velocity - cm/sec |
|----------|-----------------------|-------------------|
| 1        | 0.8                   | 6.4               |
| 2        | 1.2                   | 3                 |
| 3        | 1.7                   | 1.5               |
| 4        | 2.6                   | 0.63              |
| 5        | 3.4                   | 0.37              |
| 6        | 4.8                   | 0.18              |
| 7        | 6.8                   | 0.09              |

Table 6. Maximum diameters of the second set of tubes, and maximum velocities observed in the widest part of each tube during the experiment.

Ordinarily, only six tubes were utilised, however, when elutriating sediments with abundant silty and clayey constituents, a seventh (largest diameter) tube was added. This sharply reduced the losses of the "fines" in the overflow. Another useful modification was the addition to the system of a variable speed peristaltic pump; it made possible a closed-circuit flow of water. As a consequence, the deionized water consumption was reduced to a minimum. This innovation, obviously, was very important from the point of view of economy. For example, in the case of the first batch of samples, with an average rate of flow of 260 ml per minute and an elutriation-time of 5 hours, 78,000 litres of water were needed for each sample. Hence, without the pump, a vast amount of deionizing medium (resin) would have been required for the whole elutriation experiment; this undoubtedly, would have been very expensive.

It is of interest to note that although the elutriation experiment was a long process, and very much slower than dry-sieving, the progress of the laboratory work was not seriously hindered; because it was perfectly possible to do elutriation, heavy mineral separation, and HCl-treatment simultaneously. In passing, it must be emphasised that sizing by elutriation is influenced by specific gravity, size and shape of the materials treated.

Microscopic measurement of quartz diameters from various size-fractions were checked by computation based on Stoke's Law (Shepard, 1963). By and large, the results of the two methods

of estimation were in close agreement (Table 7).

| Fraction | First Set of Tubes |         | Second Set of Tubes |         |
|----------|--------------------|---------|---------------------|---------|
|          | Microns            |         | Microns             |         |
|          | Microscope         | Stoke's | Microscope          | Stoke's |
| 1        | 300-350            | ---     | 400-800             | ---     |
| 2        | 200-300            | 236     | 200-400             | 260     |
| 3        | 100-200            | 180     | 150-250             | 182     |
| 4        | 90-150             | 130     | 100-150             | 129     |
| 5        | 60-100             | 86      | 70-100              | 83      |
| 6        | 60- 80             | 76      | 50- 80              | 64      |
| 7        | -- --              | 40      | 40- 60              | 45      |
| 8        | -- --              | --      | < 40                | 31      |

Table 7. Comparison of the estimation of quartz diameters (in microns) by microscopic measurements and calculations based on Stoke's Law.

#### Heavy Mineral Separation

TBE (tetrabromethane), with a specific gravity of about 2.96, was the separation medium.

The classical method of using ordinary glass funnels with filter paper, was tried during the preliminary work. But this was found to be unsatisfactory because the sand could not be stirred thoroughly. The heavy minerals, especially in the very fine sand, stuck to some light particles and could not be released. Thus, separation was incomplete. Afterwards, the

ordinary funnels were replaced with modified 125 and 150 ml separatory funnels (Figure 16). The stop-cocks of the separatory funnels were cut off and substituted with polythene tubings and clips.



Figure 16. Apparatus used for heavy mineral separation.

Fifty-gram samples were treated in the modified separation apparatus; the results were similarly disappointing. Separation was very poor owing to the compactness of the sand layer floating

on the TBE; nevertheless, this was resolved by reducing the amount of sample.

With the separatory funnel half-full of TBE, 25 grams of minus 20 mesh sand was added. The stoppered separatory funnel was shaken thoroughly, and then the heavy minerals were allowed to settle down. When the TBE column was clear, the heavies were withdrawn through the polythene tube into a standard funnel with filter paper. If dealing with medium to coarse grained sediments, ordinary "kleenex tissues" were used to achieve very fast filtration. Periodic shaking of the TBE-sand combination was frequently repeated until the separation was completed. When treating very fine materials, such as the stream sediments, a centrifuge was employed to bring about satisfactory separation. By and large, the separation-time lasted from 2 to 48 hours, depending upon the grain sizes of the sediments. It was fastest in the coarse samples.

The heavy and light mineral fractions were cleaned with alcohol to remove the tetrabromethane; then they were dried, and weighed.

With the view of separating the very fine heavy minerals ( $< 53$  microns), which are likely to be easily transported by currents in the bay, a portion of heavy mineral fractions of selected samples were passed through a 197 mesh nylon screen prior to chemical analysis. The plus 197 mesh heavies were pulverised and subsequently analysed for tin.

#### HCl-Treatment

Fifty-gram sample was placed into 500-ml beaker, and 50 per cent hydrochloric acid was added. The latter was poured slowly to avoid overflowing of the bubbles which could cause notable losses. The carbonate-saturated solution was decanted, and then fresh 50 per cent HCl was introduced; this was repeated until there was no further effervescence. The carbonate-free sediments were cleaned with deionized water, dried and then weighed.

#### Colorimetric Analysis for Tin

With the exception of some selected samples which were spectrographically analysed, the analysis was largely done by colorimetric method (Stanton and McDonald, revised, 1964).

A small fraction of the prepared sample, say 0.1 or 0.2 gram was heated with ammonium iodide, and subsequently leached with 1 M hydrochloric acid. An aliquot of the extract was mixed with buffer solution, a mixture of chloroacetic acid, sodium hydroxide, and hydroxylamine hydrochloride. The buffered aliquot was further treated with gallein in ethyl alcohol, and the greyish to pink gallein-tin complex was compared with standards containing known concentration of tin.

The limit of detection was 0.5 ppm. The precision in the range of 0.5 to 100 ppm was better than  $\pm 25$  per cent at the 95 per cent confidence level. The productivity was 80 to 100 per

day depending upon the concentration of tin in the specimens. It took more time to analyse tin-rich samples because of the need of adding dilute gallein reagent.

#### Precision of Analytical Results

The precision of the colorimetric determination was controlled by including statistical series samples at regular interval, say every 10 samples, in the various analytical batches. The tin contents of the control-samples were plotted graphically (GPRC Tech. Comm. No. 46) to verify if the analytical precision fall within the acceptable limits. An example of the graph is shown in Figure 17. Analytical results which did not fall within the allowable limits were disregarded, and the samples were re-analysed.

#### Mineralogical Methods

Aside from the binocular microscope used in the mineralogical examination of selected sand specimens, the "zinc-plate test for tin" was also employed. A few grains of sand were placed on a zinc-plate, and then a drop or two of HCl was added. Grains containing cassiterite became coated with a creamy-white to silvery substance (Roger, 1937). It was easy, therefore, to detect cassiterite-bearing grains in a sample, or heavy mineral concentrate by this method.

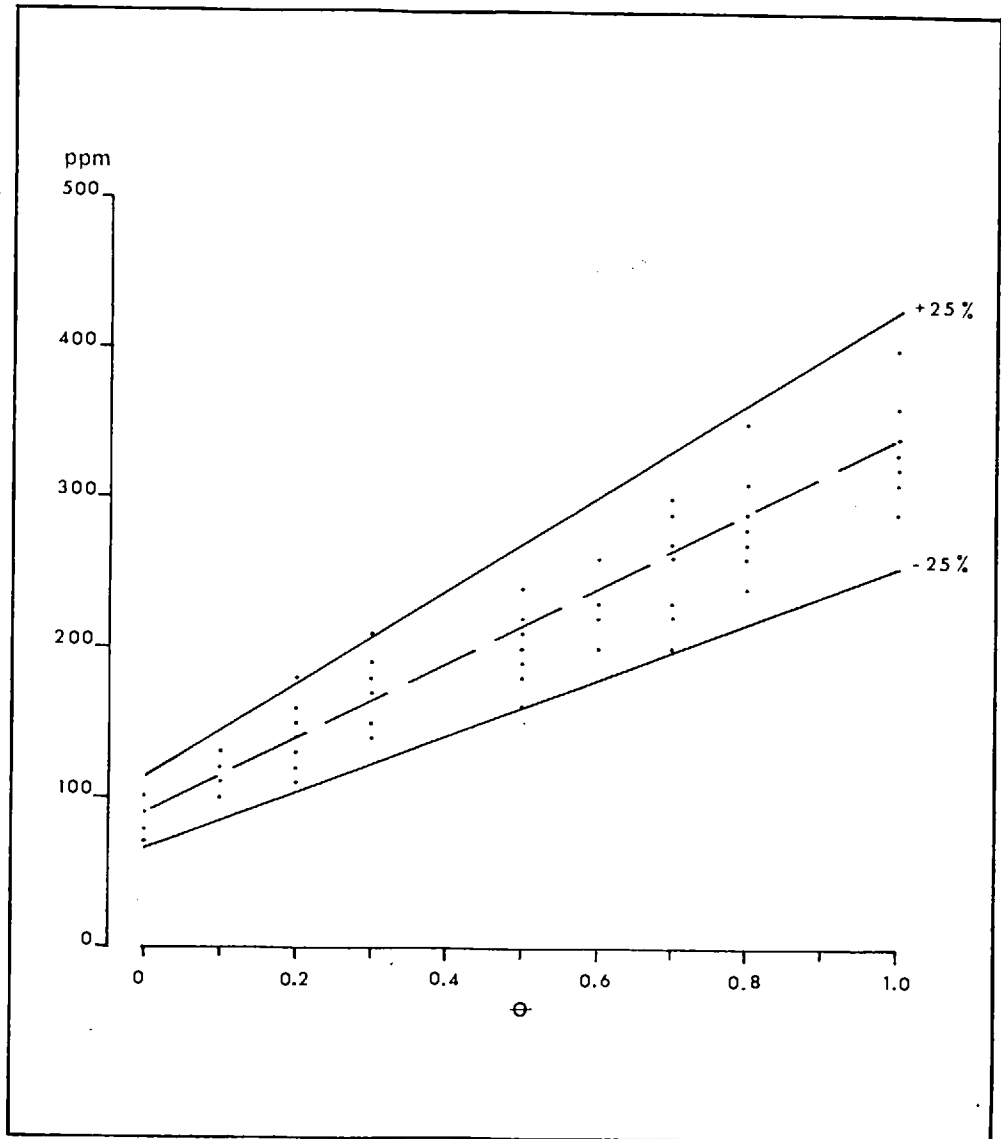


Figure 17. Composite plot of analytical results of the statistical series samples.

## PART II: GENERAL DESCRIPTION OF THE STUDY AREA

### SECTION A: LOCATION, ENVIRONMENT, AND GEOLOGY AND MINERALISATION

#### Location

The study area which covers about 40 square miles is in Mount's Bay, off the south coast of Cornwall (Figure 18). It is bounded in the west by Land's End Granite and to the north by a long stretch of coastline extending from Penzance to Porthleven, and in the east by Loe Bar. The southern limit is defined by a line joining Carn-du in the west and Baulk Head in the east.

#### Climate and Prevailing Wind

Mild temperate climate is characteristic of Cornwall, nevertheless during cold spells, snow may occur. The average annual rainfall in the immediate vicinity of the study area is from 33 to 45.5 inches (British Rainfall, 1963). The prevailing wind is west to southwest.

#### General Geology and Mineralisation

##### General Geology

The common rock types in Southwest Cornwall are the Mylor

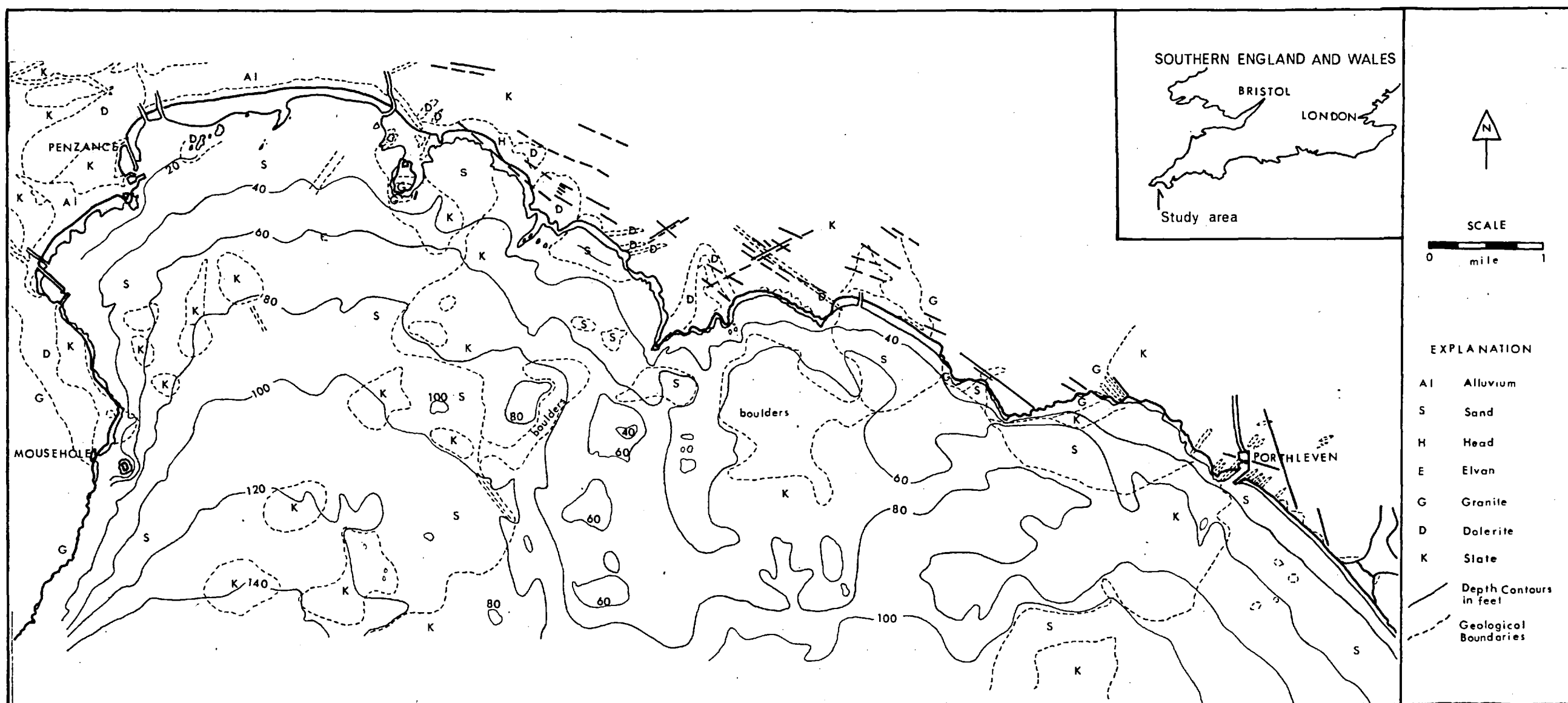


Figure 18. The bathymetry of Mount's Bay and the geology of the surrounding area.

Slate (known locally as Killas), granite, dolerite (greenstone), porphyry dykes (elvan), and head (see Figure 18).

Apart from the Lizard Complex (schist, serpentine, etc.), the oldest rocks in Cornwall appear to be of Lower Devonian (Hendriks, 1937), and overlain by Middle and Upper Devonian rocks. The youngest strata are the Culm Measures in Northeast Cornwall. Spilitic basalt and dyke-like intrusions of dolerite invaded the sedimentary rocks. All were affected by the Variscan disturbance. The basic igneous rocks were transformed to greenstone. The intensity of deformation is greatest in the south, where it is associated with the Meneage thrust-zone, faults, and other major structures. By contrast, the effect of regional metamorphism becomes less pronounced towards the north (Webb, 1947).

The essentially continuous Variscan deformation was accompanied by the intrusion into the slates of granite batholiths, such as the Godolphin, Land's End, etc. granites. Other smaller granite masses of immediate interest are the St. Michael's, and St. Agnes. It has been postulated by Hosking (1949) that the major granite outcrops are connected by non-outcropping granite ridges.

During, and after the emplacement of the granites, minor igneous bodies were intruded, giving rise to the porphyry dykes. Although appreciable occurrence of tourmaline, topaz and cassiterite is common in some dykes, on the whole, the composition of

the dykes closely resemble to that of the granite (Webb, 1947). The texture, however, is much finer.

Godolphin, Land's End, and the other granite bodies are fringed by thermally metamorphosed and hydrothermally or pneumatolytically altered rocks, typified by the spotted slates. The spots are chiefly composed of sericite and chlorite, biotite and quartz, and biotite and cordierite (Bagchi, 1947). Dolerite close to the granites were converted to hornfels, typical of which is the cordierite-amphibole variety. Other rock-types found in the metamorphic aureole are phyllite and muscovite-biotite schist.

As a general rule, the contact metamorphic zoning is not clear-cut, but in places, such as in Cligga, increasing grade of metamorphism towards the granite (St. Agnes) is discernable (Cox, 1961). The zones of metamorphism are:

- (a) Chlorite zone -- exemplified by spotted slates.
- (b) Muscovite-sericite zone -- characterised by bleached slates.
- (c) Tourmaline zone -- grading from schist to hornfels.
- (d) Andalusite-biotite contact zone -- infrequent occurrence.

Extensive subaerial erosion during the Mesozoic Era exposed the granite, and some of the associated lodes. After the Miocene ('Alpine') orogeny, Cornwall was partially submerged; nevertheless, granite islands remained. In more recent times, in the post-Pliocene, gradual emergence (or recessions of sea level) took place. This is indicated by the sea-cut benches or terraces

at a number of elevations, including in particular the well developed 400-foot and 10-foot (average) platforms. The latter is commonly manifested by raised beach deposits (Robson, 1944).

During Pleistocene, although Cornwall was not covered by continental ice sheet, it had a frigid climate which may have caused the physical disintegration of surface and near-surface rocks, and followed by chemical weathering, may have released some tin-rich minerals. In the late-Pleistocene the climate became more congenial; the accompanying thaw may have facilitated the movement of surface debris and tin-bearing detritus to lower elevations. This culminated in the deposition of the head of rubble, composed of angular rock fragments in sand-clay matrix (Hosking, et al, 1962), and perhaps some detrital tin deposits. Again, submergence occurred, so that the low-altitude areas, and the deposits thereon, such as the peat beds, were subsequently buried under estuarine and nearshore marine sediments. Finally, sand dunes were formed adjacent to some of the sandy beaches, as for example at Praa Sands.

The geological column of Cornwall, arranged in the order of decreasing age is shown in Table 8.

#### Mineralisation

The metalliferous lodes are believed to be genetically related to the granites. On the basis of the predominant mineral-components, the lodes have been grouped (Webb, 1947) into:

- (a) Tin zone
- (b) Copper zone
- (c) Lead-zinc zone
- (d) Iron zone

It must be emphasised that the different mineralisation zones, particularly the tin and copper, overlap in places. By and large, the tin-rich ore bodies are found near the granite margins. The copper lodes are commonly confined in the metamorphic aureole, as for example the lodes exposed at Trewavas cliffs. Like the tin lodes, their strike inland is northeast, but near the coast of Mount's Bay, the majority strike northwest. The lead-zinc and iron deposits were formed in the unaltered slates, outside the limits of the aureole, that is to say, farthest from the granite. Aside, from the mineralised lodes, barren quartz, and quartz-tourmaline veins, some of which pre-date the granite, are common in both the metamorphic zone and "fresh" slates (Webb, 1947).

Apart from the lodes, there are a number of placer tin deposits. The extensive erosion during the Mesozoic Era, and more particularly the weathering during the late-Pleistocene, which may have persisted into modern times, liberated cassiterite and other tin-bearing resistate minerals from the lodes. These minerals were subsequently concentrated in some valleys to form alluvial tin, a typical example is the St. Erth Valley tin deposit (Dines, 1956).

---

|                                                                                                                                                                 |                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| RECENT                                                                                                                                                          | Alluvium, peat, head                                                                    |
| PLEISTOCENE                                                                                                                                                     | Stream tin, head, raised beaches                                                        |
| PLIOCENE                                                                                                                                                        | Sand, clay, gravels                                                                     |
| There are Permo-Triassic beds containing pebbles of the granite exposed in Devon, NE of the study area.                                                         |                                                                                         |
| PERMO-CARBONIFEROUS                                                                                                                                             | Lodes, elvans, aplites, pegmatites, granites, (mica traps?)                             |
| CARBONIFEROUS                                                                                                                                                   | Culm Measures with basalt                                                               |
| The Lizard serpentine is considered by Miss Hendriks to be contemporaneous with the Meneage thrust and to be of late Upper Devonian or Lower Carboniferous age. |                                                                                         |
| UPPER DEVONIAN                                                                                                                                                  | Green and purple phyllites, calcareous shales, etc. with basic intrusions and volcanics |
| MIDDLE DEVONIAN                                                                                                                                                 | Slate in the north, grits in the south; basic intrusives                                |
| LOWER DEVONIAN                                                                                                                                                  | Slate, grits, etc. with basic intrusives                                                |
| ARCHEAN                                                                                                                                                         | Dodman and Start Schists in the Lizard Complex and on Dodman Point                      |

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Table 8. The Geological Succession of Cornwall (based on Webb, 1947).

### Description of the Coast, and Drainage

The western coast of Mount's Bay, that is, south of Mousehole, is characterised by high and rugged granite cliffs. North of Mousehole, the coast is less rugged, and consists mostly of dolerite (greenstone) and thermally metamorphosed slate. On the foreshore near Penzance, there is an alternation of slate, greenstone and hornblende-schist (Steers, 1946). Between Penzance and Marazion is an alluvial low-lying area where a narrow thin belt of sand dunes borders the beach, and in the inland portion, marshy tracts of land are found in places. Towards Praa Sands, with the exception of Cudden Point where there is a prominent greenstone outcrop, the slate cliffs are lower and less rugged than the granite cliffs. At Praa Sands, sand dunes overlie the ill-defined low head cliffs. Southeast of Praa Sands, Godolphin granite forms high cliffs especially at Rinsey Head and Trewavas Head. Farther east, in the direction of Loe Bar, the slate cliffs become lower and less jaggy. Inland, the terrain is typically gently rolling.

The major drainage systems in the study area are Newlyn, Penzance, Marazion, Praa Sands and Porthleven Rivers. There are also smaller streams in Mousehole and Perranuthnoe. On the eastern side of Mount's Bay, the River Cober, which rises about 10 miles inland, discharges into the bay through a sand barrier (Loe Bar). All the rivers generally have moderately sloping banks, and are

draining catchment areas containing numerous abandoned tin workings which have contaminated, to some degree, the stream sediments with tin-rich dump materials.

## SECTION B: MARINE FEATURES

### Currents in the Bay

Ideally, a systematic investigation of the tidal and wave-generated longshore currents, and other physical processes in Mount's Bay should have been undertaken, but this was not possible due to lack of financial resources, and time.

Flood tide produces easterly surface and near-surface currents in the bay; in the southern portion, the maximum velocities (6 hours before High Water at Dover) during neap and spring tides are 0.5 and 0.9 knot, respectively. As the ebb tide commences, southerly currents occur (2 hours before High Water at Dover), with velocities of 0.3 knot for neap tide and 0.5 knot for spring tide. At the height of the ebb tide in the bay (High Water at Dover), westerly currents are generated; the maximum velocities during neap and spring tides are the same as those of the flood tide (Pocket Tidal Stream Atlas, 1961).

In addition, the residual bottom currents in the southern portion of Mount's Bay during summer is from east to west (L.H.N. Cooper, personal communication).

### Bathymetric Features

The deepest part of the study area exceeds 160 feet, and it is located about four miles south of Penzance. Eastwards, Mount's Bay becomes shallower; the shallowest area is the central portion, south of the Marazion-Praa Sands coastline where the maximum depth is less than 90 feet. Farther east, the bay deepens to more than 100 feet.

The sea bottom in the western and eastern sides of the bay are predominantly sandy, and sloping gently towards the open sea. With the exception of the small bodies of sand near Tre-wavas, Praa Sands, Perranuthnoe and Marazion, the central portion which constitutes about one-third of the study area, is largely bare of unconsolidated sediments. Its rocky bottom is extremely irregular with some ill-defined "valleys" (Figure 18).

### Bedrock Topography

It is of particular interest to note that underneath the unconsolidated marine sediments south of Penzance and Porthleven respectively, are deep depressions in the bedrock. In the western side, two of these buried valleys extend southwards. They appear to be extensions of the valleys of Newlyn, Penzance and Marazion Rivers. Likewise, the submerged valleys in the east seem to be related to the Porthleven and Cober drainage systems (Figure 19)

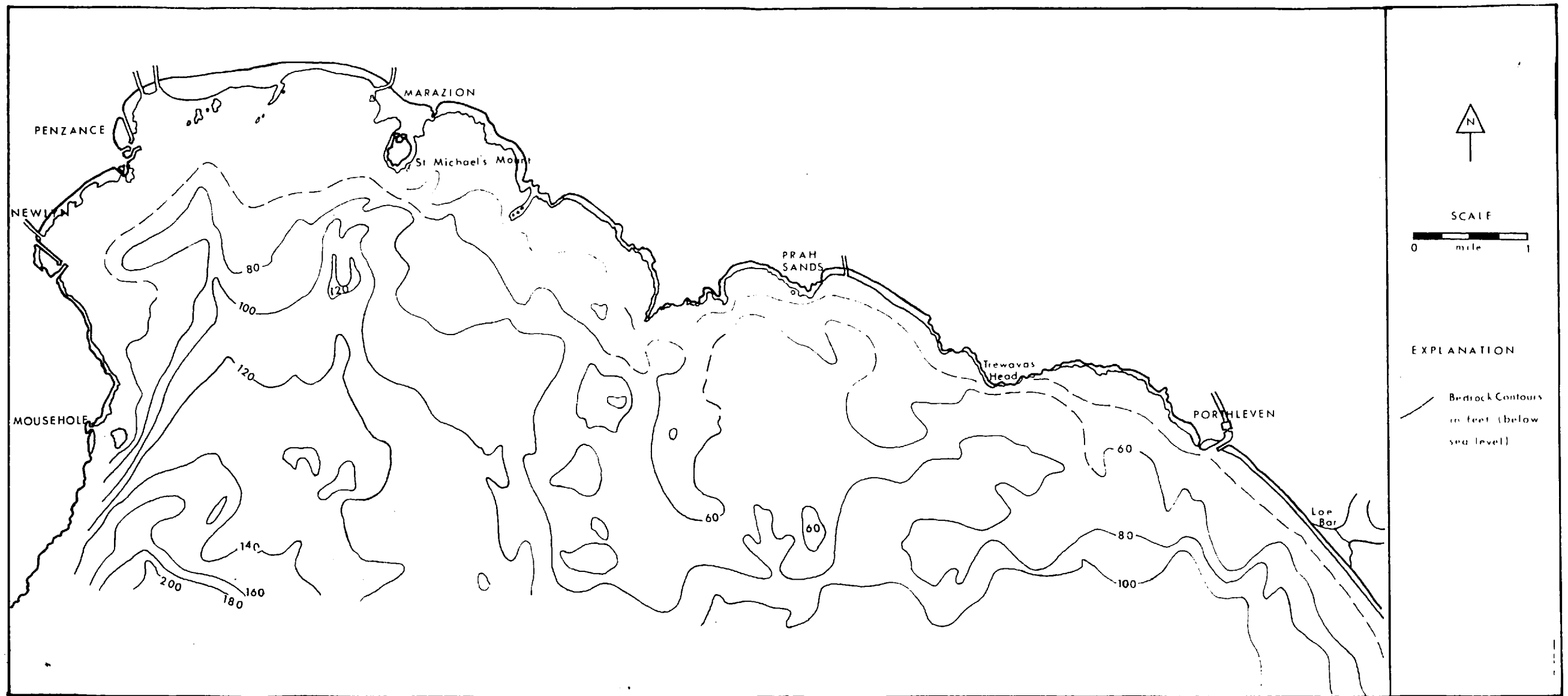


Figure 19. Bedrock topography of Mount's Bay calculated from the echometer and sparker charts.

With the meagre available information about the bedrock in Mount's Bay, it is not possible to explain adequately the genesis of the buried valleys. Nevertheless, their development could be attributed to the physiographic evolution of the British Isles. Wills (1929) had drawn attention to the fact that most parts of England were at a considerably higher elevation (relative to sea level) during the Pleistocene time, as compared to the present. He further emphasised that the data from drill holes in the Thames, Severn, and other river-valleys provided proof that there are ancient in-filled channels 60 to 90 feet below the existing sea level -- demonstrating an old land surface much higher, relative to sea level, than now. It is extremely likely that in the middle-Pleistocene Epoch (Glacial) the sea level was appreciably lower than that of today. In Cornwall, during the late-Pleistocene the mean sea level was 40 to 60 feet lower than at present (Robson, 1944). It was followed by gradual submergence, but even during the "forest epoch" (or early-Recent) the shoreline was still far south of the present shore, possibly near the 30-foot depth contour. It should be noted that from the late-Pleistocene (post-Glacial) to the modern times, the sea continued to rise, consequently the low-lying areas along the coast were flooded and then eventually buried under more recent estuarine and marine sediments. Thus, it is possible that a major portion, if not the whole, of Mount's Bay was at some time above the present-day high-water-mark. The

available evidence, therefore, suggests that the elongated depressions extend under the sea from the river mouths, and that they may have been connected with the existing river channels at some time in the recent past when the sea was relatively much lower than now.

#### Various Rock Types Under the Sea

Mylor Slates or killas has widespread occurrence in Mount's Bay. With the exception of some scattered bodies (possibly as dykes in the slates) of altered dolerite, slates constitute almost all the rocky bottom in the central portion of the bay, and the various rock outcrops south of Penzance

The seaward extensions of the outcrops of St. Michael's and Godolphin granites are very limited. Their offshore margins being only a few hundred feet from the coastline (Figure 18).

Hornfels and spotted slates are found in the vicinities of St. Michael's and Godolphin granites. Their common mineral components are tourmaline, cordierite, topaz, chlorite, muscovite, etc. South of Godolphin granite, spotted slates were observed more than one and a half miles seawards. Since spotting is normally restricted to the slates bordering the granite, it is probable, therefore, that the offshore granite-slate interface is shallow dipping. This is consistent with the low-angle dip of the granite-slate contact on the coast, near Praa Sands. By

contrast, the contact between Godolphin granite and slate in the east, near Porthleven, is steep and sharp (see Subbarao, 1960), and no well pronounced spotting is visible at the slate cliffs, along the coast, more than a mile east of the Godolphin granite.

In extremely rare instances, submarine slate with few specks of pyrite and copper sulphides were encountered. This suggests the possibility of bedrock mineralisation in some parts of Mount's Bay. In particular, the mineralised specimens were obtained from near the Godolphin granite, that is, south of the east-end of Praa Sands Beach, and from about two miles south of Cudden Point.

Only one of the divers had a proper training in geological mapping. Hence, the limited number of in-situ observations on the structures of the submarine rocks. The observed strikes of the beddings in the slates varied from N 50-75 E, and the dips from 40 NW to 10 SE.

#### The Distribution of the Marine Sediments

The unconsolidated sediments in Mount's Bay occur as several independent sand formations. The major deposits are mainly situated in the western and eastern parts of the bay. There are, however, also smaller sand formations in the minor bays off Trewavas, Praa Sands, Perranuthnoe and Marazion, respectively (Figure 20). (Hereafter, the foregoing bodies of sand will be referred to by the name of the well-known locality nearest to

each deposit, such as Penzance marine sediments, Porthleven marine sediments, Trewavas marine sediments, etc.)

On the whole, the marine sediments south of Penzance have variable texture. All sorts of grain sizes are represented; however, fine and very fine sand preponderate and they cover most of the central portion of the western half of the bay. The medium grained sands are found only as isolated patches near the coast and rock outcrops under the sea. Whereas, the pebbly and shelly coarse sands are invariably occurring in close proximity of submarine rock outcrops. The inshore sediments south of Marazion are fine to medium grained, with some patches of coarse sand particles near the shore. Off Perranuthnoe, the sediments are largely fine grained with very limited occurrence of medium grained size particles close inshore. By contrast, the Praa Sands sediments are predominately medium to coarse grained. The latter is generally confined to the southern portion of the sand formation, bordering the extensive submarine slate outcrop south of Praa Sands. Similarly, medium graine size particles constitute the small body of sand east of Rinsey Head. The Trewavas sediments is mainly fine grained; however, medium grained sands preponderate near the coves west of Porthleven, and coarse grained sand is found in the vicinity of the sand-slate interface south of Trewavas Head. Apart from the limited occurrence of sand with pebbles and shells close to

the submarine slate south of Porthleven, the offshore sediments in the east have a less variable texture than the Penzance sediments. There is a preponderance of fine grained sands which cover most parts of the eastern half of Mount's Bay, except near the middle where there is an appreciable concentration of very fine grained sediments.

The Penzance sediment formation with a maximum thickness exceeding 60 feet, is the thickest among the various sand bodies. On the other hand, Porthleven deposit has a thickness not greater than 30 feet. Trewavas-Rinsey, Praa Sands and the other smaller bodies of offshore sediments are all less than 20 feet thick.

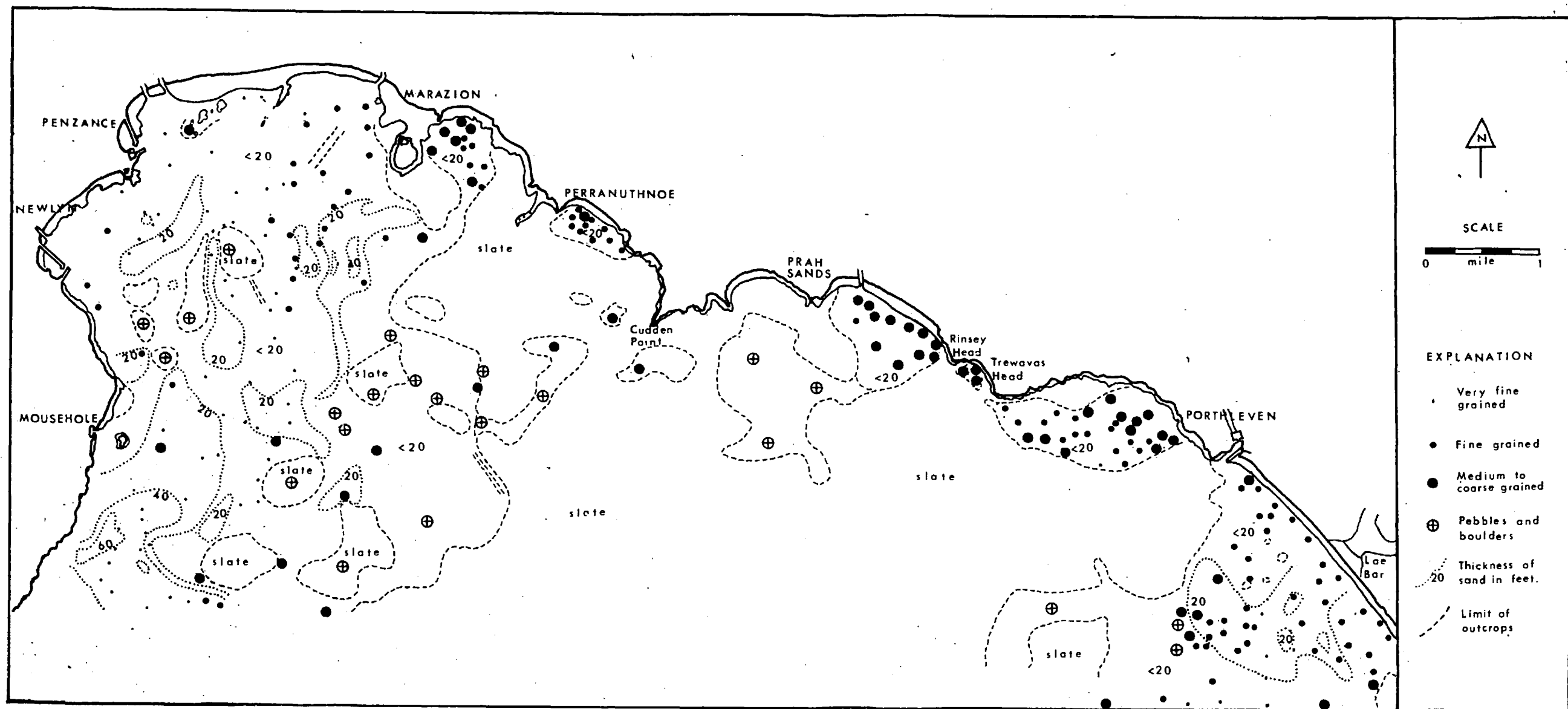


Figure 20. Thickness and character of the unconsolidated sediments in Mount's Bay.

PART III: GEOCHEMICAL RESULTS

SECTION A: THE DISTRIBUTION OF TIN IN THE VARIOUS TYPES OF  
COASTAL AND OFFSHORE ROCKS, HEAD, SAND DUNES AND  
MINE DUMPS ALONG THE COAST, AND STREAM SEDIMENTS

Tin Contents of the Offshore and Coastal Rocks

By and large, with the exception of the altered granite and slates having traces of mineralisation, the rocks under the sea are not particularly rich in tin. Of the unmineralised samples analysed, the "fresh" granite has the highest tin content, 40 to 150 ppm; most of the values being close to the global average amount of tin in the granite, that is, 80 ppm (Rankama and Sahama, 1960). Altered dolerite or greenstone contains 40 to 70 ppm, and is similar to the spotted slate which contains 40 to 60 ppm tin. The slate not affected by the thermal metamorphism (no spots) contains only 15 to 60 ppm tin --- the lowest range of tin values obtained from the submarine rocks (Table 9). No porphyry dyke was encountered underneath the sea; thus there is no analytical data for this particular rock type.

Like their offshore counterparts, the various kinds of rocks along the coast, except the lodes, are generally not rich in tin. Also, it was observed that the unaltered granite has the highest tin content (40 to 270 ppm) and is followed by dolerite which

| Sample Type        | No. of<br>Samples | Tin Contents (ppm) |      |
|--------------------|-------------------|--------------------|------|
|                    |                   | Range              | Mean |
| <u>Offshore</u>    |                   |                    |      |
| Granite            | 2                 | 40 - 150           | 95   |
| Dolerite           | 4                 | 40 - 70            | 55   |
| Spotted slates     | 2                 | 40 - 60            | 50   |
| Slates             | 21                | 15 - 60            | 40   |
| Altered granite    | 1                 | 1500               | --   |
| Slate with pyrite  | 2                 | 200 - 500          | 350  |
| -----              |                   |                    |      |
| <u>Terrestrial</u> |                   |                    |      |
| Granite            | 7                 | 40 - 270           | 135  |
| Dolerite           | 5                 | 40 - 160           | 65   |
| Spotted slates     | 2                 | 40                 | 40   |
| Slates             | 3                 | 30 - 40            | 35   |
| Elvans (dykes)     | 2                 | 30 - 40            | 35   |
| Quartz veins       | 2                 | 40                 | 40   |
| Lodes              | 3                 | 2100 - 4000        | 2900 |
| Peat               | 2                 | 10 - 20            | 15   |

Table 9. Tin contents of some typical samples from the rocks along the coast, and underneath the sea.

has a tin content varying from 40 to 160 ppm. The spotted slate has the third-highest tin content (40 ppm), while the unaltered (not spotted) slate has the least tin tenor (30 to 40 ppm) among the common rock types. The porphyry dykes from Long Rock

and Praa Sands contain 50 and 40 ppm tin, respectively. In addition, several samples of the unmineralised quartz veins in the slate and dolerite were analysed, the amount of tin in them does not exceed 50 ppm. Similarly, the peat bed at Praa Sands has a very low tin content, only 10 to 20 ppm. Finally, it is of interest to note that a composite sample of spots from the spotted slates, taken from several outcrops east of Godolphin granite, contain tin as low as 40 ppm.

#### Tin Contents of the Head Deposits Along the Coast

The head is not discussed together with the hard rocks because of its unique physical characteristics. On the whole, the matrix (clay cementing materials) and cobbles of the different head formations are poor in tin, most of the values being less than 100 ppm. However, a composite sample from the matrix of the head deposit in Perranuthnoe yielded 1,400 ppm (Table 10) tin. This is an isolated case, and it may be due to localised

| Sample Numbers   | Type of Samples | Sn - ppm  |
|------------------|-----------------|-----------|
| 1013, 1019, 1112 | Matrix          | 20 - 1400 |
| 999, 1014, 1029  | Cobbles, etc.   | 30 - 70   |

Table 10. Tin contents of some typical samples from the matrix and cobbles of the head formations along the coast.

accumulation of tin-rich minerals in some portions of this particular head formation.

Two typical head-matrix samples from Praa Sands and Porthleven were subjected to elutriation and dry-sieving (Table 11).

| Elutriation                     |    |          |        | Dry-sieving |    |          |        |
|---------------------------------|----|----------|--------|-------------|----|----------|--------|
| Microns                         |    | % Sample | Sn-ppm | Microns     |    | % Sample | Sn-ppm |
| <u>Sample 998 - Porthleven</u>  |    |          |        |             |    |          |        |
| >300                            | C  | 36.5     | 20     | >494        | C  | 23.7     | 40     |
| 200-300                         | M  | 2        | 25     | 195-494     | M  | 22.2     | 20     |
| 100-200                         | F  | 5.9      | 20     | 107-195     | F  | 5.5      | 30     |
| 90-150                          | F  | 5.9      | 20     | 53-107      | VF | 6.4      | 30     |
| 70-100                          | VF | 1.9      | 25     | <53         | SC | 39.4     | 30     |
| 60- 80                          | VF | 11.9     | 25     | --          | -- | --       | --     |
| <60                             | SC | 18.6     | 20     | --          | -- | --       | --     |
| <u>Sample 1112 - Praa Sands</u> |    |          |        |             |    |          |        |
| >300                            | C  | 28.9     | 100    | >494        | C  | 21.1     | 90     |
| 200-300                         | M  | 2.5      | 40     | 195-494     | M  | 17.8     | 80     |
| 100-200                         | F  | 6.9      | 30     | 107-195     | F  | 8.3      | 40     |
| 90-150                          | F  | 7.3      | 60     | 53-107      | VF | 5.9      | 100    |
| 70-100                          | VF | 1.9      | 50     | <53         | SC | 43.1     | 60     |
| 60- 80                          | VF | 14.2     | 50     | --          | -- | --       | --     |
| <60                             | SC | 26       | 40     | --          | -- | --       | --     |

Table 11. Elutriation (first set of tubes) and dry-sieving data of typical head-matrix specimens from the cliffs in Porthleven and Praa Sands.

Notes: 1. C-coarse, M-medium, F-fine, VF-very fine, and SC-silt and clay.

Both methods indicate a bi-modal distribution of the matrix components. The results also indicate that the tin is not significantly concentrated in any of the size-fractions. All tin values in the elutriation and dry-sieved fractions do not exceed 100 ppm.

The losses during the elutriation was rather high, 11 to 17 per cent; this is due to the preponderance of fines in the samples treated, and the inefficiency of the first set of elutriation tubes.

#### Tin Contents of Mine Dumps Along the Coast

As expected, there is an abundant occurrence of tin in the mine dumps along the coast. A composite sample from the dump near Rinsey Head yielded 2,000 ppm tin. Likewise, 4,000 ppm tin was obtained in a similar sample from the dump in the vicinity of Trewavas Head.

#### Tin Contents of Sand Dunes

The tin in the sand dunes is extremely low, the values are only in the order of 20 to 30 ppm. Nevertheless, a sample taken directly above the backshore of Praa Sands Beach contains 290 ppm tin. This abnormally high tin concentration in a normally tin-poor deposit is probably due to the contamination from the underlying beach sand which is usually rich in tin (Section C).

### Tin Distribution in the Sediments of the Streams Draining into Mount's Bay

All the analytical data<sup>x</sup> from the stream sediments show that the rivers draining into Mount's Bay have considerable amounts of tin. The minus 80 mesh fractions of the sediments in Praa Sands and Porthleven Rivers contain tin as high as 10,000 (1 per cent) and 20,000 (2 per cent) ppm, respectively. Although the sediments of Newlyn, Penzance and Marazion Rivers have lower tin contents, they are still in the range 3,000 to 10,000 ppm. A more comprehensive geochemical survey of the drainage systems in Land's End District by Hosking, et al (1964), confirms that Newlyn and Marazion Rivers, and the two streams near Penzance contain several thousands parts per million tin: the majority of the recorded values are in the range 1,000 to 5,000 ppm. Their work further indicates that the tin distribution in the smaller streams at Mousehole and Long Rock varies from 2,000 to 6,000 ppm.

### Size Analyses

Selected samples from Marazion and Porthleven Rivers have been elutriated and dry-sieved (Tables 12 and 13).

x Unless otherwise stated, all the analytical data in this thesis on the tin contents of river and stream sediments, and of soils, refer to the minus 80 mesh fractions.

The dry-sieving data, basing on the Wentworth Scale (all size descriptions in the text are based on this scale), indicate that the bulk of the stream sediments are predominantly medium grained (195 to 494 microns); this size-range comprises 40 to 68 per cent of the samples studied. Conversely, the fine, very fine and silt ( $< 195$  microns) fractions have limited occurrence, their combined percentage of the samples is less than 10 per cent. On the whole, the distribution pattern of the dry-sieved fractions suggest a bi-modal occurrence of the various size particles in the overall composition of the stream sediments.

The elutriation fractions similarly demonstrate a bi-modal texture of the stream sediments (Figure 21). The fine, medium and coarse (100 to  $> 400$  microns equivalent quartz diameters) sands being dominant; whereas the very fine (50 to 100 microns) sediments are present in minor quantities. The silt and clay ( $< 60$  microns) components, in fact, represent a higher proportion of the samples than the latter.

It should be borne in mind that the size measurements of the elutriation fractions are based on the approximate diameters of grains in every fraction. Moreover, there is no vast difference in the sizes of the various constituents of the respective fraction. In fact, with the exception of the heavy minerals which in most cases are sparse, each fraction appears nearly uniform under a binocular microscope.

| Sample MRA (1126) - Elutriation |           |        |        | Sample MRB (1058) - Dry-sieving |           |        |        |
|---------------------------------|-----------|--------|--------|---------------------------------|-----------|--------|--------|
| Frac                            | Microns   | % Smpl | Sn-ppm | Frac                            | Microns   | % Smpl | Sn-ppm |
| 1                               | C >400    | 26.6   | 7200   | 1                               | C >494    | 26.9   | 1000   |
| 2                               | M 200-400 | 36.2   | 6150   | 2                               | M 195-494 | 67.6   | 1700   |
| 3                               | F 150-250 | 15.4   | 7050   | 3                               | F 107-195 | 2.2    | 7600   |
| 4                               | F 100-150 | 10     | 3300   | 4                               | VF 53-107 | 0.1    | 5200   |
| 5                               | VF 70-120 | 0.08   | 1500   | 5                               | SC <53    | 0.2    | 4800   |
| 6                               | VF 50- 80 | 0.12   | 2500   | -                               | --        | --     | --     |
| 7                               | SC 40- 60 | 0.9    | 3100   | -                               | --        | --     | --     |
| 8                               | SC <40    | 0.6    | 3400   | -                               | --        | --     | --     |

Table 12. Elutriation (second set of tubes) and dry-sieving data of two stream sediments samples from Marazion River.

| Sample PRA (1072) - Elutriation |           |        |        | Sample PRB (1071) - Dry-sieving |           |        |        |
|---------------------------------|-----------|--------|--------|---------------------------------|-----------|--------|--------|
| Frac                            | Microns   | % Smpl | Sn-ppm | Frac                            | Microns   | % Smpl | Sn-ppm |
| 1                               | C >400    | 55.6   | 12250  | 1                               | C >494    | 49     | 8400   |
| 2                               | M 200-400 | 22     | 10000  | 2                               | M 195-494 | 40.4   | 14500  |
| 3                               | F 150-250 | 6.6    | 7200   | 3                               | F 107-195 | 4.9    | >25000 |
| 4                               | F 100-150 | 6.3    | 7200   | 4                               | VF 53-107 | 1.6    | >25000 |
| 5                               | VF 70-120 | 0.1    | 8000   | 5                               | SC <53    | 3.1    | 7600   |
| 6                               | VF 50- 80 | 0.1    | 5600   | -                               | --        | --     | --     |
| 7                               | SC 40- 60 | 7.5    | 2700   | -                               | --        | --     | --     |
| 8                               | SC <40    | 0.3    | 2600   | -                               | --        | --     | --     |

Table 13. Elutriation (second set of tubes) and dry-sieving data of two stream sediments samples from Porthleven River.

Notes: 1. C-coarse, M-medium, F-fine, VF-very fine, and SC-silt and clay.

2. Refer to Figure 22 for sample locations.

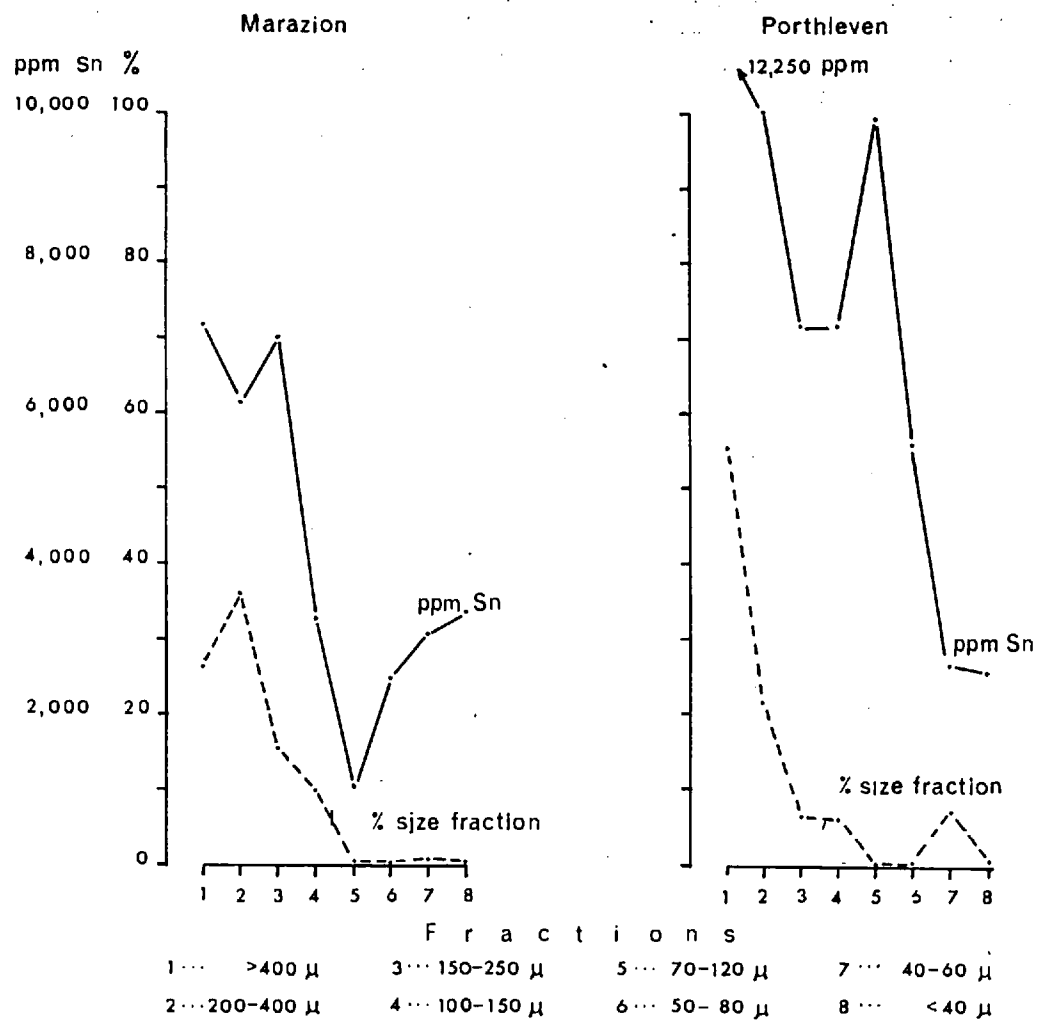


Figure 21. Distribution of tin in the elutriation size fractions of stream sediments from Marazion and Porthleven Rivers.

Although most of the tin-rich minerals are usually associated with the fine (53 to 195 microns) grained dry-sieved size fractions, which naturally have the higher tin concentration, the medium and coarse (195 to  $> 494$  microns) fractions have appreciable tin contents as well. In contrast to the dry-sieving size analysis, the coarser (150 to  $> 400$  microns) elutriation fractions have generally higher tin contents than the finer size particles (Tables 12 and 13).

This marked disparity between the distribution patterns of tin in the dry-sieved and elutriation fractions, respectively, is due to the difference of the principles involved in the techniques. This is discussed more fully in the following section, that is, in Section B (Part III).

#### Heavy Mineral Separation

Heavy mineral separation was carried out on a number of typical samples. Owing to the preponderance of fines in the stream sediments, complete separation of the heavy minerals was rather difficult to achieve. Nevertheless, in three samples from Marazion, Praa and Porthleven Rivers, with moderate amounts of very fine particles, a partially satisfactory separation was attained by employing a small centrifuge.

As shown in Table 14, apart from the very high concentration of tin in the heavy minerals, the light fractions have considerable tin contents as well. This unusually high tin distribution

in the light minerals is presumably due to the inefficiency of the technique in the treatment of very fine sediments. But there is little doubt that tin occurs in the light fractions -- this observation was confirmed by the "zinc-plate test for tin". As will be discussed in the succeeding sections, the heavy minerals are invariably rich in tin.

| Sample<br>No | Locality   | % Heavy Mineral | Sn - ppm  |           |
|--------------|------------|-----------------|-----------|-----------|
|              |            |                 | Heavy Min | Light Min |
| 1058         | Marazion   | 30.3            | 15000     | 3750      |
| 1122         | Praa       | 10.2            | 17000     | 1300      |
| 1071         | Porthleven | 27.1            | > 25000   | 1880      |

Table 14. The tin contents of heavy (sp. gr.  $>2.96$ ) and light (sp. gr.  $<2.96$ ) fractions of stream sediments from Marazion, Praa and Porthleven.

## DISCUSSION

This discussion deals mainly on the possible influence of the submarine and coastal rocks, head, mine dumps, sand dunes, and stream sediments to the composition of the marine and beach sands.

### Offshore and Coastal Rocks

The wide range of tin values in the granite is attributed to the areal position of the samples. Those with high tin contents came from the parts of St. Michael's and Godolphin granites where there are known tin mineralisation.

Owing to the predominantly low concentration of tin in the different rock types along the coast and under the sea, their potential influence on the tin distribution in the marine and beach sands, is likely to be limited. The cassiterite and other tin-bearing minerals are not concentrated to any considerable degree during the weathering of the rocks because other common components are also highly resistant to weathering. Quartz, mica, tourmaline, feldspars, chlorite, etc., remain as predominant constituents of the sediments, and they serve as "mineral-diluents" of tin. Hence, the rocks along the coast and beneath the sea cannot be expected to contribute appreciable amounts of tin to the composition of the marine and beach sediments.

As mentioned previously, the mineralised veins and lodes along the coast occur only near the granite-slate contact in St. Michael's Mount and Trewavas. Furthermore, evidence of minor mineralisation in the submarine slate were observed only in two localities (Part II, Section B). Considering the comparatively rich concentration of tin in the mineralised veins and lodes, their capacity to contribute tin to the offshore and beach sands, appear considerable at first sight. This may be so in localised instances, but is not necessarily true on a large scale because of the limited occurrence of the lodes exposed to coastal erosion.

Since the tin-rich detrital materials derived from the inland lodes are introduced into the bay via the rivers, they will be considered later, together with the stream sediments (see page 80).

#### Head Deposits Along the Coast

On account of the generally low tin concentration in the head, its capacity to influence the overall distribution of tin-rich minerals in the offshore and beach sediments is presumably restricted to a small scale. In Perranuthnoe, however, where there is widespread occurrence of head along the shore, and abnormal high concentration of tin in some portions of its matrix (1,400 ppm), it is possible that the erosion product of the head

may contribute some amount of tin to the inshore sediments. This may perhaps explain the relatively high tin concentration in the Ferranuthnoe marine sediments.

#### Mine Dumps Along the Coast

Despite the unusually high tin contents of the mine dumps, it is doubtful that they have significant contributions to the overall composition of the offshore sediments, in that: (a) the mine dumps have only moderate volumes and are not extensively distributed along the coast, and (b) the mechanical mobility of the tin-bearing minerals from the dumps is somewhat limited; this is indicated by the low concentration of tin (390 ppm) in the top-soil down slope from the dump near Rinsey Head (as compared to the 2,600 to 4,000 ppm tin in the dump). Thus the erosion of the tin-rich dump materials into the sea appears not to be extensive. Hence it is unlikely that the mine dumps have a major influence on the composition of the sediments underneath the sea. It is, nevertheless, conceivable that dump-derived materials may contribute, in limited and isolated instances, to the constituents of the inshore sediments and beaches.

#### Sand Dunes

Since the sand dunes are composed mostly of wind-blown beach materials of low specific gravity (usually poor in tin),

they cannot supply notable quantities of tin to the marine and beach sands. Due to localised erosion, certain amount of dune sands may be brought back to the landward portion of the beaches. Furthermore, strong offshore winds may carry into the bay very fine tin-poor light minerals.

#### Stream Sediments

On account of the preponderance of lodes and abandoned tin workings (Dines, 1956) in the region drained by the rivers in the study area, there is an ample supply of tin-rich detrital and dump materials available for transportation by the rivers. This is clearly manifested by the invariably high tin concentration in the stream sediments. Considering the sizes and volumes of the major drainage systems, it is, doubtless, reasonable to assume that they are capable of moving enormous amounts of tin-bearing minerals and their associated sediments into Mount's Bay. The transporting capacity of the rivers are especially efficient during floods, when all shapes and sizes (except boulders) of sediments tend to be moved by rolling and/or saltation, and indeed the silt and clay particles are likely to be transported in suspension. The capacity of certain streams in Cornwall to carry tin-bearing sediments into the sea was observed in the St. Ives Bay area (Ong, 1962). The mechanical size analysis data of a series of samples taken at regular intervals along Red River,

showed that there is a progressive increase of the per cent distribution of the fines and their tin contents downstream. The reverse is true for the coarser fractions. This, certainly, indicate that the Red River is capable of transporting into the sea fine tin-rich minerals of terrestrial origin.

It is highly probable, therefore, that the streams have a much greater influence on the overall composition of the marine and beach sands, as compared to the erosion products of the mine dumps, and rocks in-situ along the coast and underneath the sea.

## SECTION B: THE DISTRIBUTION OF TIN IN THE MARINE SEDIMENTS

Inasmuch as the overall deposit of unconsolidated marine sediments in Mount's Bay consists of several formations, for convenience, the tenor of tin, and size distribution of the tin-bearing and siliceous<sup>x</sup> sediments in every sand body will be considered separately. The sequence of presentation is based on the relative volume of each formation, and not on the degree of tin concentration. The factors controlling the dispersion and deposition of the sediments in the various formations, including the significance of the observed data, will be discussed in a separate sub-section.

From the tin analysis results of all reconnaissance sand samples, a regional mean was calculated, amounting to 410 ppm. Moreover, for the purpose of comparison, local mean, that is, the average of tin values in each sand formation was determined as well.

### Penzance Offshore Sediments

The unconsolidated sediment south of Penzance cover almost two-thirds of the western half of Mount's Bay, and as mentioned

x Siliceous sediments include the quartz sand, and other tin-poor sediments.

previously, it is the thickest (maximum thickness is over 60 ft.) of all the sand formations.

The surficial occurrence of tin in the Penzance deposit is markedly variable. The analysis results are in the order of 10 to 2,100 ppm; giving a local mean of 150 ppm which is the lowest among the six separate bodies of sand. As shown in Figure 22 all the lowest tin values (less than 50 ppm) are found in the southern half of the Penzance sediments. Some of them are associated with the coarse and shelly sand which usually occur in the proximity of the submarine slate outcrops, or as thin unconsolidated cover of the bedrock and/or boulders. The tin values ranging from 50 to 100 ppm are broadly distributed; whereas the concentrations in the 100 to 500 ppm range, which comprise more than 50 per cent of the analytical data from Penzance deposit, are largely confined to the northwestern corner of the bay, that is, northwest of a line joining Mousehole to the St. Michael's Mount. All the 500 to 2,000 ppm tin values are located close to the shoreline, as for example near Penlee, Long Rock, and the mouth of Marazion River; not one sample containing this degree of tin concentration is located more than two miles offshore. The highest tin concentrations (2,100 ppm) are found only in the vicinity of Newlyn Harbour and St. Michael's Mount, respectively.

Owing to the ineffectiveness of the type of corer employed, only a limited investigation was possible on the vertical or

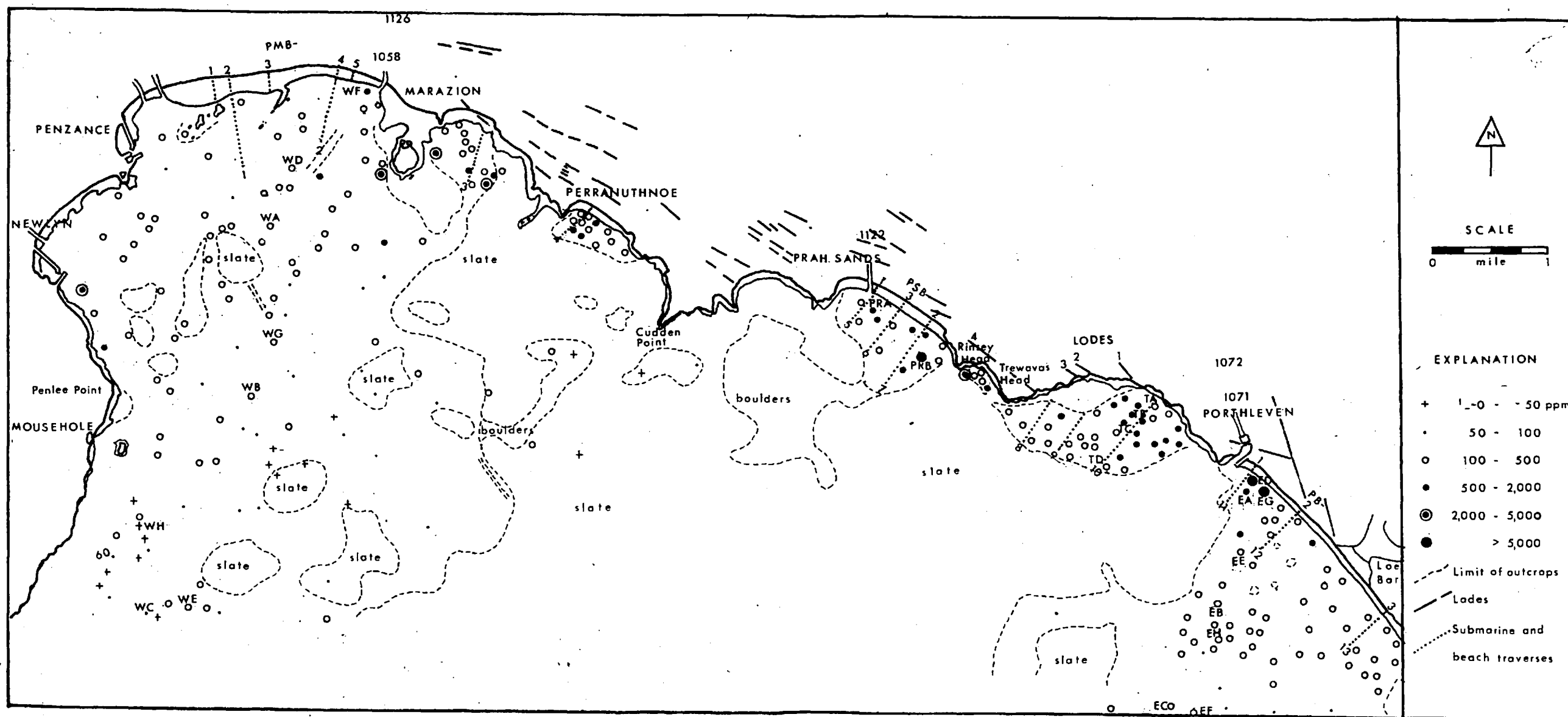


Figure 22. Tin content of the minus 80 mesh fraction of marine sediments in Mount's Bay.

profile distribution of tin. Two 4-foot core samples (gravity corer) from two points located, about 10 feet apart, one-third of a mile northeast of Penlee Point, show that the tin distribution decreases downwards to the lower sand horizons. The concentration of tin on the surface is about twice as much as than that of the sand horizon 4 feet below the sea (Table 15) floor.

| Depth in Feet | Sn - ppm | Description of Sediments          |
|---------------|----------|-----------------------------------|
| Core 1 0 - 1  | 120      | Fine to medium grained sand       |
| 1 - 2         | 120      | - do -                            |
| 2 - 3         | 80       | - do -                            |
| 3 - 4         | 70       | Medium to coarse sand with shells |
| Core 2 0 - 1  | 170      | Fine to medium grained sand       |
| 1 - 2         | 90       | - do -                            |
| 2 - 3         | 60       | - do -                            |
| 3 - 4         | 50       | Medium to coarse sand with shells |

Table 15. Vertical distribution of tin in two 4-foot cores from one-third of a mile northeast of Penlee Point.

#### Mechanical Size-Analyses

In order to determine the distribution pattern of the various size particles, and the size distribution of tin in the Penzance offshore sediments in relation to increasing depth of water, elutriation and dry-sieving size analyses were undertaken

on typical surface samples from different depths.

#### Elutriation:

The elutriation experiment was done in the new set of tubes (see page 41).

In each sample, regardless of its location, the fine grained (100 to 250 microns) particles preponderate; by comparison, the coarse ( $> 400$  microns), medium (200 to 400 microns), very fine (50 to 120 microns), and silt-clay ( $\leq 40$  to 60 microns) fractions constitute much smaller percentage of the respective sample.

Table 16 show that in sample WA which was taken from a water depth of 60 feet, the combined distribution of fine to coarse (100 to  $> 400$  microns) grained sand is 97.4 per cent. In sample WB from 100-foot depth, this size-range represents 87.7 per cent, and in sample WC from 150-foot depth, 78.3 per cent. By contrast, there is little change in the distribution trend of the very fine sand, but the quantity of the silt-clay particles ( $< 40$  to 60 microns), increases from 1.7 to 18.2 per cent.

On the whole, the elutriation data illustrate that the marine sediment-constituents have a bi-modal size distribution. The primary maximum which is composed of the 100 to 400 microns sand particles decreases in magnitude with increasing distance from the north-shore; on the other hand, the secondary maximum, represented by the 40 to 60 microns (silt and clay)

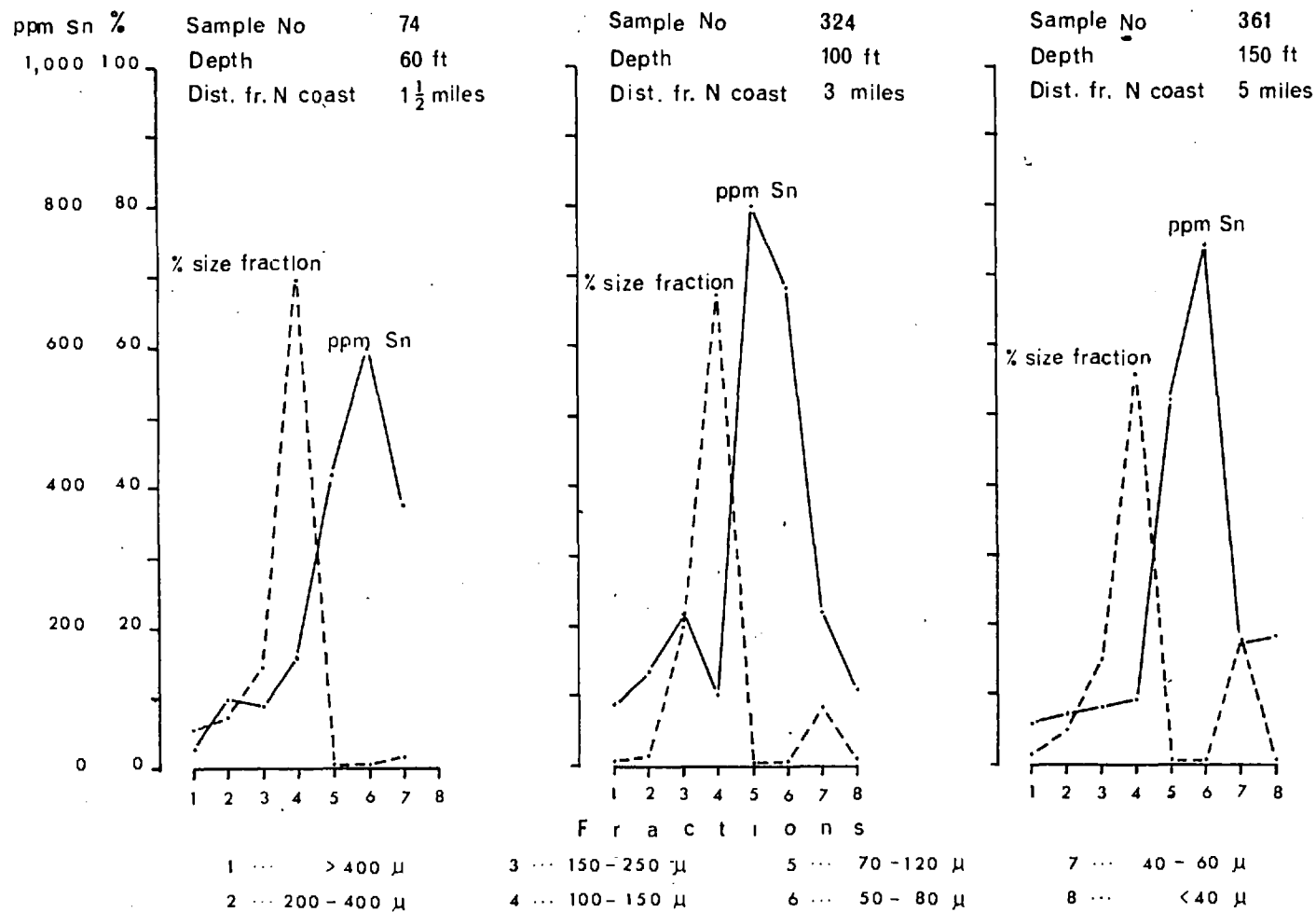


Figure 23. Distribution of tin in the elutriation size fractions of surficial marine sediments at increasing depths south of Penzance.

fractions, increases seawards (Figure 32). Moreover, the foregoing data clearly indicate that the Penzance sediments become generally finer towards the deeper parts of the bay.

In every one of the samples elutriated, the tin distribution among the different size fractions is highest in the very fine grained (50 to 120 microns) sands, and the second-highest concentration is in the silt-clay (< 40 to 60 microns) components. Conversely, the tin distribution in the fine to coarse (100 to > 400 microns) grained constituents is usually lower.

By and large, the tin contents or tenors of most of the fine to coarse (100 to > 400 microns) grained size fractions decrease towards the southern limit of the study area, but the tin tenors of the very fine and silt-clay fractions (< 40 to 50 microns) is somewhat irregular (see Table 16). By comparison, the proportion of tin (tenor multiplied by per cent distribution and divided by the computed total tin in the sample) in the fine to coarse grained fractions diminish seawards; whereas, those of the very fine and silt-clay components increase in the same direction.

#### Dry-sieving:

That the Penzance marine sediments become generally finer towards the open sea, as manifested by the elutriation experiment, was confirmed by the dry-sieving results. Table 17 shows that the fines (< 53 to 107 microns) quantitatively increase

| Frac | Microns | WA-60 ft. Deep |      |                       | WB-100 ft. Deep |                       |      | WC-150 ft. Deep |                       |      |
|------|---------|----------------|------|-----------------------|-----------------|-----------------------|------|-----------------|-----------------------|------|
|      |         | %              | Tin  |                       | %               | Tin                   |      | %               | Tin                   |      |
|      |         | Quartz         | Smpl | ppm Prop <sup>x</sup> | Smpl            | ppm Prop <sup>x</sup> |      | Smpl            | ppm Prop <sup>x</sup> |      |
| 1 C  | >400    | 5.3            | 30   | 1.1                   | 0.9             | 90                    | 0.6  | 1.6             | 60                    | 0.9  |
| 2 M  | 200-400 | 7.4            | 100  | 5.1                   | 1.5             | 140                   | 1.6  | 5.4             | 70                    | 3.7  |
| 3 F  | 150-250 | 14.9           | 90   | 9.3                   | 19.9            | 220                   | 32.4 | 15.2            | 80                    | 12.1 |
| 4 F  | 100-150 | 69.8           | 160  | 77.8                  | 67.4            | 100                   | 50   | 56.1            | 90                    | 50   |
| 5 VF | 70-120  | 0.3            | 420  | 0.9                   | 0.1             | 800                   | 0.6  | 0.2             | 520                   | 1.4  |
| 6 VF | 50- 80  | 0.3            | 600  | 1.3                   | 0.2             | 680                   | 1.1  | 0.2             | 750                   | 1.5  |
| 7 SC | 40- 60  | 1.7            | 380  | 4.5                   | 8.2             | 220                   | 13.2 | 17.2            | 170                   | 29   |
| 8 SC | < 40    | - -            | - -  | - -                   | 0.6             | 110                   | 0.5  | 1               | 180                   | 1.8  |

Table 16. Elutriation results of typical surficial samples from different depths in the western half of Mount's Bay.

| Frac | Microns  | WA-60 ft. Deep |      |                   | WB-100 ft. Deep |     |                   | WC-150 ft. Deep |     |                   |
|------|----------|----------------|------|-------------------|-----------------|-----|-------------------|-----------------|-----|-------------------|
|      |          | %              | Tin  |                   | %               | Tin |                   | %               | Tin |                   |
|      | Sizes    | Smpl           | ppm  | Prop <sup>x</sup> | Smpl            | ppm | Prop <sup>x</sup> | Smpl            | ppm | Prop <sup>x</sup> |
| 1 C  | >1040    | 1.4            | 50   | 0.7               | - -             | - - | - -               | - -             | - - | - -               |
| 2 C  | 494-1040 | 5.2            | 60   | 3.2               | 3.2             | 50  | 1.8               | 1.2             | 50  | 0.9               |
| 3 M  | 195- 494 | 6.2            | 50   | 3.1               | 8.6             | 50  | 4.8               | 8.6             | 50  | 6.5               |
| 4 F  | 107- 195 | 63.1           | 50   | 32.5              | 54.8            | 40  | 24.2              | 51.4            | 40  | 31.2              |
| 5 VF | 85- 107  | 1.2            | 30   | 0.4               | 1.8             | 20  | 0.4               | 2.1             | 40  | 1.3               |
| 6 VF | 65- 85   | 20.8           | 110  | 23.3              | 28.8            | 80  | 25.4              | 23.5            | 50  | 17.8              |
| 7 SC | 53- 65   | 1.3            | 1500 | 19.9              | 3.5             | 140 | 5.4               | 1.7             | 100 | 2.6               |
| 8 SC | < 53     | 0.7            | 2400 | 17.1              | 4.4             | 900 | 43.6              | 9.6             | 260 | 37.9              |

Table 17. Dry-sieving results of typical surficial samples from different depths in the western half of Mount's Bay.

- Notes: 1. x Proportion of the total tin content in each size fraction.  
2. C-coarse, M-medium, F-fine, VF-very fine, and SC-silt & clay.  
3. Refer to Figure 22 for location of samples.

as the bay deepens. For instance, the combined distribution of the aforesaid size-range in sample WA from a depth of 60 feet, and in sample WC from the deepest part of the study area (150 feet) are 24 and 36.9 per cent respectively. As expected, the per cent distribution of the coarser (107 to  $> 1040$  microns) grained constituents diminish in the direction away from the north-coast. This is exemplified by the clear-cut reduction in the percentage of the coarsest fraction ( $> 1040$  microns) from 1.4 per cent in sample WA to nil in samples WB and WC.

Like the elutriation results, the dry-sieving data indicate that the overall occurrence of the different size particles in the Penzance offshore sediments is, on the whole (Figure 24), bi-modal. The particles which preponderate are 107 to 195 microns (fine grained), this size range is strikingly similar to the elutriation Fraction 4 (100 to 150 microns) which was found to comprise a greater part of the Penzance sediments.

The size distribution pattern of tin in the dry-sieved fractions differs distinctly from that of the elutriation fractions. In elutriation, the tin distribution is low in the coarsest particles, then increases in the fine to very fine, and decreases again in the silt-clay components; whereas, the dry-sieving results show that, in every sample, the tin concentration increases as the fraction becomes finer. As a matter of fact, the highest tin distribution among the various fractions of the dry-sieved samples is invariably in the silt-clay components (Table 17).

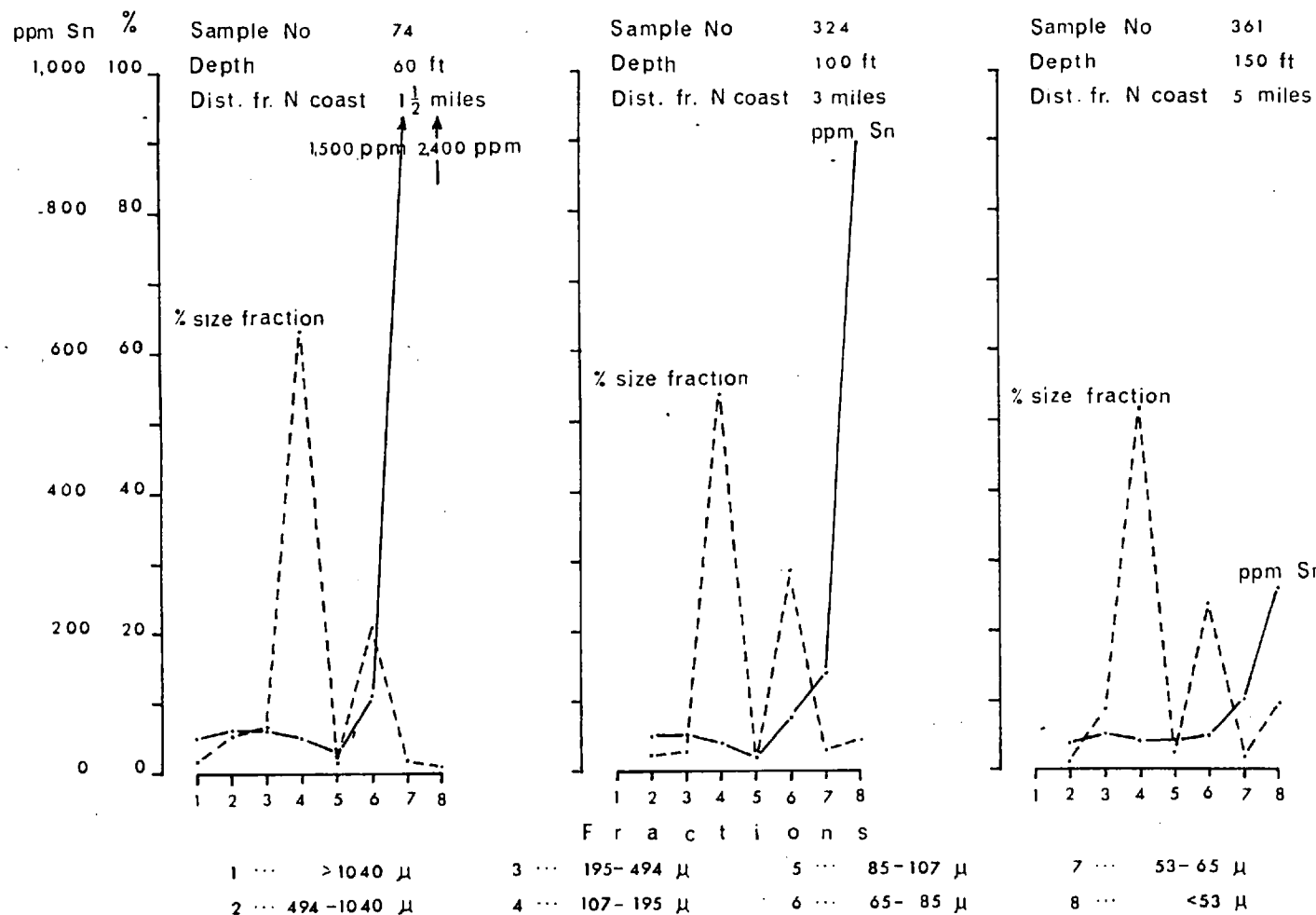


Figure 24. Distribution of tin in the dry-sieved size fractions of the elutriated samples presented in Figure 23.

In general, as Table 17 quite clearly indicate, the tin contents of the dry-sieved size fractions decrease as the sea gets deeper.

The foregoing information on the size distribution, and the variation of tenor and proportion of tin towards the deeper parts of the bay, are substantiated by the results, shown in Table 18, of the dry-sieving analysis of two samples from 40 and 160 feet deep, respectively.

| Frac   | Size<br>Microns | WD-40 ft Deep |        |                   | WE-160 ft Deep |        |                   |
|--------|-----------------|---------------|--------|-------------------|----------------|--------|-------------------|
|        |                 | % Smpl        | Sn-ppm | Prop <sup>x</sup> | % Smpl         | Sn-ppm | Prop <sup>x</sup> |
| 1 C    | > 1040          | ---           | ---    | ---               | ---            | ---    | ---               |
| 2 C    | 494-1040        | 0.8           | 110    | 0.3               | 0.5            | 50     | 0.4               |
| 3 M    | 195- 494        | 3.3           | 100    | 1.2               | 4.5            | 50     | 3.2               |
| 4 F    | 107- 195        | 72.7          | 100    | 26                | 54.3           | 50     | 38.2              |
| 5-7 VF | 53- 107         | 22.5          | 230    | 18.6              | 22.8           | 50     | 16.1              |
| 8 SC   | <. 53           | 0.6           | 25000  | 53.8              | 13.2           | 200    | 37.3              |

C-coarse, M-medium, F-fine, VF-very fine, and SC-silt and clay, Prop<sup>x</sup> - Proportion of the total tin content in each size fraction.

Table 18. Dry-sieving results of a second set of selected samples from different depths in the western half of Mount's Bay.

The disparity between the elutriation and dry-sieving data, with regards to the per cent distribution of the size fractions and their tin contents, is fundamentally due to the basic difference in the techniques. In elutriation, sizing is dependent

on both the diameter and specific gravity of the particles. Sorting is achieved by the varying water velocities inside the tubes where the different size particles move in suspension. Since cassiterite and other tin-bearing minerals are heavier than quartz grains of the same diameter, during the elutriation they tend to be associated with larger quartz particles; thus most of the coarser elutriation fraction contain more tin than the corresponding dry-sieved fractions. Conversely, the very light materials, such as shell fragments of bigger diameter may be associated with the fine quartz grains; this may partly explain the generally low tin contents of the finer elutriation fractions. It is of interest to note that the disparity of sizes in every elutriation fraction is not very striking. Individual fraction, in fact, appear uniform megascopically. For the sake of simplicity, the size of each fraction is expressed in terms of the estimated diameter-range of the quartz grains (equivalent diameters).

On the other hand, the size analysis by dry-sieving is done by using a series of screens so that a sample is divided into different size fractions irrespective of specific gravity. Hence, the dry-sieving data provide the true size distribution of tin.

It is noteworthy that in the sample with abundant fines the tin contents of fine dry-sieving fractions tend to be higher than those of the equivalent elutriation fractions because in the latter, apart from the abundance of shell fragments, some of the

tin-rich silt-clay components are lost with the overflow.

In spite of the aforesaid drawback of elutriation, it has an advantage of vital importance, that is: one can estimate the size-range of sediments transported in suspension at a known velocity.

#### Heavy Mineral Separation

In an attempt to establish the dispersion pattern of the heavy minerals from the shore towards the deeper parts of the bay, a number of samples from near the mouth of Marazion River (WF), the middle of the Penzance sediments (WG), and the deepest part of the bay (WH) were subjected to heavy mineral separation.

| Smpl | Per cent   | Sn - ppm   |            | Water        | Dist. fr.   |
|------|------------|------------|------------|--------------|-------------|
|      | Heavy Min. | Heavy Min. | Light Min. | Depth in Ft. | Marazion R. |
| WF   | 3.7        | >10000     | 1000       | 10           | 1/6 mile    |
| WG   | 2.1        | 1650       | 50         | 90           | 2.3 miles   |
| WH   | 1.5        | 2100       | 10         | 110          | 4 miles     |

Table 19. Per cent distribution of heavy minerals, and the tin contents of heavy and light fractions of selected samples from different depths (water) in the western half of Mount's Bay.

From the tabulated results in the above table (19), it is clear that the concentration of heavy minerals decreases as the distance from the north-shore increases. Also the tin contents

of the heavy and light fractions decrease in the same direction. For example, the tin content of the heavy minerals of sample WF, nearest to the mouth of Marazion River, is more than five times as much of those from the deeper parts of the bay (WG and WH). There is, moreover, an even bigger reduction in the tin contents of the light fractions.

The strikingly high tin contents of the heavies and lights in the inshore sand from the vicinity of Marazion River outlet is compatible with the heavy minerals studies in the stream sediments of Marazion River, where it was observed that both the heavy and light mineral fractions contain appreciable amounts of tin.

#### HCl-Treatment

With a view to ascertaining the mode of distribution of the shell fragments and other HCl-soluble materials with respect to water depth changes, the samples examined for heavy mineral properties, were also subjected to HCl-treatment.

The data in Table 20 clearly demonstrate that the spread of shell fragments and the other HCl-soluble constituents considerably increase in the direction away from the coast. Sample WH, for instance, which came from a depth of 110 feet contains 52 per cent HCl-soluble, and contrariwise, the sample WF nearest to the shore contains only 15 per cent.

| Sample | Per Cent of HCl-soluble | Depth in Feet |
|--------|-------------------------|---------------|
| WF     | 15                      | 10            |
| WG     | 19                      | 90            |
| WH     | 52                      | 110           |

Table 20. The per cent distribution of HCl-soluble components of sand samples from different water depths.

The seaward increase of the shell fragments distribution, although well-pronounced, is by no means uniform. It was observed in the field that, in majority of cases, abundant concentration of coarse shell fragments are found in the immediate vicinities of the scattered submarine slate outcrops situated near the shore, and in the deeper parts of the western half of Mount's Bay. Similarly, coarse shell fragments are common constituents of the thin and pebbly unconsolidated sand cover of some depressions in the wide-spread submarine slate outcrop south of St. Michael's Mount.

In passing, it might be mentioned that even if the tin content of the light fraction is calculated on the basis of the materials insoluble in HCl, the decrease of tin content, with respect to increasing distance from the north-coast, is very much greater in the lights than in the heavies. The ratio of the tin contents of the heavy mineral fraction in sample WF to WH is 5:1 but the ratio of tin calculated from the HCl-insoluble lights of the same samples is 56:1.

### Porthleven Offshore Sediments

The Porthleven unconsolidated sediments formation is, in terms of areal extent and thickness (maximum thickness is over 20 feet), next to Penzance deposit. It covers the greater part of the eastern half of Mount's Bay. In general its texture is less variable but slightly coarser than the Penzance sediments.

The surficial distribution of tin in the Porthleven formation is generally much higher than in the Penzance deposit (see Figure 22). No tin concentration below 50 ppm was observed; the lowest and highest values are 60 and 5,000 ppm, respectively. The local mean is 340 ppm which is more than twice than that of the Penzance sediments, but still below the regional mean. Only few analytical results which fall within the limits of the lower range (50 to 100 ppm) were observed, and their occurrence is restricted to the southern portion of the formation. Most of the values are between 100 to 500 ppm, and they are widely distributed. The 500 to 2,000 ppm range are confined to near the shore. Similarly, the 5,000 ppm values are only found a few hundred feet southeast off Porthleven Harbour.

### Mechanical Size-Analyses

In an attempt to determine the distribution trend of the different size particles and also the size distribution of tin, with respect to increasing water depth in the eastern half of

Mount's Bay, selected samples were elutriated and/or dry-sieved.

In addition, a set of profile samples were elutriated. The profile constitute a group of samples from the surface of the sea bed and those from underneath it. Unfortunately no depth of sampling and thickness measurements could be obtained because the samples were collected with a suction pump, and this technique was still in the experimental stage. Owing to the limitation of the technique, it is not unlikely that most of the profile samples are unrepresentative. Hence, the results of studies on them may have lesser significance than of the other samples.

#### Elutriation:

The elutriation results confirm the field observation that, on the average, the Porthleven sediments formation is comparatively coarser than the Penzance deposit. Apart from the negligible occurrence of clay particles ( $< 40$  microns) in the samples treated, in general the distribution pattern of the size fractions is similar to that of the latter, that is, the sediments become finer towards the deeper part (Table 21) of the bay. In a similar way to the Penzance deposit, the overall size distribution of the Porthleven sediments is weakly bi-modal (Figure 25). It should be noted that the abnormally high percentage of coarser (200 to  $> 400$  microns) fractions in sample EB from a depth of 80 feet is due to its appreciable content of shell fragments.

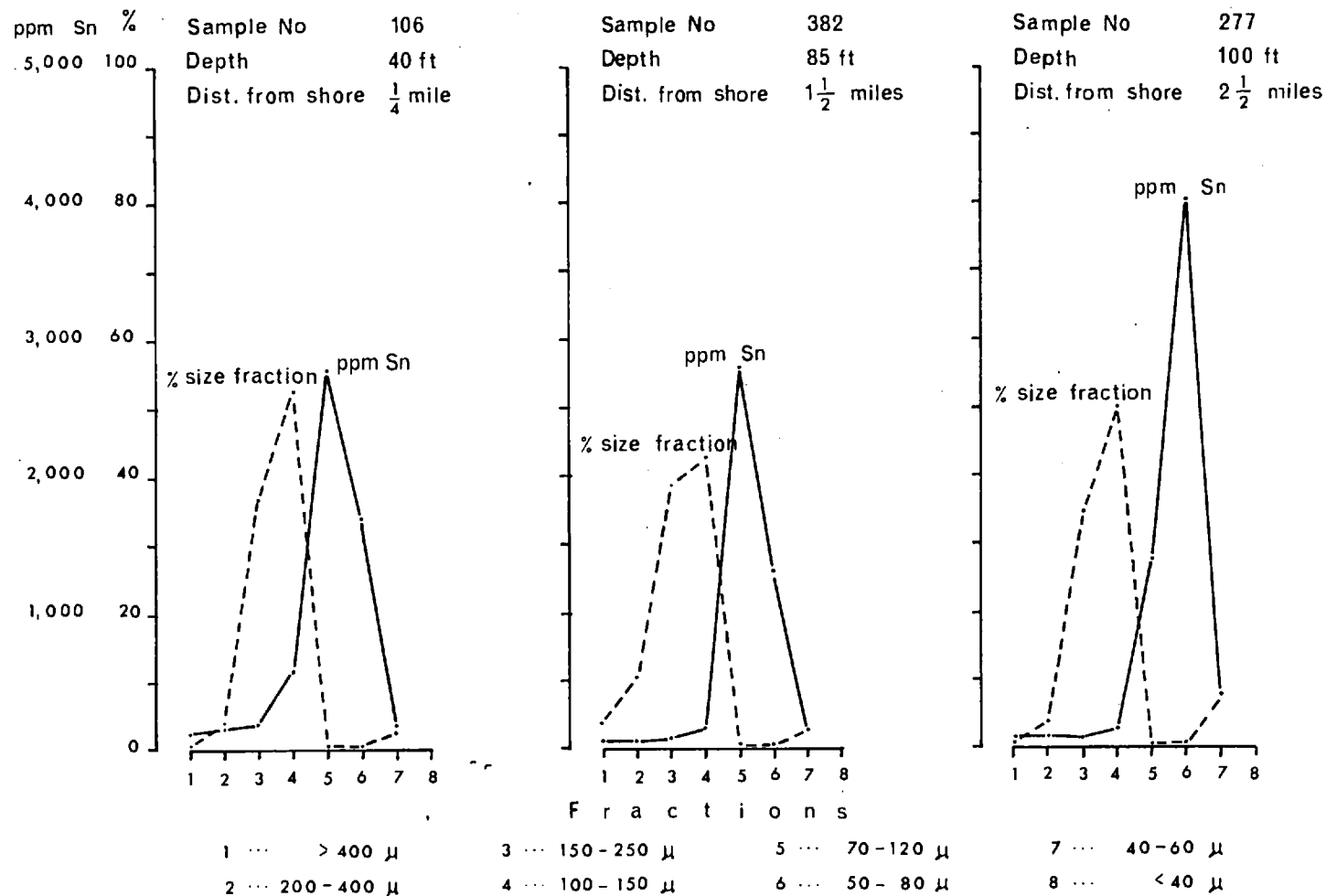


Figure 25. Distribution of tin in the elutriation size fractions of surficial marine sediments at increasing depths south of Porthleven.

Although the tin contents of the different size fractions of the Porthleven samples are 14 to 40 per cent higher than those observed in the elutriated Penzance sediments, by and large, the tin size distribution trend is similar to that of the latter. The high tin tenor is usually associated with the very fine grained (50 to 120 microns) fractions, while the high proportion of tin is in the fine grained (100 to 250 microns) components (Table 21).

Table 21 further indicate that, on the whole, the tenor and proportion of tin in the fine to coarse grained (100 to >400 microns) sediments decrease as the water depth and distance from Porthleven increase. By contrast, in the very fine (50 to 120 microns) grained fractions, the tin tenor does not follow a definite pattern, but the proportion of tin increases steadily seawards. Associated with this, there is a slight increase of the tenor and proportion of tin in the silt (40 to 60 microns) fraction.

In the elutriation of the profile samples from half a mile south of Porthleven, the per cent distribution of the various size fractions indicate that the sediments become finer towards the subjacent sand horizons. In the surface and middle-horizon samples, the maximum tin concentration is in the lower range of the very fine (50 to 80 microns) grained fractions; whereas, in the deeper horizon, it is associated with Fraction 3 (150 to 250 microns) which represents the upper range of the fine grained fractions (see Table 22). It is interesting to note that

| Frac | Microns | EA-40 ft. Deep               |      |                       | EB-80 ft. Deep                |                       |      | EC-100 ft. Deep               |      |      |
|------|---------|------------------------------|------|-----------------------|-------------------------------|-----------------------|------|-------------------------------|------|------|
|      |         | $\frac{1}{4}$ mi S of Porth. |      |                       | $1\frac{1}{3}$ mi S of Porth. |                       |      | $2\frac{1}{6}$ mi S of Porth. |      |      |
|      |         | % Tin                        |      |                       | % Tin                         |                       |      | % Tin                         |      |      |
|      |         | Quartz                       | Smpl | ppm Prop <sup>x</sup> | Smpl                          | ppm Prop <sup>x</sup> | Smpl | ppm Prop <sup>x</sup>         |      |      |
| 1 C  | > 400   | 0.5                          | 100  | 0.1                   | 2.4                           | 50                    | 1.2  | 0.3                           | 80   | 0.2  |
| 2 M  | 200-400 | 3.7                          | 160  | 1.4                   | 10.4                          | 50                    | 5    | 3.5                           | 90   | 2.5  |
| 3 F  | 150-250 | 38.8                         | 190  | 18.2                  | 38.9                          | 70                    | 26.5 | 35.1                          | 80   | 21.8 |
| 4 F  | 100-150 | 52.7                         | 600  | 77.1                  | 42.8                          | 140                   | 58.2 | 50.1                          | 120  | 47.1 |
| 5 VF | 70-120  | 0.1                          | 2800 | 0.7                   | 0.1                           | 2800                  | 2.7  | 0.3                           | 1400 | 3.3  |
| 6 VF | 50- 80  | 0.2                          | 1700 | 0.8                   | 0.2                           | 1300                  | 2.5  | 0.2                           | 4000 | 6.2  |
| 7 S  | 40- 60  | 2.7                          | 190  | 1.3                   | 2.8                           | 130                   | 3.5  | 7.9                           | 260  | 16   |

Table 21. Elutriation results of selected samples with increasing distance from Porthleven coastline.

| Frac | Microns | Surface Sample      | Middle Sample | Deepest Sample |
|------|---------|---------------------|---------------|----------------|
|      | Quartz  | % Smpl Sn-ppm       | % Smpl Sn-ppm | % Smpl Sn-ppm  |
| 1 C  | > 400   | 2.2 10              | 3.5 60        | 0.4 30         |
| 2 M  | 200-400 | 6.8 90              | 4.1 40        | 1.5 100        |
| 3 F  | 150-250 | 52.5 290            | 44 250        | 33.3 950       |
| 4 F  | 100-150 | 35 210              | 46 210        | 59.6 250       |
| 5 VF | 70-120  | 0.1 60 <sup>z</sup> | 0.1 300       | 0.5 200        |
| 6 VF | 50- 80  | 0.2 2000            | 0.2 2000      | 0.2 200        |
| 7 S  | 40- 60  | 1 110               | 1.3 230       | 1.4 210        |

Table 22. Results of the elutriation of profile samples from south of Porthleven.

- Notes: 1. Distribution of clay particles (Fraction 8) is negligible.  
2. x Proportion of the total tin content in each size fraction.  
3. z Unchecked because of limited material available.  
4. C-coarse, M-medium, F-fine, VF-very fine, and S-silt.  
5. Refer to Figure 22 for location of samples.

the coarsest components (  $> 400$  microns) of the middle-horizon sample contains much higher tin than the same fractions of the surface and bottom horizons. As will be discussed later, this may suggest local derivation of some tin-bearing minerals.

#### Dry-sieving:

Unlike in the dry-sieving analysis of the Penzance sediments where eight screens were employed, only five screens were used for the Porthleven samples (Table 23). Consequently, the size-range of Fraction 5 is rather wide; thus the bi-modal occurrence

| Frac | Microns  | ED-40 ft. Deep |            |                   | EE-60 ft. Deep |            |                   | EF-110 ft. Deep |            |                   |
|------|----------|----------------|------------|-------------------|----------------|------------|-------------------|-----------------|------------|-------------------|
|      |          | %<br>Smpl      | Tin<br>ppm | Prop <sup>x</sup> | %<br>Smpl      | Tin<br>ppm | Prop <sup>x</sup> | %<br>Smpl       | Tin<br>ppm | Prop <sup>x</sup> |
| 1 C  | $> 1040$ | -              | -          | -                 | -              | -          | -                 | -               | -          | -                 |
| 2 C  | 494-1040 | 0.2            | 30         | 0.02              | 0.2            | 60         | 0.07              | 4.3             | 25         | 0.75              |
| 3 M  | 195- 494 | 8.3            | 30         | 0.7               | 3.4            | 40         | 0.7               | 30.1            | 30         | 6.2               |
| 4 F  | 107- 195 | 69.8           | 160        | 32.2              | 59.1           | 110        | 35.3              | 45.7            | 30         | 9.4               |
| 5 VF | 53- 107  | 20.3           | 600        | 34.8              | 36             | 210        | 40.8              | 15.7            | 360        | 39.1              |
| 6 SC | $< 53$   | 1.2            | 9300       | 32.3              | 1.1            | 3900       | 23.3              | 3.2             | 2000       | 44.1              |

C-coarse, M-medium, F-fine, VF-very fine, and SC-silt and clay  
Prop<sup>x</sup>- Proportion of the total tin content in each size fraction.

Table 23. Dry-sieving data of selected samples from different water depths south of Porthleven.

of the sediment-constituents is not reflected by the dry-sieving data (Figure 26). The data, nevertheless, confirm the observation

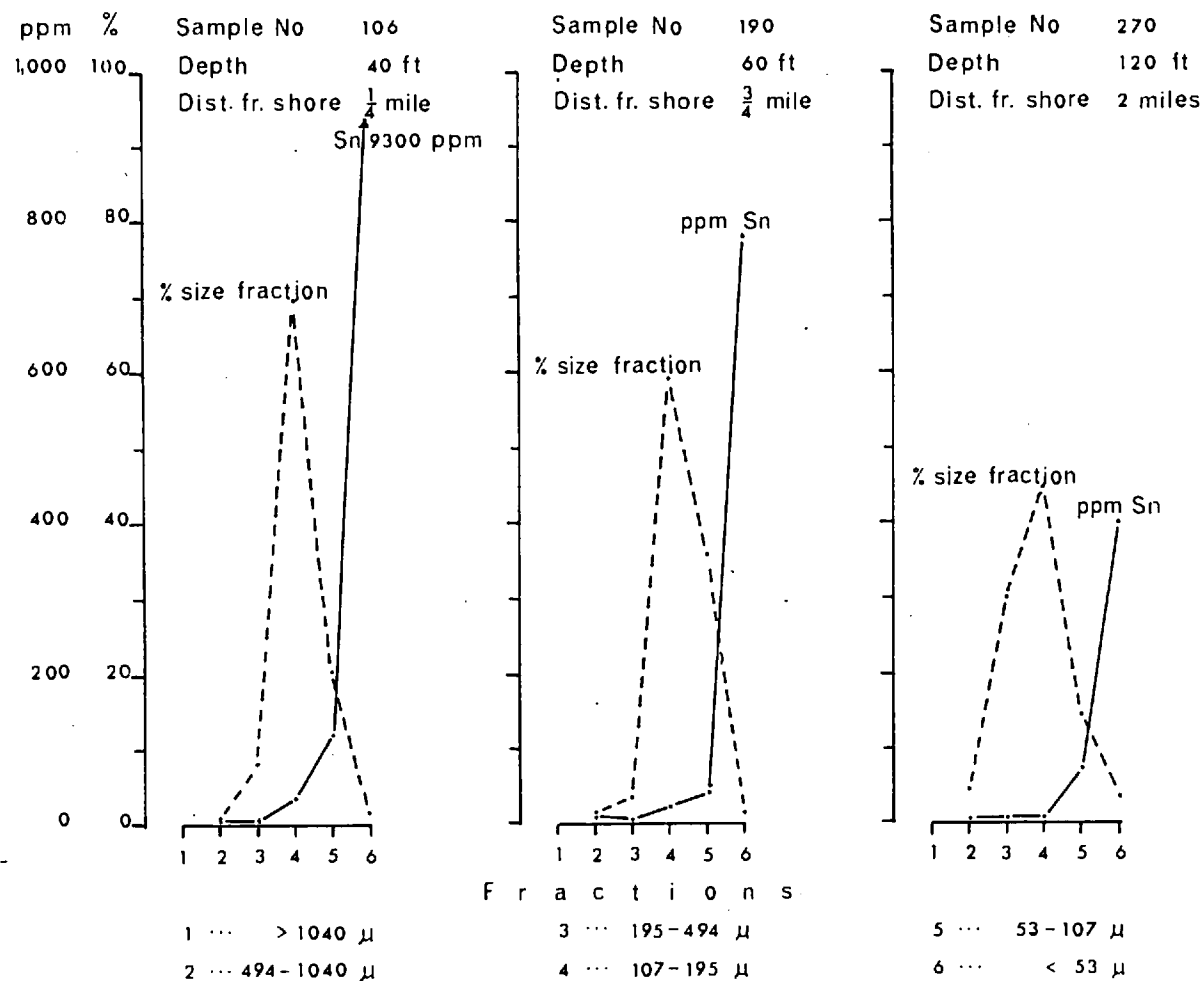


Figure 26. Distribution of tin in the dry-sieved size fractions of surficial marine sediments at increasing depths south of Porthleven.

in the elutriation experiment of the preponderance of size particles between 100 to 200 microns (Fraction 4). Likewise, the increase of tin distribution in the very fine and silt ( $< 53$  to 107 microns) components is clearly demonstrated. As in the case of sample EB (see Table 21), the unusually high distribution of the medium and coarse grained particles in sample EF (see Table 23) is attributed to the presence of appreciable amount of shell fragments.

In general, the results indicate that the tin contents of almost all the size fractions diminish with increasing distance from the coast (Table 23).

#### Heavy Mineral Separation

With a view to ascertaining the concentration of the heavy minerals relative to distance from the coast, tests were made on typical inshore and offshore samples.

As shown in the following table (24), the difference between the concentration of heavy minerals in the sample which came from about one-fifth of a mile south of Porthleven and the sample from one and a half miles offshore is considerable -- the former has 2.1 times more heavies than the latter. Similarly, the heavy and light fractions of the inshore sample have higher tin tenors than those of the offshore sample. The tin content of the heavies decreases from 7,500 to 4,350 ppm, while in the lights the reduction is from 260 to 130 ppm. There is, therefore,

even with the limitation of the analytical technique, a similar percentage decrease in the tin tenors of both heavy and light fractions of the Porthleven sediments.

| Sample        | Depth in<br>Feet | %   | Sn - ppm   |            |
|---------------|------------------|-----|------------|------------|
|               |                  |     | Heavy Min. | Light Min. |
| Inshore (EG)  | 30               | 3.8 | > 7500     | 260        |
| Offshore (EH) | 100              | 1.8 | 4350       | 130        |

Table 24. Per cent distribution of the heavy minerals, and the tin contents of the heavy and light fractions of selected inshore and offshore samples.

#### HCl-Treatment

With the primary aim of determining the spread of shell fragments and other HCl-soluble materials in the eastern half of Mount's Bay, selected inshore and offshore samples were treated with 50 per cent HCl. Unlike the heavy minerals, the distribution of the HCl-soluble components markedly increases towards the open sea. For example, the inshore sample contains only 18.4 per cent HCl-soluble particles, by contrast, the offshore sample contains 44.5 per cent.

Like the Penzance formation, the seaward increase of shell fragments in the Porthleven sediments is not uniform. Apart from their abundant occurrence in the deeper part of the bay, they are also notably concentrated in the vicinities of the scattered submarine slate outcrops nearer to the shore.

### Trewavas-Rinsey Offshore Sediments

This sub-section considers mainly the Trewavas marine sediments formation, and in part, it deals with the adjoining small body of sand in Rinsey Cove, that is, between Trewavas Head and Rinsey Head.

The Trewavas formation, which is the third-largest among the various marine sand bodies in Mount's Bay, has a maximum thickness of less than 20 feet. It covers the whole submarine depression between Trewavas Head and Porthleven. Although medium and coarse sands occur near the coast, and in the vicinity of the sand-slate interface south of Trewavas Head, on the whole, the Trewavas deposit is fine to medium grained.

By comparison, the contiguous Rinsey deposit is very much smaller and thinner than Trewavas, but its overall texture is somewhat coarser than the latter. The predominant sand components are medium and coarse grained.

Despite the absence of tin concentration in excess of 5,000 ppm in Trewavas, this formation is decidedly richer than Penzance, Porthleven and Perranuthnoe sediments, but appear to be poorer than Praa Sands. The range of tin values obtained from the surface sediments is 170 to 2,000 ppm; providing a local mean of 700 ppm which is well above the 410 ppm regional mean. A great majority of the lower values (100 to 500 ppm) are commonly found in the western half of the formation, and the higher (500 to 2,000 ppm)

values chiefly occur in the eastern portion -- prominently in the immediate vicinity of the offshore projections of the four small iron-rich (mainly pyrite) copper-tin lodes exposed at the cliffs in Trewavas (Figure 22).

The surficial tin distribution in the Rinsey sediments is slightly higher than that of Trewavas. The analytical results are in the order of 270 to 2,700 ppm, and the local mean is 770 ppm. The high values between 500 and 2,000 ppm are concentrated near the granite-sand interface in the eastern and western sides of Rinsey Cove, respectively; elsewhere the tin distribution varies from 140 to 310 ppm.

#### Mechanical Size Analyses

Both elutriation and dry-sieving were employed in the size analyses of selected samples from the Trewavas sediments.

##### Elutriation:

The distribution pattern of the various size particles of the sediments along Traverse 10, which cuts across the possible offshore extensions of the coastal lodes, was investigated by elutriating (using the first set of tubes) the 200-foot interval samples. The diagram in Figure 27 shows that the concentration of the medium to coarse grained constituents (equivalent quartz median diameter is 320 microns) is well-pronounced near the shore, and from a depth of 45 feet, it markedly decreases

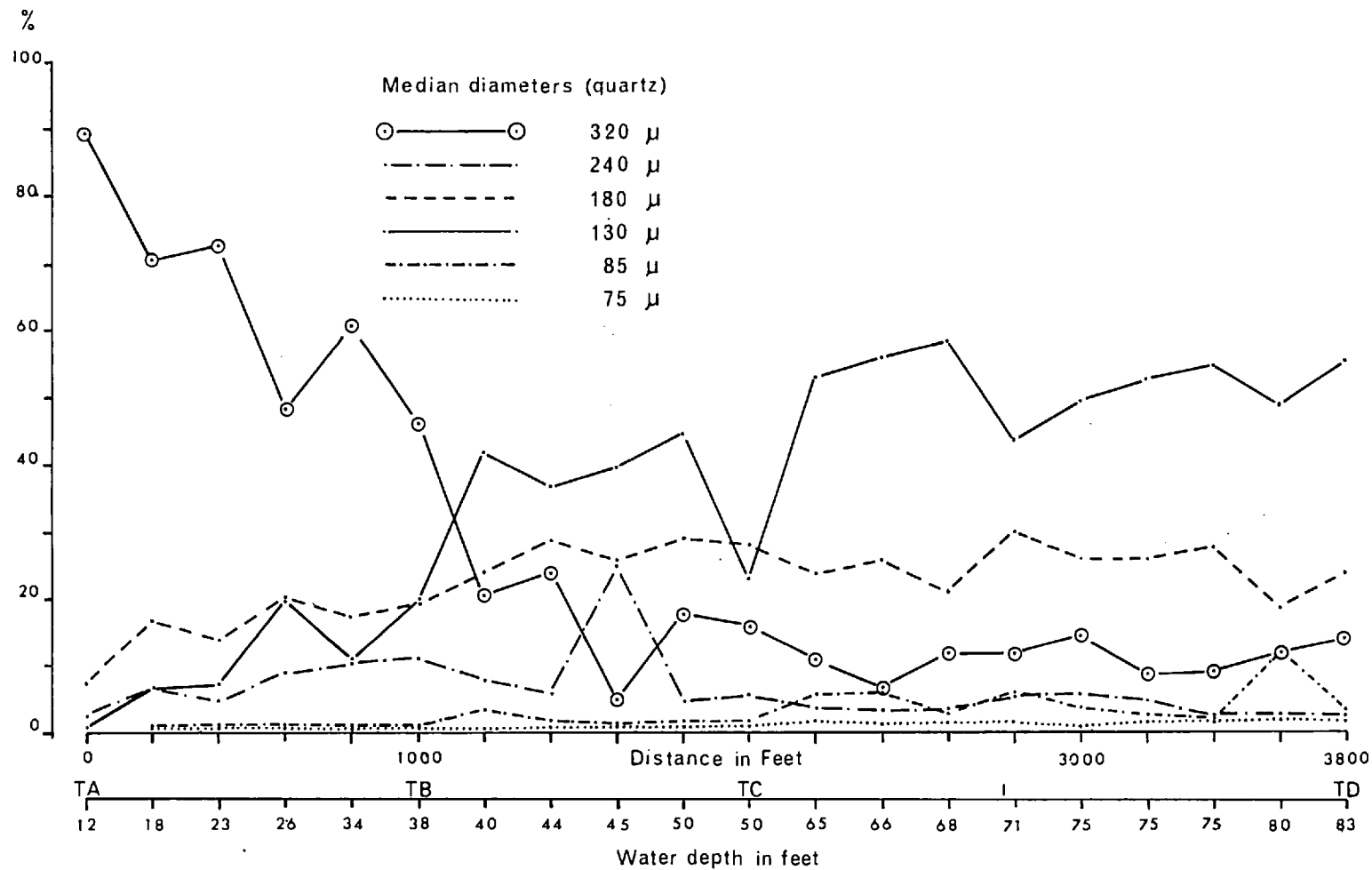


Figure 27. Elutriation results of surficial marine sediments along Traverse 10, Trewavas.

seawards. Similarly, the distribution of the particles in the upper limit of the fine grained size-range, Fraction 2 (240 microns), generally diminishes in the same direction. Conversely, the occurrence of the particles in the lower limit of the fine grained size-range, Fraction 4 (130 microns), considerably increases towards the deeper part of the bay. The intermediate particles (Fraction 3, 180 microns) of the fine grained size-range, and the very fine grained (85 microns) fraction, together with the silt (< 75 to 75 microns) components slightly increase as the bay deepens. On the whole, the elutriation results indicate that the unconsolidated sediments off Trewavas become finer as one goes farther from the shore.

The size fractions of two samples from the extremities of Traverse 10, and two from near the possible location of the seaward continuation of the aforementioned coastal lodes, were examined for their tin contents (Table 25).

A significant feature of the results is the comparatively high tin contents of the coarser (100 to >300 microns) size-fractions of the samples (TA, TB and TC) from the immediate vicinity of the offshore projections of the lodes along the coast (see Figure 22). By contrast, the higher concentration of tin in the sample (TD) farthest from the possible submarine mineralisation is in the very fine (70 to 100 microns) and silt (60 to 80 microns) fractions (Table 25).

| Frac  | Microns | TA-12 ft Deep | TB-38 ft Deep | TC-50 ft Deep | TD-83 ft Deep |
|-------|---------|---------------|---------------|---------------|---------------|
|       | Quartz  | Sn-ppm        | Sn-ppm        | Sn-ppm        | Sn-ppm        |
| 1 C   | >300    | 100           | 110           | 160           | 50            |
| 2 M   | 200-300 | 120           | 100           | 320           | 50            |
| 3 F   | 100-200 | 110           | 190           | 230           | 50            |
| 4 F   | 90-150  | 110           | 390           | 380           | 230           |
| 5 VF  | 70-100  | ---           | 240           | 160           | 230           |
| 6 VFS | 60- 80  | ---           | 130           | 140           | 500           |

Table 25. The occurrence of tin in the different elutriation (first set of tubes) fractions of selected samples along Traverse 10, Trewavas.

| Frac | Microns  | TA-12 ft Deep |      |                   | TB-38 ft Deep |       |                   | TC-50 ft Deep |      |                   | TD-83 ft Deep |      |                   |
|------|----------|---------------|------|-------------------|---------------|-------|-------------------|---------------|------|-------------------|---------------|------|-------------------|
|      |          | %             | Tin  |                   | %             | Tin   |                   | %             | Tin  |                   | %             | Tin  |                   |
|      | Sizes    | Smpl          | ppm  | Prop <sup>x</sup> | Smpl          | ppm   | Prop <sup>x</sup> | Smpl          | ppm  | Prop <sup>x</sup> | Smpl          | ppm  | Prop <sup>x</sup> |
| 1 C  | >1040    | --            | --   | --                | --            | --    | --                | --            | --   | --                | --            | --   | --                |
| 2 C  | 494-1040 | 31.5          | 40   | 6.9               | 4.2           | 260   | 3.5               | 0.3           | 30   | 0.03              | 4.7           | 40   | 0.9               |
| 3 M  | 195- 494 | 63.9          | 160  | 56.2              | 60.4          | 90    | 17.3              | 18.3          | 160  | 9.2               | 5.9           | 30   | 0.8               |
| 4 F  | 107- 195 | 4.2           | 1600 | 36.9              | 28            | 500   | 44.4              | 52.1          | 500  | 80.9              | 56.3          | 120  | 32.8              |
| 5 VF | 53- 107  | 0.1           | --   | --                | 7             | 500   | 11.1              | 28.1          | 50   | 4.4               | 28.6          | 310  | 42.9              |
| 6 SC | <53      | --            | --   | --                | 0.3           | 25000 | 23.8              | 1.1           | 1700 | 5.8               | 2.9           | 1600 | 22.6              |

Table 26. Per cent distribution of the different dry-sieving size fractions, and the tenor (ppm) and proportion of tin in each size fraction of selected samples from Traverse 10, Trewavas.

Notes: 1. x Proportion of the total tin content in each size fraction.

2. C-coarse, M-medium, F-fine, VF-very fine, VFS-very fine and silt, and SC-silt and clay.

3. Refer to Figures 22 and 27 for locations of lodes and samples.

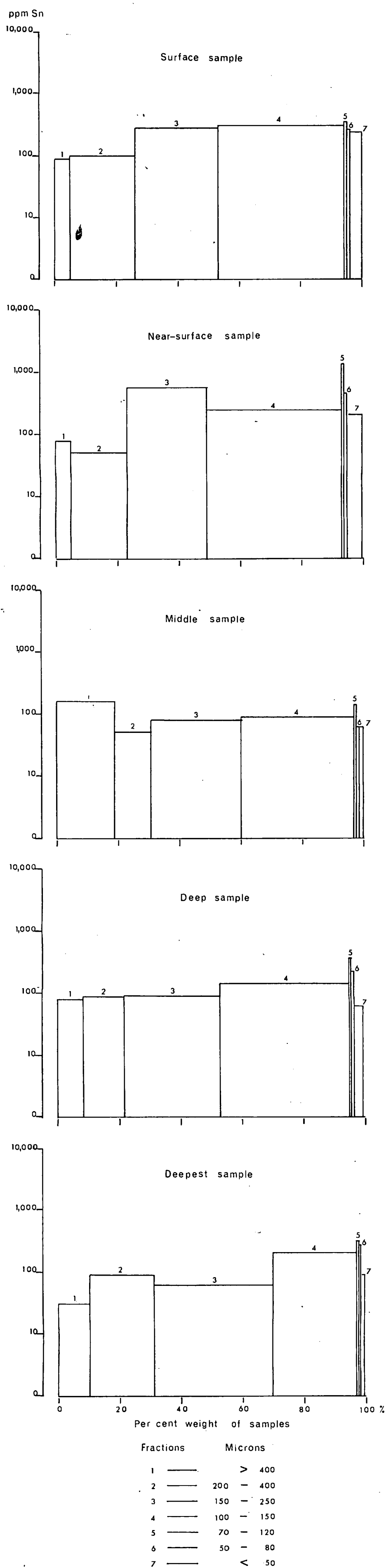


Figure 28. Elutriation results of profile samples from the Trewavas marine sediments.

In addition, a set of profile samples from near the middle of Trewavas sand formation were elutriated. The series of graphs in Figure 28 show that the sand becomes somewhat coarser towards the bottom. Apart from the sample immediately below the surface where the fine (150 to 250 microns) and very fine (50 to 120 microns) size fractions contain much higher tin than those of the same size particles on the surface, there is a general reduction of tin concentration in the fines towards the lower horizons.

#### Dry-sieving:

The four selected samples from Traverse 10 whose elutriation fractions were analysed for tin were likewise subjected to dry-sieving.

It is obvious from the results tabulated in Table 26 that the Trewavas sediments become finer in the direction away from the shore.

Although the high tenors of tin are commonly associated with the silt ( $< 53$  microns) fractions, the fine to medium (195 to 494 microns) grained fractions of samples TA, TB and TC which all came from the place where the possible submarine extensions of the coastal lodes are supposed to be, also have appreciable tin contents. This is a marked contrast to the low tin contents of the same size fractions of the sample (TD) farthest offshore, which is in no way related to a probable

submarine mineralisation. The glaring difference of the occurrence of tin in the sediments near, and far from the supposed undersea mineralisation is further manifested by the proportions of tin in the coarse size fractions (Table 26). For example, the proportions of tin in the medium (195 to 494 microns) grained fractions of the samples from the vicinity of the probable offshore extensions of the lodes are 11 to 70 times more than that of the farthest sample.

The conspicuous disparity between the tin distribution in the elutriated and dry-sieved size fractions is due to: (a) In elutriation, the fine tin-bearing minerals tend to be associated with the coarser siliceous particles, thus elutriation fractions 1 and 2 (200 to >300 microns) generally contain more tin than the corresponding dry-sieved fractions (195 to >494 microns) (b) The first set of elutriation tubes was used, and as stated previously, these tubes were inefficient so that there were notable losses of the tin-rich very fine sediments and silt-clay particles; consequently, the finest elutriation fractions (60 to 80 microns) in Table 25 are considerably poorer in tin than the equivalent (< 53 microns) dry-sieved fractions in Table 26.

#### Heavy Mineral Separation

In order to ascertain the significance of the heavy minerals distribution (and their tin contents) with respect to the locations of the possible offshore continuation of the lodes

outcropping at the slate cliffs in Trewavas, the 200-foot interval samples along Traverse 10 were subjected to heavy mineral separation. As can be seen from Figure 29, an outstanding feature of the results is the apparent connexion between the tin contents of the plus 197 mesh ( $> 53$  microns) heavy minerals (the minus 197 mesh were separated before the analysis) and the coastal lodes. The peak values appear to be directly related to the locations of the possible offshore extension of the lodes. Assuming that the lodes have uniform strikes, "peak 1" overlies (Figure 29) the seaward projection of Lode No. 1 (indicated in Figure 22). Similarly, "peak 2" coincides with the offshore extensions of Lodes Nos. 2 and 3.

On the other hand, the tin contents of the whole heavy mineral fractions, that is, without removing the minus 197 mesh constituents, do not give a sharp definition of the supposed anomalies. Presumably, the tin in the silt-size-range ( $< 53$  microns) is chiefly of extraneous origin, thus it obscures the dispersion pattern of the coarser tin which may have been derived from local sources.

It is of interest to note that the tin contents of the minus 80 mesh ( $< 107$  microns) fractions of the original samples (without separating the heavies from the siliceous materials), although much lower than the tin concentration in the heavy mineral separates, also indicate ill-defined tin "highs" where the offshore extensions of the lodes are suppose to be (Figure 29).

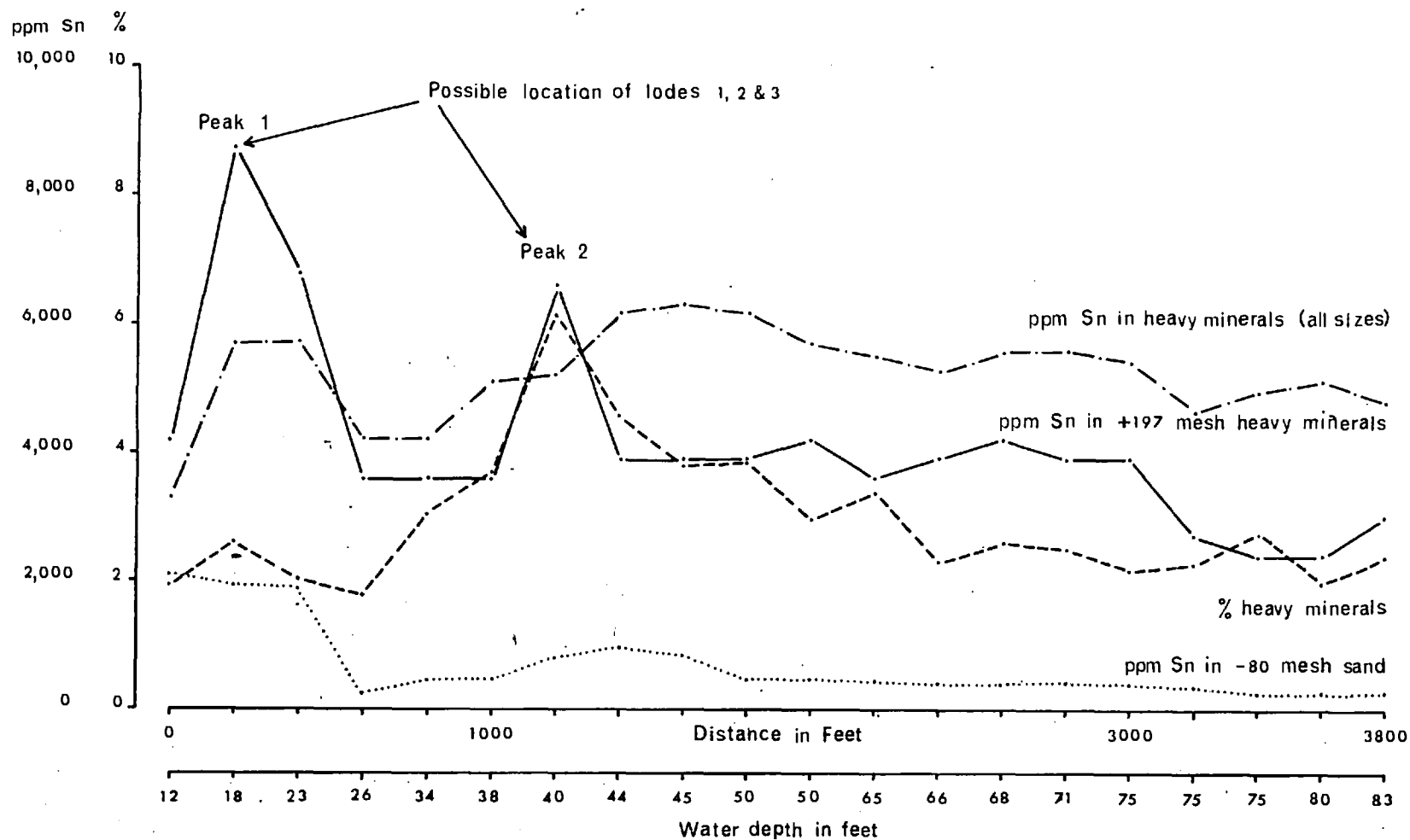


Figure 29. Tin contents of heavy mineral fractions of the surficial marine sediments from Traverse 10, Trewavas.

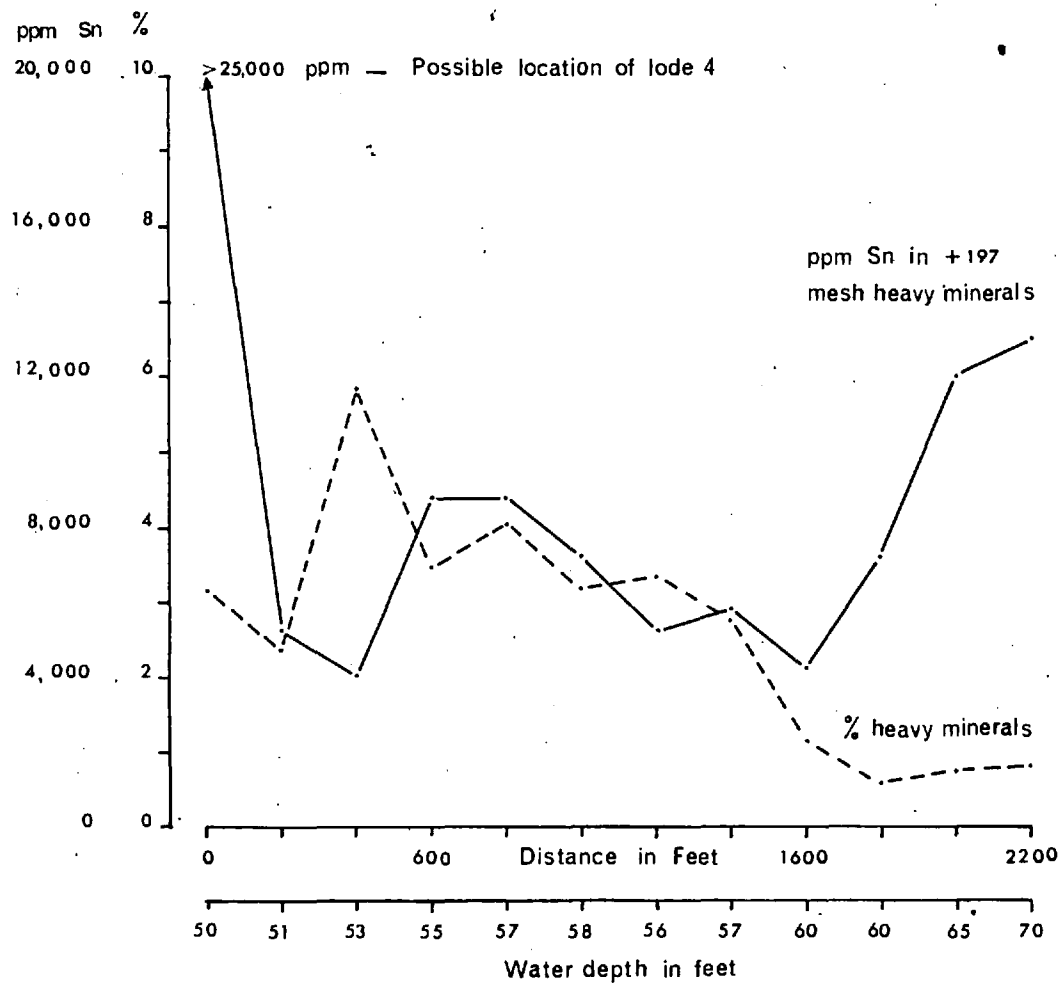


Figure 30. Tin contents of heavy mineral fractions of the surficial marine sediments from Traverse 8, Trewavas.

In addition, and to verify the observation in Traverse 10, heavy mineral separation was done on the 200-foot interval samples from Traverse 8 (see Figure 22). This traverse also cuts across the seaward projection of a lode (No. 4) in the granite cliff east of Trewavas Head. Like Traverse 10, the per cent distribution of the heavy minerals is somewhat higher in the vicinity of the possible submarine extension of the lode, and diminishes farther away from it (Figure 30). More specifically, the tin content ( $> 25,000$  ppm) of the plus 197 mesh ( $< 53$  microns) heavies is highest over the projected offshore extension of Lode No. 4. Then it decreases near the middle of the sand formation but increases again in the seaward-end of the traverse, near the sand-slate interface.

This high tin concentration at the seaward-end of Traverse 8 is explained more fully in the sub-section for discussion.

#### Praa Sands Offshore Sediments

The unconsolidated sand formation off Praa Sands is predominantly medium to coarse grained, and on the average, it is coarser than any of the other marine sand bodies in Mount's Bay. This formation is under 20 feet thick, and it is, in terms of areal extent and relative volume, next to Trewavas-Rinsey sediments.

The Praa Sands deposit appears to have the highest tin tenor among the different bodies of sand in Mount's Bay. In so far as

the degree of surficial tin concentration is concerned, it varies from 180 to 5,000 ppm, and about 50 per cent of them are greater than 1,000 ppm. The local mean of 1,150 ppm is more than twice the regional mean (410 ppm). The tin values in the lower range, 100 to 500 ppm are not confined to any particular section of the formation, but the higher values (500 to 2,000 ppm) are commonly found nearer to the shore, and the granite-slate contact. A most notable feature is the location of the  $> 5,000$  ppm tin concentration near the spot where the mineralised (pyrite and copper sulphides) slate was observed.

#### Mechanical Size Analysis (Dry-sieving)

Two selected samples from near the mouth of Praa River, and close to the granite-slate contact southeast of Praa Sands were dry-sieved (Table 27).

The sediments in the vicinity of Praa River outlet are predominantly fine to medium (107 to 494 microns) grained. The coarser (107 to 1040 microns) fractions have low tin contents; whereas, the very fine (53 to 107 microns) and silt ( $< 53$  microns) particles have high tin tenors. In fact, the latter has the maximum tin concentration among the various size fractions. Another interesting feature of the results is the appreciable proportion of tin in all the size fractions.

By contrast, the sediments in the proximity of the granite-slate contact are mostly coarse grained. With the exception of

| Frac | Microns  | PRA-Near Praa River |            |                   | PRE-Near G-S Contact |            |                   |
|------|----------|---------------------|------------|-------------------|----------------------|------------|-------------------|
|      |          | %<br>Smpl           | Tin<br>ppm | Prop <sup>x</sup> | %<br>Smpl            | Tin<br>ppm | Prop <sup>x</sup> |
|      | Sizes    |                     |            |                   |                      |            |                   |
| 1 C  | > 1040   | - -                 | - -        | - -               | - -                  | - -        | - -               |
| 2 C  | 494-1040 | 6.4                 | 260        | 6.5               | 89.3                 | 100        | 42.3              |
| 3 M  | 195- 494 | 54.4                | 60         | 12.7              | 9.4                  | 1000       | 44.4              |
| 4 F  | 107- 195 | 36.6                | 210        | 29.9              | 0.7                  | 3900       | 12.9              |
| 5 VF | 53- 107  | 2.3                 | 4100       | 36.9              | 0.2                  | 400        | 0.4               |
| 6 SC | < 53     | 0.4                 | 9000       | 14.2              | 0.2                  | 200        | 0.2               |

x Proportion of the total tin content in each size fraction.  
C-coarse, M-medium, F-fine, VF-very fine, and SC-silt and clay.

Table 27. Dry-sieving data of two selected samples from near the mouth of Praa River and near the granite-slate (G-S) contact.

the coarsest (494 to 1040 microns) fraction, the coarser (107 to 494 microns) particles have higher tenor and proportion of tin than the fines (< 53 to 107 microns). In this connexion, it should be noted that not far from the granite-slate boundary, clay, which is apparently the submarine weathering product of the spotted slate, was obtained (stuck to the anchor), and its tin content is 80 ppm.

The genesis of the clay is described in greater detail under the sub-section for discussion.

#### Heavy Mineral Separation

In order to investigate further the observations from

Trewavas which suggest the apparent relationship between the "tin-in-heavies" distribution and the lodes on the coast, the dispersion of heavy minerals (and their tin contents) in the part of Praa Sands deposit where there is least likelihood of a submarine bedrock mineralisation was investigated.

Heavy mineral separation was carried out on the 200-foot interval samples along Traverse 6. The Praa Sands results display an entirely different pattern from those of Traverses 8 and 10 in Trewavas.

The per cent distribution of the heavy mineral fractions increases seawards: the highest concentration is close to the sand-slate interface south of Praa Sands, and where there is no evidence of bedrock mineralisation. Figure 31 further indicate that the tin content of the plus 197 mesh ( $> 53$  microns) heavy minerals progressively increases towards the middle of the formation, and decreases as the bay deepens, but slightly rises again in the vicinity of the sand-slate contact. By and large, the distribution of tin in the plus 197 mesh heavies does not exhibit a well-defined "high" anywhere along Traverse 6.

On the other hand, the tin contents of the whole heavy mineral fractions (without removing the minus 197 mesh) yielded much higher values near the middle of the formation. But the tin "peaks" are not related to any significant geologic feature in the bay or along the coast. As will be discussed later, the minus 197 mesh heavies may have been derived from Praa River.

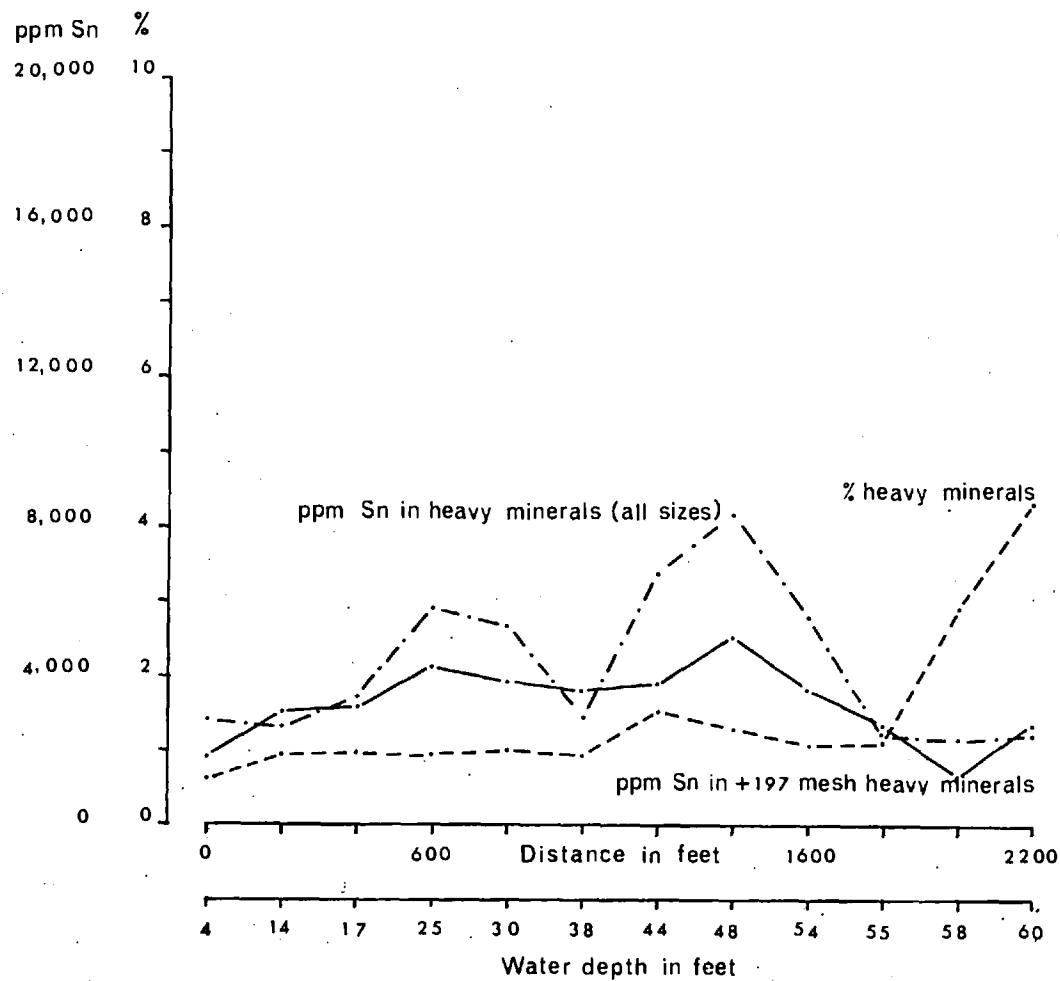


Figure 31. Tin contents of heavy mineral fractions of the surficial marine sediments from Traverse 6, Praa Sands.

### Perranuthnoe Offshore Sediments

Perranuthnoe marine sediments formation is predominantly fine grained, and with patches of medium grained sands near the shore and the submarine rock outcrops. On the whole, its texture is finer than Praa Sands sediments. It is also smaller in areal extent than Praa Sands. The maximum thickness is less than 20 feet.

The overall tin distribution in the Perranuthnoe formation is higher than Porthleven marine sediments but lower than Tre-wavas. The range of tin concentration is from 150 to 1,550 ppm, giving a local mean of 650 ppm -- this is almost 1.6 times more than the regional mean (410 ppm). The high tin values tend to be concentrated in the vicinity of the mouth of the streamlet draining an abandoned mine located a few hundred feet inland.

### Mechanical Size Analysis (Dry-sieving)

Dry-sieving size analysis of a composite sample confirms the field observation that the Perranuthnoe deposit is generally fine to medium grained. Table 28 shows that the fine and medium grained fractions comprise 94.5 per cent of the sample studied.

Unlike Penzance and Porthleven sediments, in which the size distribution of tin gradually increases as the particles become finer, in Perranuthnoe, the occurrence of tin is distinctly bimodal (Table 28). The tin distribution in the coarsest fraction is 60 ppm and it rises to 70 ppm in the medium grained particles

and increases further to 210 ppm in the fine grained but sharply diminishes to 60 ppm in the very fine grained fraction, and then rises again to 4,800 ppm in the silt-clay components.

| Frac | Size Microns | % Sample | Prop <sup>x</sup> | Sn-ppm |
|------|--------------|----------|-------------------|--------|
| 1 C  | >1040        | --       | --                | --     |
| 2 C  | 494-1040     | 2.2      | 0.9               | 60     |
| 3 M  | 197- 494     | 51       | 24.8              | 70     |
| 4 F  | 107- 197     | 43.5     | 63.4              | 210    |
| 5 VF | 53- 107      | 2.2      | 0.9               | 60     |
| 6 SC | < 53         | 0.3      | 10                | 4800   |

x Proportion of the total tin content in each size fraction.  
C-coarse, M-medium, F-fine, VF-very fine, and SC-silt and clay.

Table 28. Per cent distribution of the different dry-sieving size fractions (and their tin contents) of a composite sample from Perranuthnoe sediments.

#### Marazion Offshore Sediments

The northern portion of Marazion sediments formation is mostly thin sand overlying partially outcropping rocks. Thus, although the Marazion formation seem to have a wide extent, it is smaller than Perranuthnoe. It would appear therefore that Marazion is the smallest sand formation in Mount's Bay. Like Trewavas and the other smaller (in comparison to Penzance and Porthleven) sand deposits, Marazion has a maximum thickness not exceeding 20 feet.

| Frac | Size Microns         | % Sample | Sn-ppm |
|------|----------------------|----------|--------|
| 1 C  | >494                 | 92       | 110    |
| 2 M  | 195-494              | 3        | 60     |
| 3 F  | 107-195 <sup>x</sup> | 0.1      | 1200   |

Table 29. Results of the dry-sieving size analysis of a surface sample from the Marazion inshore sediments.

| Frac | Microns             | Top Horizon |        | Middle Horizon |        | Deep Horizon |        |
|------|---------------------|-------------|--------|----------------|--------|--------------|--------|
|      |                     | % Smpl      | Sn-ppm | % Smpl         | Sn-ppm | % Smpl       | Sn-ppm |
| 1 C  | >400                | 6.9         | 120    | 11.2           | 1000   | 72.1         | 150    |
| 2 M  | 200-400             | 1.6         | 320    | 1.1            | 1300   | 0.6          | 2600   |
| 3 F  | 150-250             | 0.2         | 110    | 16.2           | 70     | 6.2          | 230    |
| 4 F  | 100-150             | 43.9        | 220    | 69.4           | 260    | 20           | 150    |
| 5 VF | 70-120              | 0.1         | 1100   | 0.2            | 530    | 0.1          | 300    |
| 6 VF | 50- 80              | 0.2         | 1050   | 0.3            | 1000   | 0.2          | 420    |
| 7 SC | 40- 60 <sup>z</sup> | 1.2         | 310    | 0.4            | 320    | 0.8          | 320    |

Table 30. Results of the elutriation of profile samples from the Marazion inshore sediments.

| Horizon | % Heavies | Sn in Heavies - ppm |
|---------|-----------|---------------------|
| Top     | 2.7       | 4800                |
| Middle  | 3.6       | 4800                |
| Deep    | 2.3       | 8200                |

Table 31. Per cent distribution of heavy minerals, and their tin contents, in the surface and subsurface samples from Marazion inshore sediments.

- Notes: 1. x No very fine and silt fractions  
 2. z No fraction finer than 40 microns.  
 3. C-coarse, M-medium, F-fine, VF-very fine, and SC-silt and clay.

The Marazion deposit has the second-highest local mean (920 ppm), exceeded only by Praa Sands. The tin distribution varies from 100 to 4,400 ppm. Generally, the nearshore sands have lower tin contents (100 to 500 ppm) than those in the southern part of the deposit, especially in the vicinity of St. Michael's Mount, where the tin concentration is in the range of 2,000 to 5,000 ppm.

#### Mechanical Size Analyses

Dry-sieving was employed in the determination of the size distribution of siliceous and tin-bearing particles in the surface sample, and elutriation was utilised for a similar purpose in the profile samples.

##### Dry-sieving:

A sample from near the middle of the Marazion formation was subjected to dry-sieving, and no very fine and silt constituents were observed. By and large, the results (Table 29), together with the field observations, indicate that on average, this formation is coarser than Penzance sediments.

In so far as the size distribution of tin is concerned, it is mostly found in the fine (107 to 195 microns) grained particles. Nevertheless, appreciable amount of tin also occur in the coarsest ( $> 494$  microns) fraction. This is manifested by the data presented in Table 29 which shows that the fine and coarse grained fractions contain 1,200 and 110 ppm tin, respectively. By contrast, the medium grained particles contains only 60 ppm tin.

#### Elutriation:

A set of profile samples were elutriated. It can be seen from the results tabulated in Table 30 that from the top down to the deeper horizons, the sediments become generally coarser. For instance, the distribution of the coarsest ( $> 400$  microns) fraction in the surface sample is only 6.9 per cent, and it increases to 11.2 per cent and 72.1 per cent in the middle and deeper samples, respectively.

A more significant feature of the results is the occurrence of high tin in the coarse and medium grained constituents of the middle and deeper horizons, and as will be discussed later, this phenomenon suggest local origin of some tin-bearing sands.

#### Heavy Mineral Separation

The dispersion pattern of heavy minerals in the profile samples was examined. The results (Table 31) indicate that the heavy minerals concentration on the surface is 2.7 per cent and rises to 3.6 per cent in the middle horizon, but decreases to 2.3 per cent in the deeper horizon.

With respect to the tin contents of the heavy mineral fractions, the top and middle samples have the same, 4,800 ppm, but the deeper sample has much higher tin tenor, 8,200 ppm.

This odd "tin-in-heavies" distribution in the profile samples will be discussed in greater detail in the sub-section for discussion.

## DISCUSSION

It is apparent that a number of sedimentology problems are involved in this study. Certain principles of sedimentology were considered at several stages of this research. However, the emphasis in the investigation has been on the application of geochemical techniques to the search for offshore placer and/or bedrock mineralisation. Accordingly, in the following discussion, the data are largely considered from an applied geochemical view point.

The data observed from the two largest marine sand formations (Penzance and Porthleven) and the smaller (Praa Sands, Trewavas-Rinsey, etc.) deposits raise a number of relevant problems which need to be elucidated. For convenience they have been grouped under the following headings:

1. Penzance and Porthleven Offshore Sediments.
  - (a) Distribution of the siliceous<sup>x</sup> sediments.
  - (b) Distribution of heavy minerals in the surface sediments with particular reference to cassiterite.
  - (c) Vertical (profile) distribution of tin in the sediments.
  - (d) Sources of the siliceous and tin-bearing sediments.

x Siliceous sediments include the quartz sand, and other tin-poor sediments.

- (c) Origin, and the distribution of shell fragments.
- 2. Origin, and the distribution of siliceous and tin-bearing sediments in Praa Sands and the other smaller sand deposits.
  - (a) Praa Sands offshore sediments.
  - (b) Trewavas-Rinsey offshore sediments.
    - (1) Significance of the heavy mineral tin content.
  - (c) Marazion offshore sediments.
  - (d) Perranuthnoe offshore sediments.
- 3. Feasibility of the economic exploitation of tin from the marine sediments.

#### Penzance and Porthleven Offshore Sediments

The Penzance and Porthleven deposits, which are situated in the western and eastern sides of Mount's Bay, respectively, have many characteristics in common. Both are large bodies of sand which extend beyond the limits of the study area. A number of rivers contribute sediments to the two deposits: Newlyn, Penzance and Marazion Rivers flow directly into the Penzance formation, and the Porthleven River drains into the Porthleven sediments. Moreover, there are common features between the tin distribution patterns in the two formations. Hence, the problems encountered in both formations are relatively similar.

### Distribution of the Siliceous Sediments

As was observed in the field, and verified by the elutriation and dry-sieving size analyses, the Penzance and Porthleven sediments tend to be coarser near the beaches and become progressively finer with increasing distance from the shore. However, there are some isolated, limited areas of coarse and sometimes pebbly materials near rock outcrops at some distance offshore. Excluding the anomalous areas of coarse sands, the overall distribution pattern is consistent with seaward transportation of materials, by a transporting agency which diminishes in strength, from a source or sources in the north coast. The source of the sediments may be the rivers, shore (including the head) cliffs, and submarine rocks near the shore. The nature of the probable dominant sources will be discussed later. Irrespective of source, the fines are not likely to settle close to the shore because of the turbulence-effect of the waves. They tend to be transported in suspension seawards.

In the case of the river-borne sediments, the coarse particles are usually deposited not far from the river mouth because the velocity of the river is considerably reduced when it enters the bay. On the other hand, the suspended silt and clay particles require a much longer time to settle owing to the tendency of the fresh river water to form a film above the denser (Holmes, 1960) sea water. Likewise, the intense turbulence associated with the

mixing of fresh and saline waters, especially during periods of wet weather when the rivers tend to be in spate, can be expected to slow down considerably the coagulation rate of the sediments in suspension. In consequence, the fines are widely dispersed in the transgressing masses of surface water which may extend several miles out to sea (see Revelle and Shepard, 1938). Furthermore, there are times (2 hours before High Water at Dover) when the prevalent ebb tide flow in the study area is due south (Pocket Tidal Stream Atlas, 1961). This current, which presumably occurs on and near the surface, has a velocity varying from 0.3 (neap) to 0.5 (spring) knot, that is, 15.4 to 25.8 centimeters per second. The southerly ebb tide flow is much faster than any of the recorded velocities in the elutriation tubes. It must be borne in mind that this comparison is only approximate because in elutriation the flow is vertical, and the tide-current is horizontal. Nevertheless, since the ebb tide current is considerably greater than the observed elutriation velocities, it is very likely that the turbulence at the sediment-water interface will be sufficient, during the ebb tide, to keep the clay, silt, very fine, and fine (< 53 to 250 microns) particles in suspension and thus permit their transport from nearshore and rivers sources towards the open sea.

The southerly ebb tide is of course intermittent, and moreover, before the tide reversal (change from ebb to flood tide) in the area, a slack occurs east of the Lizard Peninsula (3 hours

after High Water at Dover), so that the ebb tide flow in the bay is greatly weakened. Also the northeasterly flood tide current is at first weak. Thus at these times, the settling of the suspended silt-clay materials in the less disturbed parts of the bay is facilitated.

Therefore, the increase of silt-clay ( $< 53$  microns) particles towards the southern portions of Penzance and Porthleven formations, and the decrease of the coarser particles in the same direction can be correlated with the seaward migration of the sediments from dominant sources in the north coast.

The isolated coarse sands and pebble deposits located some distance from the shore cannot be accounted for by present day transportation processes. This anomalous occurrence of coarse materials may be relics of deposits laid down at some time in the past. Either they were deposited in places which are topographically higher than the sand-filled submarine depressions so that they were never covered by the more recent finer sediments, or they were exposed due to the removal of a fine sediment cover. Alternatively, they may represent materials of local origin. It should be emphasised that there are a number of data which suggest local derivation of the coarse sands, pebbles, etc. Firstly, their mineralogical composition is most often distinctly related to the lithology of the nearest submarine rock outcrops. For example, the coarse sand contiguous to the submarine extension of St. Michael's Mount has a very high

proportion of quartz grains. By contrast, the coarse sediments partially covering a slate outcrop located about two miles south of St. Michael's has slate fragments in abundance. Elsewhere, the occurrence of quartz grains, or slate fragments is less pronounced. The aforesaid phenomena could be attributed to coastal and, to a lesser degree, submarine weathering. The former is easily understood because the incessant pounding of strong waves upon St. Michael's Mount granite liberate a certain amount of quartz and other siliceous materials; the coarse fragments are mostly deposited with the surrounding marine sands. The latter is somewhat problematical because weathering under the sea is less active than on dry land (see Kuenen, 1950). It is probable, none the less, that slate fragments are released from the faulted or highly crushed sections of the undersea slate outcrops because this does not require any strong force. Even the weak bottom currents, aided by the softening-effect of sea water, may be able to do it. One can then assume that local derivation of some marine sediments is likely, but only to a minor extent.

In addition, there are cobbles and boulders of slate (adjoining slate outcrops) and dolerite (near dolerite outcrops) found in some shallow depressions in the rocky bottom. Considering their sizes, which are too large to be water-borne, it is improbable that they have been transported from the rivers. Moreover, submarine weathering of the rocks is unlikely to have resulted in the production of fairly or well-rounded cobbles and

boulders. It is therefore suggested that these materials are relics of submerged head deposits and/or physical-chemical weathering products of nearshore bodies of slate and dolerite when some parts of Mount's Bay were still above the sea, or were still very shallow. Evidence (the presence of drowned valleys, the submerged forest off Marazion River mouth, etc.) suggesting that sea level at some time in the past was lower than that of the present day is discussed in Part II, Section B.

Distribution of Heavy Minerals in the Surface Sediments with Particular Reference to Cassiterite

The preponderant minerals in the "offshore heavies" and "stream heavies" are the same, namely: magnetite, cassiterite, zircon, tourmaline and epidote. This suggests a similar source, possibly the same group of rock types.

On both the western and eastern halves of Mount's Bay, the heavy mineral particles tend to be concentrated close to the shore, especially in the vicinity of the mouths of Marazion and Porthleven Rivers, and decrease seawards. Likewise, the tin contents of the heavy mineral fractions from near the shore are several times higher than those from the deeper parts of the bay (Tables 19 and 24).

The distribution of tin in the minus 80 mesh fractions decreases as the distance from the shore increases (see Figure 22).

Similarly, the tin contents of almost all the dry-sieved size fractions diminish towards the deeper parts of the bay (Tables 17 and 23). The seaward decrease of the tin distribution is further demonstrated by the elutriation (Tables 16 and 21) data. The tin tenors of the coarser (100 to 400 microns) fractions decrease as the sea deepens. In the very fine and silt-clay fractions (< 53 to 100 microns), the reduction is negligible, and may be reversed in some cases.

On the whole, the evidence demonstrates that the tin content of the total sediments (including heavy minerals) decreases with increasing distance from the shore. The contrary data, such as the erratic distribution pattern of tin in the very fine and silt-clay elutriation fractions, is presumably due to the inefficiency of the technique, that is, the losses of the fines in the overflow.

In a similar manner to the siliceous sediments, the overall data is compatible with a landward source of cassiterite and the other heavy minerals. Owing to their high specific gravity, most of them accumulate near to the source; hence, the higher concentration of heavies near the shore than farther offshore. Furthermore, when the heavy minerals move on the sea bottom, they tend to be lodged between the coarser light particles, thus there is the tendency for the finer siliceous sediments to be shifted preferentially. In addition, the moving heavies are subjected to differential sorting. Only the very fine move to a larger extent,

so that the seaward decrease in their distribution is somewhat irregular.

It follows therefore that the seaward reduction of the overall tin distribution can be attributed to the migration of tin-bearing sediments from sources in the north coast.

Inshore, there is generally higher tin concentration near the river mouths than elsewhere. This may be due either to the "barrier-effect" of the out-flow of the rivers on longshore drift, or to the rivers being the source of tin. The first possibility would result in the heavy minerals and coarser siliceous sediments accumulating adjacent to the river outlets, only the fine light minerals being transported farther along the shore (across the river mouths) or out to sea. The net effect would be an enrichment of the whole sediments in tin but no, or little enrichment of the various elutriation fractions. Accordingly, considering that the stream sediments are very much richer in tin than the other possible sources of the metal, it is reasonable to assume that the high tin concentration close to the river mouths are due to the dumping of coarse (in contrast to the silt-clay fractions) tin-rich fluvial sediments. They are, of course, further concentrated by the preferential movement of the low specific gravity particles towards the deeper parts of the bay.

The other tin "highs" near the shore, but not in the proximity of the river mouths, or tin-rich lode outcrops, such as

those near Penlee Point, and between Forthleven and Loe Bar, respectively, are not clearly understood. They are apparently due to localised tin enrichment resulting from the interplay of waves, tidal currents and longshore drift.

Like the siliceous sediments, there are some peculiar tin distribution trends. They are associated with the coarse sands in the vicinity of some submarine rock outcrops. The degree of tin concentration can invariably be correlated with the character of the nearest rock body. For instance, the coarser elutriation fractions (100 to > 400 microns) of the quartz-rich sand beside the undersea extension of St. Michael's granite contains 210 to 330 ppm tin; by contrast, similar fractions of the chlorite-rich sand situated close to the slate body south of St. Michael's yielded only 80 to 140 ppm. It has been shown that the granite is normally richer in tin than the slate. The above data which show higher tin content of the sediments adjoining the granite, and the opposite for the sediments near the slate outcrops, certainly imply genetic relationships between some isolated bodies of sand and the nearest submarine rock outcrops. As discussed earlier, this could be brought about by submarine or coastal weathering.

Therefore, as in the case of the siliceous sediments, limited local derivation of the marine tin-bearing sediments is possible. This theory is further supported by the high tin (950 ppm) content of the coarser elutriation fraction (150 to 250 microns)

in the deepest profile sample from the south of Porthleven (see Figure 22). The tin-rich minerals in this size-range could not have been transported from a distant source because of their high specific gravity. The likely source is the adjacent extensive submarine slate outcrop. That certain portions of the above slate is mineralised, is not at all a remote possibility because if the lodes on the Trewavas cliffs have long and straight seaward projection, they may extend as far as this particular body of rock.

#### Profile or Vertical Distribution of Tin in the Sediments

The vertical distribution of tin in the sediments has only been investigated at three sites. In each case, there is a decrease of tin concentration with depth. This distribution pattern is somewhat surprising because the "jigging" effect of the bottom currents would induce the sinking of heavy minerals to some depth within the sediment column. Moreover, it is difficult to postulate a mechanism by which the current selectively removes light particles and leave behind the heavies on the surface. At any rate, such mechanism would have to have been operative only at the present time. Changing conditions of sedimentation due, for example, to the variation in sea level, is also unlikely to account for the appreciable reduction in tin concentration from the surface down to the subjacent sediment

horizons. If the sea level changes affected the tin distribution at all, the effect would have been more obvious on the horizontal variation rather than the vertical.

Accordingly, it is assumed that the variation of the tin distribution with depth reflects a major change in the tin contents of the detrital materials supplied into Mount's Bay. This can be correlated with the mining history of Southwest Cornwall (see page 140, for further discussion).

Neither the corer nor the "pump sampler" was able to penetrate down to the bedrock. Beyond four feet it is not known whether the vertical tin distribution decreases steadily downwards. It is possible that stream tin was deposited in the "buried valleys" when they were still above the sea level. If deposited in a similar manner to that of St. Erth Valley placer tin, a "fossil" tin deposit may exist on the floor of the "buried valleys". But if head was deposited, it is possible that, during the submergence, it was disintegrated and the silt-clay components of the matrix removed. The residual tin-rich heavy minerals resistates may have been concentrated in the "valleys" floor. It is obvious, of course, that a thorough subsurface sampling is required in order to ascertain the above possibility.

#### Sources of the Siliceous and Tin-bearing Sediments

It has been concluded that the predominant source of the

sediments is the coast. The coastal sources can be divided into: (a) the rivers, (b) slate, dolerite, granite and head cliffs, and (c) submarine rocks within the zone of wave action.

Since the rate of weathering along the coast is very slow and the readily-eroded rock outcrops along the coast are not extensive, the quantity of their weathering products is limited. Similarly, chemical and physical decomposition of rocks under the sea is a very slow process, thus the submarine weathering product is not wide-spread. Given the above conditions it follows that the most likely dominant sources of the sediments on the coast are the rivers. Furthermore, it has already been demonstrated that the rivers introduced a considerable volume of siliceous and tin-bearing sediments into Mount's Bay. In addition, the data for the vertical distribution of tin are consistent with a major change in the nature of the sediment-supply.

Notwithstanding that there may have been recent changes in the rate of erosion of the coastal rocks, there is no reason to suggest that there has been a significant change in the tin contents of the rocks and head being eroded. However, there has been certainly a marked change in the nature of the materials supplied into the rivers which can be correlated with the mining history of Southwest Cornwall. Before the area bordering the coast was extensively prospected and explored, there was naturally lesser amount of tin-rich detritus introduced into the streams. Hence, most of the earlier terrestrial sediments

discharged into the bay, which now constitute the lower (not necessarily the bottom) horizons of the unconsolidated marine sediments column, are poor in tin. But during the mining of the tin lodes, where the recovery of tin was relatively poor, much of the fine tin was lost to the rivers, or was deposited as easily erodable dumps on the river banks. Thus the amount of tin supplied by the rivers into Mount's Bay during and after the mining era was considerably greater than at any time in the past. The observed tin-enrichment on the surface, therefore, confirms the previous conclusion that the rivers are the major sources of the stanniferous sediments.

It should be emphasised that although the rivers are considered the major sources of the marine sediments, the erosion of the coastal rocks have supplied, as manifested by the composition of the sands below the cliffs, notable amounts of detritus into the bay. Evidence has also been presented that weathering of the submarine rocks have contributed to the offshore sediments.

The head, which may have been deposited in the "valleys" and other depressions in the bedrock when some parts of Mount's Bay were still above the sea, is likewise a possible source of the marine sediments. Neither in Penzance nor in Porthleven deposit was any indication of head-derivation observed; however, it was noticed in Perranuthnoe formation which will be discussed later. Other probable sources are the raised beaches. They could

be easily disintegrated by wave action, and their constituents re-deposited in the bay and/or on the modern beaches.

Other subsidiary sources which are believed to play very minor roles are (a) the extremely fine terrestrial materials blown offshore by winds, (b) rain-wash of the subaerial weathering products of coastal rocks (in particular the head), and (c) the very fine sea-borne sediments which may have been introduced into the bay from the English Channel by ocean currents.

Most of the materials derived from the last source are presumably tin-poor, and are likely to be deposited in the less turbulent parts of Mount's Bay. Like the shell fragments, they serve as "dilutents" of tin; thus their deposition in the deeper parts of the bay, may partly explain the low tin distribution in the southern portions of Penzance and Porthleven deposits.

#### Origin, and the Distribution of Shell Fragments

It is noteworthy that on both sides of Mount's Bay, that is to say, in the Penzance and Porthleven deposits, the quantity of shell fragments and other HCl-soluble materials become greater as one goes farther away from the coast. Presumably, some of the sea animals (shells) which inhabit the intermediate and near-shore zones of the bay are transported shorewards by the inflowing tidal or wave-generated currents, and subsequently broken into small pieces by the pounding of the waves --- especially

during gales. Since the prevalent current in the bay is seawards (as deduced from the movement of the siliceous and stanniferous sediments) and inasmuch as the specific gravity of the shells is low, the fine shell fragments are re-transported towards the open sea. Furthermore, as the water depth increases, the turbulent-effect of waves and currents oscillations weaken; so that the deposition of fine shell fragments in the deeper and quieter parts of the bay is facilitated.

Undoubtedly, the shell fragments serve as "diluent" of tin; thus their high concentration in the deeper parts of Mount's Bay accounts for the generally low tin-tenors of the offshore sediments.

#### Origin, and the Distribution of Siliceous and Tin-bearing Sediments in Praa Sands and the Other Smaller Sand Deposits

Praa Sands, Trewavas-Rinsey, and the other smaller marine sand deposits are discussed separately from the major sand formations off Penzance and Porthleven because they have different physical environments. Each deposit occurs as an isolated body of limited extent near the coast, and each is enclosed by submarine slate outcrop. Furthermore, the tin-tenor of each formation is conspicuously higher than either of Penzance or Porthleven.

Praa Sands Offshore Sediments

The Praa Sands marine sediment formation is separated from the other bodies of sand by an extensive submarine slate outcrop which rises higher than the sediment surface.

Coarse quartz grains comprise the major components of the sand below the granite cliffs, but slate fragments predominate in the sand adjoining the submarine slate outcrop. Elsewhere, the occurrence of quartz and slate grains is less pronounced.

By and large, the Praa Sands formation is medium to coarse grained. Field data clearly indicate that this formation is, on the average, coarser than any of the other bodies of sand in Mount's Bay. The pronounced coarseness of this deposit suggests, although no current measurement has been made, that Praa Sands Bay is affected by strong currents.

Since the prevailing wind in the study area is west and southwest, the dominant waves are southwesterly. These waves approach Praa Sands Beach at an angle so that southeasterly longshore currents may be generated. This current, together with the flood tide which will be discussed later, presumably transport the fines, particularly those of low specific gravity towards Rinsey and/or Trewavas Bay. This perhaps explains the pronounced low distribution of the silt-clay, and very fine particles in Praa Sands sediments.

In contrast, it is unlikely that the silt-clay, and very

fine sediments are introduced into Praa Sands Bay from other parts of Mount's Bay. Even if there is suitable southeasterly current from Marazion, it is highly improbable that the suspended fines reach Praa Sands. Most of them are presumably deflected seaward by the bold headlands along the coastline, or deposited in the coves, as for example in Perranuthnoe. Owing to the less prevalence of southerly waves which are necessary to propagate northwesterly longshore currents, it is doubtful whether notable amounts of fines are transported, in suspension, from the mouth of Porthleven River towards Praa Sands Bay. Besides, even if the fines move northwestwards from Porthleven, in all probability, they are largely deposited in Trewavas.

The highest tin concentration ( > 5,000 ppm) is found in the coarse, quartz-rich sand close to the granite-slate interface. The second highest concentration (1,500 to 1,900 ppm) is situated off the mouth of Praa River. Other tin concentrations exceeding 1,000 ppm are all found near the granite-slate contact. In the vicinity of the submarine slate outcrop, and elsewhere, the tin distribution is somewhat lower.

#### Origin of the Siliceous and Tin-bearing Sediments:

The striking similarity in mineral composition between the coarse sands and the adjacent rock outcrop implies a genetic relationship, that is, the former is presumably the weathering product of the latter. It appears that the coarse sands are

not affected by the currents; even if they are, they cannot be moved beyond Praa Sands Bay because the surrounding slate outcrop which stands higher than the sandy bottom is likely to impede their rolling and saltation. By the same reason, it is equally improbable that coarse sands are brought in from other parts of Mount's Bay.

The clayey sample from the vicinity of the undersea granite-slate interface, contains 80 ppm tin. This clayey material may be (a) part of a slump from a clay formation along the coast, (b) clay-matrix of a submarine head deposit, (c) in-situ weathering product, or (d) ice-rafted clay -- which is least likely. However, the clay has a distinctive shade of greenish-grey which is an inherent colour of the slate, and there are some partly weathered slate fragments associated with it. This colouration has not been observed in the head. It is, therefore, probable that the clay is the product of subaerial or subaqueous weathering of the underlying slate. It is less likely that it is a subaerial weathering product because, unless there was sudden subsidence (which is unlikely), the clay would have been eroded during submergence. It is more probable that the clay is the product of submarine weathering of a faulted or strongly crushed slate (see page 132 for discussion of submarine weathering).

If the fines in the clay were removed, its tin content (80 ppm) can be concentrated to several hundred parts per million. It is possible, therefore, that the high tin concentration

( $> 5,000$  ppm) in the minus 80 mesh fraction of the sample nearby, is mainly due to the weathering product of the partly mineralised slate (mentioned earlier in Part II, Section B) in the vicinity. Such a source may also have contributed, along with the granite, to the high tin content of the coarser (107 to 494 microns) grained fractions of the sand near the undersea extension of Godolphin granite (Table 27). The high tin concentration close to the shore, southeast of Praa Sands, is also probably the influence of the granite.

It is reasonable to assume that the bulk of the coarse siliceous and stanniferous sediments in Praa Sands Bay are of local derivation.

Furthermore, the very fine and silt ( $< 53$  to 107 microns) size fractions of the samples from near the mouth of Praa River have high tin contents (Table 27). Likewise, the tin tenors of the fine to very fine ( $< 107$  microns) fractions of the other samples in this vicinity is higher than those of the same size fractions of the samples (with the exception of those adjacent to the granite) from farther offshore. In addition, along Traverse 6 which is located not far from Praa River outlet, the distribution pattern of tin in the whole heavy mineral fractions, that is, without separating the minus 197 mesh ( $< 53$  microns) heavies, is highest near the middle of the traverse. Since this particular part of the bay is deeper than 50 feet, and contains relatively fine sediments, it is believed not to be affected

strongly by the oscillation of the waves. This high concentration of tin-rich minerals, which include the very fine heavies, not far from the mouth of Praa River cannot be solely ascribed to relative tin enrichment due to the removal of tin-poor light particles by bottom currents. Bearing in mind that the minus 80 mesh sediments in Praa River contain as much as 10,000 ppm tin (which is comparable to Marazion and Porthleven Rivers) and giving credence to the capacity of rivers to carry fine detritus into the sea, it is assumed that the tin-rich very fine sediments in the vicinity of Praa River outlet, are of fluvial origin.

#### Trewavas-Rinsey Offshore Sediments

Two adjoining unconsolidated sediment deposits comprise the Trewavas-Rinsey sediments. They are the small body of sand between Rinsey Head and Trewavas Head, and the main body of the Trewavas formation extending from Trewavas Head to Porthleven.

It was observed in the field that the Rinsey deposit is, on the whole, medium to coarse grained, but somewhat finer than the Praa Sands offshore sediments.

The main Trewavas deposit, which is the largest among the smaller sand bodies, has a more variable texture than Rinsey, or Praa Sands sediments. Although medium to coarse sand prevail near the sand-slate interface south of Trewavas Head, and in the

northeastern portion, especially close to the shore, by and large, the formation is fine grained.

The mineralogical composition of some inshore sediments is strikingly similar to the contiguous rock outcrops. For example, quartz grains preponderate in the coarse sand below the granite cliffs, but slate fragments characterise the sand adjacent to the submarine slate outcrops.

The high concentration of tin in the Rinsey sediments are found near Rinsey Head and Trewavas Head, respectively; they do not appear to be directly related to any lode or similar salient features underneath the sea or along the coast.

It is significant, however, that the high tin concentration in Trewavas is mainly associated with the coarser sands in the northeastern portion of the formation -- most prominent in the vicinity of the probable offshore extension of the lodes on the coast. Moreover, both elutriation and dry-sieving results in Tables 25 and 26 indicate appreciable occurrence of tin in the coarser size fractions (plus 80 mesh or  $> 107$  microns) of the samples from near the seaward projection of the coastal lodes, whereas, similar fractions of the sample from the sediments situated farther away have low tin contents.

#### Origin of the Siliceous and Tin-bearing sediments:

It must be noted that there is no river draining into the Trewavas "basin", and that it is bordered by an irregular rocky

bottom which rises markedly higher than the sandy floor. The latter serves as barrier to the saltation and rolling of unsuspended sediments into the "basin" from outside sources. Extraneous origin of the coarser tin-bearing and siliceous sediments, and the heavy minerals can be largely ruled out. Local derivation is more likely, and this may be brought about by combined coastal and submarine weathering. The repeated pounding of strong waves upon the granite cliffs produces physical disintegration of limited extent. The liberated coarse particles of quartz, feldspars, and other common granite minerals are mostly deposited close to the shore. Consequently, these materials preponderate in the sands below the granite cliffs.

Likewise, the continuous wave action causes some degree of physical decay of the tin-bearing lodes along the shore. Owing to the high specific gravity of the stanniferous minerals, those released from the lodes, are largely deposited not far from the source. Hence, there is comparatively high tin concentration in the vicinity of the seaward projections of the lodes.

Furthermore, submarine weathering may liberate crushed materials from the strongly sheared bodies of slate. If the slate fragments are flaky (ordinarily difficult to move by rolling and saltation) and too large to be transported by bottom currents, they remain close to the bedrock source. As a result, slate fragments are the dominant components of the coarse sands near the sand-slate interface.

It is very likely, therefore, that the coarser siliceous and tin-bearing sediments in Trewavas are mostly of local origin. Likewise, the outcome of the heavy minerals investigation, which is presented in the following sub-section, supports the above hypothesis.

Apart from the southeasterly longshore currents mentioned earlier, in the southern portion of the study area, the maximum neap and spring flood tide currents reach as much as 0.5 and 0.9 knot (see Pocket Tidal Stream Atlas, 1961), that is, 25.8 and 46.5 cm per second, respectively. These are several times faster than the elutriation currents shown in Tables 5 and 6. It is conceivable, therefore, that the flood tide is able to propagate turbulent coastal currents with sufficient velocity to transport the fines from Prae Sands towards Rinsey and/or Trewavas. When the wave-generated longshore currents and coastal tide-currents occur simultaneously, there is a pronounced increase in the velocity of the southeasterly nearshore currents. The likely result is a larger volume of suspended fines moved in the direction of Trewavas. The coarser and heavier particles are, in all likelihood, deposited nearer to the source, possibly in Rinsey Cove. By contrast, the extremely fine and silty sediments may be transported farther towards Trewavas where most of them presumably settle because of the greater depth of water and therefore decreased effect of waves and currents forces. This is believed to account for the relatively coarser nature

of the Rinsey deposit in comparison to Trewavas, and the preponderance of fines in the western half of the latter. Hence, it is probable that there is dilution of the Rinsey and Trewavas sediments by very fine and silty particles moved, in suspension, from Praa Sands Bay.

In addition, northwesterly currents may occur in the vicinity of Porthleven. The waves from the south, which are generated by the southerly and southeasterly winds, approach Porthleven obliquely so that they may propagate longshore currents northwestwards. Similarly, the ebb tide currents, as in the case of the flood tide, have maximum velocities of 0.5 (neap) and 0.9 (spring) knot. The westerly ebb tide generate coastal currents towards the northwest. Like the wave-propagated longshore currents, they are likely to have sufficient velocity to move the suspended siliceous and tin-rich sediments discharged by Porthleven River, towards Trewavas. When the above two types of currents occur at the same time, the velocity of the northwesterly nearshore currents is considerably increased. In consequence, an appreciable volume of the suspended fines may be transported from the mouth of Porthleven River into Trewavas Bay. Since this place is deep and comparatively quieter, that is, less disturbed by the oscillation of the waves, the settling of some of the suspended sediments, particularly the tin-rich materials, is likely to be facilitated; thereby, enabling the accumulation of notable quantity of the tin-rich fines in the

Trewavas formation -- especially near the middle. This may explain partly the high tin contents of the very fine and silt-clay fractions of the sediments in the deeper part of Trewavas Bay, such as those observed in the seaward-end of Traverse 10 (Tables 25 and 26).

#### Significance of the Heavy Mineral Tin Content:

The tin content of the heavy mineral fraction of the sediments coarser than 53 microns (plus 107 mesh) was investigated along three traverses: two at Trewavas and one at Praa Sands.

At Praa Sands, there is no systematic variation in the tin content of the heavy minerals along the whole of Traverse 6. The minor variations which do occur are not related with any significant geologic feature in the bay or on the coast. By contrast, in the traverses across the Trewavas sediments, the "highs" in the distribution pattern of tin in the heavy minerals appear to coincide with the seaward projection of the lodes on the coast. In particular, the positions of peaks 1 and 2 in the plot of the tin content of the heavies along Traverse 10 (see Figure 29) overlie the probable offshore continuations of Lode Nos. 1, 2 and 3 (see Figure 22). Presumably, the tin-rich heavy minerals are the weathering products of the tin-bearing lodes on the coast. On account of their high specific gravity, most of them, particularly the coarser heavies (plus 197 mesh), remained in the immediate vicinity of the lodes. It should be

noted as well, that there is no other likely source of tin nearby because the adjacent granite and slate cliffs are not particularly rich in the metal. Moreover, there is no mine dump on top of the nearest cliff.

A similar distribution pattern of tin in the plus 197 mesh heavy minerals in relation to the offshore projection of the coastal lodes is indicated along Traverse 8 (Figures 22 and 30). The tin-rich heavies concentrated in the inshore-end of the traverse is believed to have come from the erosion of the lode (No. 4) to the east of Trewavas Head. It should be emphasised that although Lode No. 4, like Lode Nos. 1, 2 and 3, are predominantly cupriferous, the analytical results (Part III, Section A) show that they also contain appreciable amounts of tin.

Apart from the high tin concentration at the inshore-end of Traverse 8, there is also an anomalous high tin content in the plus 197 mesh heavy minerals at the seaward-end of the traverse, that is, near the southwestern limit of the unconsolidated sediments. This high tin concentration may reflect the influence of the adjacent undersea slate outcrop, or a local source. The outcrop which is higher than the sediment surface probably serves as a barrier so that some of the heavies being moved by rolling and saltation are trapped near the sand-slate interface. The non-stanniferous lighter minerals, on the other hand, are presumably elutriated from the unsuspended sediments in preference to the coarse stanniferous grains. The alternative explanation

that the high tin concentration in the sediments reflects the tin content of the underlying or adjacent rock mass, gains some support from the fact that the slate from the area contains 100 ppm tin, which is abnormally high for this particular type of rock. Thus there is the possibility of nearby bedrock mineralisation.

The marked disparity of the "tin-in-heavies" distribution trends between Trewavas and Praa Sands presupposes that different factors control the concentration of heavy minerals in the various parts of Mount's Bay. Apart from the mechanical processes, as for example, the interplay of waves, tidal currents and longshore currents, the character and proximity of the sediment-source would influence the distribution pattern of the tin-rich heavy minerals (and of course the siliceous materials). It is reasonable to assume that the tin-rich coarser heavy minerals in Trewavas are mostly from local sources, such as the lodes on the coast, and that the maxima in the tin contents of the heavies along Traverse 10 and in the inshore-end of Traverse 8, are essentially related to the offshore projections of the lodes.

#### Marazion Offshore Sediments

The unconsolidated sediment deposit in the small bay off Marazion (between St. Michael's Mount and Perranuthnoe) is mainly medium to coarse grained, especially near St. Michael's

Mount and the mainland.

The high surficial tin concentrations occur as scattered patches, most prominent of which are situated quite close to St. Michael's Mount and in the southern portion of the deposit not very far from the Mount.

As in the case of Trewavas, no river drains into Marazion Bay. Although in the earlier geological history of Cornwall, St. Michael's Mount appeared to be connected with the mainland, there is no evidence that Marazion River was, at any time, directly draining into this small bay.

#### Origin of the Siliceous and Tin-bearing Sediments:

The island of St. Michael's Mount, the rock outcrops protruding prominently above the sea floor between St. Michael's Mount and the mainland, the uneven configuration of the submarine rocks surrounding St. Michael's, and the causeway above the low-water-level connecting the Mount to the mainland, all hinder the mass transportation of the medium and coarse grained sediments from the mouth of Marazion River into Marazion Bay. In addition to the above factors which may check the southwards migration of unsuspended sediments, Marazion area is partially sheltered by the western coast from the southwesterly and westerly waves so that strong southeasterly wave-generated longshore currents are unlikely to occur in the vicinity. Even the waves from the south are not likely to propagate longshore

currents towards the southeast because they approach Penzance-Marazion coastline almost perpendicularly. Accordingly, only a limited quantity of the suspended very fine, silty and clayey siliceous and tin-bearing sediments can be expected to be move from Marazion River towards Marazion Bay. On the whole, extraneous origin of the bulk of Marazion sediments, especially the coarser components, can be ruled out.

Although the slate, dolerite and head along the coast are all poor in tin, and the quartz veins exposed on the shore are barren of mineralisation, tin-bearing veins are common in the St. Michael's granite (Hosking, 1954). It is expected that these veins extend under the sea. The subaerial and submarine weathering of the granite and the associated veins, no matter how slow, is likely to liberate tin-rich minerals. On account of their high specific gravity, the coarse tin-rich erosion products are not transported far from the Mount, but deposited locally. This is manifested by the high tin content of the coarse quartz-rich sands in the vicinity of the St. Michael's Mount. There are, therefore, tangible indications of the local derivations of at least a proportion of Marazion sediments, particularly the coarser particles.

On a broader context, the higher tin concentration in the southern portion of Marazion sands in comparison to the lower concentration near the shore cannot be explained by differential transportation unless the tin occurs in the easily transportable

finer fractions. There is no evidence of such occurrence, so that it is possible that the above-mentioned high tin concentration reflect a local source.

Of particular interest is the marked difference between the profile distribution of tin in the samples from near the St. Michael's Mount as compared to those of Penzance and Porthleven. Near St. Michael's, the tin contents of some coarser elutriation fractions increases towards the deeper horizons. This distribution trend is the type which is expected if the sands have been subjected to the "jigging" effect of wave-generated bottom currents resulting in the sinking of some heavy minerals through the surface sand layer. The tendency for tin to concentrate downwards does not, of course, necessarily signify that the materials have been transported from a distance. Minor vibrations due to waves breaking could cause the observed phenomenon even though the currents are not capable of moving coarse particles across deeper waters. The lack of a well-pronounced surface tin enrichment implies that there has been no major change in the nature of the source in recent times. This is consistent with the absence of any river draining a tin mining area.

The alternative explanation of the higher tin contents of the coarse particles (200 to 400 microns) in the middle and bottom horizons, in contrast to the low tin tenor in the equivalent fraction of the surface sediments, is local derivation of the tin. It is conceivable that during the early stages of

weathering especially when the area off Marazion was still above the sea level (see page 58), or was very shallow, the liberated heavy minerals, specifically cassiterite, may have remained in the immediate vicinity of the Mount. By contrast, the light (low specific gravity) particles and heavy minerals lighter than cassiterite may have been shifted elsewhere resulting in the relative concentration of cassiterite in some sand horizons which now comprise the bottom portion of the unconsolidated sand profile. The heavy minerals with a high proportion of cassiterite were later buried under more recent locally derived detritus and any fine extraneous sediments which may have been introduced into the Marazion Bay. As the water depth increased, the bottom currents became less effective so that the amount of light materials and heavy minerals lighter than cassiterite, which were separated from cassiterite, decreased. Consequently, the proportion of cassiterite in the surface and near-surface sediments is lower than in the underlying sand horizons.

#### Perranuthnoe Offshore Sediments

Fine grained sediments preponderate in the Perranuthnoe deposit. There are, nevertheless, scattered accumulation of medium grained sand near the shore and the underwater rock outcrops.

High concentrations of tin occur as isolated patches in the middle portion of the formation. Their locations do not appear

to be related to lodes in the bay or along the coast, but they are not far from the outlet of a streamlet.

#### Origin of the Siliceous and Tin-bearing Sediments:

Apart from the very small drainage of an abandoned mine, there is no big river in Perranuthnoe capable of bringing into the bay stream sediments of any considerable quantity. The nearest rivers which have the capacity to do so are Marazion and Praa. It is hardly possible that the terrestrial detritus discharged into the sea by Marazion River are transported to and deposited in Perranuthnoe Bay because (a) the configuration of the sea bed between Marazion and Perranuthnoe is highly irregular, thus unsuitable for movement by rolling and saltation, and (b) in addition to the factors enumerated earlier which obstruct the movement of the water-borne sediments from Marazion River into Marazion Bay, the dolerite "tongue" (the Greeb) prominently extending seawards from Perranuthnoe is an additional barrier to the southeasterly movement of the sediments from Marazion.

On similar grounds, it is an exceedingly remote possibility for the suspended sediments from Praa Sands to be transported westwards because Hoe and Cudden Points and other prominent headlands along the coast, are likely to block their movement. Besides, the sea floor off Perranuthnoe-Praa Sands coastline is extremely rough so that the bottom transportation of coarse sediments from Praa Sands to Marazion is virtually impossible. The

rest of the rivers are too far away to merit consideration.

Given the above conditions, it is unlikely that the bulk of Perranuthnoe sediments originated from other parts of Mount's Bay.

It is possible, on the other hand, that the mine drainage had a greater volume in the past, especially when the mine was being explored or was in operation, so that it may have carried into the bay some amounts of stanniferous minerals. This may account for the comparatively high tin concentration near its outlet.

In addition, as mentioned earlier in Section A (Part III), a composite sample of the head-matrix in Perranuthnoe yielded 1,400 ppm tin. Although the average tin content of the head might be lower than the above value, nevertheless, the stanniferous minerals, being resistant to weathering, seem to have been concentrated in the small bay off Perranuthnoe; the light components of the silt-clay fraction having been removed in suspension, and deposited in the deeper parts of the study area. The feasibility of deriving tin from the head and other rocks in the area is indicated by the bi-modal size distribution of tin (Table 28). The tin in the silt-clay (< 53 microns) fraction may have come from the matrix of the head, while the tin in the coarser fractions (107 to 494 microns) may have been derived from the disintegration of the pebbles and cobbles of the head, and other rocks near the shore.

Accordingly, it is concluded that the sediments in Perranuthnoe are largely derived from the coastal erosion of the head and slate cliffs, and from the abandoned mine near the shore.

#### Feasibility of the Economic Exploitation of Tin from the Marine Sediments

From an economic point of view, considering the cost of exploitation and difficulties of engineering problems, it is doubtful whether any of the unconsolidated marine sediments deposit is workable at the present time unless there are appreciable tin concentrations on the bedrock surface.

However, on the available data, the Trewavas-Rinsey and Praa Sands deposits appear to be the most promising. Similarly, Perranuthnoe and Marazion formations, and the inshore sands near the mouths of Marazion and Porthleven Rivers may prove to be of economic interest. On the other hand, the offshore sediments, that is to say, those situated in the deep parts of Mount's Bay have the least economic prospects.

Moreover, before one can definitely establish which, if any, sand formation contains exploitable tin, or the specific location of an economic body, detailed surface and subsurface sampling are needed, and the tonnage of any promising deposit (or deposits) would need to be investigated. Other factors of immediate importance which should be taken into consideration as well, are mining methods, and above all, the price of tin.

SECTION C: THE DISTRIBUTION OF TIN ON THE VARIOUS BEACHES

FRINGING MOUNT'S BAY

The beaches fringing Mount's Bay do not occur as one continuous formation, but as separate stretches; prominent among them are Penzance-Marazion, Porthleven, Perranuthnoe, and Praa Sands Beaches. The rest are short and narrow; some of which are found in coves, such as those in Prussia, Kenneggy, Rinsey, Trewavas, etc.

Since the different beaches occur as disconnected bodies, the character and distribution of the tin-bearing minerals and the associated siliceous sand particles in every beach formation, are considered separately. The origin of beach materials, and the factors controlling their movements and deposition are discussed in a separate sub-section.

It has already been mentioned in Part I, Section C that the bulk of the beach samples were collected along traverse lines laid across the major beaches, and the rest were taken at random from the small beaches in the coves. The beach sampling, as a whole, is reconnaissance in nature.

Penzance-Marazion Beach

Penzance-Marazion Beach is about three miles long, and has a variable width. It is widest near Penzance, and narrows down

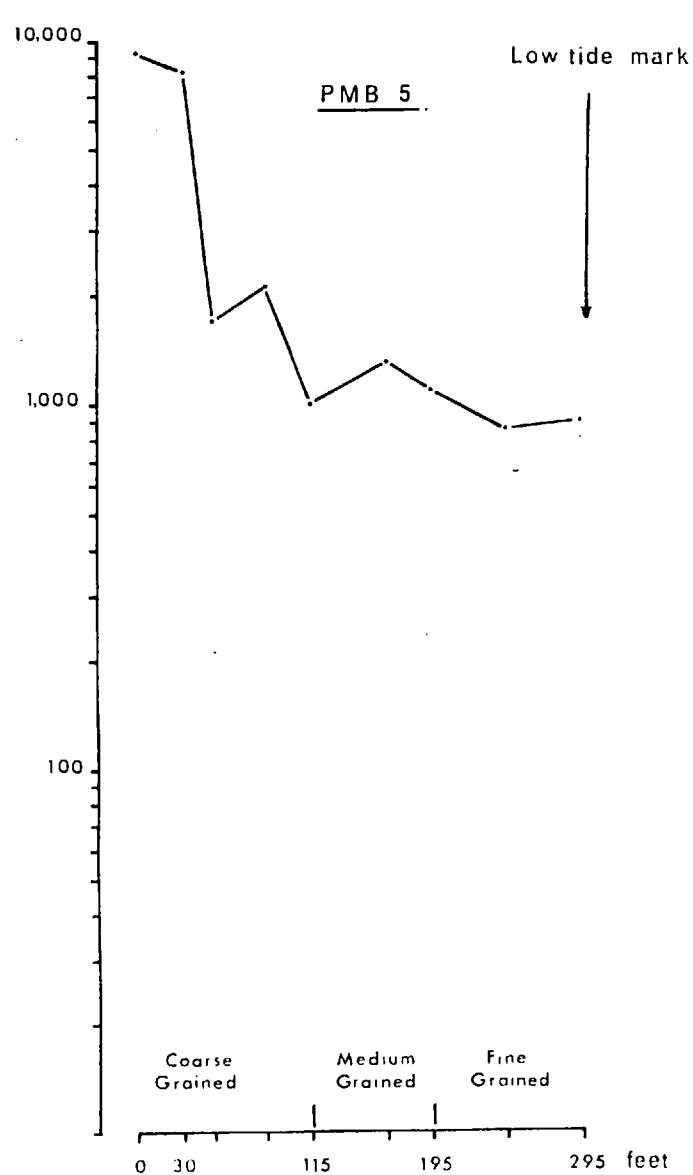
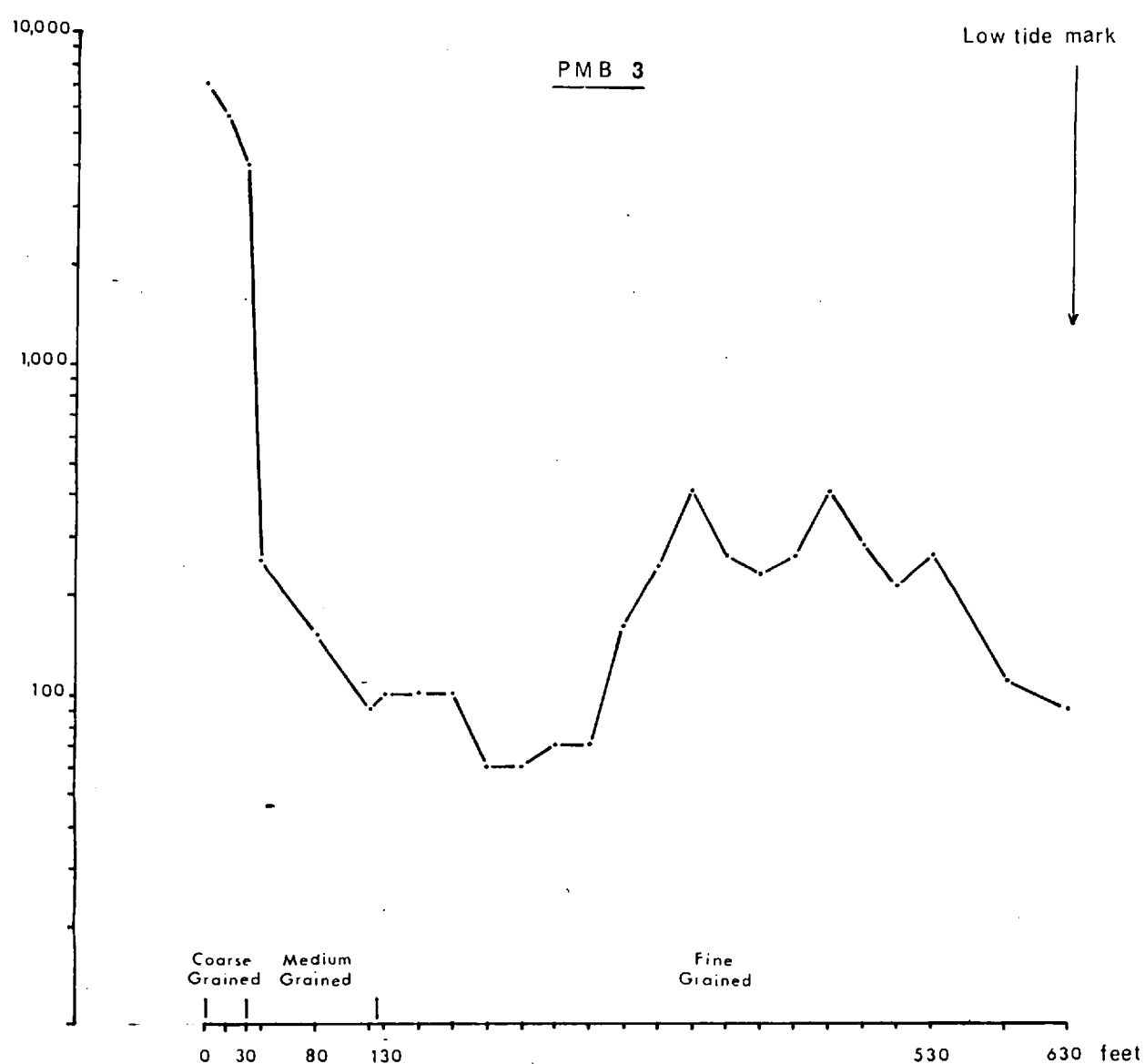
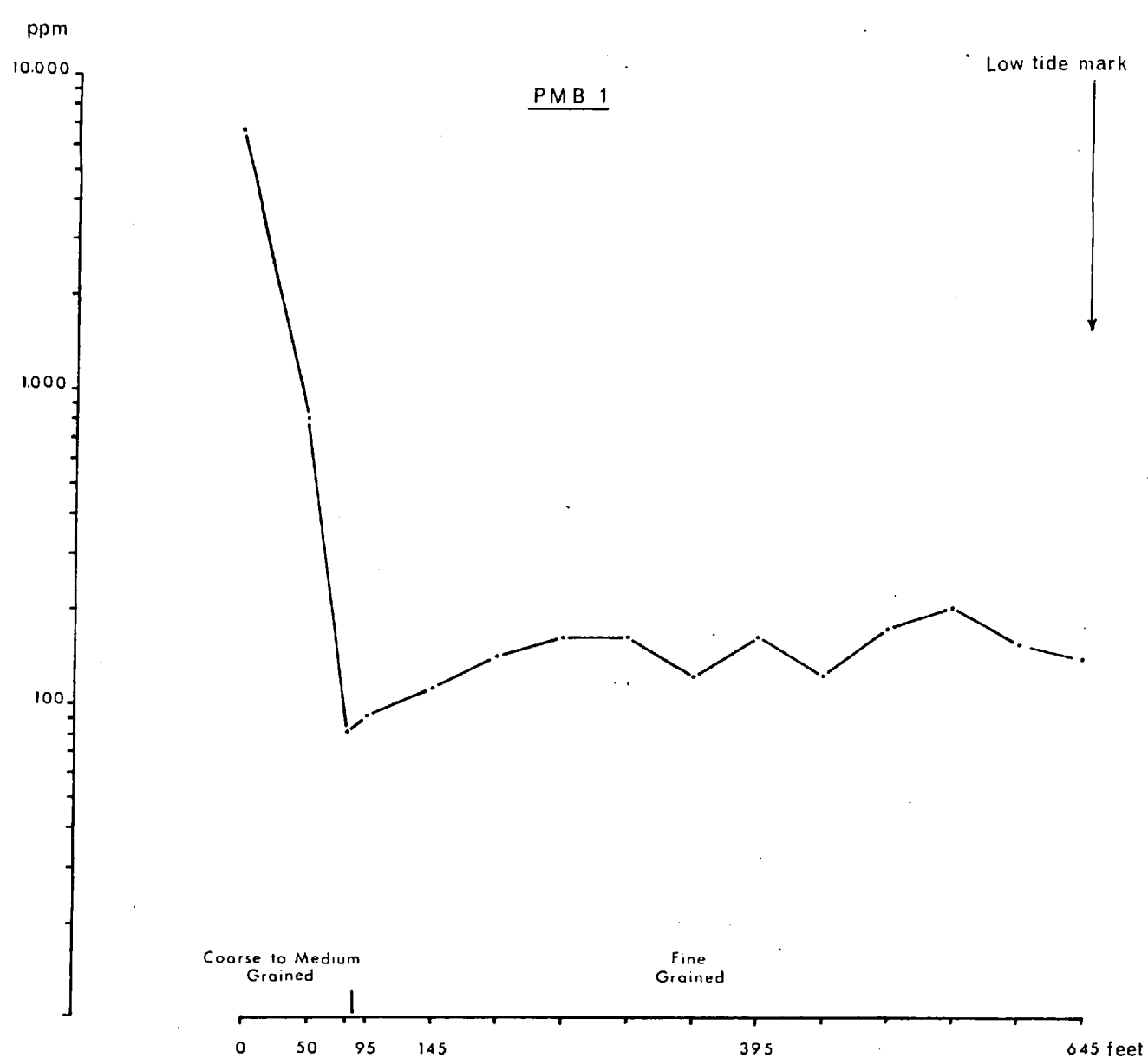


Figure 32. Distribution of tin (minus 80 mesh) across Penzance-Marazion Beach, Traverses PMB 1, 3 & 5

towards Marazion.

The backshore, especially in the western half of the beach, is mainly characterised by coarse sand particles, and preponderance of pebbles and cobbles, in places. However, the distribution of the beach gravels becomes sparse in the direction of Marazion. By comparison, the foreshore zone of the whole beach is largely medium to fine grained.

Surface and near-surface samples were collected from five traverse lines across the beach located in the following places: (a) PMB-1, three-quarters of a mile east of Penzance, (b) PMB-2, a mile east of Penzance, (c) PMB-3, south of Long Rock Village, (d) PMB-4, three-quarters of a mile west of Marazion, and (e) PMB-5, half of a mile west of Marazion (see Figure 22).

The tin values (determined from minus 80 mesh fractions) along Traverse PMB-1 vary from 90 to 6,600 ppm; PMB-2, 130 to 650 ppm; PMB-3, 90 to 7,000 ppm; PMB-4, 800 to 9,200 ppm, and PMB-5, 1,200 to 8,000 ppm.

It is quite clear from the above data that the lateral surficial distribution of tin increases eastwards, that is, the tin concentration is much higher in the vicinity of Marazion than near Penzance.

Across the beach, as indicated by Figure 32, the tin distribution is highest in the landward side of the backshore, and decreases towards the beach face wherein the foreshore joins the backshore; then rises moderately in the middle portion of the

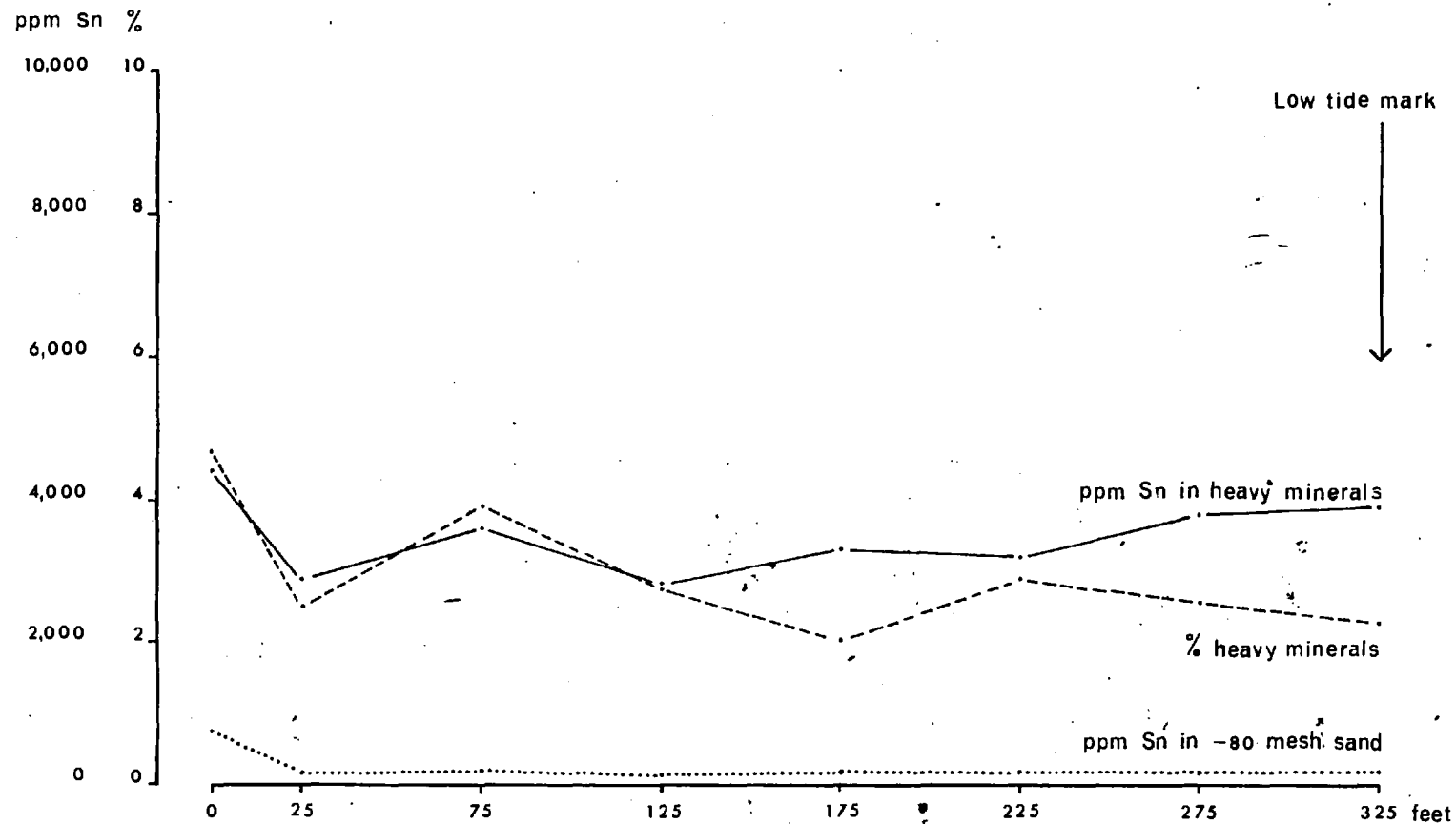


Figure 33. Tin contents of heavy minerals across the western end of Penzance-Marazion Beach (Traverse PMB-2).

foreshore, and eventually decreases seawards.

The distribution of heavy minerals across the western end (PMB-2, Figure 33) is similar to the aforesaid distribution pattern of tin determined from the minus 80 mesh fractions. On the eastern end of the beach, more specifically along Traverse PMB-4 (Figure 34), the distribution of the heavies resembles to that of Traverse PMB-2, except that the concentration of the heavies close to the low-water-mark is higher than in the middle of the foreshore.

Traverses PMB-2 and PMB-4 indicate that the maximum tin content of the heavy minerals is in the backshore and decreases towards the backshore-foreshore interface, but then slightly rises near the low-water-level (Figures 33 and 34).

By and large, the samples from the Marazion-end of the beach have greater percentage of heavy minerals, and their tin content is comparatively higher than those from near Penzance.

On a limited number of observations of the profile or vertical distribution of tin from the surface down to a depth of two feet, it was noted that the top one-foot thick layer of sand generally contain more tin than the subjacent horizon. Typical examples appear in Table 32 in which the samples from Penzance and Marazion, respectively, show that the minus 80 mesh and heavy mineral fractions of the top one-foot layer of sand have higher tin contents than those of the subjacent horizon.

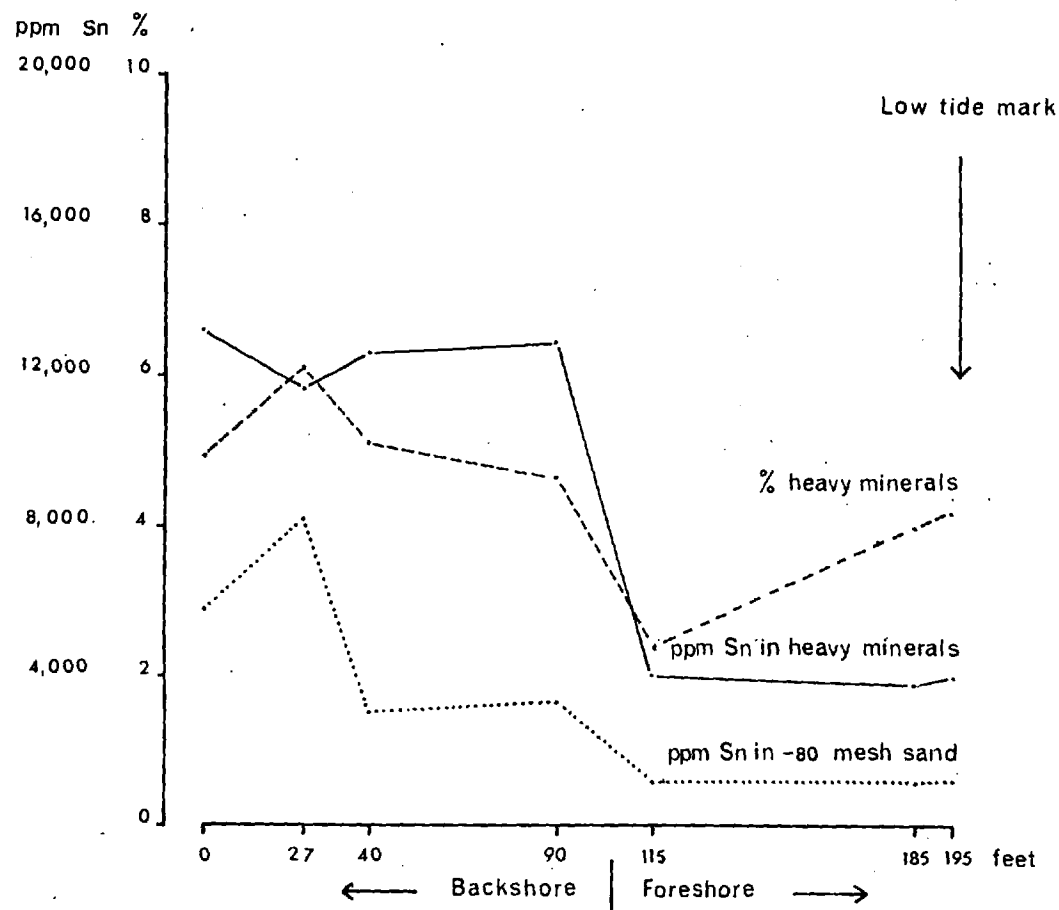


Figure 34. Tin contents of heavy minerals across the eastern end of Penzance-Marazion Beach (Traverse PMB-4).

| Depth<br>in<br>Feet | Near Penzance-Foreshore |         | Near Marazion-Backshore |         |
|---------------------|-------------------------|---------|-------------------------|---------|
|                     | Minus 80 mesh           | Heavies | Minus 80 mesh           | Heavies |
|                     | Sn-ppm                  | Sn-ppm  | Sn-ppm                  | Sn-ppm  |
| 0 - 1               | 200                     | 3600    | 6600                    | 12900   |
| 1 - 2               | 120                     | 3400    | 3300                    | 11700   |

Table 32. The vertical tin distribution (down to a depth of 2 feet) as determined from the minus 80 mesh, and heavy mineral fractions of the beach sands near Penzance and Marazion, respectively.

#### Porthleven Beach

Porthleven Beach is roughly two and a half miles long. The main part, that is, between Porthleven and Loe Bar, is very much coarser than the constituents of Penzance-Marazion Beach, but shingles or beach gravels are uncommon. Southeast of Loe Bar, the beach is somewhat thinner, and there are prominent rock outcrops below the shore cliffs. An unique feature of Porthleven Beach is the abundance of very coarse chert-sand particles, presumably they were derived from cherty beds which may have been completely eroded from near the shore. Durney (personal communication) reported of finding submarine chert beds immediately south of the study area, off the Lizard Point.

The surface samples from two traverses across the beach, located a quarter and three-quarters of a mile southeast of

Porthleven respectively, were analysed for tin. The first traverse (PB-1) yielded 40 to 260 ppm, and the latter (PB-2) 50 to 240 ppm tin. In a similar manner to Penzance-Marazion Beach, the highest tin concentration across the beach is found in the backshore, and decreases in the backshore-foreshore interface; then increases in the middle portion of the foreshore, and subsequently decreases seawards.

#### Praa Sands Beach

Praa Sands Beach is much shorter than either Penzance-Marazion or Porthleven Beach, it is only a mile long. Like the latter, cobbles and pebbles are sparsely distributed; the texture is predominantly medium to fine grained.

The tin values along PSB-1 traverse, which is located near the mouth of Praa River, vary from 40 to 2,100 ppm; on the other hand, the tin distribution along the traverse (PSB-2) in the southeastern-end of the beach is much lower, 40 to 90 ppm only. Both traverses point out to the fact that, across the beach, the tin distribution is highest in the landward portion of the backshore, and diminishes near the backshore-foreshore contact. In the middle part of the foreshore, the tin distribution slightly rises, and then decreases seawards.

The different layers of the laminated beach sands exposed at the bank of Praa River (on the beach) were analysed separately

for tin. The light-grey, medium to fine grained surface layer contain 3,000 ppm tin, while the subsurface dark-grey lamina of similar texture contain 10,750 ppm. In contrast, the tin content of the pale coloured, coarse subjacent layer is less than 300 ppm.

#### Perranuthnoe Beach

Perranuthnoe Beach is about half a mile long. Although boulders and cobbles are common close to the base of the cliffs, the rest of the beach is characterised by medium to fine grained sand. The overall texture is similar to Praa Sands Beach, and finer than Penzance-Marazion and Porthleven Beaches.

Only one traverse was laid across Perranuthnoe Beach. The tin values are in the order of 560 to 6,200 ppm. Like Penzance-Marazion, Porthleven and the other major beaches, the tin distribution across Perranuthnoe is highest in the backshore; then decreases near the contact of the backshore and foreshore, and rises again in the middle portion of the latter, and finally decreases towards the inshore sediments.

#### Minor Beaches, Including Those in the Coves

The beach south of Newlyn Harbour is predominantly very coarse grained and pebbly. Furthermore, it is undoubtedly contaminated by rock derivatives from the Penlee Quarry; thus

it was not sampled. Similarly, no sampling was undertaken on the beach between Marazion and Perranuthnoe because of the abundance of cobbles and boulders. Random sampling was done on the small beaches in Prussia, Kenneggy, Rinsey, and the coves between Trewavas and Porthleven.

The beach sands in Prussia and Kenneggy Coves are medium to coarse grained, and slate fragments preponderate. The tin contents vary from 40 to 90 ppm. In Rinsey Cove, the beach is fine to medium grained, and it has an appreciable tin concentration, ranging from 450 to 4,300 ppm. The beaches in the small coves between Trewavas and Porthleven are largely coarse grained, and slate pebbles, cobbles and boulders predominate. The tin values are in the order of 50 to 150 ppm.

## DISCUSSION

Inasmuch as the beach sampling is, on the whole, reconnaissance in nature, the discussion presented below is largely generalised. Since none of the beaches was sampled extensively, it is not practicable at present to give detailed descriptions of the factors controlling the distribution of the tin-rich and siliceous sands, and the tenor of tin in each beach formation. Moreover, since it is highly probable that similar agencies control the migration and deposition of the sands in the different beaches, the overall discussion is mainly based on the observations from Penzance-Marazion, Praa Sands, Porthleven, and Per-ranuthnoe Beaches.

The relevant problems which need to be discussed are the following:

1. Origin of the tin-bearing and siliceous beach sands.
2. Factors controlling the distribution of the beach components.
  - (a) Movement of sand particles across the beach.
  - (b) Movement of sand particles along the beach.
3. Profile or vertical distribution of tin in the beaches.
4. Influence of coastal mine dumps on the beach composition.
5. Feasibility of the economic exploitation of tin from the beaches.

Origin of the Tin-bearing and Siliceous Beach Sands

In Penzance-Marazion Beach, the backshore is invariably coarser than the foreshore. On the whole, there is a general tendency of the beach constituents to become finer in the direction of Marazion.

Although Traverses PMB-1 and 2 are not far from the mouths of the streams near Penzance, the tin contents of the beach sands along these traverses are much lower than those in proximity to Marazion River outlet. This difference of tin concentrations is presumably due to the influence of stream sediments on the beach constituents close to the river outlets. As was mentioned in an earlier discussion, the coarser tin-rich particles of the fluvial sediments introduced into the bay usually settle near the river mouths, and most of them are washed onshore by waves and may be deposited on the adjoining beaches. It is likely therefore that the composition of the beaches near river outlets are dependent, to a large degree, upon the character of the river sediments. Hence, it is not surprising that the beach sands close to the Marazion River mouth contain higher tin than those at the Penzance-end of the beach because the Marazion stream sediments are in fact richer in tin than the sediments in the streams near Penzance.

Similarly, in Praa Sands Beach where the texture of the constituents does not vary markedly along the beach, the sands

near the mouth of Praa River have higher tin content than those situated farther away. This phenomenon could be correlated, as in the case of the Penzance-Marazion Beach, to the presence of tin-rich sediments in the nearest river -- the Praa River.

In Porthleven, the texture of the sands along the beach does not change noticeably. Here, again, the tin concentration is highest in the vicinity of the river outlet. This could be attributed to the high tin content of the sediments in Porthleven River.

By contrast, the distribution of tin on the small beaches in the slate coves between Trewavas and Porthleven, Kennegey, Prussia, etc., is generally low. In these beaches, the predominant constituents are grains, fragments, pebbles and cobbles of slate -- indicating that some beach components are derived from the weathering of the adjacent cliffs and other slate outcrops near the shore.

#### Factors Controlling the Distribution of the Beach Components

As stated earlier, when the terrigenous tin-bearing and siliceous detrital materials reach the sea, the coarser particles, especially of the heavy minerals, are mostly deposited not far from the river mouths. The finer low specific gravity minerals, and the easily transportable very fine heavies, are moved farther offshore or along the shore. This is indicated

by the data in Section A, Part III in which the tin content of the sediments near the outlets of Marazion and Porthleven Rivers are higher than those in the deeper parts of the bay, and near the middle of the beaches. Consequently, the amount of stanniferous minerals available for onshore movement, are greater in the vicinity of the river mouths than farther away.

#### Movement of Sand Particles Across the Beach:

The swash or uprush, especially by the storm-waves, move ashore a mixed assemblage, that is, regardless of the weights and sizes of the nearshore sediments. Aside from the slackening of the swash (during the high tide) immediately before the backwash or backrush starts, percolation through the coarse grained backshore greatly reduces the volume of water flowing back into the sea: so that the backwash velocity is considerably weakened (Duncan, 1964). In consequence, a large proportion of the tin-rich heavy minerals carried onshore by the swash may be left behind in the backshore and trapped in between the interstices of the pebbles and/or cobbles. Only the tin-poor fine and light particles may be returned seawards. The to and fro movements of the succeeding waves may further facilitate the sinking of the heavies through the top layer of pebbly coarse sands. As a result, there is a strong tendency for the heavy minerals to be concentrated at the landward side of the backshore thus giving rise to the tin "highs" in the backshore of

Penzance-Marazion, Perranuthnoe, Praa Sands, and Porthleven Beach, respectively.

The transition zone between the backshore and foreshore normally coincides with the high-water-level. Here, the velocity of the backrush during high tide approaches nil. Thus most of the sands, including the tin-poor minerals, carried by it either in suspension or rolling and saltation, are deposited close to the backshore-foreshore interface. Even if the uprush during low tide, deposits tin-rich minerals in this part of the beach (in a similar manner to the deposition of tin in the backshore by the swash during high tide), there would be no appreciable concentration of tin because the tin-poor particles deposited by the backrush during the high tide serve as "dilutents" of tin. Hence, there is generally low tin distribution below the berm, that is, near the boundary of the backshore and foreshore.

On the foreshore, the beach components are much finer, and more compact than on the backshore. Thus there is less chance for the heavies to be trapped between the interstices of pebbles, or to sink through the top layer of sand. Similarly, owing to the compact nature of the foreshore, the degree of percolation of the uprush (during low tide) is much less than that in the backshore, so that the backrush has still sufficient velocity to carry back seawards most of the materials previously transported

landwards by the swash. The succeeding swash may meet the backwash near the middle portion of the foreshore, resulting in the reduction of their velocities. This may facilitate the settling of the landward or seaward-bound heavy minerals (which are normally rich in tin) in the middle section of the foreshore. From the available data, it appears that the swash-backwash movements give a net result of concentrating a small amount of tin-bearing minerals in the middle zone of the foreshore. By contrast, the lights may have been moved farther landwards, or brought back to the sea. This may explain the slightly high tin concentrations in the middle section of the foreshores in the various beaches studied.

Close to the low-water-level, the backwash has a very weak velocity thus whatever materials are carried by it, including the tin-poor light minerals, are presumably deposited in this part of the beach. There is, therefore, no notable concentration of tin in the foreshore-offshore interface zone (Figure 32).

Along Traverses PMB-4 and 5 which are located not far from the mouth of Marazion River, the tin content of the minus 80 mesh sands just below the low-water-level is somewhat higher than those on the foreshore. Similarly, the percentage of the total (including plus 80 mesh) heavy mineral fractions and their tin contents, along Traverse PMB-4 (Figure 34), are higher on the seaward side of the low-water-mark than on the middle of the foreshore. This is an isolated case, but it is understandable

because the heavy minerals recently discharged into the bay by Marazion River, irrespective of size, are presumably deposited near the shore. During the summer when the waves are, as a rule, not very strong, possibly the recently discharged heavies still remained with the sediments very close to the shore-- they have not been moved onshore yet.

In this connexion, the anomalous "tin-in-heavies" distribution in the seaward-end of Traverse FMB-2 near Long Rock, should be noted. The heavy minerals decrease quantitatively from the middle of the foreshore (the backshore is not considered in this particular part of the discussion) towards the sea, but their tin contents moderately increase in the same direction. There is no clear-cut explanation of this. It is unlikely that the medium to coarse grained (plus 80 mesh) heavy minerals have been derived from the rivers near Penzance because the nearshore outcrops west of Traverse FMB-2 serve as impediments to their movement eastwards. It is surmised, nevertheless, that the medium to coarse heavy minerals, in particular cassiterite, may have been derived from the coastal weathering of the porphyry (elvan) dyke (this rock type has much higher tin content than slate) off Long Rock Village, and are deposited locally. Presumably, the proportion of cassiterite in the heavies associated with the in-shore sediments close to Traverse FMB-2, is higher than that of the heavies on the foreshore. So that, although the percentage of the total heavy minerals fraction in the foreshore-offshore

interface zone is lower, as compared to those situated on the middle of the foreshore, the tin contents of the heavies in the former is higher than those found on the latter.

It must be borne in mind that the preceding remarks on the anomalous "tin-in-heavies" distribution concern mainly medium to coarse grained stanniferous heavy minerals, and it has very little significance, if any, on the distribution pattern of tin in the minus 80 mesh sands. Thus, the "tin-in-heavies" distribution along Traverse PMB-2 must not be confused with the distribution, along the same traverse, of tin in the minus 80 mesh sands which manifest a gradual decrease from the foreshore towards the marine sediments.

#### Movement of Sand Particles Along the Beach:

The deposition of sands across the beach is likely to be modified by beach drifting, which may vary from time to time. This may be brought about by waves reaching the beach obliquely, and strong winds parallel to the beach during dry days.

Beach drifting is not believed to play a very significant role on Penzance-Marazion Beach because the predominant waves strike the coast almost perpendicularly. Besides, there are several rock outcrops near the shore which are likely to hinder the movement of sands (close to the low-water-mark) parallel to the beach. Nevertheless, strong westerly wind may move some dry, fine, light particles eastwards. By contrast, the easterly

wind seldom occurs; when it does, it is partly blocked by St. Michael's Mount. Consequently, the effect on the beach, if any, is insignificant. The above agencies, however, cannot explain adequately the marked variation of the beach texture near Penzance and Marazion, respectively. This disparity is presumably due to the different natures of the source materials. In general, the rivers near Penzance have greater gradient and narrower channels than Marazion, so that they have the capacity to move downstream coarse and pebbly materials. On the other hand, Marazion River passes through a swampy area; thus its velocity is considerably reduced before it reaches the sea. Therefore, the materials it carries into the bay, are generally finer (but richer in tin) than those discharged by the streams near Penzance.

In Porthleven Beach, the southwesterly and westerly waves approach obliquely, thus they may induce beach drifting towards the southeast. Consequently, some of the tin-poor light particles are presumably moved in the same direction, and the tin-rich heavy minerals largely remain near the mouth of Porthleven River. Also, the southerly waves strike the beach at an angle, but the beach drifting they may produce is to the opposite direction. This balances, to a certain extent, the southeastwards movement of light particles. Hence, although the tin content of the beach sands in the vicinity of Porthleven River outlet is higher than elsewhere on the beach, the lateral variation of the sands texture is not well-pronounced. The effect of the westerly,

southwesterly and southerly winds on the beach is minimal because they are transverse to the beach; their transporting capacity is towards the cliffs.

Similarly, in Praa Sands Beach, the southerly and westerly waves approach obliquely from different directions. Thus, they may propagate, at different times, beach drifting in opposite directions. There appears to be no cumulative effect of either forces. As a result, the texture along the beach does not change noticeably. But as expected, the concentration of stanniferous minerals is higher near the river mouth than in the other parts of the beach. Like Porthleven Beach, the westerly, southwesterly and southerly winds are transverse to Praa Sands Beach. The very light particles are not transported along the beach but inland, to form sand dunes.

Ferranuthnoc and the other small beaches in the coves are not significantly affected by beach drifting because they are protected from the longshore currents by the rock outcrops protruding into the bay. Likewise, the high cliffs protect them from the winds parallel to the beaches. Consequently, the lateral variation of grain sizes along these beaches is insignificant.

#### Profile or Vertical Distribution of Tin in the Beaches

On account of the scanty subsurface sampling because of the

inadequacy of the sampling instruments available at the time of the fieldwork, only a limited discussion can be presented on the vertical distribution of tin in the beaches.

The higher tin content of the upper one-foot layer of sand as compared to the subjacent one-foot thick horizon, near Penzance and Marazion respectively, is consistent with the assumption of a changing nature of the source. As mentioned earlier, the fluviatile sediments introduced into the bay after the mining activities in the coastal area are richer in tin than the older sediments.

In addition, the observation from the stratified portion of the Praa Sands Beach foreshore is worthy of mention. The banding may have been brought about by variation in weather conditions. During periods of small waves, the easily transported particles of quartz, feldspars, and of the other low specific gravity materials are deposited on the beach. If they are fine grained and uniformly graded, they form well compacted lamina. When strong waves occur, all sorts of sands are washed ashore; since the backrush of these type of waves normally has appreciable velocity, most of the lighter minerals are re-transported seawards. Only the heavy mineral are concentrated on top of the layer composed of light minerals.

The high tin contents of the dark-grey laminae is undoubtedly the result of the high proportion of tin-rich heavy minerals in them as compared to the pale-coloured layers where quartz,

feldspars, and other tin-poor minerals of low specific gravity are the common constituents. This phenomenon was also observed in Gwithian Beach, St. Ives Bay (Ong, 1962).

It is not known at present whether the tin distribution in the beaches steadily decrease downwards to the bedrock, or vice versa. This, indeed, merits further study.

#### Influence of Coastal Mine Dumps on the Beach Composition

The appreciable concentration of tin in the small beach in Rinsey Cove is apparently due to the erosion of the mine dump on top of the cliff. This is compatible with the previous assumption that mine dumps may contribute, in localised instances, to the composition of the beaches.

#### Feasibility of the Economic Exploitation of Tin from the Beaches

Bearing in mind the meagre information about the tin distribution in the various beaches, a definite conclusion cannot be drawn yet regarding the economic potential of the beach deposits from the point of view of tin exploitation. It is believed, however, that the backshore of the beaches offers more promise than the foreshore because most of the cassiterite and other tin-rich heavy minerals are usually concentrated in it. Furthermore, the tin-bearing minerals may be readily separated from the pebbly coarse sand simply by screening and tabling. Whereas,

it would be much more difficult to recover fine tin from the fine sediments -- this undoubtedly would require a more complicated mineral processing technique. Besides, the backshore is invariably above the water level, so that simple conventional mining methods can be employed, and operations can proceed without being hampered by tide conditions.

SECTION D: GENERAL COMPARISON OF THE TIN DISTRIBUTION IN THE  
MARINE AND BEACH SANDS OF MOUNT'S BAY AND ST. IVES  
BAY

Marine Sediments

The sediments deposit in St. Ives Bay, near the mouth of Red River, has already been thoroughly explored by the Union Corporation. There is a good possibility that it will be exploited economically. Therefore, in order that the Mount's Bay sediments may be compared with a similar deposit which has been proven to have economic potential, a number of samples were collected from the sediments near the mouth of Red River. The tin values (analysed in the minus 80 mesh fractions) obtained from 50 samples vary from 1,700 to 12,500 ppm, and the calculated local mean is 4,400 ppm.

Table 33 indicates that the regional and local means in Mount's Bay are much smaller than the St. Ives Bay mean<sup>x</sup>. Even in Praa Sands, where the offshore sediment deposit appears to be the richest in tin among the various Mount's Bay sediment formations, the local mean is only about one-fourth of the St. Ives Bay mean. Similarly, the known highest tin concentration

x This value represents only for the inshore sediments near the mouth of Red River, and not for the whole of St. Ives Bay.

in Praa Sands deposit, which is also the highest in the whole of Mount's Bay, is less than half of the tin maximum in St. Ives Bay.

| Locality          | No of<br>Samples | Range of Sn<br>Values - ppm | Mean of Sn<br>Values - ppm |
|-------------------|------------------|-----------------------------|----------------------------|
| St. Ives Bay      | 50               | 1700 - 12500                | 4400                       |
| Mount's Bay       | 285              | 10 - 6000                   | 410                        |
| Penzance Sed.     | 116              | 10 - 2100                   | 150                        |
| Porthleven Sed.   | 76               | 60 - 5500                   | 340                        |
| Trewavas Sed.     | 47               | 170 - 2000                  | 700                        |
| Rinsey Sed.       | 6                | 270 - 2700                  | 770                        |
| Praa Sands Sed.   | 13               | 180 - 6000                  | 1150                       |
| Perranuthnoe Sed. | 13               | 150 - 1550                  | 650                        |
| Marazion Sed.     | 14               | 90 - 4400                   | 920                        |

Table 33. Comparison of the tin distribution in St. Ives Bay, near the mouth of Red River, and in the different marine sediment formations in Mount's Bay.

In addition, a set of profile samples from near the mouth of Red River in St. Ives Bay, which were collected in a similar manner (by the suction pump) to the Mount's Bay profile samples, were elutriated (Figure 35).

The St. Ives Bay profile data are compared specifically with similar data from the Trewavas formation because the latter is one of the few economically promising sand bodies in Mount's Bay.

In Trewavas, all the elutriation fractions are sufficiently

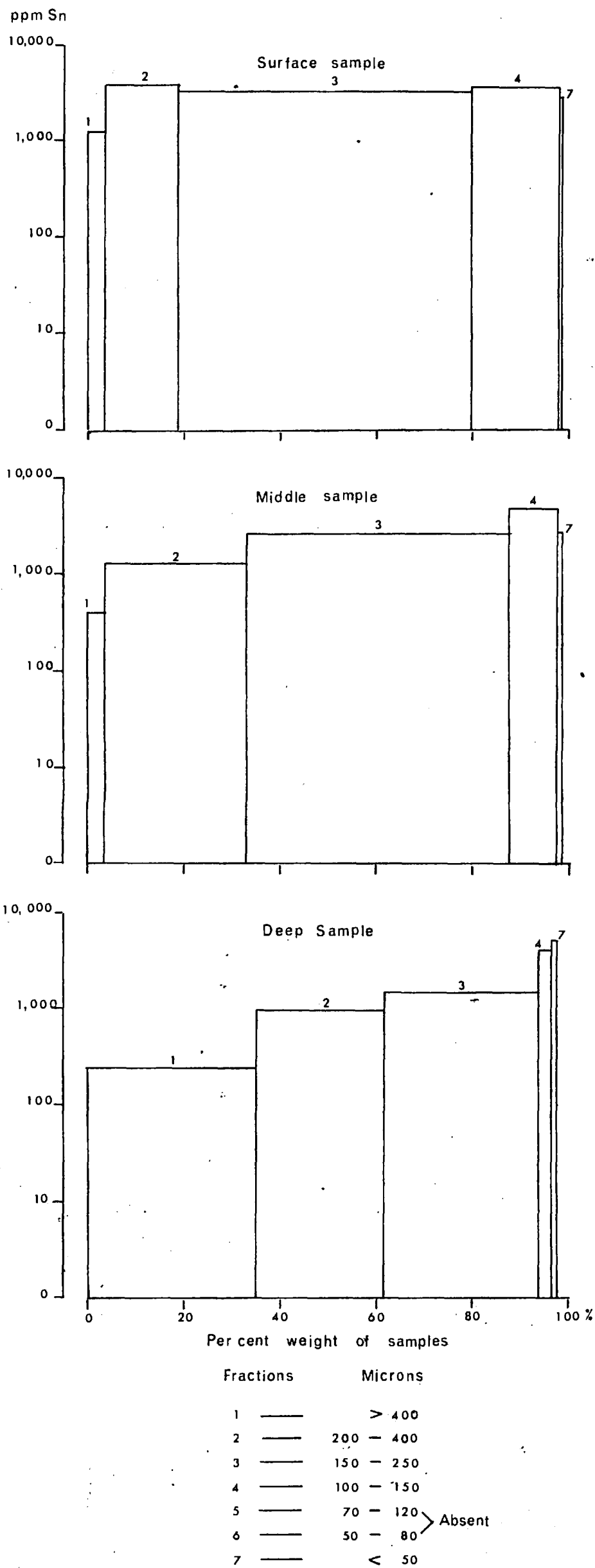


Figure 35. Elutriation results of profile samples from the marine sands near the mouth of Red River, St. Ives Bay.

represented in all the horizons sampled, and their per cent distribution and tin contents do not exhibit a definite trend from the surface down to the deeper horizons (Figure 28). By contrast, in the profile samples from the sediments near the Red River outlet, the very fine (60 to 120 microns) grained particles have negligible occurrence, and similarly, the silt-clay (< 60 microns) fraction have very small percentages in all the samples. The fine grained (120 to 250 microns) components distinctly decrease, in quantity, downwards, and the medium to coarse (200 to 400 microns) grained constituents markedly increase in the same direction. Moreover, the tin contents of all the size fractions, with the exception of the very fine grained, diminish towards the subjacent horizons; the reduction is especially conspicuous in the coarser fractions.

On the whole, the sediments near the mouth of Red River, St. Ives Bay, are coarser and richer in tin than the Trewavas formation.

#### Beach Sands

Like the marine sediments, the distribution of tin in the Gwithian Beach (St. Ives Bay) is very much higher than any of the beaches fringing Mount's Bay.

The minimum and maximum surficial tin concentration in Gwithian (Ong, 1962) are 25 and 1.27 times more than the corresponding

tin values in the beaches fringing Mount's Bay.

It was pointed out in the preceding section (Section C, Part III) that in Penzance-Marazion Beach, the top one-foot layer of sand has higher tin concentration than the subjacent one-foot thick horizon. This tendency of tin distribution to diminish downwards was likewise recorded in Gwithian Beach. According to Krishnan (1963), his analyses results of the banka drill cores manifested a general decrease of tin distribution towards the bedrock.

With respect to the tin distribution in the laminated beach sands, it was observed both in Praa Sands and Gwithian Beaches that the dark-grey layers have higher tin contents than the light-grey and pale-coloured laminae.

## DISCUSSION

The marked disparity of the tin distribution between the marine and beach sands deposits in St. Ives Bay and Mount's Bay, is due to the different degree of tin concentration in the stream sediments introduced into the respective bay.

Red River, which is the major carrier of tin-bearing minerals into St. Ives Bay, is draining the Camborne-Redruth tin mining district. Aside from the tin-bearing detritus derived from the lodes in the catchment area, the tin-rich mine and mill-tailings of South Crofty Mine are discharged into Red River so that there

is considerable amount of tin being transported by this river into St. Ives Bay. At this point, it might be mentioned that Hayle River is believed not to carry much tin into St. Ives Bay because the tin-bearing heavy minerals in the stream sediments are mostly trapped in the Hayle estuary. Hosking, et al, (unpublished studies) have demonstrated that the estuarine sediments deposit at Hayle contains appreciable amount of tin. On the contrary, the beach sands at the mouth of the Hayle River is not particularly rich in tin (Ong, 1962): the tin content is less than those of the middle portion of Gwithian Beach, and the inshore sediments near the Red River mouth.

On the other hand, the tin-bearing sediments in the rivers draining into Mount's Bay are mainly derived from the old mine dumps, and the weathering products of the lodes and the associated country rocks in the catchment areas. Moreover, there are no operating mines and mills to contribute tin-rich tailings and slimes into the streams. As compared to Red River, there is, therefore a limited supply of tin to the rivers draining into Mount's Bay.

The difference between the vertical (from the surface of the sediment formation downwards) size distribution of tin in the St. Ives Bay and Trewavas marine sediments may be attributed to the type of the sediment-sources. As was suggested in Section B discussion (Part III), the tin-bearing sediments in Trewavas may have been derived from both local and extraneous sources, thus it is

not unusual that the tin vertical size distribution is somewhat irregular. The higher tin concentration in the coarser fractions of the near-surface and middle samples (see Figure 28), in comparison to the surface and subjacent horizons, may be due to locally derived tin-rich minerals; as for example from the lodes along the coast. The high tin contents of the very fine and silt-clay fractions, particularly those on and near the surface, may be due to the tin-bearing sediments derived from extraneous sources. By contrast, the St. Ives Bay marine sediments, especially near the mouth of the Red River, are mainly river-transported, and this being the case, surface and near-surface tin-enrichment are more likely. Thus the tin contents of the top horizon is higher than the deeper horizons (Figure 35).

## SECTION E: SOME ELEMENTS ASSOCIATED WITH TIN

With the view of obtaining information on the elements present, other than tin, in the marine sediments and various rock types of Mount's Bay, a number of selected samples were spectrographically analysed. Owing to the limited number of determinations, it is not intended to discuss in detail the geochemistry of each element detected in the samples. This is essentially a qualitative investigation, nevertheless, it is hoped that the present data will help future detailed investigation on the geochemistry of the various elements associated with tin (Table 34).

Apart from the considerably richer distribution of tin in the marine sediments as compared to the rocks, which has already been explained in the text, the most striking feature of the spectrographic results are the noticeable difference between the distributions of zinc and gallium in the marine sediments, and in the rocks. The former has very much lower zinc and gallium contents than the latter. This is presumably due to the fact that zinc as well as gallium are readily removed in solution during weathering (Rankama and Sahama, 1960). Inasmuch as gallium is normally associated with aluminium-bearing minerals (Goldschmidt, 1958), it probably occurs in the marine sediments as a constituent of tourmaline. Another interesting feature is the higher concentration of copper in the Trewavas sediments in

| Ele | Marine Sediments |        |        |       | Rock Types |         |      |       |       |
|-----|------------------|--------|--------|-------|------------|---------|------|-------|-------|
|     | Penz             | Praa S | Trewav | Porth | Grnt       | Spt Slt | Slt  | Dole  | Elvan |
|     | No 74            | 166    | 234    | 192   | 551        | 563     | 406  | 1044  | 1016  |
| Sn  | 30               | 150    | 1000   | 7000  | 100        | 120     | 10   | 30    | 40    |
| Bi  | <5               | <5     | <5     | <5    | <5         | <5      | <5   | <5    | <5    |
| Cr  | 60               | 60     | 60     | 80    | 2          | 400     | 150  | 400   | 12    |
| Co  | 10               | 10     | 10     | 10    | 5          | 40      | 15   | 40    | 5     |
| Cu  | 10               | 30     | 40     | 7     | 10         | 40      | 40   | 50    | 80    |
| Ga  | 8                | 7      | 8      | 10    | 40         | 30      | 30   | 15    | 20    |
| Pb  | 18               | 25     | 30     | 30    | 10         | 30      | 30   | 7     | 20    |
| Mn  | 200              | 300    | 300    | 600   | 200        | 400     | 700  | 1000  | 300   |
| Mo  | <2               | <2     | <2     | <2    | <2         | <2      | <2   | <2    | <2    |
| Ni  | 40               | 40     | 60     | 60    | 5          | 5       | 60   | 90    | 10    |
| Ag  | <0.2             | <0.2   | <0.2   | <0.2  | <0.2       | <0.2    | <0.2 | <0.2  | <0.2  |
| Ti  | 1000             | 2000   | 2000   | 3000  | 100        | 10000   | 6000 | 10000 | 2000  |
| V   | 30               | 30     | 50     | 40    | 2          | 2       | 70   | 200   | 8     |
| Zn  | 50               | 50     | 50     | 50    | 70         | 100     | 150  | 100   | 100   |
| Zr  | <200             | <200   | <200   | <200  | <200       | <200    | <200 | <200  | <200  |

Note: Penz - Penzance, Praa S - Praa Sands, Trewav - Trewavas, and Porth - Porthleven.

Grnt - granite, Spt Slt - spotted slate, Slt - slate, Dole - dolerite, and Elvan - porphyry dyke.

Table 34. The distribution (ppm) of some elements associated with tin in the marine sediments, granite, spotted slate, slate, dolerite, and elvan in Mount's Bay.

comparison to Penzance and Porthleven deposits. Because of the high pH (about 8) of sea water, the solubility of copper is limited, and since one can assume that the pH in Mount's Bay does not

vary much, the solubility of copper in the different parts of the bay would be roughly the same. Under these conditions, the disparity of the copper distribution in the various marine sand formations in the bay is not primarily due to the difference of the solubility rate of copper, but may depend more on the nature of sediment-supply. The copper "high", therefore, in Trewavas may be attributed to the presence of cupriferous lodes in the immediate vicinity, typified by the lodes exposed at the cliffs in Trewavas.

PART IV: SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE  
STUDIES

SECTION A: SUMMARY OF CONCLUSIONS

The conclusions drawn in the light of the available data are enumerated below and in the succeeding pages.

Summary of Conclusions Regarding Techniques

Field Techniques

1. So that sampling operations can be planned systematically, it is necessary to have sparker and echometer surveys to determine the bathymetric features, and the limits of the unconsolidated sediments formations.
2. In the absence of a Decca Navigator, a sextant (with a sextant chart) is more accurate and simpler to use than a compass. During rough weather, however, the compass is easier to handle.
3. For reconnaissance sampling of surface marine sediments, a grab sampler is reasonably accurate, and much less expensive than divers. Furthermore, it can be operated with or without a winch from a small boat, say a 10- or 15-footer gig.
4. In the detailed sampling of marine sediments, it is of vital advantage to employ divers so as to achieve accurate location of samples.

5. Piston and gravity corers cannot attain deep penetration in well-compact sand.
6. Sand or peat auger is not effective either on the beach or in the submarine sediments.
7. Divers are indispensable in the collection of submarine rock samples.
8. Chisel and hammer may be employed by the diver in sampling slate and other soft rocks. But in the hard and massive rocks such as granite, dolerite, etc., it is necessary to use a compressed air (percussion) operated hammer.

#### Laboratory Techniques

1. It is not necessary to cone and quarter the sand sample in order to obtain a representative fraction for analysis. A reasonably representative fraction can be obtained by thoroughly mixing the sample and then sieving a portion of it through an 80 mesh nylon screen.
2. Sizing by elutriation is effective in the sand, particularly where there is no abundance of silty and clayey particles. Although it does not give the true size distribution data of the mineral or element concerned, as in the case of dry-sieving, it has the advantage over the latter of providing data on the size-range of sediments which are transported in suspension at a known water current velocity.
3. Notwithstanding that elutriation is a very slow process, it

does not hinder the progress of laboratory work because dry-sieving size analysis, heavy mineral separation, or chemical analysis can be done simultaneously with it.

4. The conventional method of heavy mineral separation, that is, by employing ordinary glass funnels, is not applicable to very fine sands. It is better to use small separatory funnels (modified) where periodic shaking can be done to facilitate separation of heavies sticking to the light particles.
5. Ammonium iodide attack does not liberate all the tin from the sand, especially from the coarser fractions.

#### Summary of Conclusions Regarding Physical Features in Mount's Bay

##### Rocks

1. The rock types in the bay are similar to those found on the coast. The most common is slate; it is exposed extensively in the central portion of the bay, south of the coastline between Marazion and Porthleven.
2. Submarine dolerite occurs sporadically, possibly as dykes in the slate.
3. The offshore outcrops of St. Michael's Mount and Godolphin granites do not extend far into the bay.
4. Hornfels and spotted slates are found near the St. Michael's and Godolphin granites. South of Godolphin, spotted slate was observed more than one and a half miles offshore. Since

spotting is normally restricted to the slates bordering the granites, it appears therefore that the granite-slate contact under the sea is shallow-dipping.

5. Evidence of mineralisation in the submarine rocks was seen only in two localities. From the present density of rock sampling, no definite conclusion can be drawn regarding the frequency of the occurrence of lodes in Mount's Bay.
6. There are buried valleys beneath the Penzance and Porthleven sediments deposits; they seem to be connected with the channels of Newlyn, Penzance, Marazion and Porthleven Rivers.

#### Stream Sediments

1. The overall size distribution of the stream sediments components is perceptibly bi-modal. The fine and medium grained (100 to 400 microns) particles predominate. The secondary maximum is constituted by the silt-clay (< 60 microns) fractions: the very fine (50 to 100 microns) grained materials being present only in minor quantities.
2. The proportion of medium and coarse grained particles in the stream sediments is higher than that of the marine sediments.

#### Unconsolidated Marine Sediments

1. The marine sediments deposit in Mount's Bay is composed of several formations. The Penzance deposit is the thickest (maximum thickness is over 60 feet) and largest, followed

by the Porthleven sediments with a maximum thickness of over 20 feet. Trewavas-Rinsey, Praa Sands, and the other small bodies of sand are all less than 20 feet thick.

2. On the average, Praa Sands marine sediments formation is comparatively coarser than the rest.
3. The coarse sand grains in Penzance, Trewavas-Rinsey, Porthleven, Perranuthnoe and Marazion commonly occur near the shore and rock outcrops under the sea.
4. Quartz grains are the predominant components of the coarse sands near the submarine extensions of the granites. By contrast, slate fragments occur in abundance close to the slate bodies.
5. The size distribution of the marine sediments appears to be bi-modal. Fine to medium (100 to 400 microns) grained particles, and silty sediments (< 60 microns) preponderate; whereas, the very fine (50 to 100 microns) grained particles have limited occurrence.
6. The marine sediments become generally finer towards the deeper parts of Mount's Bay.
7. By and large, the heavy minerals distribution (and their tin contents) decrease seawards.
8. The concentration of shell fragments and other HCl-soluble sand constituents increases as the bay deepens.
9. Cobbles and boulders of slate and dolerite are found, far from the shore, in some shallow depressions in the bedrock.

### Beaches

1. The backshore zone of every beach is coarse, and in places, pebbly.
2. The foreshore of each beach is finer and more compact than the backshore.
3. Excluding the pebbles and cobbles, on the whole, Porthleven Beach is much coarser than the other beaches.
4. Unlike Penzance-Marazion and the other major beaches, the composition of the small beaches in the coves are mostly fragments, pebbles and cobbles of slate.

### Summary of Conclusions Regarding the Distribution of Tin

#### Rocks

1. All the unmineralised rocks along the coast and in the bay contain low tin. Granite has the highest tin content, followed by dolerite, spotted slate, porphyry dyke, and "unaltered" slate.
2. The cupriferous lodes along the coast are rich in tin.
3. The coastal and submarine rocks contribute to a minor extent to the composition of the marine sediments.

#### Stream Sediments

1. The sediments in the streams draining into Mount's Bay are rich in tin.

2. Stream sediments are the major sources of the tin-bearing and siliceous sediments in Mount's Bay.

#### Head, Sand Dunes, and Mine Dumps

1. Except in isolated cases, such as in Perranuthnoe, the head have low tin content.
2. Sand dunes are invariably poor in tin.
3. Mine dumps along the coast are rich in tin, but they are not widely distributed.
4. To a very limited extent, the head and mine dumps contribute tin to the beach sands and marine sediments (particularly those near the shore), but sand dunes do not.

#### Unconsolidated Marine Sediments

1. The high concentrations of tin (surficial) are usually situated close to the shore, particularly near the river mouths. By and large, the tin distribution decreases with increasing distance from the north-shore.
2. Inshore sediments found close to the submarine granite outcrops contain higher tin than those in the neighbourhood of slate.
3. The vertical tin distribution, that is from the sediment surface downwards (at least to a depth of four feet), tends to decrease with depth. However, the possibility of an appreciable tin concentration immediately above the bedrock,

- particularly in the buried valleys, has not been ruled out.
4. In a given sample, the tin-tenor tends to increase with decreasing particles size.
  5. Both the heavy and light mineral fractions contain tin. The heavies, however, are much richer in tin than the lights.
  6. The tin content of the heavy minerals in Trewavas sediments appears to indicate the position of the offshore extensions of the coastal lodes.
  7. On the whole, Praa Sands, Trewavas-Rinsey, Marazion and Pen-ranuthnoe deposits appear to have higher tin-tenors than Penzance and Porthleven sediments.
  8. From the point of view of economic exploitation, Praa Sands, Trewavas-Rinsey marine sediments formations, and those near the mouths of Marazion and Porthleven Rivers, are the most promising.
  9. By comparison, Mount's Bay marine sediments have lower tin contents than the inshore sands near the mouth of Red River in St. Ives Bay.

#### Beaches

1. By and large, the Penzance-Marazion Beach contains more tin than any of the other beaches. The small beaches in the coves, except Rinsey, are especially poor in tin.
2. The tin distribution on Penzance-Marazion Beach tends to increase eastwards, and the highest concentration is in the

vicinity of the Marazion River outlet.

3. Across every beach studied, the surface and near-surface tin distribution is highest in the landward-side of the backshore and decreases towards the backshore-foreshore interface, then increases slightly near the middle portion of the foreshore, and eventually diminishes seawards.
4. The dark grey sand layers, where there are substantial accumulation of heavy minerals, are richer in tin than the pale-coloured laminae where quartz, feldspars, mica and other low specific gravity minerals preponderate.
5. The vertical distribution of tin appears to decrease, at least to a depth of two feet, downwards.
6. Generally, the Mount's Bay beaches contain less tin than the Gwithian Beach in St. Ives Bay.

#### General

1. The tin content of the coarser ( $> 197$  mesh) fraction of the heavy minerals appears to be reliable guide to the location of submarine mineralisation.
2. The common constituents of coarse marine sediments reflect the lithology of the nearest rock outcrops.
3. It is possible to obtain a general picture of the hinterland geology by studying the mineralogy and geochemical distribution of various elements in the coarser fractions of inshore and beach sands, particularly those near the river mouths.

4. Geochemical techniques would be useful for prospecting and/or exploring submarine mineral (metallic) deposits.

#### SECTION B: RECOMMENDATIONS FOR FUTURE STUDIES

In order to substantiate the informations at hand, and to verify the present observations, the following investigations are suggested:

1. The vertical distribution of tin in the marine sediments is not well understood. Thus sub-surface sampling should be done, particularly in the Trewavas deposit, near the mouth of Marazion River, and in the sediments (Penzance and Porthleven) filling up the submerged valleys. In addition, sub-surface sampling may be undertaken in the following places: Praa Sands, Marazion, Perranuthnoe and near the mouths of Porthleven and Cober Rivers. Ultrasonic vibro-drill may be employed. And it is understood that the Japanese have developed this instrument.
2. The apparent significant relationship between the offshore extensions of the coastal lodes and the tin contents of the heavy minerals (in the marine sediments) should be further investigated. This may be done by studying the surficial distribution of the heavy minerals during different seasons, and the tin contents of the heavies in the deeper horizons (sub-surface).

3. The form of tin in the heavy and light mineral fractions should be studied in detail. Moreover, the recovery process of tin may be investigated.
4. With the view of understanding the movements of sediments, surface, near-surface, and bottom currents should be investigated. Special attention should be given to areas close to the mouths of the rivers. This may be done with a buoy detectable by radar. Furthermore, transportation of beach and inshore sands should be studied by tracing the movements of glasses, or sands induced with radio-activity.
5. The isolated tin "highs" close to the shore but not near the river mouths should be investigated further.
6. Periodic sampling on the beaches and inshore sands in order to ascertain the variation of the sediments, especially the heavy minerals, distribution with respect to climatic changes. This may be undertaken during different seasons, or after major changes of weather conditions.
7. Detailed sampling should be done on the beaches, including sub-surface sampling by banka drill so that additional information of the tin distribution on the beaches can be obtained.
8. The influence of submarine rocks on the composition of the marine sediments should be investigated further. This may be done by sampling sands directly overlying rock outcrops and at increasing distance from them.

9. Verify the mineralisation in the submarine bedrock by collecting additional rock samples from the localities where the mineralisation was observed.
10. Detailed sampling should be undertaken in the vicinity of Wherry (tin-impregnated elvan) Mine off Penzance.
11. The dispersion of lead should be investigated in the vicinity of the seaward extension of the lead-bearing lodes on the coast.
12. In order to gain information on the amount of sediments introduced into the bay relative to time, or climatic conditions, measure the sediment-discharge capacities of the rivers draining into Mount's Bay.
13. The tin contents of the sediments in Cober River and Swan Pool (inside Loc Bar) should be investigated.
14. Examine the nature of materials which could have been introduced into Mount's Bay during the pre-mining period. This may be done by: (a) detailed study of the uncontaminated soils, and various types of lodes in-situ and their associated country rocks, and (b) comprehensive investigation of the nature of tin in the different horizons of the marine sediment formations.
15. Study of the geochemical and mineralogical compositions of the dump materials found in the catchment areas of the rivers draining into Mount's Bay. Compare with the stream and surficial marine sediments.

16. The geochemistry of the various elements associated with tin should be examined.
17. The extraction capacity of ammonium iodide attack of tin from the various size particles should be further investigated.

## APPENDIX

### DETERMINATION OF TIN

#### Sample Preparation

1. Dry the sample.
2. Mix thoroughly.
3. Sieve a portion through an 80 mesh nylon screen.

#### Reagents

1. Ammonium iodide.
2. 1 M hydrochloric acid: add 45 ml of concentrated acid (sp. gr. 1.18) to 455 ml of water, and mix.
3. Buffer solution: dissolve 26 g of sodium hydroxide (A.R.) in 400 ml of water, and when cold, mix this solution with 106 g of chloroacetic acid and 20 g of hydroxylamine hydrochloride dissolved in 400 ml of water. Dilute to 1 litre with water.
4. Stock reagent solution: dissolve 0.1 g of gallein in 100 ml of ethyl alcohol by heating gently and filter through a Whatman No. 41 filter paper. Dissolve 0.03 g of methylene blue in 200 ml of water, warming gently. Combine these two solutions in equal proportions to form the stock reagent solution.

5. Dilute reagent solution: mix 10 ml of the stock reagent solution with 400 ml of buffer solution and 90 ml of 1 M hydrochloric acid.
6. Gelatine solution: dissolve 1 g of gelatine in 100 ml of water by heating gently.
7. Standard tin solution:  
100 ug of tin per ml-- dissolve 50 mg of tin powder in 50 ml of concentrated hydrochloric acid and dilute to 500 ml with water.  
5 ug of tin per ml-- dilute 5 ml of the 100 ug per ml tin solution to 100 ml with 1 M hydrochloric acid.

#### Preparation of Standards

1. To 12 test tubes add respectively 0, 0.25, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 ug of tin.
2. To each of the first six tubes add 0.5 ml of 1 M hydrochloric acid.
3. Add 0.2 ml gelatine solution to all tubes.
4. Dilute to 5 ml with buffer solution.
5. Add 0.1 ml of reagent stock solution.
6. Mix, and allow to stand for at least 10 minutes before using.

#### Procedure

1. Weigh 1 g of sieved sample into a pyrex test tube.

2. Mix thoroughly with 1 g of ammonium iodide.
3. Heat until the ammonium iodide ceases to sublime and the residue becomes red hot.
4. Allow to cool, and add 5 ml of 1 M hydrochloric acid.
5. Leach by bringing to the boil, and then allow the residue to settle.
6. Pipette 1 ml of the clear solution into a test tube. Use an 18 x 180 mm test tube, calibrated at 5, 10, 15 and 20 ml.
7. Dilute to 5 ml with buffer solution.
8. Warm gently to reduce iodine and allow to cool.
9. Add 0.1 ml of stock reagent solution.
10. Mix and allow to stand for at least 10 minutes.
11. Compare with standards.
12. When the test solution is greater than the highest standard, add dilute reagent solution until the colour is grey, and allow to stand for at least 10 minutes before matching with standards.
13. If the test solution is still above the top standard, repeat with an aliquot of 0.1 ml. Before proceeding to step No. 7, add 0.5 ml of 1 M hydrochloric acid.
14. Calculate parts per million of tin:

$$\text{Tin (in ppm)} = \frac{b \times v \times d}{w \times a \times 5}$$

b -- matching standard (microgram)

v -- volume of final solution (ml)

d -- volume of the leach solution (ml)

w -- weight of sample (g)

a -- aliquot taken (ml)

Remarks

1. The lower limit of determination is 0.5 ppm. If this sensitivity is not required, use a smaller sample weight and/or an increased leach volume.
2. The leach solution must not be allowed to stand over-night in contact with the residue before it is analysed.
3. As described above, the range covered is 0.5 to 100 ppm, which may be extended to 1,000 ppm by using an aliquot of 0.1 ml.
4. The buffer solution should be at  $\text{pH } 2.65 \pm 0.25$ .
5. Results may be obtained with  $\pm 25$  per cent over the range 0.5 to 100 ppm.
6. Eighty samples can be analysed per man-day of 8 hours.
7. For further informations refer to R.E. Stanton and A.J. McDonald, Trans. Inst. of Min. Metall., London, 1961/62, 71, 27-29.

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