A

THESIS

entitled

GEOCHEMICAL DISPERSION OF TIN IN MARINE SEDIMENTS, MOUNT'S BAY, CORNWALL

Submitted for the

degree of

DOCTOR OF PHILOSOPHY

in the

FACULTY OF SCIENCE IN THE UNIVERSITY OF LONDON

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April, 1968

ABSTRACT

Problems of the geochemical dispersion of tin in the marine sediments are dominantly approached from a sedimentological point of view.

Section 1 - The transport of Marazion River was studied with the help of fluorescent tracers. Rainfall and stream velocity were high during the period of observations. All material was transported, but only particles of medium and smaller sizes reached the beach. River characteristics did not greatly influence the nature of the transport. Heavy minerals were transported, provided their particle size was equal to or smaller than fine sand.

Section 2 - The current pattern in Mounts Bay was studied using bottom drifters. There are two currents in the Bay; the main one is a clockwise current, increasing in strength towards the east. The second current is a smaller clockwise eddy current in the western part of the Bay. No information has been obtained on current velocity. Transport of heavy minerals in the marine environment was studied by using irradiated tantalite/columbite (sp. gr. 6,95) of minus 200-mesh size. Transport occurred in four directions related to the main tidal current, the eddy current, currents induced by the ebbing tide and currents induced by ground swell. A small proportion of the total material only was affected by transport, and overall dispersion did not exceed 1 mile during the period of observation.

Section 3 - Groups of samples forming traverses have been collected in western Mounts Bay. Grainsize distribution and tin content were studied and indicated a uniform sand body with the maximum tin content confined to the smallest sizes. Interpretation of the data on the Rubey and Rittenhouse application of Stokes law, indicate that the majority of the tin content of the sediments is related to terrestrial sources. In addition, primary mineralisation is postulated for persistant anomalies south of St. Michaels Mount. Furthermore, there is an additional source of tin in composite grains, whose dispersion is restricted to the eddy current. Discussion is given on the distribution of material and the dispersion of tin in wave action, subsurface samples and fossil beaches. Finally, the copper content of selected surface samples indicate that maxima in tin and copper content coincide.

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INTRODUCTION

A. GENERAL

Cornwall, the most south-westerly county of Britain has since long been famous for its resources of minerals such as tin, copper and china clay.

Especially with respect to tin and copper, the mining history of Cornwall goes back a long way. Although after the hey-day of mining in the last century, the total output of tin decreased substantially, increased world demand for this mineral has renewed the interest in the potential of this mineral province which still remains considerable. Exploration is not confined to the land alone. On the north coast of Cornwall for instance, mining from the land has proceeded well under the sea, while as recent as 1968 preliminary investigations are carried out on an offshore mineralisation known to occur in the vicinity of Penzance. Offshore mining and prospecting is not limited to primary sources, but alluvial deposits are presently being mined in St. Ives Bay, while an extensive survey is being carried out along the south coast.

To assess the potentials of a recent sediment containing a detrital mineral such as tin, it is essential to obtain an understanding of the sources of the mineral as well as its dispersion in the sediment. This was the primary object of the research of which this thesis is the result. Mounts Bay, on the south coast of the peninsula, was chosen as the study area, mainly since the present work is essentially a continuation of the research carried out in this area by P.M. Ong in 1964/65. Much of his data, therefore, is used in the present thesis and for overall information regarding the bay, the reader is referred to Ong (1966).

B. SCOPE OF THE THESIS

The thesis is divided into three main sections. The first deals with some aspects of the transport by rivers of detrital tin and its discharge into the sea. This study has been carried out with the help of fluorescent tracers.

Section 2 is concerned with the current pattern in Mounts Bay and the transport of material in this environment. Use has been made of bottom drifters and radio-active tracer techniques.

The third and last section presents the geochemical data of the offshore sediments and discusses the geochemical dispersion of cassiterite and its origin on the basis of Sections 1 and 2.

The sections form units on their own. Consequently, techniques used in the research will not be discussed together, but in each relevant section. Likewise, a review of previous work is not treated in a single section but is incorporated in the text.

C. ACKNOWLEDGEMENTS

The writer wishes to express his sincere gratitude to the Dutch Government, Curatoren van de Rijks Universiteit te Leiden and Curatoren van het fonds "Noorthey" for their financial support, without which the opportunity to study abroad would never

have occurred.

To my supervisor, Dr J.S. Tooms, I can only say that his guidance and advice, in and outside the field of the study, will have value for the rest of my life; I owe him very much.

I should like to express sincere thanks to Mr D.B. Smith and Mr. T.V. Parsons of the Atomic Energy Research Establishment Wantage (Berks). The knowledge and experience, as well as the facilities they made available were indispensable for the success of the tracer experiments. To work with them was a great pleasure.

Thanks are due to the Union Corporation, who provided the "Wheal Geevor", to Alpine Geophysics Ass., who made available some cores, and to the Penzance Borough Council for making available reports concerning their sewage disposal schemes which contained valuable information with respect to the current system in western Mounts Bay.

The advice given by the Hydraulic Laboratories, Wallingford with respect to fluorescent tracers is gratefully acknowledged.

Finally, the writer should like to thank the members of the Imperial College underwater club who participated in the sampling operations.

D. GENERAL GEOLOGY OF S.W. CORNWALL

Pre-Devonian rocks in S.W. Cornwall are known to occur as lenses in the Meneage crush zone in the Lizard serpentinite complex (Hendriks, 1937). This complex, however, occupies a limited area on the far eastern side of Mounts Bay and will not be considered further here.

The dominant sedimentary rocks, which have been dated as lower to upper Devonian, consist of non-calcareous, potassium-rich slates. They are interbedded with limestones, grits, tuff and agglomerate and spillitic lavas. Other basic, dyke-like intrusions, known as greenstone, occur locally. They are considered to be altered dolerites.

The sediments, which were deposited near the northern perimeter of the Hercynian geosyncline, have a dominant E-W strike. The Variscian orogeny with a roughly N-S compression gave Cornwall its complex east west structure mainly during the Asturian phase (Upper Carboniferous). Deformation was accompanied by regional metamorphism, the most intensive metamorphism occurring in the south.

During the Asturian phase, and probably also during the Salic (Permian) phase (Webb, 1947), intrusion of tin bearing acid rocks took place. The granite outcrops, which are suggested to be cupolas of a great granite batholite (Hosking, 1949) can be followed from the Scilly Islands in the south-west to Bodmin in the north-east. The instrusions caused contact metamorphism and hydrothermal or pneumatolytic alteration of the host rocks; resulting in the so-called spotted slates.

Contact metamorphic zoning is apparently not well developed but has been observed in a number of places (Cox, 1961). Genetically related, and general parallel to the trend of the granites, are the porphyry dykes (known as elvan dykes) and hydrothermal lodes. The dykes are contemporaneous with the late period of the granitic intrusions, but have a much finer texture and contain appreciable amounts of tourmaline and topaz.

The formation and origin of the mineral lodes have been the subject of many studies. Webb (1947) has classified the lodes into a number of zones. They are as follows:

1. A tin zone, dominantly in the granite, near its margins.
2. A copper zone on the granite/killas contact.
3. A lead-zinc zone in the metamorphic aureole, and
4. an iron zone in the unaltered slates.

Zones, especially those of tin and copper, often overlap.

The only existing Mesozoic sedimentary deposits in Cornwall occur in the north and consist of granite pebbles originating from Devon. Much of the remainder of the peninsula was, probably, land during the whole of this period.

With the Alpine orogeny, Cornwall was almost completely submerged, leaving only isolated granite outcrops above the sea level. In post Pliocene times, gradual emergence took place. This is illustrated by a number of platforms and raised beaches, ranging from 1000 feet to 10 feet above the sea level, with an especially well developed 400 foot platform. Furthermore, the emergence is illustrated by valleys filled with sediment to a depth of 40 feet underneath the present sea level (Robson, 1944), which more recently have again been submerged. Extensive evidence of the effect of the glacial climate is provided by the periglacial solifluction product, head, consisting of a non-homogeneous mass of clay and rock fragments deposited in the valleys and on the 10 foot raised beach.

E. GEOLOGICAL ASPECTS OF MOUNTS BAY

The geology of Mounts Bay is fundamentally the same as the surrounding land. The following summary is based on a joint geochemical and geophysical survey carried out in 1965 by the Imperial College (Tooms et al, 1965).

Although no granite outcrop occurs in the Bay beyond the immediate coast line, the other prevailing rock types are frequently encountered, including slates which are locally spotted, possibly indicating a granite at shallow depths, and dolerite and porphyry dykes with a NE-SW strike. Bedrock mineralisation occurs in the vicinity of Penzance and may possibly be expected near St. Michaels Mount (Hosking, 1954). Additional indications of seaward extension of Cu/Sn lodes known on land exist near Trewavas Head (Ong, 1966).

The Bay is up to 160 feet deep, but the main part has a depth range between 70 and 100 feet. The bedrock topography is undulating in so far that there are pronounced depressions which appear to form the seaward extension of the present drainage system.

This period of emergence (i.e. when the valleys were formed), was characterised by dense vegetation, which resulted in the so called submerged forest layer. It was in this time that the buried leads of alluvial tin were formed (Henwood, 1873; Robson, 1944). The depressions in the Bay are filled with sand. The largest sand body occurs in the western part of the Bay and has a maximum thickness of 60 feet. The sand in the eastern part of the Bay also has a considerable extent, while smaller sand bodies occur in the baylets at Prah Sands, Perranuthnoe and Marazion.

The coast-line consists of granite cliffs (Lands End, St. Michaels Mount and the Godolphin granite), greenstone cliffs (Mousehole and Cudden Point), slate cliffs (Prussia cove, Perranuthnoe and Porthleven), and cliffs formed of head (east of Marazion and Prah Sands), whilst sand-dunes and bars on top of alluvium form the coast at Marazion, Prah Sands and Looe.

F. CLIMATE AND PREVAILING WINDS

The climate of Cornwall is very temperate. The annual rainfall is circa 45 inches. Micro-climatic variations occur with respect to the north and south coast of the peninsula. The Lands End corner current (see section 2) gives rise to fog formation and in general more precipitation on the north coast than on the south coast. The prevailing wind is south to south/west.

Table 1 Geological time scale in Cornwall (based on Robson, 1944 and Webb, 1947)

Holocene	Blown sands and bars Alluvium (human relics) Lower submerged forest Stream tin, all levels
Pleistocene	Head of the Rubble Raised beaches (10 feet) 50' and 100'-180' platforms
Post Pliocene	430' platform
Pliocene	(marine) gravels and sand (St. Erth)
Miocene	750' platform 1000' platform
Eocene	Gravels (St. Martins) Phonolite
Trias	Pebble beds originating from granites exposed in Devon
Permian	Granites, pegmatites, applites, elvans and lodes
Carboniferous	Culm measures with basalt
Upper Devonian	Phyllites, calcareous shales, basic intrusion and volcanic activities
Middle Devonian	Slates (in the north), grits (in the south), basic intrusives
Lower Devonian	Slates, grits and basic intrusives
Pre-Cambrian	Dodman and Start schists in the Lizard Complex. (The Lizard is regarded to be Upper Devonian/Lower Carboniferous; Hendriks, 1937)

SECTION 1

TRANSPORT OF MATERIAL BY MARAZION RIVER

Introduction

The aim of this section is to obtain some understanding of the function of rivers with respect to the supply of material and especially cassiterite to the marine sediments of Mounts Bay. Prior, however, to discussing the nature of transport of rivers, for which Marazion River was selected (see later), it is essential to consider the possible sources of tin which may have contributed to the fluviatile sediments. It is, therefore, proposed to discuss the sources of tin and to give an account of previous work on the occurrences of alluvial placers in the area first, followed by a discussion on the actual transport.

CHAPTER 1 SOURCES OF DETRITAL TIN

A. Review of Alluvial Placer Deposits

In any discussion of detrital tin in Cornwall, one should differentiate between two sources of supply. Firstly, there is the tin derived from lodes as the result of normal geological processes of weathering and erosion and, secondly, tin made available for transport as a result of accelerated erosion, i.e. mining and other human activities. Although the latter is insignificant in terms of time, the absolute quantity of tin made available for dispersion and consequently for alluvial and marine deposits is considerable. Thomas (1913) estimates an average loss of 30% of cassiterite during the main mining period in the last century.

Pre-human liberation of tin out of the host-rock resulted in the formation of alluvial tin deposits. These placers, locally referred to as "tin-grounds" have been subject to several papers, such as Colenso (1828), Carne (1830), Henwood (1829 and 1873) and Robson (1944). The majority of these tin-grounds have an alluvial origin. Reviewing the literature, it became apparent that these deposits, at least the ones occurring in the south of the peninsula and of major interest for the present study, have certain features in common. In the first place, they are always overlain by organic material referred to as a submerged forest. In some places this submerged forest lies underneath marine deposits with abundant unbroken shell fragments (Colenso, 1829). As may be remembered from Table 1, this organic layer and the associated tin grounds post date the late Pleistocene head. It is, therefore, not entirely impossible that after the periglacial period ended and the solifluction material had moved away from the hills, fresh material was exposed to erosion giving rise to increased supply of tin. A second feature, recorded by several authors, is the consistent depth at which the coastal tin grounds occur; 40 feet below the present sea-level. Colenso (1829) estimates on the basis of the depth of the submerged forest layer, a continuation of the river valley at Pentuan (near St. Austel) of at least one mile into the sea. In Mounts Bay the bedrock configuration is consistent with the extension of the Marazion River valley 2 miles beyond the present coast. A third aspect, common in the recorded tin-grounds, is the coarseness of the cassiterite. Colenso (1829) describes the detrital tin as being of fine sand size, while Carne (1830) and Henwood (1873) refer to tin of "granular appearance". Almost all the tin deposits show traces of transport; grains are rounded and sub-rounded, some showing traces of fracturing.

Tin-grounds of this nature have been described, occurring in the Marazion marsh underneath the forest layer, but they are, according to Henwood (1873), of inferior quality. He also describes a second tin deposit at a depth of 15 feet half a mile downstream from Crowlas. This tin bed lies on weathered killas which "disintegrates on exposure to semi-fluid mud" (op. cit.). Apart from a peat layer of 6 feet thickness, no traces of trees have been recorded.

Not all tin grounds in this area are alluvial. Henwood (1873) refers to several residual placers, amongst which the one at Cold Harbour, near the head of Marazion River (for location see Fig. 1,2) is of special relevance to the present study. Underneath a 2,5 foot peat layer and three feet of "disintegrated subangular granitic matter unequally mixed with blue clay", tin grounds occur. The more productive proportion of this 6,5 foot layer is reddish-brown, with angular and more or less rounded masses of tin bearing vein stones. The granite underneath presents an "undulating" surface of unequal hardness. Like so many other places in Cornwall, this matter could not be further investigated as the site to which Henwood refers is completely obscured by numerous relics of mining activities.

Although some of the cassiterite in these placers may have been derived from weathered granites, the majority undoubtedly originated from outcropping veins. Unfortunately, however, it is difficult to study the nature of these sources and their contribution to the river sediments as they were at the locations of the earliest mining activities. Contamination of the surrounding soils imposes great difficulties for reliable geochemical investigations. A discussion on the contamination problems in an extensive exploited area like the west of Cornwall is given by Hosking (1959).

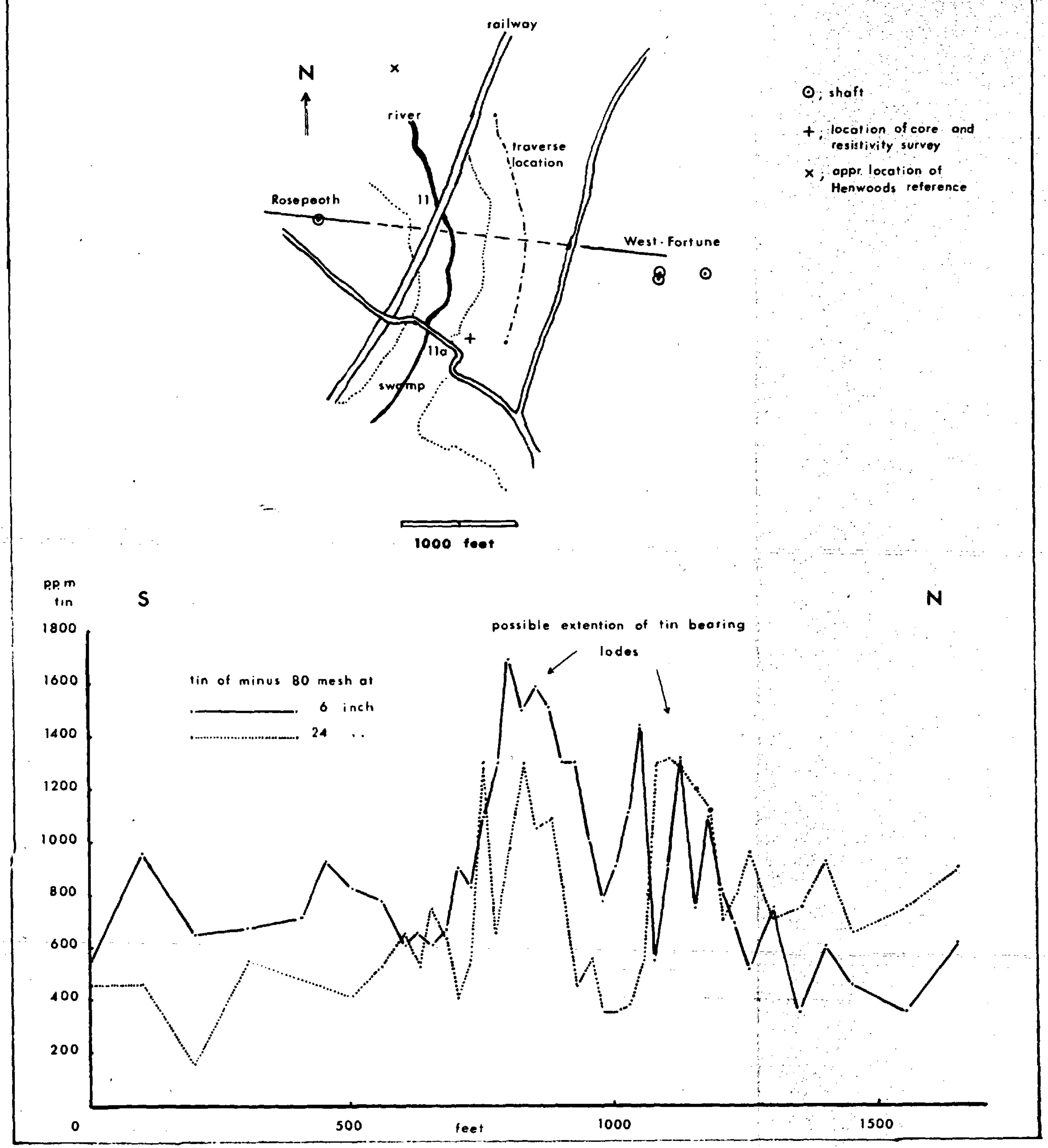
B. Geochemical Dispersion of Tin in Soil Traverses near Rosepeath

A locality where primary tin mineralisation is known to exist in the Marazion River valley, occurs approximately ¾ miles downstream from Crowlas. Here, just north of the Marazion swamp, the projected extension of a lode crosses the valley at right angles. The strike is roughly east/west and the lode has been mined at several locations; the nearest shafts are at Rosepeath, 250 yards west of the river and at West Fortune, 500 yards east of the river (Fig. 1.2)

A recent drill hole near the possible extension of this lode revealed "a 43 foot alluvium layer, a 21 foot clay with gravel layer, followed by 71 feet of weathered killas, and underlain by solid bedrock". No information could be obtained on the tin content of the core samples. A geophysical resistivity survey, carried out at the writer's request by student from the Applied Geophysical Group of Imperial College gave similar results; 45 feet of alluvium and valley gravel, followed by weathered bedrock of which the base has not been recorded. This weathered bedrock is probably the same as described by Henwood (1873) as killas for a site several hundred yards upstream.

Samples have been collected along a traverse of 1600 feet length. The traverse is located on the eastern slope of the valley to minimise possible contamination. This slope is gentler than the western slope and the workings of the West Fortune mine are twice as far from the river as those of Rosepeath. The sample interval was 100 feet at the extreme ends of the traverse, decreasing to

FIG 1,1



soil profile over the **Rosepeath/West-Fortune lodes**

25 feet over the postulated extension of the lode. The traverse follows the contour line. At each location two samples were taken, one at 6 inches and one at 24 inches. In addition, samples have been taken upslope and downslope from selected sampling points of the main traverse. The soil along the traverse consists of a dark red/brown stony loam.

The main features of the data obtained on the traverse (Fig. 1,1) are:

1. The presence of two anomalies as expressed by samples from both depths.
2. The high "local background" value.
3. The difference in tin content of surface samples as compared to subsurface samples at the extremities of the traverse.

The high tin content for the extremities of the traverse is rather conflicting. Contamination from the West Fortune workings is a possibility and would explain the higher tin tenor for the samples from the 6 inch depth at the southern part of the traverse as this end is located closer to the road. However, this does not explain the higher subsurface tin content for samples from the northern end of the traverse. Furthermore, in the case of contamination, one would expect a smaller difference between the apparent anomaly and "background" values for samples from the surface as compared to samples from the 24 inch depth. The alternative is a concentration at the surface by either plants or fractional removal of light material. The first possibility can be ignored as plants do not accumulate tin to any significant extent (Millman, 1957). Preferential removal of lights may contribute to the overall higher surface tin content. It is of interest that the slope is slightly steeper at the southern end as compared to the northern end.

Whatever the reason may be, the fact remains that the tin content of all samples is extraordinarily high. Especially the width of the anomalies, which occur over a distance of 100 feet must be considered as surprising (Hosking, 1959). The configuration of the soil as established by drilling and geophysical techniques may be significant in this context. The upper part consists of alluvium in which Henwood has recorded the existence of tin-grounds. The tin content of this alluvium may be in part responsible for the high values. On the other hand, there is no information as to whether the soil at the traverse location has a similar profile as at the locality of the drill hole which occurs slightly downslope from the traverse location. Secondly, there is the 70 feet of weathered killas. In order to get such an extensive weathering of bedrock compared to other localities, the rock must have been relatively weak, probably by joints and fissures. It could be possible that these fissures have facilitated the movement of ore-forming agents. Whatever the cause may be (contamination from West Fortune, contribution from the tin containing alluvials or bedrock mineralisation), there exists a distinct anomaly over the possible extension of the lode. The second maximum at 1200 feet, and especially well reflected by samples from the 24 inch depth, may reflect an unknown or unrecorded lode.

The main question, to what extent mineralisation contributes to the tin content of the stream sediments, could not be answered. Size analysis on a number of samples showed that the percentage of fractions coarser than 100 mesh is negligible while the finer fraction, even with their heavy mineral content, will be transported easily by the river, as will be shown later. Secondly, any possible cut-off in the tin content of the stream sediments of Marazion River at this location is completely overshadowed by the very high proportion of tin originating from the mining area further upstream. Furthermore, due to the existence of the swamp near the river bed, it is impossible to obtain samples from river deposits which predate mining activity and which might have shown some effects of the mineralisation at Rosepeath/West Fortune.

C. Tin Content of Stream Sediments

The contribution of tin to the stream sediments by mining activities was very high (Thomas, 1913) and enabled tin streamers to recover substantial amounts of this mineral downstream from the mines. The form in which tin was lost has been described by Hosking (1956) as "low gravity, cassiterite bearing composite grains" and "the unavoidable generation of slimes from which a large percentage is coated with iron" together with cassiterite of "colloidal to near colloidal size". At present day, this material can be seen in the Red River, which drains tailings from the South Crofty mine. The same type of sediment can also be seen in the Marazion River valley, which also used to be called Red River. A red clay layer occurs downstream from Crowlas at a depth of approximately 1,5 feet. This layer, which is 2-3 inches thick can be traced through the swamp and has been seen under the present beach. Its tin content is definitely higher than the adjacent strata (Table 1,2).

Table 1,2 Tin content of red clay and adjacent strata at Marazion Beach

Fraction in mesh	ppm Sn under clay	ppm Sn red clay	ppm Sn above clay
-20 +36	-20	-	720
-36 +60	-20	-	1125
-60 +100	-20	1400	225
-100 +200	275	1875	375
-200	275	8250	1500

The higher values above the clay as compared to the strata underneath reflect that, although the mining activity had stopped after the formation of the clay layer, there was still ample supply of tin bearing material.

Not only the older sediments have high tin content, but also the sediments forming the present day river bed (Table 1,3).

Table 1,3 Tin content (in ppm Sn) of stream sediments of some rivers draining into Mounts Bay

Fraction in mesh	Marazion River			Newlyn River			Porthleven River		
	highest	average	lowest	highest	average	lowest	highest	average	lowest
-20 +36	3000	1000	-25	5500	4200	400	1300	950	750
-36 +60	13000	2500	175	7000	5300	2250	+2,5%	+1%	930
-60 +80	9000	3400	340						
-80 +100	+2%	7700	75	11000	8000	5500	+2,5%	13000	1140
-100 +150	+2%	9600	650	13000	7500	1300	+2,5%	9000	1240
-150 +200	+4,6%	11300	275	6600	4000	1350	+2,5%	11300	7500
-200	+2%	8100	360	6750	5750	1300	+2,5%	16000	7700
		(20 samples)			(10 samples)			(4 samples)	

The lowest values for Marazion River all come from a sample location just upstream from the mining area at Nancledra (Fig. 1,2) and form the best evidence that most of the tin in these river sediments is introduced from the relic mines.

The nature of the geochemical survey as discussed in the previous pages is far too superficial to establish any differentiation of the sources of tin contributing to the stream sediments. This distinction between "natural" sources on the one hand and mining activities on the other is, however, of importance to the study of the dispersion of tin in the marine sediments. One of the differences it seems is the grain size of tin made available for transport. Size analysis on soil samples at Rosepeath indicated that there is no material coarser than 100 mesh, while the first column of Table 1,2 shows that no tin occurs in fractions coarser than 100 mesh in sediments which predate the mining activity. Present day river sediments, on the other hand, have tin in all fractions. Furthermore, it may be possible that the two sources will release tin of different mineralogical habits. Due to lack of time these aspects could not receive the attention they deserve and although the contribution of human activity overshadows the amount of tin derived from natural cources it is desirable that detailed research should be carried out.

CHAPTER 2 TRANSPORT OF MATERIAL BY MARAZION RIVER USING FLUORESCENT TRACERS

A. Choice of River

In the previous chapter most of the attention has been paid to the catchment area of Marazion River only. In addition, there are three other rivers draining into the Bay, the **Cober** River in the east, draining a major proportion of the Carnmanellis granite, the Newlyn River in the west, draining part of the Lands End granite and the Porthleven River, draining part of the Godolphin granite. Unfortunately, all four river systems have features limiting the possibilities of investigations on their transport capacities.

Newlyn River has been dammed for domestic purposes. The amount of water reaching the sea is determined by the daily demand for water. Downstream from the dam, the river bed has very little sediment; the artificial lake acts as a sediment trap. **Cober** River does not discharge any material into the sea either. It flows through a swamp into a fresh water pool which is separated from the sea by a sand and gravel bar. There is evidence, however, that the closure of the sand bar is very recent. Porthleven River originally discharged into the harbour, but was diverted in the last century from its natural course, and flows through a sewer, which extends 100 yards offshore.

The only remaining river, the Marazion River has been canalised through the Marazion marsh, to improve the drainage of the adjacent agricultural land. However, this river was considered the most representative one, and was therefore selected for studies of the transportation of (stanniferous) sediment.

B. Description of Marazion River

The head of the river, at a height of 700 feet above the present sea level, is located 0,5 miles west from Cold Harbour. Its total length is approximately 8 miles with an overall gradient of 1:84 (Fig. 1,2). The main rock types of its catchment area are granite and killas. The river valley over the granite is narrow with steep slopes, while the valley in the killas is flat and wide. There is a sharp boundary between the two rock types west of Crowlas and the river profile at this location is characterised by a number of waterfalls. The stream bed near the source consists of peat overlying weathered granite (see Chapter 1, Henwood, 1873). Downstream of Nancledra, the river flows mainly over bedrock and, below the granite contact, it runs over its own sediment deposited in the valley. In its lower course, south of Rosepeath, the river is canalised through the marsh. This, however, is very recent. The maximum width and depth of the river are 10 and 5 feet respectively.

The stream sediments, mainly consisting of quartz and feldspar, are very coarse and angular. Size analysis on 21 samples collected along the river profile showed that 75% of the sediment is coarser than 36 mesh. Sorting in each sample is poor, but tends to be better over a stretch of one mile downstream from Nancledra.

The proportion of finer material increases, in general, towards the river mouth. The tin content of the river sediment, as mentioned previously, is very high for all fractions (Table 1,3).

C. Field and Laboratory Techniques

1. Choice of tracer

Many methods have been developed to trace the movement of marine and fluviatile sediments. They include materials such as pulverised coal, broken brick, magnetic concrete, painted cobbles and non-fluorescent dyed grains. However, most studies that have been carried out, involved radio-active and fluorescent dye techniques. As radio-active tracers have been applied in the study of material movement in the offshore environment, discussion of this method is postponed to Section 2.

The first contribution to literature involving fluorescent dyed grains, is that by Medvedev and Aibulatov (1956), rapidly followed by many workers in this field all over the world (Ingle, 1966). The advantages of fluorescent dye techniques include:

1. the cost of dyeing is relatively low;
2. no legal or health hazards;
3. different hues can be applied to differentiate between successive tests, and/or location, and/or grain sizes;
4. dyes do not affect the hydraulic characteristics of the labelled sand grains (Jolliffe, 1963).

However, there are some disadvantages including:

1. samples have to be collected;
2. abrasion induces an uncontrollable time factor;
3. counting of fluorescent grains is laborious;
4. difficulties in distinguishing fluorescent grains of very fine sand and silt, and of organic material and dust.

Amongst the dyes which have generally been used are: Rhodamine B (red), Primuline (blue), Kitton yellow (green/yellow), Erosine (brown/yellow), Unitex (blue) and Araldite (blue/green).

2. Collection and coating of material

In order to obtain a picture as realistic as possible, sand of Marazion River itself was collected, as opposed to commercially available fluorescent sand. A total of 7 cwt was collected, dried and sieved through a 0,5 inch sieve. The sand was then washed several times. Due to the fact that the sand contained much organic material and that many grains were iron coated, the red fluorescent dye, Rhodamine B could not be used. A green fluorescent dye had to be chosen. Unfortunately, the writer had some difficulties in distinguishing the very fine green fluorescent particles from the blue reflecting dust and carbonate contents in the samples. Results, therefore, of the minus 100-mesh fraction will not be discussed. Details of fluorescent dyeing techniques are given by Newman (1964) and Ingle (1966).

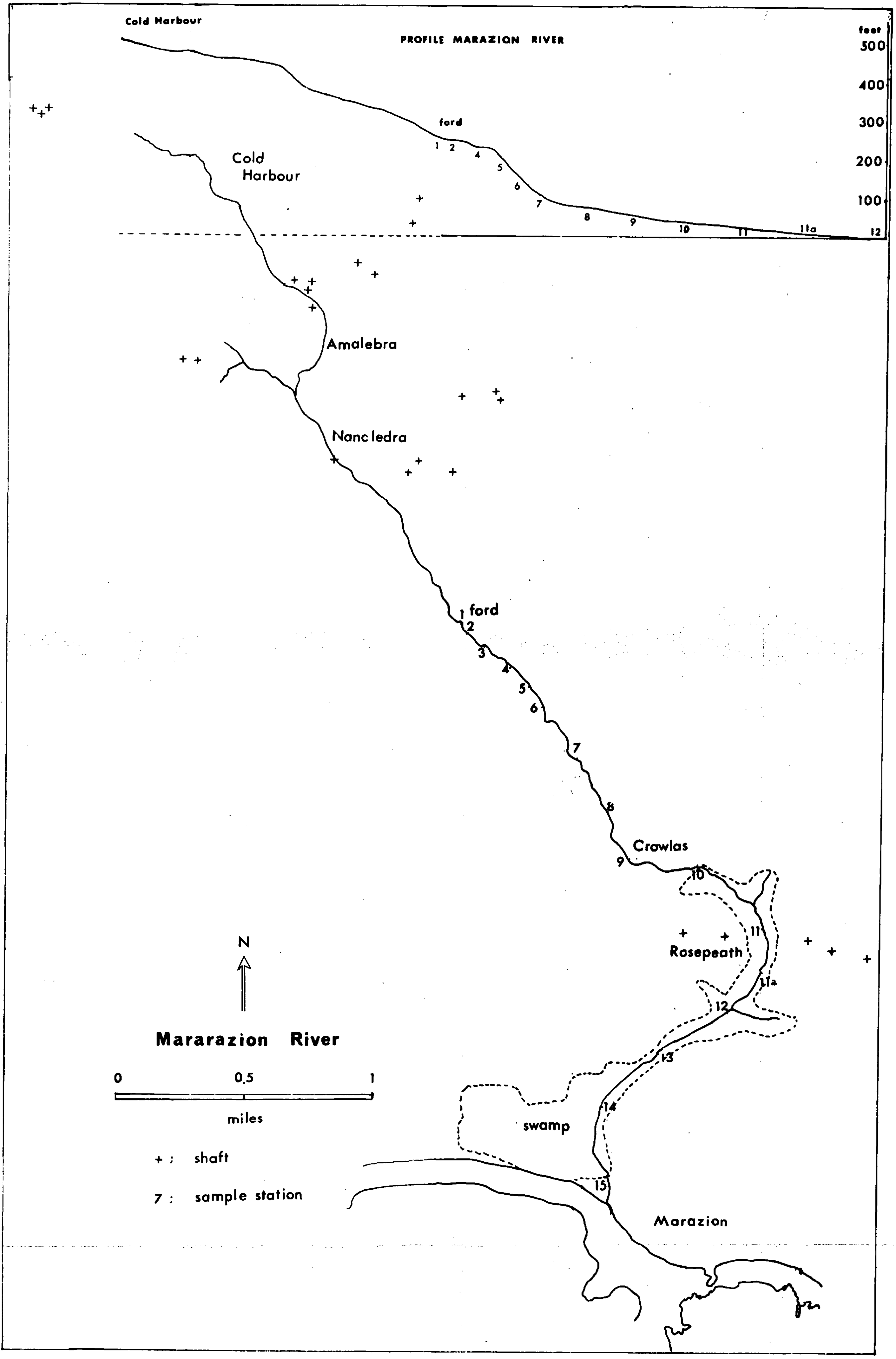
3. Rainfall measurements

Transport of material is ruled by the stream velocity which is strongly affected by the rainfall. Consequently, the daily rainfall was measured during the experiment with a rain-gauge. Simultaneously, data was obtained from the Penzance meteorological station and from the Cornish Water Board. The daily data was averaged and is presented in Fig. 1,3. The average annual rainfall in Cornwall is circa 48 inches. The total rainfall during the period of observation was 4,2 inches, which is above normal for that period of the year. Data obtained from the Penzance meterological station showed that the period previous to the experiments had been unusually wet as well. This has some effects on the stream velocity, as will be discussed later.

4. Stream velocity measurements

Stream velocity was measured with a Watts current meter, provided and calibrated by the Wallingford Hydraulic Laboratories. Measurements were carried out at nine different stations along the river profile. The averaged results are presented in Fig. 1,3B, while those at the ford (which was the dumping location) are presented in more detail (Fig. 1,3C). Due to a failure in the instrument, observations could not be carried out during the full period of sample collection.

FIG 1,2



Mararazion River

5. Dumping of material and sample collection

The bags in which the dyed sand was stored prior to the experiment, were lowered on the river bed at the location where the sand was collected (station 1, Fig. 1,2). In this way the material was soaked before release, which was necessary to avoid flotation and coagulation of the very fine particles by air bubbles. The bags were removed on the morning of February 19th, 1966. The quick release of the whole mass of material at one location modified the river cross section and might consequently have affected the stream velocity at this location. However, as will be shown later, the effect on stream velocity was negligible. This form of release, directly on the river bed, avoided immediate transport of material by the faster stream velocity at the surface.

On the day of dumping, three series of samples were taken at 5 hour intervals at increasing distances downstream. Collections were made twice on the second day, once a day for the following week and every other day during the second week. After this period samples were taken every three days and finally once every four days. Over 200 samples were collected, each representing a surface area of approximately 2 sq. ft. The location of sample stations is given in Fig. 1,2.

6. Comparison between natural and coated sand

The reliability of experiments of this kind depend in the first place on the extent to which the hydraulic properties of the tracer compares with the natural sand. Tests carried out by workers in this field showed that there was no significant change in the physical properties by dyeing the particles (Ingle, 1966). An attempt to verify this in the present case did not give satisfactory results, as the experimental procedure was far from ideal.

50 grams of coated sand was separated into fractions by elutriation (Pryor et al, 1953). A full discussion on the elutriation is given by Ong (1966) as well as in Section 3 of this thesis, consequently only the principle will be mentioned here.

The elutriator consists of a number of vertical glass tubes with increasing diameters. A constant supply of water through the system results in decreasing velocity in tubes with increasing diameter. Material introduced in the smallest tube therefore, will be separated into fractions based on the hydraulic properties of the individual grains. After the tracer had been elutriated for 5 hours, the weight percent of each fraction was determined. The fluorescent dye was then dissolved with a mixture of concentrated nitric acid and concentrated sulphuric acid. This strong reagent not only dissolved the dye but also other components of the material, while in addition, some reduction of grain sizes occurred. Results of renewed elutriation on the decoated sand, therefore, could not be compared with the original material. A better procedure would have been to carry out the experiment in reverse order. This, however, was not possible as the sand was handed out to a commercial firm for coating.

7. Counting of fluorescent grains

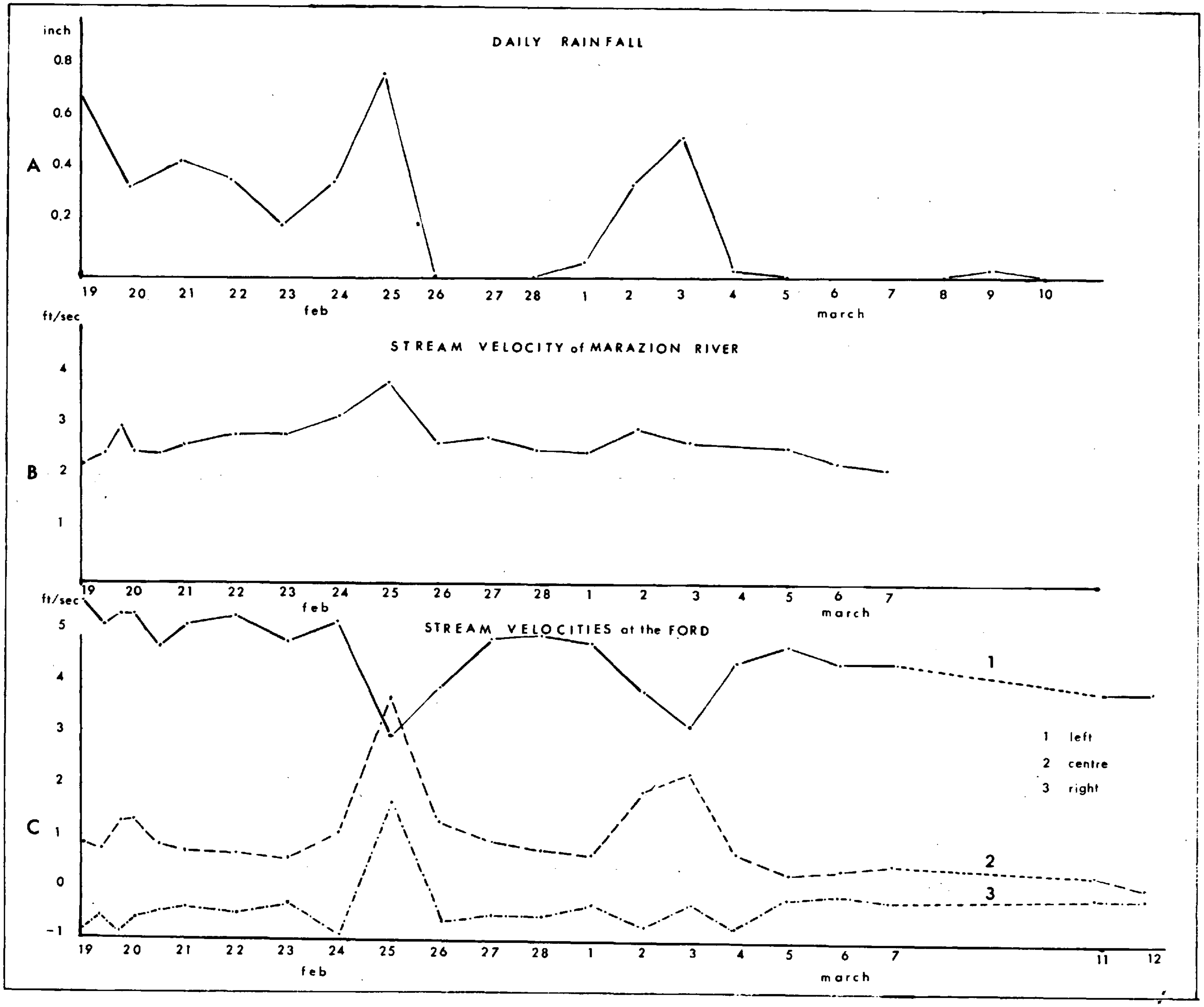
Each sample was separated into 6 fractions by screening, and the number of fluorescent grains per gram was counted, using a long-wave ultra-violet lamp. The minus 100-mesh fractions were ignored due to optical difficulties, as mentioned previously. Better information on the transport of individual fractions would have been obtained by establishing the number of fluorescent grains per fixed number of natural grains rather than per gram. The low concentration of the tracer in most samples makes this, however, impractical (Table 1,4).

Table 1,4 Convertion of fluorescent grains per gram to number of fluorescent grains per 1000 uncoated grains, sample 560559

Fraction	Number of fl. gr. per gram	Number of grains/ gr.	Theoretical number of fl. grains per 1000
very coarse	0,1	approx. $1x10^2$	1
coarse	1	" $1x10^4$	0,1
medium	3	" $1x10^5$	0,03
fine	7	" $4x10^5$	0,017

very coarse sand consists of particles of 10 to 36 mesh; consequently it does not conforms to the Wentworth classification (see section 3)

FIG 1,3


DAILY RAINFALL
inch
0.8
0.6
A
0.4
0,2
19
20
21
22
23
24
25
26
27
28
1
2
3
4
5
6
7
8
9
10
feb
march
ft/sec
STREAM VELOCITY of MARAZION RIVER
4
3
B
2
1
19
20
21
22
23
24
25
26
27
28
1
2
3
4
5
6
7
feb
march
ft/sec
STREAM VELOCITIES at the FORD
5
4
3
2
C
1
0
-1
1
2
3
1 left
2 centre
3 right
19
20
21
22
23
24
25
26
27
28
1
2
3
4
5
6
7
11
12
feb
march

D. Presentation and Discussion of Data

1. Relationship between stream velocity and rainfall

Stream velocity at a specific location of the river profile depends to a large extent on the nature of the river at that point of observation. The overall discharge, however, is dependent on the rainfall and nature of the soil in the catchment area of the river. Under normal circumstances the soil will absorb rain water and discharge it slowly into the river. In the period previous to the experiment, precipitation was well above normal and the soil was saturated. Rainfall during the investigations therefore, was directly reflected by changes in stream velocity (Fig. 1,3A, B and C). The stream velocity at the dumping ground will be considered in more detail.

At the ford, which is located at the end of a right hand meander, the greatest velocity occurs at the **left** hand side of the river cross section (Fig. 1,3C1) which is also the deepest part. The right hand side shows a reverse flow (Fig. 1,3C3). With increasing water supply, the location of highest velocity alters towards the middle (although this is not the deepest part) and there is also downstream movement on the right hand side. This change in flow characteristics is due to water deflected towards the right bank having been obstructed (when the water level is high) by the support of a foot-bridge. The change in flow pattern has a marked effect on the river bed. Prior to the 25th of February, the middle of the river bed consisted of medium to coarse sand. After the 25th there was almost no sand left, and it took the river several days to return to its former state. The reason for discussing this in detail is to illustrate the effect of the **tracer on flow pattern.** Sand was dumped in the middle and at the right hand side of the river cross section. A minor part of the sand was carried away directly, another part was transported to a limited distance upstream by the reverse flow, but the bulk of the material was transported downstream during the 25th.

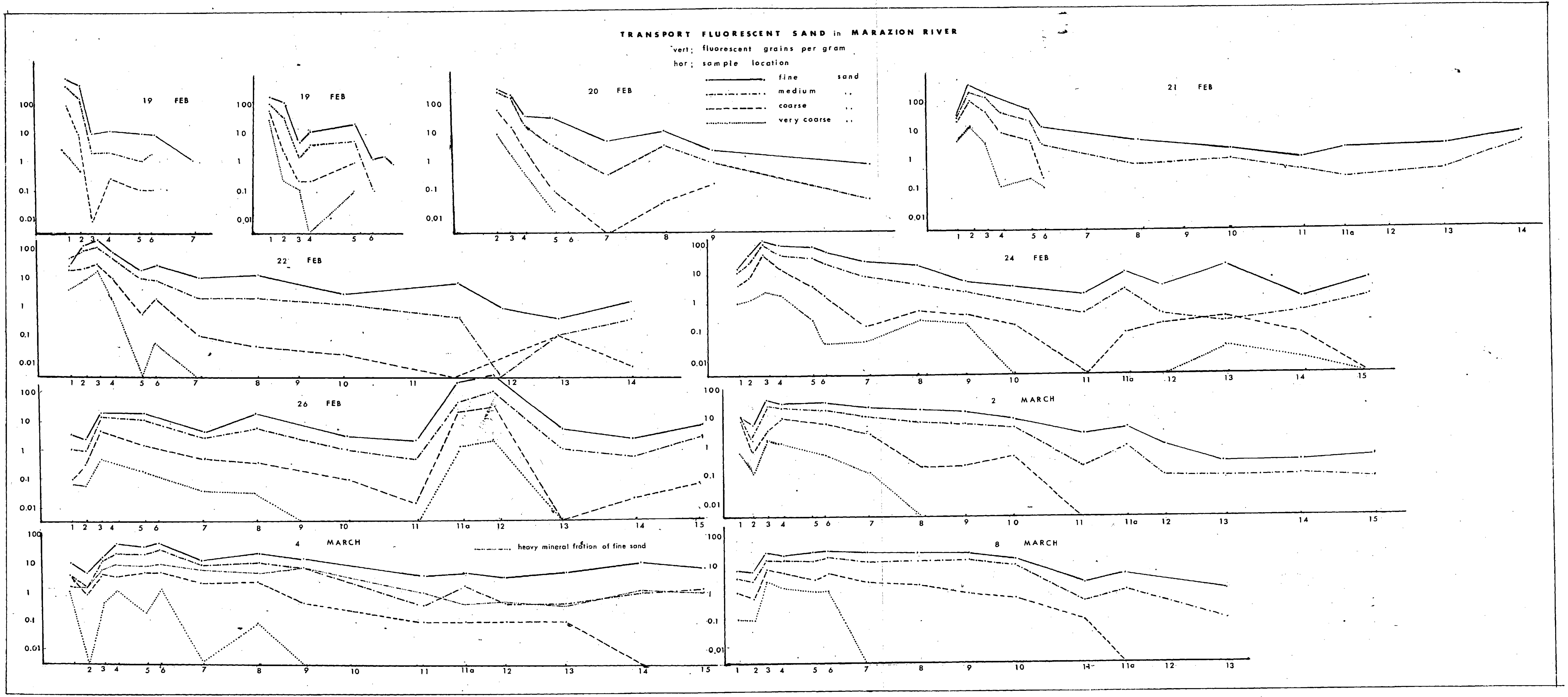
2. Transport of tracer

Prior to the discussion of the results, two aspects of the investigation should be emphasised. Firstly, results represent the transport over a short period of time only. Details of the distribution of sediment becomes less significant if transport over, for instance, a whole year is considered. Besides, less rainfall in summer and the consequent lower stream velocity will result in a completely different transport pattern. Secondly, data is expressed as grains per gram, so an absolute amount rather than as a percentage. Consequently, only a qualitative information is obtained. This will be illustrated later in the discussion.

(a) Transport with distance

10 sets of observations are presented, extending over a period of almost three weeks. Each sample has been divided into four fractions and their tracer content established (Fig. 1,4).

FIG 1,4



TRANSPORT FLUORESCENT SAND in MARAZION RIVER

The first and main feature shown by the diagrams is the fast transport of fluorescent grains. Three days after dumping, fine and medium sand could be traced 2,75 miles downstream from the release point. On the fifth day, these fractions were encountered in the river mouth, 3,5 miles downstream. Although coarse and very coarse sand did not reach the river mouth during the period of the experiment, their transport is very fast as well. Within 5 days, fluorescent grains of these fractions were found in the swamp.

The location where the maximum amount of tracer grains occurs (i.e. the bulk of the material), moves much slower but still considerably; three days after dumping it had moved over 50 yards and 5 days later it was found some 300 yards downstream from the ford. The actual amount decreases rapidly, which is probably due to the combined effects of the spread of the tracer grains along the stream and the supply from upstream of uncoated grains. The overall distribution of the tracer along the river profile, with the exception of stations 11a and 12 on the 26th, appears to be fairly uniform, especially for the last three diagrams. This can only be explained by postulating a consistent form of transport, irrespective of river characteristics at any given station such as gradient of river profile, width of river, depth of water, etc.

The way in which transport can take place, falls broadly into three groups:

1. transport by rolling;
2. transport by saltation;
3. transport by suspension.

Transport by rolling depends largely on the nature of the river and the grain sizes involved. Accumulation of material will occur at localities where the river characteristics such as gradient, depth of water etc. change. Transport by suspension on the other hand will carry material irrespective of these river characteristics and does not, in theory, deposit any material on the river bed. In practice, however, there is an equilibrium between suspended load and bed load. If the stream is saturated with suspended load, variation in the stream velocity will tend to discharge material when the velocity decreases and to pick up material when the velocity increases; for instance, at the inner and outer curves of a meander. Transport by saltation forms the transition zone between rolling and suspension.

The fast transport and the uniform distribution of fluorescent grains of fine and medium sizes, seem to suggest that the stream velocity during the experiment was high enough to transport these fractions by suspension or an advanced form of saltation. Transport for the coarse and very coarse fractions on the other hand, took place somewhere in the transition zone between rolling and saltation, as illustrated by their more erratic distribution.

The only indication of the effect of the nature of the river bed is given by stations 11a and 12 on the 26th February. Just after Rosepeath (station 11a) the river depth increases by a factor of 3, as the river is canalised from here onwards. The stream velocity has a direct relationship with depth, assuming constant width, and any increase in water discharge will affect the shallower part to a greater extent than the deeper part (Table 1,5).

Table 1,5 Stream velocity in ft/sec at 3 successive stations

Date	Crowlas (station 10)	Rosepeath (station 11a)	Marazion Bridge (station 15)
24th February	4,36	4,33	1,92
25th "	7,98	4,34	2,21
26th "	3,76	3,76	2,35
27th "	4,25	3,76	2,47

Material transported by the stream at Crowlas on the 25th will accumulate with the sudden drop of velocity at Rosepeath as demonstrated by the fluorescent grain content.

However, it is peculiar that the accumulation of the tracer grains at stations 11a and 12 is not diluted by accumulation of uncoated grains of the same fraction. Upstream from these stations, as well as the period previous to the 26th, the tracer appears to be well mixed and an inherent part of the sediment, as expressed by the fairly constant amount of fluorescent grains in each sample. This relationship suddenly ceases to exist. From the same diagram it is clear that the amount of fluorescent grains at and near the dumping ground decreases drastically as compared to the previous diagram. Furthermore, it may be remembered that with the high rainfall on the 25th, almost all sediment at the ford was carried away. Consequently, it seems that most of the fluorescent grains have been transported right through from the dumping place to stations 11a and 12, probably by suspension. This form of transport is illustrated by a sample taken that same day just downstream from station 12. At that location the river broke through the levee and flooded the swamp. The sample represents material deposited behind the levee and some fluorescent grains were found in the very fine sand fraction.

The fact that the sediment between the ford and Rosepeath is not mixed to any significant extent with the transported material from the ford, is explained by assuming that by transporting all material from the ford, the stream was saturated with suspended load. Consequently, it was unable to pick up more material. Furthermore, it may be important that the only locations with abundant sediment in the river bed are the ford, which was the reason to select this point for the collection of the material, and from Rosepeath in downstream direction. Sample stations in between were always in very sheltered locations, such as behind boulders, fallen trees etc., and the sediment these samples represent was only available in small quantities.

A difficulty is the fact that the diagram representing the dispersion on the 2nd of March which follows the 26th February has no traces of the accumulation at the stations 11a and 12, while the coarse and very coarse fractions are not represented at all. Although there is an interval of 4 days, and continued supply of material may have diluted the fluorescent grain considerably, one would still expect some differences between successive sample stations.

Results for the coarse and very coarse fractions are slightly erratic. As can be seen in Fig. 1,4 many samples have a tracer content for these fractions in the order of 0.1 or even 0,01 grains per gram. It is therefore very likely that samples having no tracers in these fractions but which occur between samples with fluorescent grains are purely accidental, as for instance sample 10 on the 26th February.

In the later stages of the experiment no more tracers were found in samples from the last stations. This is due to the diluting effect of two tributaries joining the Marazion River in the swamp, while the very slowly decreasing tracer content further upstream is also partly due to the diluting effects of uncoated material transported from beyond the ford.

(b) Transport with time

Results from two sample stations, 50 yards downstream from the ford and from the river mouth, have been presented on a time basis (Fig. 1,5A and B). From Fig. 1,5A it can be seen that an initial rise in the fluorescent grain content of the samples there is a steady decrease until the 26th. From this day onwards, the amount of fluorescent grains remains constant within narrow limits for each fraction.

The increase in tracer content for the first 48 hours, followed by this decrease is entirely due to the relationship between the supply and the removal of fluorescent grains. For the first period supply exceeds removal, and for the second period the reverse is true. The sudden change on the 26th once more has to be explained by the very heavy rainfall of the previous 24 hours. Almost all material has been transported and the constant tracer content for the next 16 days means either of two things; supply from the remainder at the ford and the removal at this location were in perfect balance, or the heavy transport during the 25th/26th left behind only relatively sheltered grains which were not transported by the subsequent lower stream velocities. The writer favours the latter possibility because:

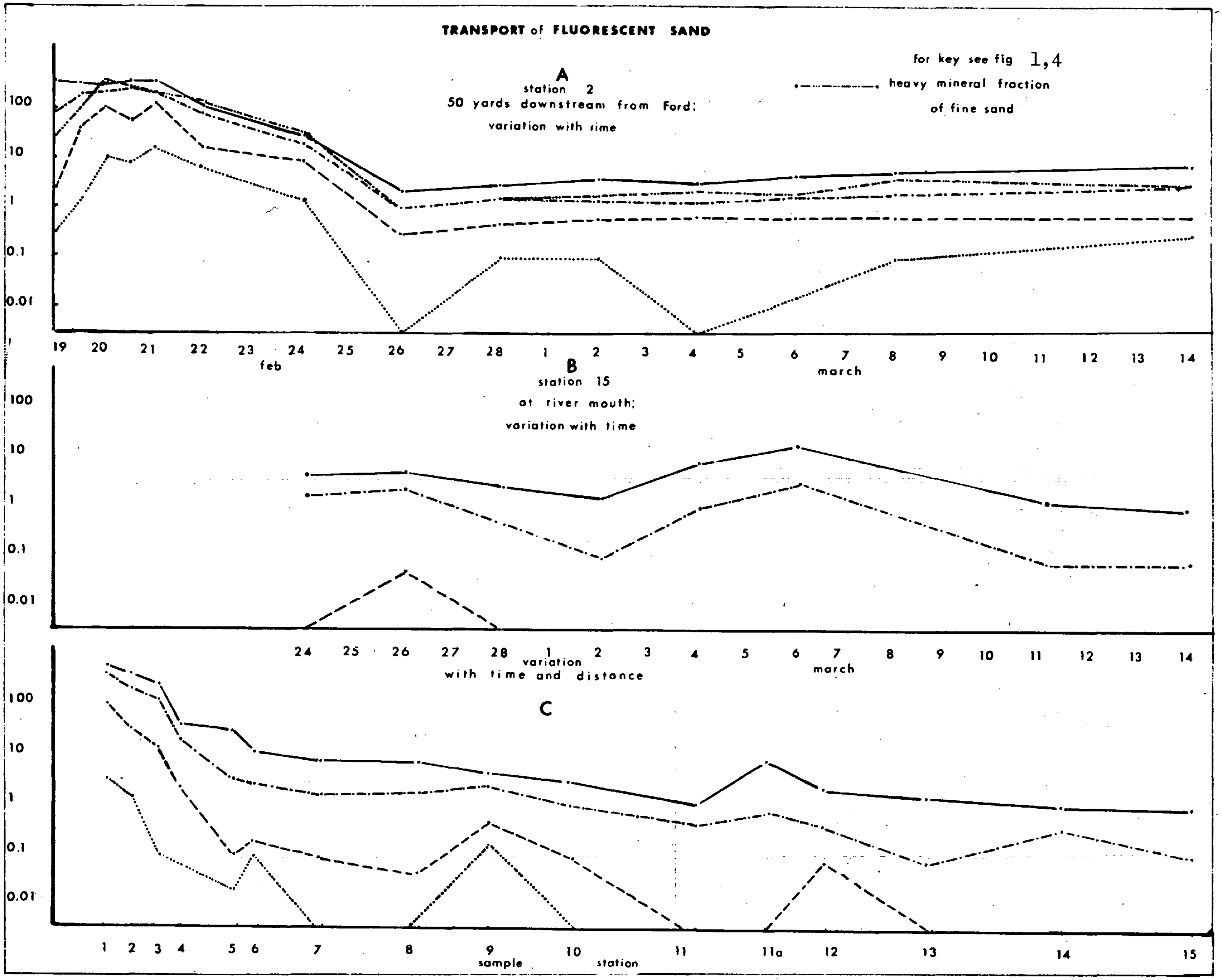
1. Apparent equal supply and removal would still result eventually in an overall decrease of the tracer content as the source is limited and diluted by material from upstream.
2. After the 25th it was extremely difficult to obtain enough sample as the river bed consisted of pebbles and boulders with the sand in between.

The relationship with time of station 15 near the river mouth is presented in Fig. 1,5B. At this locality there are three factors influencing sediment transport, which do not apply to the other locations. The first factor, the contribution of the tributaries, has been mentioned previously. Secondly, there is the existence of the swamp itself. Several drainage canals have been dug and they join the river circa 500 yards before the mouth. The discharge from these canals will not be subject to rapid variations and consequently they will act as stream velocity regulators.

A third factor, only effective on rare occasions but operative during the experiment, is the periodic (once or twice a year) shift of the river mouth towards the west by cutting a channel through the storm beach. This results in a temporary increase in the river gradient, which has a great impact on the stream velocity at station 15. The reconstruction of the mouth was carried out on the 5th March. The stream velocity before that date was 2 ft/sec. On the 5th it increased to over 4 ft/sec, decreasing slowly during the next three days to 3 ft/sec. No more velocity measurements have been carried out after that day, due to failure of the instrument.

No changes occurred in the stream velocity at the other stations. The increased tracer content at the 5th March at station 15 is believed to be due to this third factor. The **effect** is not expressed by samples from stations further upstream in the swamp as the increased discharge at the river mouth is fully

FIG 1,5


TRANSPORT of FLUORESCENT SAND
for key see fig 1,4
heavy mineral fraction
of fine sand
A
station 2
50 yards downstream from Ford;
variation with time
100
10
1
0.1
0.01
19
20
21
22
23
24
25
26
27
28
1
2
3
4
5
6
7
8
9
10
11
12
13
14
feb
march
B
station 15
at river mouth;
variation with time
100
10
1
0.1
0.01
24
25
26
27
28
1
2
3
4
5
6
7
8
9
10
11
12
13
14
march
variation
with time and distance
C
100
10
1
0.1
0.01
1
2
3
4
5
6
7
8
9
10
11
11a
12
13
14
15
sample
station

intercepted by the drainage channels of the swamp. The small increase in the number of fluorescent grains on the 4th, one day prior to the construction of the river mouth is not fully understood. The stream velocity on that day was slightly higher than the previous days, but the difference was very small; 0,3 ft/sec which, however, may have been sufficient to account for the increase.

(c) Transport with time and distance

In Fig. 1,5C, results of transport with distance, as well as with time, have been combined, by plotting the tracer content of station 1 on the first day, the tracer content of station 2 at the second day and so on. It shows that the fine and medium sizes of material are equal in their behaviour with respect to transport and are able to reach the sea. Sorting between these two fractions does not seem to be well developed. Coarse and very coarse fractions are not transported very far during the time of observation and the sharper decrease in the number of grains per gram as compared to the two finer fractions indicates that, if sorting occurs, it is best expressed between the medium and coarse sand fractions.

3. Representativity of tracers

So far discussion has been limited to the transport of fluorescent tracers only, and the question as to whether they are representative of the transport of uncoated material has been left aside. The low concentration in many samples, especially the coarser fractions made a presentation of fluorescent grains as a percentage of uncoated grains extremely unreliable. Nevertheless, it is of great importance to obtain information in this respect.

In order to investigate this matter, the fine, medium and coarse fractions of samples from stations 3 to 10 of the 8th March have been converted to percentile fluorescent grains, while the actual grain size distribution for these fractions has been obtained by screening (Table 1,6). The reason for selecting these samples is the fact that the samples represent the largest interval between release of the tracer and sample collection and thus were expected to be the most homogenous. In addition, the number of fluorescent grains per gram for individual fractions remains very constant.

Table 1, 6 Comparison between size distribution of selected samples as obtained by fluorescent sand and screening

Fraction	No. of fl. grains/gr.	No. fl. grains per 1000	% fl.gr.	Weight % (screening)
fine sand	20	0,05	11%	16%
medium sand	12	0,12	29%	31%
coarse sand	2,7	0,27	61%	52%

The table illustrates that the grain size distribution as obtained by screening and computation compares reasonably. Differences between the two sets of data are most likely due to assumptions made for the calculations, as the total number of grains (uncoated) per gram in any given fraction is essentially an approximation. Nevertheless, it is concluded that the transport pattern as indicated by the tracer may be considered as representative of the sediment as a whole. In view of the limited accuracy, however, no attempt has been made to give any quantitative interpretation of the transport of material.

4. Transport of heavy minerals

Of major interest with respect to the main object of the present study, the dispersion of tin in the offshore sediments, is the behaviour of the heavy mineral fraction. The fine sand fraction of all the samples collected on the 4th March (Fig. 1,4) as well as all samples collected from station 2 (Fig. 1,5A) have been subjected to heavy mineral separation and the number of fluorescent grains has been counted. From the diagrams it can be seen that the number of fluorescent grains per gram of the heavy mineral fraction roughly coincides with the distribution of the fluorescent grains of the medium sand size fraction.

As mentioned previously, the tracer may be considered as representative for the size fraction it represents. Consequently, it must be concluded that the heavy mineral fraction of the fine sand range is transported in a similar way as the sand of the medium range. This conclusion is in agreement with Stokes law on the velocity of particles in a viscous medium. On the basis of this law, one can calculate the corresponding grain sizes of other light and heavy mineral fractions to be transported together. Thus, cassiterite of the medium size is equivalent of quartz of very coarse size, and cassiterite of very fine sizes will be transported together with sand of the fine size range.

As will be remembered, analytical results not only showed the existence of tin in the finer fractions of the stream sediments, but also in the coarse and very coarse fractions. On Stokes law, these coarse tin sizes are transported in similar ways as granules or even small pebbles. The tracer experiment showed that these fractions are not transported to any significant extent. Consequently, as tin in these sizes occurs throughout the river sediments, one must assume that tin occurs in the form of, as Hosking puts it, "low gravity, cassiterite bearing composite grains". It is fully appreciated that these conclusions of similar transport of "hydraulic equivalent" grains needs to be considered further. However this discussion is more relevant for data of Section 3. It is, therefore, proposed to postpone further discussion to that section.

E. Summary of Conclusions

With the extraordinary environmental conditions in mind, it is concluded that:

1. Transport for all fractions is extremely fast.

2. Sand of medium and smaller sizes is able to reach the marine environment.
3. Transport of sand of medium and smaller sizes takes place by saltation, probably reaching proportions of suspension.
4. Transport of sand of coarse and greater sizes takes place by saltation, probably decreasing to rolling.
5. Due to the nature of the transport, sorting between successive fraction is not well expressed, but may occur between sand in the coarse to medium range.
6. The canalised part of the river acts as a site of deposition for coarse sand.
7. Transport of heavy minerals and their equivalent light fractions is similar.

SECTION 2

TRANSPORT OF MATERIAL IN MOUNTS BAY

Introduction

In the offshore environment, the dispersion of material depends to a large extent on the quantity and quality of the transport media. It is, therefore, essential that, prior to any interpretation of the results obtained from the geochemical survey, the environmental conditions are fully understood.

This section, which deals with these processes, consists of two separate chapters. In the first one, an attempt is made to establish the current pattern in the Bay. The second chapter deals with the transport pattern of material with special reference to cassiterite in the western half of Mounts Bay.

CHAPTER 1 CURRENT SYSTEMS IN MOUNTS BAY

A. Introduction and Previous Work

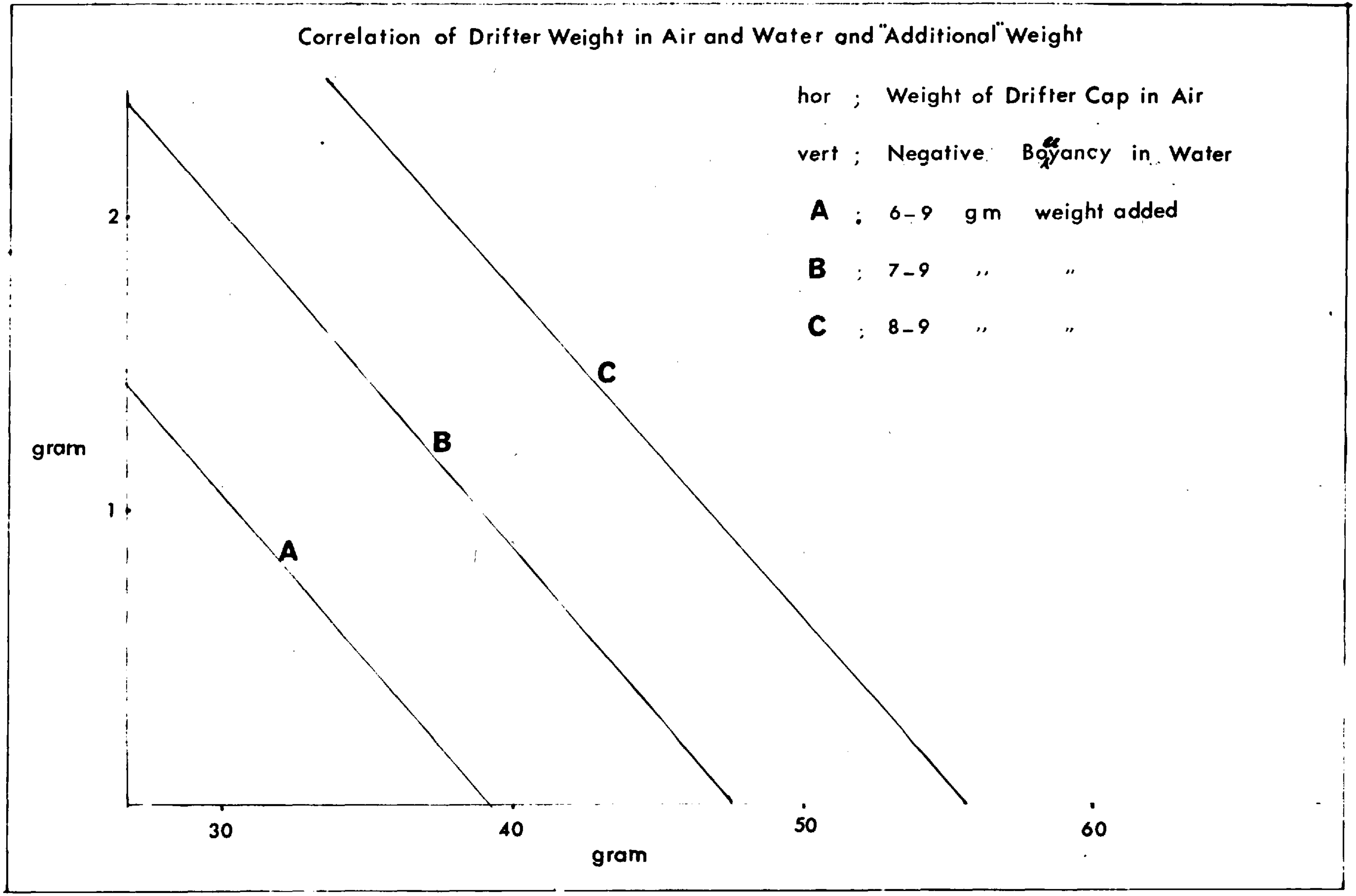
The main currents in Mounts Bay are tidal. The average difference between low and high tide is 15 feet, with a maximum of 18 feet for spring tides and a minimum of 13 feet for neap tides.

Cooper (1960a) in a paper dealing with the water exchanges between the English and Bristol channels around Lands End, comes to the conclusion that "a narrow well mixed corner current flows intermittently around Lands End from the south to the north coast of Cornwall". Furthermore, it appeared from a survey undertaken by the Marine Biology laboratories, Plymouth, that Mounts Bay is relatively isolated from the tidal system along the S/W coast of England. Drifters released near Plymouth were recovered on the beaches and bays of the north coast of the Cornish peninsula. The effect of this main water movement on the direction and magnitude of currents within the bay is not known, but from the Pocket Tidal Stream Atlas (1961) and the Admiralty chart, it appears that flood tides produce easterly surface and near surface currents in the bay. The maximum velocity (6 hours before high water in Dover) during spring and neap tides are 0,9 and 0,5 knots respectively. As the ebb tide commences, southerly currents occur with velocities of 0,5 knots for spring tides and 0,3 knots for neap tides. At the height of the ebb tide in the bay (high water at Dover) westerly currents are generated; the maximum velocities during spring and neap tides are the same as those of the flood tide.

Data on current directions and velocities obtained by Binnie and Partners (1965) in the western part of the bay close to Penzance, give lower results. Between high and low water the direction of the tidal current is mainly between east and south, with a maximum velocity in the subsurface water of 0,1 knot 3 hours after high tide. During the incoming tide, the current directions are mainly between west and north with the same maximum velocity. The minimum velocity measured in the subsurface water during the tidal cycle was 0,01 knot half an hour before high tide. Surface and bottom currents are similar in direction, but the maximum velocity measured was slightly higher at the surface; 0,15 knot.

The movement of the sediment will be controlled by the bottom currents and wave action. As these currents may be different in direction and velocity to those at the surface, negative bouyant bottom drifters have been used, in preference to surface drifters, to investigate the water movement. The bottom drifters used consist of a circular, slightly concave downward, plastic cap of 7 inches diameter. Four holes of one inch diameter allow any trapped air to escape. From the centre of the cap there is a shaft of 20 inches long to the end of which a weight is attached to compensate for the bouyancy of the plastic.

FIG 2,1



Correlation of Drifter Weight in Air and Water and "Additional" Weight

This weight is determined by the weight of the drifter cap in air. The relationship between the drifter density in water, weight of the cap and additional weight on the shaft is presented in Fig. 2,1. An average weight of 8 grams was used. However, in some cases it proved necessary to add an additional 0,5 gram weight as some of the drifters kept floating.

B. Field Techniques

1. Selection of release points

Although the survey was aimed to investigate the current pattern, it also intended to select a point near Marazion River for the release of radio-active tracers, which have been applied for the study of transport of material (see next chapter). In practice, 5 dropping points were used. Three of these in the vicinity of St. Michaels Mount and marked +, o, and x in the figures, were specially selected with the above aim in view. They also provide with the two other points (symbols ■ and ◐, Figs. 2,7 and 2,5) information on the general tidal system. In addition, the most westerly point, off Mousehole (symbol ⊙), enabled a check on the conclusions drawn from the radio-active background values in this area, which indicate a transport in northern direction (Chapter 2).

2. Time of release

In an area so close to the shore, the dropping time is of critical importance. Wave induced currents will be superimposed on the tidal changes and may limit the effects of the latter. In the case of the dropping points in the vicinity of Marazion River and St. Michaels Mount, drifters were released half an hour after high tide, in order to enable an offshore dispersion of the drifters before the incoming tide would affect them. Drifters near Mousehole were released just after low tide. Dispersion on this location was expected to be in a northern direction with incoming tide. Release time offshore from Porthleven was not considered to have the same importance, as the water depth at the dropping point, 60 feet, would eliminate to a great extent the effect of wave action at the bottom. However, it appeared during the course of the investigation that the above considerations did not carry too much weight as the time between release and recovery included in general many tidal cycles.

3. Method of dropping

50 drifters were released at each point. In the case of the dropping points near Marazion River mouth, care was taken to avoid dispersion by wave action during the slow sinking of the drifters. The drifters were loosely bound together with a rope on which a weight was attached. Once the drifters reached the bottom, the rope with weight was detached.

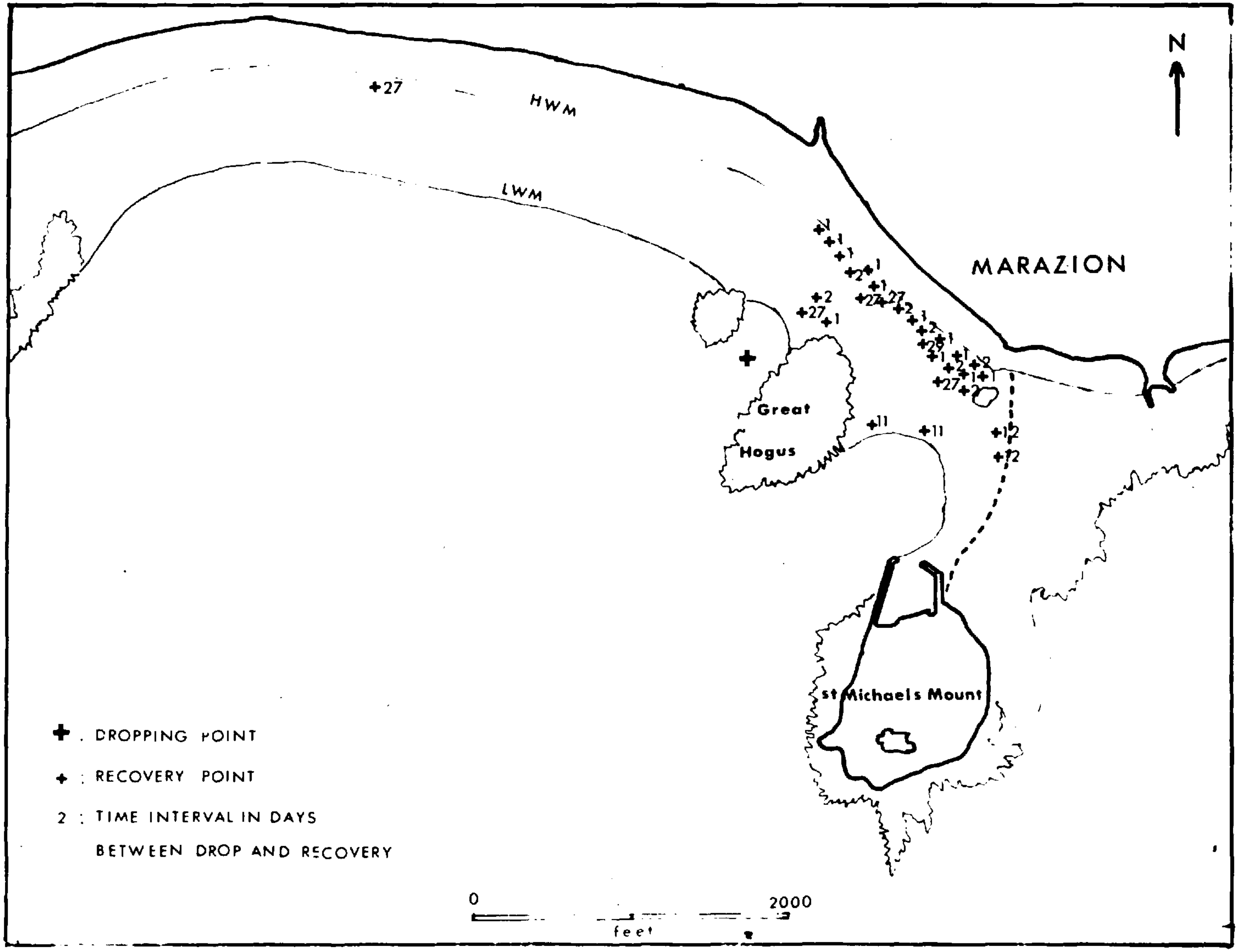


fig 2,2

dispertion of first group of bottom drifters

4. Recovery of drifters

Each drifter was marked with its dropping location. During the first week intensive patrolling along the beach was undertaken. Location and time was recorded for each recovered drifter. After the first week drifters arrived only sporadically and from then on the recovery was dependent on the cooperation of the public. On returning the drifters to Imperial College a small reward was paid, provided the time and location were given.

C. Presentation of Results

It is proposed to mention the general data of each dropping point, followed by tables combining the details from all drifters. The discussion will deal with each point in detail.

Station 1 (symbol +, Fig. 2,2)

This first release point is located about 100 yards offshore from the low water mark and outside the breaker zone, at the time of dropping. It is flanked by two parallel rock outcrops; Great and Little Hogus, of which Little Hogus submerges at high tide. The choice of this point was determined by the fact that at the time of the experiment the Marazion River outlet was located between these two rocks.

Drifters were released at 10.30 a.m. (half an hour after high tide), the following morning at 6.30 a.m., 24% of the drifters were recovered. The area of dispersion was not more than 0,5 miles wide, i.e. between the Marazion River mouth and the causeway to

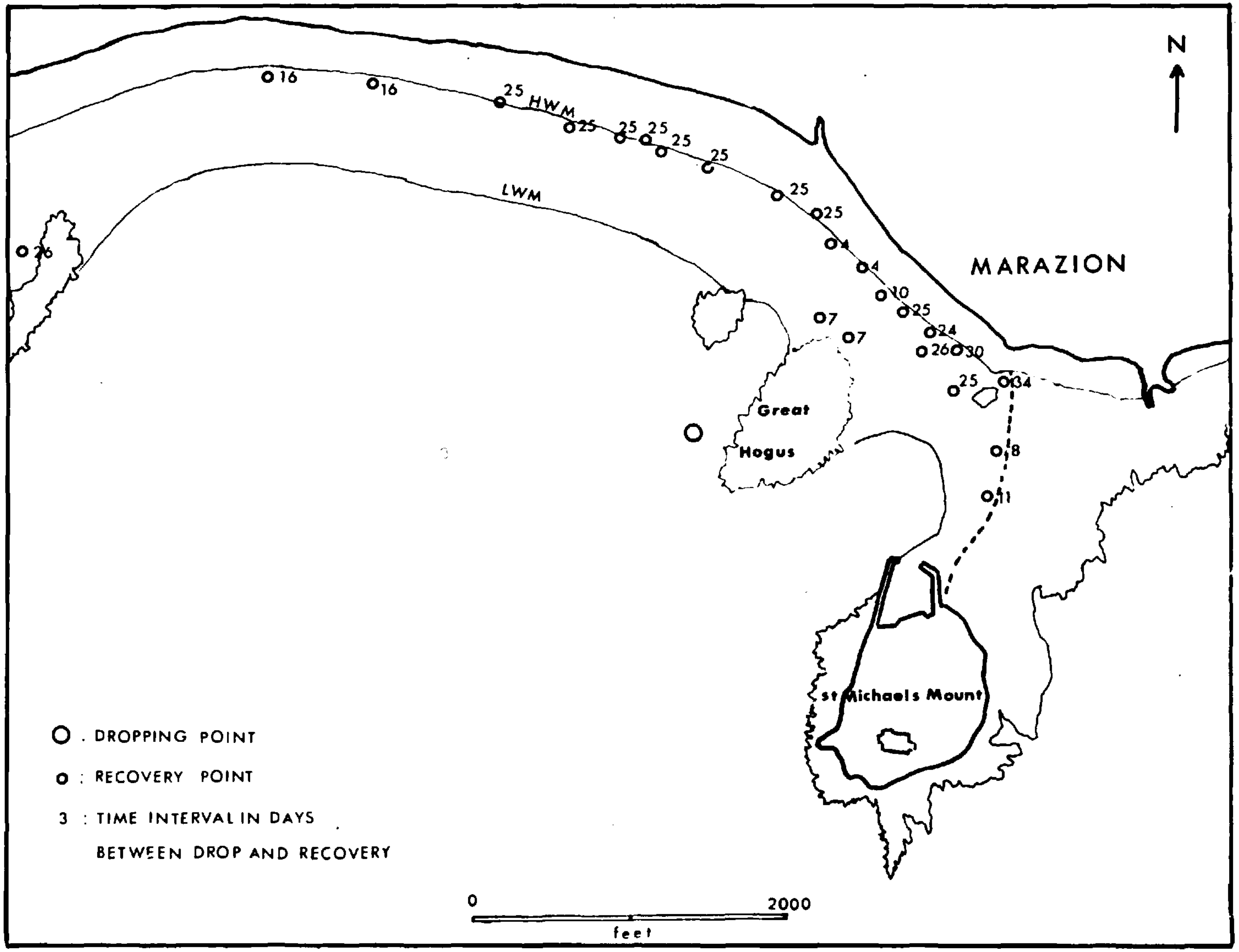


fig 2,3

dispertion of second group of bottom drifters

St. Michaels Mount. In the same period a great amount of kelp was washed ashore, probably originating from the submarine rock outcrops of the mount. Although recovery did not continue with the same speed, more than 50% of the drifters were recovered within three weeks. The maximum dispersion did not exceed the one mile of beach between Marazion station and Marazion village, with a slight concentration east of the release point. After four weeks no more drifters arrived, with a significant exception of one drifter, recovered 20 weeks after release on the quarry beach S.E. of Newlyn.

Station 2 (symbol o, Fig. 2,3)

The second release point was basically a repeat of the first one, but a little bit more in an offshore direction. This location, 250 yards from the low water mark, is still in the vicinity of Great Hogus, but offshore from Little Hogus. Although recovery was not as fast as from the first group of drifters, the overall pattern was the same; 58% recovery spread over 5 weeks, with a dispersion of almost two miles from Long Rock village to St. Michaels Mount. As with the first drifters, the maximum concentration occurred east from the dropping point. Two drifters were recovered outside the main area of dispersion, one in the outer harbour of Penzance 19 weeks after release, and the other on the Newlyn/Penzance beach 20 weeks after release.

FIG 2,4

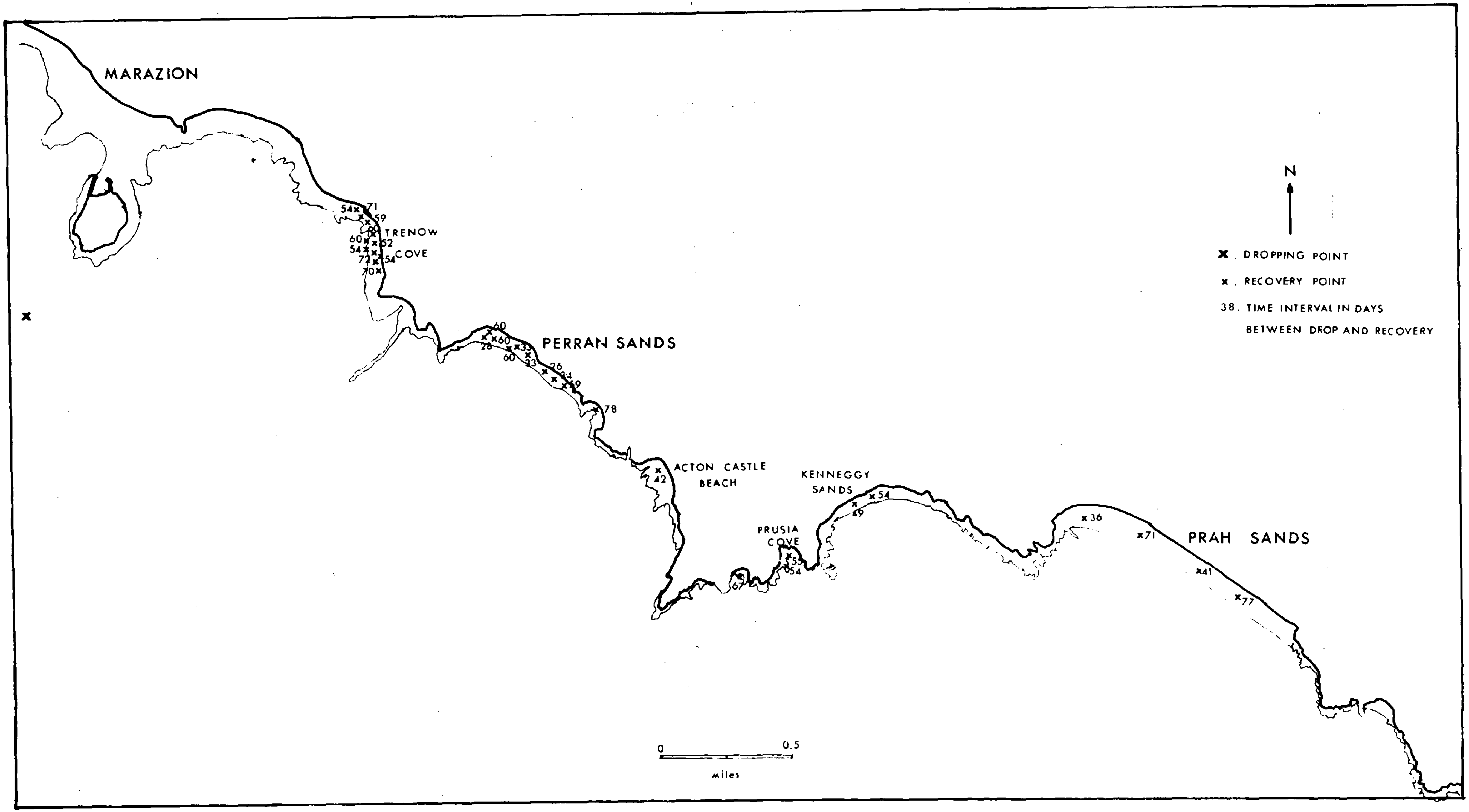


fig 2,4

dispertion of third group of bottom drifters

Station 3 (symbol x, Fig. 2,4)

The third point was located just south-west of St. Michaels Mount. 50 drifters were released one hour after high tide. The recovery picture is quite distinct from the previous two points, and stretches over a length of 6 miles towards the east. The first drifters to be collected were not on the nearest beach, and arrived on Perranothnoe beach (Perran Sands) 2,5 weeks after release, followed by four other drifters during the next weeks. The second location was Trenow cove, one mile east of Marazion and the nearest beach to the dropping point. Drifters arrived here 5 weeks after release. Prah Sands was the location of several recoveries 36 days and more after release. Small coves and beaches, such as Prussia cove, Acton castle and Kennegy beach, were also recovery locations of several drifters. On the whole, there is no distinct advancement of recovery with time, although the direction of movement is easterly. The total recovery was 58% and the last drifter to arrive was found 78 days after it had been dropped.

Station 4 (symbol ⊙, Fig. 2,5)

The fourth point is located east of the Penlee lifeboat house and north/east of Mousehole. This point was selected to establish the direction of the current pattern in the western part of the bay. As will be discussed in more detail in Chapter 2 of this section, radio-active background values suggested a movement of material in a northerly direction.

FIG 2,5

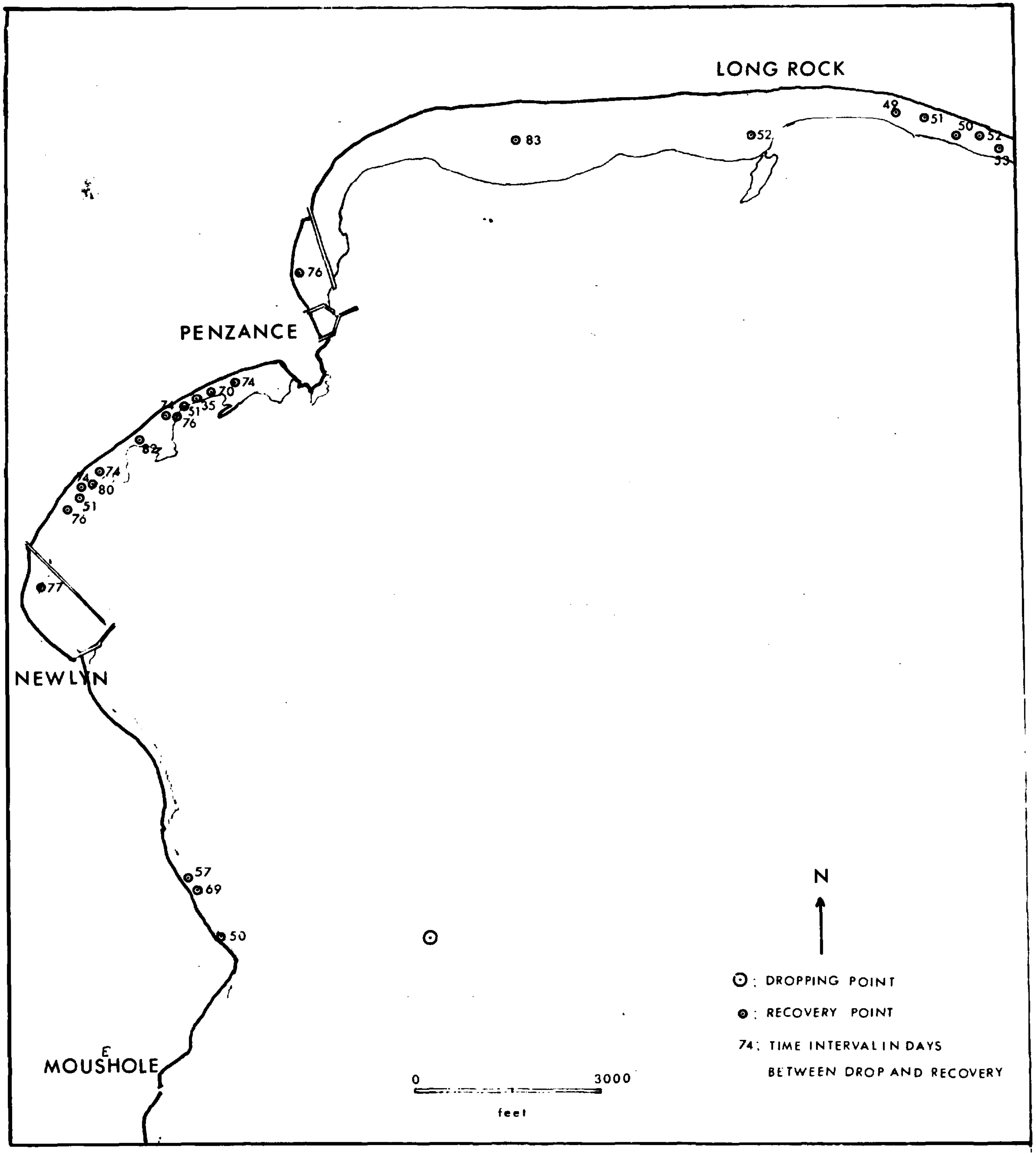


fig 2,5
dispertion of fourth group of bottom drifters

The first drifter to arrive was collected off the Penzance promenade 35 days after release. 14 days later a second drifter was recovered just east of Long Rock village. From then onwards, a consistent number of drifters was washed ashore during the next few weeks. The main area of recovery being the Newlyn-Penzance beach and the area near Long Rock, halfway between Penzance and Marazion. The last recovery took place 115 days after release at Newquay on the north coast of Cornwall. One drifter was also found in Newlyn harbour, while another which had lost its shaft was found at the Perran Sands. Altogether, 50% of the drifters had been recovered.

Station 5 (symbol ■ Fig. 2,7)

The fifth and last dropping point was located 0,5 miles offshore from Porthleven. Recovery took place with a greater speed than was shown by the other offshore dropping points, i.e. stations 3 and 4. 44% were found within the first week, all east from the dropping point. Two concentrations were observed, near Porthleven and at Gunwalloe, which is 1,5 miles further east. The difference shown by this group of drifters to those from elsewhere, is the dispersion all over the bay. Two drifters were recovered at the Penzance-Marazion beach, one on Perran Sands and three on Prah Sands and adjacent beaches.

Table 2,1 Station 1

Symbol	Location	Depth of water	Date of release	Time of release	Wind direction and force
+	50°7'21" 5°28'50"	5 feet	6.9.1966	10.30 a.m.	NW 3

Number of drifters recovered	Time in days after release	Wind direction and force	Location
12	1	W 1	Between Chapel rock
6	2	N 3	and Marazion River
2	11	SE 2	"
2	12	ESE 3	Causeway St. M.M.
5	27	SE 8	Marazion beach and
1	29	SW 2	Long Rock
1	137	NW 4	Quarry beach, Newlyn

Table 2,2 Station 2

Symbol	Location	Depth of water	Date of release	Time of release	Wind direction and force
o	50°7'15" 5°29'0	10 feet	8.9.1966	12.15 p.m.	N 3

Number of drifters recovered	Time in days after release	Wind direction and force	Location
2	4	W 3	Chappel rock
2	7	NW 4	Great Hogus
1	8	N 2	Causeway St. M.M.
1	10	ESE 3	Marazion beach
1	11	ESE 3	Causeway St. M.M.
2	16	SE 2	Long Rock beach
1	24	SE 2	Marazion beach
10	25	SE 8	Between Marazion and Long Rock
1	26	SE 2	West of Long Rock
1	30	NW 3	East of Marazion
1	34	SSE 8	"
1	133	NW 2	Penzance Harbour
1	139	SE 3	Newlyn beach

Table 2.3 Station 3

Symbol	Location	Depth of water	Date of release	Time of release	Wind direction and force
x	50°6'36" 5°28'38"	47 feet	8.11.1966	12.15p.m.	NW 3

Number of drifters recovered	Time in days after release	Wind direction and force	Location
1	26	NW 3	Perran Sands
1	28	NW 2	"
2	33	SW 2	"
1	34	NW 8	"
1	36	SW 1	Prah Sands
1	41	W 3	"
1	42	NW 4	Acton Castle beach
1	49	NW 3	Kennegy beach
1	52	WNW 8	"
5	54	NW 2	Trenow cove
1	55	SE 1	Prussia cove
1	59	NW 2	Perran Sands
4	60	NE 3	Perran Sands, Trenow
1	67	NE 2	Prussia cove
1	70	SW 3	Trenow cove
2	71	SE 4	"
2	72	SW 8	"
1	77	SW 8	Prah Sands
1	78	WNW 5	Trevean beach

Table 2,4 Station 4

Symbol	Location	Depth of water	Date of release	Time of release	Wind direction and force
⊙	50°5'24" 5°31'21"	66 feet	8.11.1966	3.15p.m.	N 2

Number of drifters recovered	Time in days after release	Wind direction and force	Location
1	35	NW 7	Penzance beach
1	49	NW 3	Marazion
2	50	WSW 5	"
3	51	W 6	"
2	52	WNW 8	"
1	53	WNW 3	"
1	57	SW 1	Roskilly
1	69	SE 3	"
1	70	SW 3	Penzance
5	74	NW 4	Newlyn & Penzance
1	75	SW 8	Perran
3	76	SW 8	Penzance
1	80	SW 5	"
1	81	SW 4	"
1	82	SW 7	"
1	83	SW 3	Eastern Green

Table 2.5 Station 5

Symbol	Location	Depth of water	Date of release	Time of release	Wind direction and force
■	50°4'50" 5°19'5"	60 feet	10.9.1966	13.00p.m.	SW 2

Number of drifters recovered	Time in days after release	Wind direction and force	Location
1	2	W 3	Porthleven beach
6	3	NW 4	" & Gunwalloe
3	4	W 2	" "
8	5	NW 4	" "
1	10	ESE 3	"
1	18	SE 3	Penzance
2	23	SE 8	Rinsey
3	24	SE 2	Porthleven
1	25	SW 1	Perran Sands
1	29	NW 1	Prah Sands
1	136	NE 2	Gunwalloe

Table 2.6 Relationship between wind direction and force and number of recovered drifters

number without brackets refers to the number of days on which indicated wind conditions occurred

number in brackets refers to the number of drifters recovered under indication wind conditions

	Wind force (Beaufort scale)							
	1	2	3	4	5	6	7	8
N		5		1	1			
NNW		1	2					
NW	4(1)	13(7)	4(13)	6(5)	2	1	1(1)	3(10)
WNW			1		2(2)	1		2(3)
W		2(3)	4(1)	6		2(3)		
WSW		2	1		1(2)			1
SW	5(2)	6(3)	7(2)	2(3)	1(1)		1(1)	4(7)
SSW				2(5)				
S				1				1(1)
SSE						1		1(16)
SE	2	7(5)	7(6)	1				1
ESE		1	2					
E								
ENE								
NE		4(3)	4					
NNE								
Total days	11	41	32	19	7	5	2	13
Total drifters	(3)	(21)	(22)	(13)	(5)	(3)	(2)	(37)

Data of stations 3, 4 and 5 only

D. Discussion

It should be emphasised that the discussion and conclusions are based on a total recovery of just over 50%. The whereabouts of the other half remains obscure, although the recovery of some drifters outside the main area of dispersion have given some valuable indications as will be shown later. A second point, which should be mentioned prior to the discussion, is that the actual recovery of drifters is mainly due to the wave action, although their transport will take place through tidal currents. Detailed discussion on wave action will follow in Section 3. However, it may be mentioned here that **in general**, waves induce inshore currents which are related to the wave dimensions. The greater the dimensions the further offshore (in other words the deeper) wave action will become important.

It is significant, with respect to the last point, that relatively speaking, most of the drifters were recovered during or after storms (Table 2,6). 37 drifters were recovered during the 13 days which had a wind force of 8, while, for instance, during the 41 days on which the wind force was 2 only 21 drifters were collected.

In the area west of St. Michaels Mount, there are probably three media affecting the dispersion of the drifters of dropping points 1 and 2. They are:

1. The Marazion River outlet
2. The wave action
3. The tidal currents.

The first one, the discharge of fresh water in the bay, does not seem to have any significant effect, compared with the other two. Firstly, drifters were collected in the mouth itself which fans over the beach. Secondly, the area of maximum recovery was the stretch of beach in the vicinity of Little and Great Hogus, which is also the location of the river outlet.

The wave action is more important. The wind which generates some of the waves, will be most effective when it comes from any direction between SW and NW (this is also the prevailing wind direction, Table 2,6). These winds generated waves which approach obliquely this particular beach, resulting in an easterly drift. This oblique approach is also helped by the refraction of waves against the mount. The effect of this easterly longshore current is demonstrated by the drift in easterly direction of Marazion River mouth, the decreasing grain size of beach material as compared to the material forming the beach near Long Rock village and finally by the concentration of recovered drifters east of the dropping points. The piling up of water through this current will result in a compensating current in an offshore direction, the rip-current, especially when the causeway to St. Michaels Mount is emerged, which is the case during a great part of the tidal cycle. This current system is held responsible for the large number of unrecovered drifters, although it has to be mentioned that a substantial number may have been trapped in the kelp, which is known to occur round the Mount.

The influence of the tide is difficult to estimate in this area. The difference between high and low tide is in the order of 14 feet, but it is doubtful if there are any tidal current movements; it is likely that the bottom waters and therefore the drifters will normally only move a few feet inshore during the incoming tide and vice versa. The main effect of the tidal range is that waves will act on the bottom over a fairly large zone. For this reason, the area extending several hundred feet seaward from the low water mark was unsuitable as location for the radio-active tracer work.

The results of station 3 (symbol x, Fig. 2,3 and Table 2,2) speak for themselves; drifters have travelled in an easterly direction. The reason that there is no distinct progress (in terms of distance) of recovery with time, is explained by the fact that transport takes place through tidal currents but recovery is determined by wave action. This is not shown by Table 2,2. However, most of the recovery days were preceded by wind forces ranging from 6 to 8.

The long time interval between release and first recovery is explained in the same way; the first day which has a wind force of 8 occurred 23 days after the release date. An important feature shown by this group of drifters is the fact that submarine rock outcrops, for example the Creep (west of Perran Sands) and Cudden point (west of Prah Sands) do not act as major obstacles. In other words, the Perran Sands, Prah Sands with their submarine sand bodies as well as smaller coves such as Prussia cove, Trenow cove and Acton

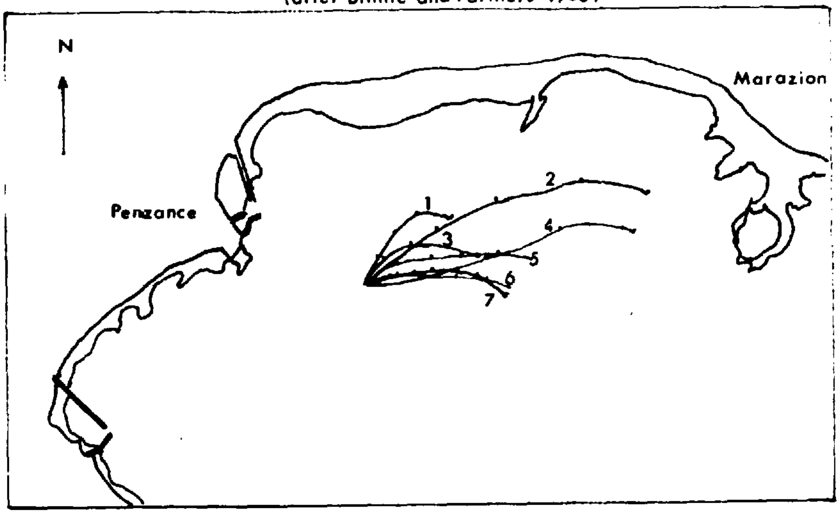
Castle beach are not as isolated from the bay was was presumed.

Drifters released at the fourth station (symbol ⊙, Fig. 2,5 and Table 2,4) show a very distinct and important distribution. The first drifter arrived offshore off the Penzance promenade followed by a group of drifters recovered at the Marazion beach. The next two drifters arrived on Roskilly beach close to the dropping point. This suggests a clockwise movement in the western part of the bay and this suggestion is supported by the fact that the next drifters arrived once more on the Penzance/Newlyn beach, followed by a drifter recovered 83 days after release at the Penzance/Marazion beach (Eastern Green).

There are three more arguments in support of the above hypothesis. Firstly, drifters released from stations 1 and 2, which "escaped" the main dispersion area, as indicated by the main dispersion area of the drifters of these points, were recovered not eastwards, but at Roskilly beach and in the Penzance harbour. Secondly, as shown in the second chapter of this section, measurements of radio-active background values in this area suggested a transport in northern direction for the western part of the bay. The third supporting feature is provided by the results of a hydrographic survey carried out in this area by Binnie and Partners at the request of the Penzance Borough Council. This survey, amongst other things, made use of fluorescent dye in an area close to Penzance. The results of 14 experiments to establish current

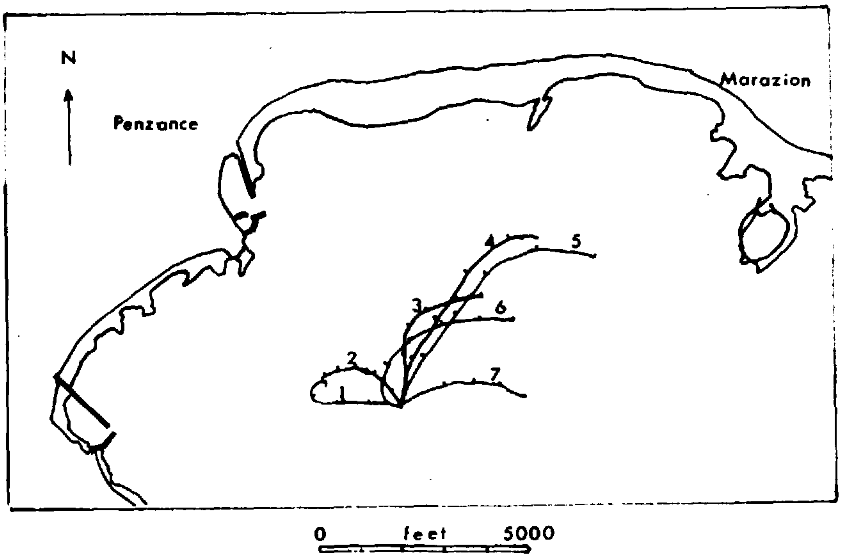
VELOCITY AND DIRECTION OF SURFACE CURRENTS IN WESTERN MOUNTS BAY

(after Binnie and Partners 1965)



1 – 770	feet/hr		5 – 880	feet/ hr		
2 – 1410	..		6 – 810	..		
3 – 840	..		7 – 540	..		
4 – 1740	..					

length of experiments in hours



1 – 690	feet/hr		5 – 1340	feet/hr
2 – 340	..		6 – 910	..
3 – 790	..		7 – 790	..
4 – 1160	.			

fig 2,6

direction and current velocity, indicated that with incoming tide northerly to north easterly currents are generated which, at high water, changed to easterly currents. With ebbing tide, the direction was in general south-east.

It is of considerable interest that the dispersion of fluorescent dye patches showed that the average current velocity in the middle of the western half of Mounts Bay (approximately in the middle of the proposed circular movement) not only were lower, but also more erratic in direction (Fig. 2,6) compared to locations closer to the shore. This indicates a stronger current velocity away from the centre. Furthermore, it appeared from experiments with floating objects that the wind affected the surface waters only when its force exceeded 2 to 3 mark on the Beaufort scale. In addition to this discussion, it may be mentioned that the tin content of the surface sediments within this circular system has some distinct aspects not revealed by samples from outside this current location.

It is not completely understood why the first drifter to arrive took 35 days to travel a distance of no more than two miles. This is the more surprising as there occurred a storm (WSW 8-9) on the twenty-third day after the drop. It indicates at least that in an experiment like this one, information may be obtained on the general direction of the currents but not on the current velocity.

There are two main differences between the dispersion pattern as obtained by drifters from station 5 (symbol ■ Fig. 2,7 and Table 2,5), compared to stations 3 and 4. Firstly, the speed of recovery; 18 drifters within the first 5 days, although no heavy winds occurred during this period. This indicates that the tidal current has a much closer inshore effect than elsewhere in the bay. The fact that the shore line is not broken by submarine rock outcrops over at least 2,5 miles may be significant in this case. The stronger inshore current is also reflected in the grain size distribution of the beach material, which is very much coarser for the Porthleven beach than for any of the other beaches. The second point of interest is the recovery of 5 drifters on beaches west of the dropping point. Their dates of recovery suggest once more a general transport direction from west to east; the drifter found near Penzance arrived one week earlier than those found at Perran Sands, Prah Sands and Rinsey beach.

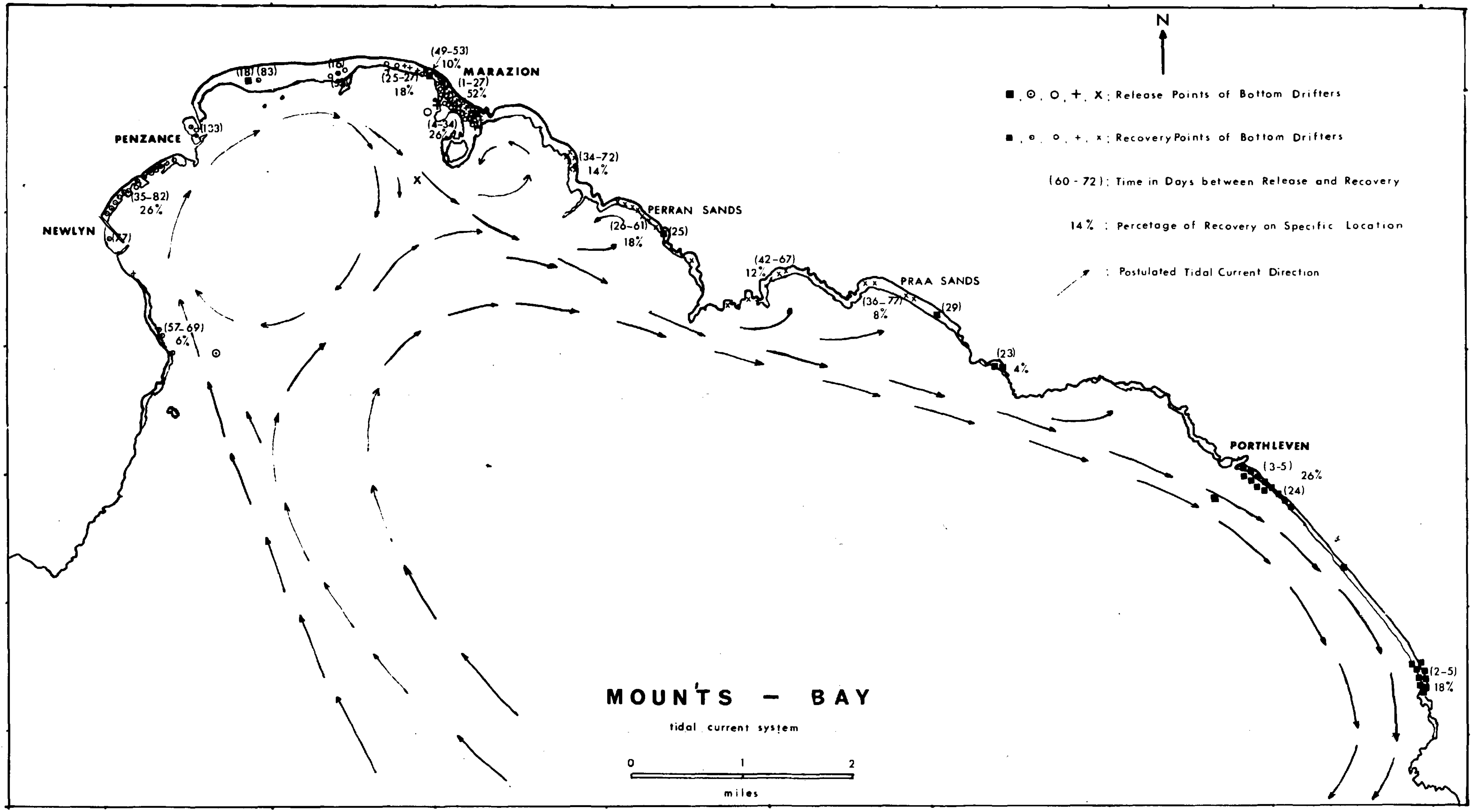
Although the number of drifters which are recovered west of Porthleven is rather limited, the writer suggests that based on the above discussion and the general information as revealed in the introduction, there exists an overal clockwise tidal current pattern in Mounts Bay, with an eddy for the most western part.

E. Summary of Conclusions

Based on the above discussion it is suggested that:

1. The main tidal current shows a clockwise pattern which may well be induced by the general tidal system

FIG 2,7


N
■, ⊙, O, +, X : Release Points of Bottom Drifters
■, ◦, ○, +, x : Recovery Points of Bottom Drifters
(60 - 72) : Time in Days between Release and Recovery
14 % : Percetage of Recovery on Specific Location
: Postulated Tidal Current Direction
(49-53)
10%
MARAZION
(1-27)
52%
(18) (83)
(16)
(25-27)
18%
PENZANCE
(133)
(4-34)
26%
(34-72)
14%
(35-82)
26%
NEWLYN
(77)
PERRAN SANDS
(26-61)
18%
(25)
(42-67)
12%
PRAA SANDS
(36-77)
8%
(29)
(23)
4%
(57-69)
6%
PORTHLEVEN
(3-5)
26%
(24)
(2-5)
18%
MOUNT'S - BAY
tidal current system
0
1
2
miles

along the south-west coast of Britain.

2. The western part of the bay, occupying roughly the triangle Mousehole, Penzance and St. Michaels Mount, shows an isolated circular pattern whose current velocity is less than for the main tidal current as the time interval between release and recovery of the relevant drifters in this part of the bay is very much greater than elsewhere, regardless of the weather.
3. The individual beaches and coves are not isolated from the main current, despite the presence of submarine outcrops or cliffs.
4. The dispersion force of the river outlets is rather insignificant.

On the results as obtained on the five dropping points and the general available information, a tidal current chart has been constructed (Fig. 2,7). The number of co-linear arrows indicates the postulated relative current velocity.

The disaster of the Torrey Canon in March, 1967 has confirmed the current pattern as postulated above. Most of the oil passed along the north coast of Cornwall. Some oil was blown into the bay and contaminated the Porthleven beaches badly, while Prah Sands and Perran Sands had only traces of oil. The triangle Mousehole, Penzance, St. Michaels Mount remained completely oil free. Although the wind direction was mainly responsible for the transport of oil from the wreck into the bay, and contamination of the shore line, the tidal system certainly has had an important effect.

CHAPTER 2 MOVEMENT OF MATERIAL IN WESTERN MOUNTS BAY USING RADIO-ACTIVE TRACERS

A. Introduction

The main aim of the present study, as stressed previously, is to establish and possibly to solve some of the problems involved in the plural origin of the tin in the marine sediments. It has also been mentioned that this problem is dominantly a sedimentological one. The first section, therefore, dealt with some of the aspects of material reaching the bay, while the first chapter of this section assessed the current pattern in the bay. In this present chapter, an attempt is made to study the movement of detrital tin in this offshore environment. The movement of sediment and the distribution of tin in the zone of wave action have been considered in isolation in Section 3 dealing with the geochemical aspects of near-shore traverses.

The western part of the bay has been selected as the most suitable study area. This selection was based, amongst other reasons, on the fact that submerged valleys in this part of the bay form a far more distinct continuation of the present rivers (Marazion and Newlyn) than elsewhere in the bay. Secondly, transport investigations in this part of the bay form a logical continuation of those of Marazion River. Thirdly, because placer deposits have been reported from western rivers only, and finally, the Penzance/Marazion sand body is by far the largest of the isolated sediment bodies in Mounts Bay.

B. Previous Work

In section 1, several tracer techniques have been mentioned. Although fluorescent tracers have been used successfully under marine conditions, there are certain shortcomings when applied in deep waters. In the first place, there is the quantity of material involved, which is considerable. Secondly, there are the problems of sampling and location. Jollife (1963) and Ingle (1966) developed a sampling technique involving greased cards. The main disadvantages of that method are; the representativity of the collected sample depends on the thickness of the grease and the grain size distribution of the sand; especially in sediment of an unsorted nature, finer grains tend to be protected by coarser grains and therefore not come into contact with the card; furthermore, the taking of individual samples is time consuming and requires a very accurate positioning technique.

Radio-active tracers on the other hand, have the advantage that with continuous readings along traverses, only a limited number of fixations are required. Other advantages are that:

1. no sampling is required (measurements in situ);
2. small amounts of material are involved;
3. highly efficient as very low concentrations will still be detected.

However, there are a number of disadvantages which are listed below.

1. Coast of irradiation is high.
2. The total amount of gamma emission is limited by health considerations.

3. Artificial tracers are seldom hydraulically equivalent to the naturally occurring material.

Investigations in the movement of nearshore and littoral sediments have made great advances since the advent of radio-active and fluorescent techniques. In the U.K. the first use of radio-active tracers was made in 1954. Since then these tracers have been applied in a number of investigations, both of scientific and industrial value (Putman et al, 1954, 1956; Smith, 1956, 1957, 1958, 1965; Goldberg, 1955; Hours et al, 1956; Inose et al, 1956; Allman et al, 1957, 1960; Davidson, 1958; Kidson, 1958; Joffy, 1959; Inman, 1959; Crickmore, 1962, 1963; Chabert et al, 1963; Kato et al, 1963). An excellent review of the use of radio-active tracers with over 250 references has been given by Courtois (1966).

Several radio-active tracing techniques have been developed and are discussed briefly below.

<u>1. Neutron irradiation of quartz</u> (Goldberg and Inman, 1955; Crickmore and Lean, 1962)

The advantage of this method, which involves the activation of silicon, lies in the fact that the hydraulic properties of the material involved remains unchanged. However, there are some shortcomings in this method in that the half life-time is very short (T silicon 31 = 2,6 hours), while the emission of 1,8MeV consists of beta particles only. Good results have been obtained by using an artifically activated isotope of Phosphorus 32 found within naturally occurring quartz sand grains (Goldberg and Inman, 1955; Inman and Chamberlain, 1959).

2. Surface labelling (Steers and Smith, 1956; Kidson et al, 1958; Davidson, 1958; Hours et al, 1955, etc.)

This method has the same advantages as the previous one; hydraulic properties remain the same. However, activity in this case is a function of the surface area rather than mass, which prevents a quantitative interpretation of the data. Several techniques have been developed for surface labelling, to minimise the effect of abrasion, including drilled holes in pebbles.

3. Mass labelling

This method is by far the most frequently used. It makes use of glass with identical density as the material to be traced. In this glass an element is incorporated which can be made radioactive. After grinding to the required grain size, the material is irradiated. As the glass grains are very angular, they sometimes are blow through a gas flame to obtain a more or less rounded shape.

In the Netherlands, experiments have been carried out on the basis of an ion exchanger. The inorganic zeolite greensand (also known as Ionac C 50) is treated with a radio-active isotope by means of exchange reaction (Arlman, 1955). However, the hardness of the zeolite is less than sand, heating increases the hardness, but decreases the absorbtion capacities.

The choice of the isotope is controlled by several factors, which may carry a different weight according to the type and nature of the experiment. The most important ones are given below.

1. The half-life of the isotope used.
2. The energy emission of the isotope, gamma emission, is preferable as beta emission is easily absorbed by the sediment and water.
3. Specific activity of the isotope; the higher it is the less quantity of activated material is required. For mass labelling this limits the choice of isotope to those with a high neutron activation cross section.
4. The strength of bonding of the isotope to the grains when surface labelling is used.
5. The toxicity; individual grains must be harmless to human beings. (The maximum allowable activity of any grain is 0,1 micro Curie; A.E.R.E. radio isotope review sheet C 13, 1965) This point needs special consideration where there are densely populated beaches as in Cornwall.

The most generally employed isotopes are listed in Table 2,7. In addition, ^{198}Au, ^{31}Si, ^{24}Na and ^{32}P (the last three occurring in natural sand) have been used. However, the most widely applied isotope is ^{46}Sc.

Table 2,7 Elements generally used for radio-active tracer experiments

Element	Atomic weight	Energy MeV gamma emission	%	Half life time in days
Ag	110	0,51	17	253
Rb	86	1,08	20	18
Cr	51	0,32	10	28
Zn	65	1,11	45,5	245
Sc	46	0,89 and 1,12	100 and 100	85
Ba La	140	1,60	40	12,8 (+40,2 hours)

C. Choice of Tracer

Although the movement of the sediment as a whole is of interest, the main purpose of the study was to investigate the transport of cassiterite. Ideally, therefore, one should take naturally occurring detrital cassiterite for neutron irradiation. However, the existing isotopes of Sn doe not have the required physical properties. Amongst the 10 available isotopes, only two have a suitable half-life; ^{113}Sn and ^{123}Sn. ^{113}Sn has a maximum gamma emission of 0,39 MeV, which is 65% of the total emitted energy. This low energy emission will be absorbed by the water and the brass of the detector. The other isotope, ^{123}Sn has a gamma emission of 1,08 MeV. Unfortunately, this 1,08 MeV forms only 2% of the total emitted energy as compared to 200% for the 0,89 MeV plus 1,12 MeV of ^{46}Sc. More important, however, is the fact that the active cross section of natural tin for ^{123}Sn production is only 5.10^{-5} barn and 0.012 barn for ^{113}Sn. (The activation cross section of natural scandium for ^{46}Sc production is 22 barn.) In other words, to produce this isotope in sufficient quantities would require an uneconomic period of irradiation plus enormous amounts of cassiterite.

Any alternative tracer material should have similar density and hardness to cassiterite. The compounds of two elements received particular consideration; silver and tantalum. The isotope of silver, as can be seen in Table 2,7, has very suitable radio-active properties, although its half live time is rather long. The only compound of silver which has a similar density to cassiterite (7,01 g/cm^3) is silver sulfide (specific gravity of Ag_2S is 7,31 g/cm^3). However, its hardness is low, namely 2. In order to establish the effect of this on intensive transport and abrasion, the following experiment has been carried out. Medium sand, mixed with very fine silver sulfide in a ratio of 10 to 1 was stirred in water for 5 hours. After drying and screening with the same set of sieves, a considerable reduction in the grain size of Ag_2S was noted, and the ratio between the proportions of original material had increased to 14 to 1. The experiment has been repeated using other grain size combinations. All results showed a substantial pulverisation of silver sulfide. It was, therefore, decided to abandon Ag_2S as an artifical tracer.

Tantalum appeared to have a greater potential. The half-life of the isotope ^{182}Ta is 115 days. Its gamma emission spectrum falls into two groups; one below 0,2 MeV and the other above 1,0 MeV. The proportion of the gamma emission above 1,0 MeV is 89%. The dose rate of tantalum, given in Rontgen per hour at 1 cm distance from a 1 milli-curie source is 6,8 as compared to scandium which has a dose rate of 10,9. The detection sensitivity for Ta is therefore lower than for scandium.

The way in which tantalum could be applied for the specific experiment is twofold. In consequence of the physical properties of Ta_2O_5 and SnO_2, one can expect on theoretical grounds (Steele, pers. comm.) that cassiterite and tantalite will form a solid solution containing up to 5 mol % of the latter. This solid solution could be prepared in two ways; (1) by means of sintering, (2) by means of chloride disproportionation: $4TaCl_5+5SnO_2 \rightleftarrows 2Ta_2O_5+5SnCl_4$. Although this form of mass labelling would be ideal, the method has not been reported as far as the writer is aware, and this method belongs more to the field of powder metallurgy, and falls consequently outside the scope of the present thesis.

The other possibility is naturally occurring tantalum in the form of the solid mixture of columbite/tantalite. The density of this mineral depends on the Ta_2O_5 percentage and ranges from 5,36 g/cm^3 for 3% Ta_2O_5 to 7,03 g/cm^3 for 65,6% Ta_2O_5. Through the generosity of Mr. Monro of Bikita Minerals Ltd. Rhodesia, the writer was able to obtain 3 lbs of tantalite with a tantalum pentoxide content of 50% resulting in a density of 6,95 g/cm^3.

D. Preparation of Tracer

Granular tantalite was ground down to minus 75 microns (=200 mesh). All material finer than 50 microns (= 300 mesh) was separated off. The maximum grain size was based on the fact that the majority of the cassiterite in the marine sediments occurred in the minus 200-mesh fraction. The lower boundary was chosen in order to avoid the possible suspension of tantalite during transport of the very fine particles. This would result in unreliable results but more important, could have hazardous effects if washed ashore.

In order to establish the activity required, the following matters have to be considered.

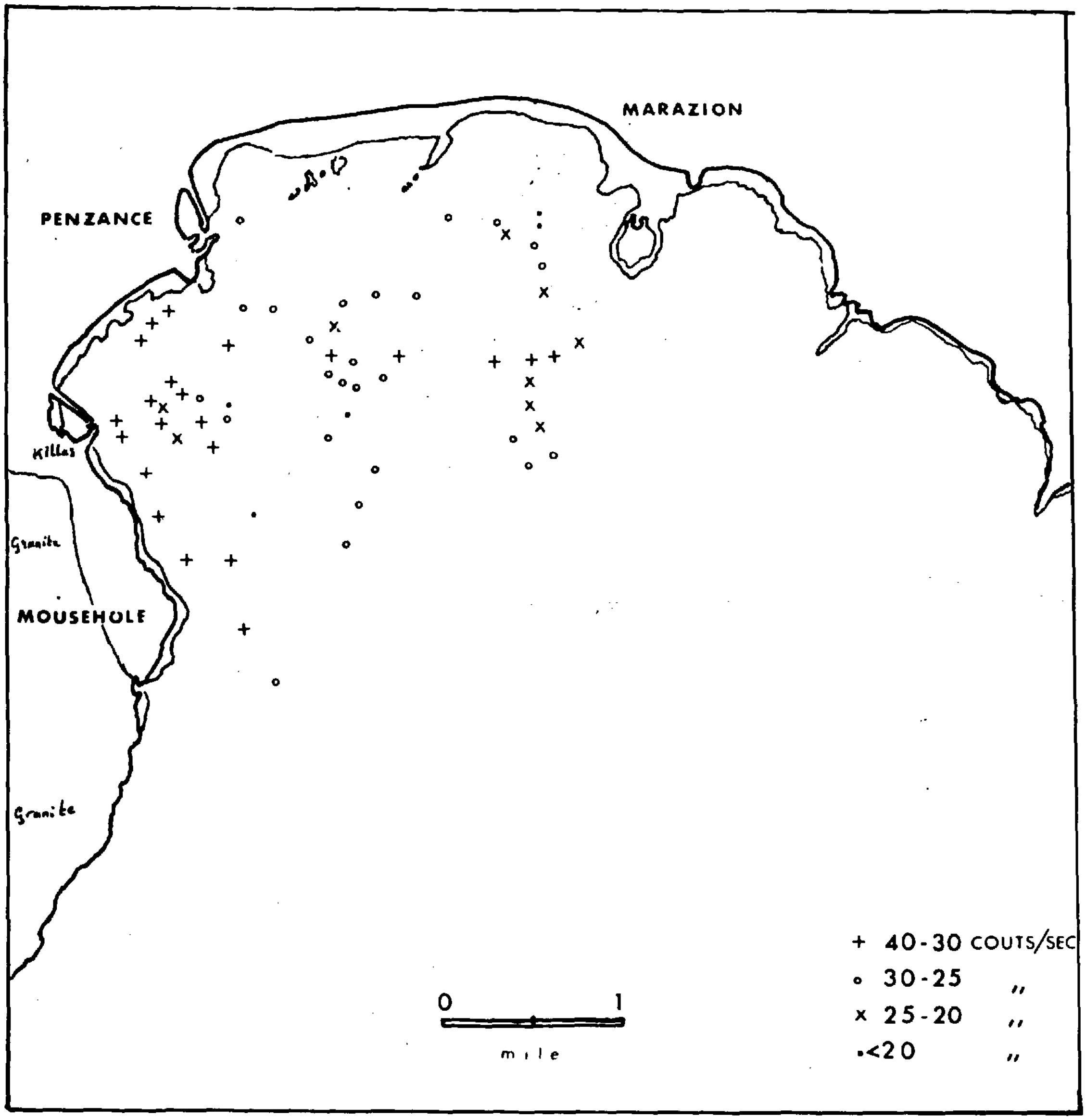
1. The background counting rate.
2. The area of dispersion.
3. The length of the experiment.
4. Health considerations.
5. The quantity of material involved.
6. The efficiency of the detector.
7. The statistical accuracy demanded.

By far the most important points are 1 to 4. For instance, with a background rate of 35 counts per second (c/sec), which is equal to 35.10^{-9} Curie/foot^2 and an assumed dispersion area of 1,5 square miles, the total radio-activity in this area is 35.10^{-9} Ci/foot^2 x $4.2.10^7$ foot^2 = 1.5 Curie. So the activity of the tracer must be in excess of 1.5 Curie, in order to be detected, provided its spread is uniform. In practice, however, dispersion will take place in a concentrated area rather than in all directions. It was, therefore, decided to give the tantalum an activity in excess of 2,0 Curie (total activity after the irradiation was 2.6 Curie). With a quantity of 500 grams of tantalum pentoxide the activity of each individual grain is far below the health limit.

The tantalite was divided between 10 ampoules of 50 grams each, and irradiated for 18 hours in a nuclear reactor at Harwell (Berks.). Short lived isotopes, especially Mn, which occurs in natural tantalite, was produced during the radiation with an activity of 100 Curie, and was allowed to decay for several days. The ampoules were stored in a lead container until the start of the experiment.

E. Radio-active Background Survey

A background survey, as explained above, is essential in order to establish the activity required for the tracer. In this case, however, the survey was also undertaken with another aim in view. A preliminary survey of the rivers and beaches fringing Mounts Bay, revealed that the river sediments had, in general, a natural radio-activity three times as high as the activity of the beaches. Whether this aspect is caused by differences in mineral composition and/or grain size distribution of the two types of sediment has not received further attention, but as these sediments are undoubtedly related to some extent, it was hoped that the background survey of the marine sediments



WESTERN MOUNTS BAY

background radio activity
of
surface sediments

FIG 2,8

would reveal a variable pattern which in turn could give some indications on the movement of material discharged by the rivers.

Comparison of data obtained on land and in the sea is not possible as measurements on land and sea were carried out with different equipment. Furthermore, it is difficult to make allowance for the absorbtion of gamma radiation in the water. Without a complete understanding of the nature and the source of natural activity, a survey of the transport pattern of material on the basis of natural activity may not be justified. However, since the background survey had to be carried out anyway, special attention has been paid to the above possibility.

The background survey in the bay was carried out with a plastic phosphor scintillation counter and a sodium iodide scintillation counter. (The sensitivity of the latter is 50% of the former but is more stable. Both have a high efficiency for gamma detection.) For financial reasons, the work could not be as detailed as would be desirable. However, the data obtained indicate that high values are concentrated close to the western shore. Intermediate values occur more in the middle of the surveyed area, while low values are dominant close to St. Michaels Mount (Fig. 2,8). Also of interest is the occurrence of five high values roughly in a line with a W/E strike, south-west of Penzance.

The only local source of material with high natural radio-activity is the Lands End granite. High values in the marine sediments, however, occur much farther to the north than the granite outcrop, possibly indicating a dispersion in a northerly direction, at least for the area close to the western shore. The five high values in west/east direction more or less coincide with the current pattern at that location as established by the fluorescent dye tests by Binnie and Partners (see Chapter 1). The apparent parallelism between the natural radio-activity and the postulated current direction, at least for the area covered by the background survey, suggest that a detailed study of the natural activity dispersion may prove to be valid in an area like western Mounts Bay as additional evidence for transport direction. It will be appreciated that far more work is required to investigate this possibility.

F. Location of Release Point of Radio-active Tracer

As mentioned previously, a release point close to the Marazion River mouth is not feasible from health considerations. It was, therefore, decided to select a point S.W. of St. Michaels Mount at the beginning of the submerged valley. Its location is a little westward of the third release point of bottom drifters and its exact position is 50°6'41"/5°29'3". It was hoped by positioning the actual release point more towards the west, to obtain dispersion by the main current as well as the eddy current, while in addition it was hoped to find out as to whether the location of the submerged valley affected transport in any way.

G. Release Technique

Transport of the tracer from Harwell to Penzance took place in a 10 cwt lead container. A smaller container shielded by sand bags was placed on the boat. Ampoules were transferred to the boat using a portable container. The release device consisted of a pneumatic cylinder, 10 inches long and 2 inches diameter. On one end an 8 inch long brass tube was mounted which could be closed by a perforated lid. A crusher in this tube was connected with the piston in the cylinder. A high pressure double hose connected the cylinder with a nitrogen cylinder. A two way valve enabled the operator to move the piston forwards and backwards.

An ampoule was placed in the brass tube by means of a 6 ft long pair of tongs. The equipment was lowered over the side of the ship. The ampoule was crushed within 2 to 3 feet of the bottom. The process was repeated until all the ampoules were crushed. The reason for crushing the ampoules above rather than on the bottom was to enable the material to be spread over a limited area. Accumulation at one single spot would hamper transport due to the dense packing of the heavy tracer, while a small initial spread also facilitated the location of the dumping ground.

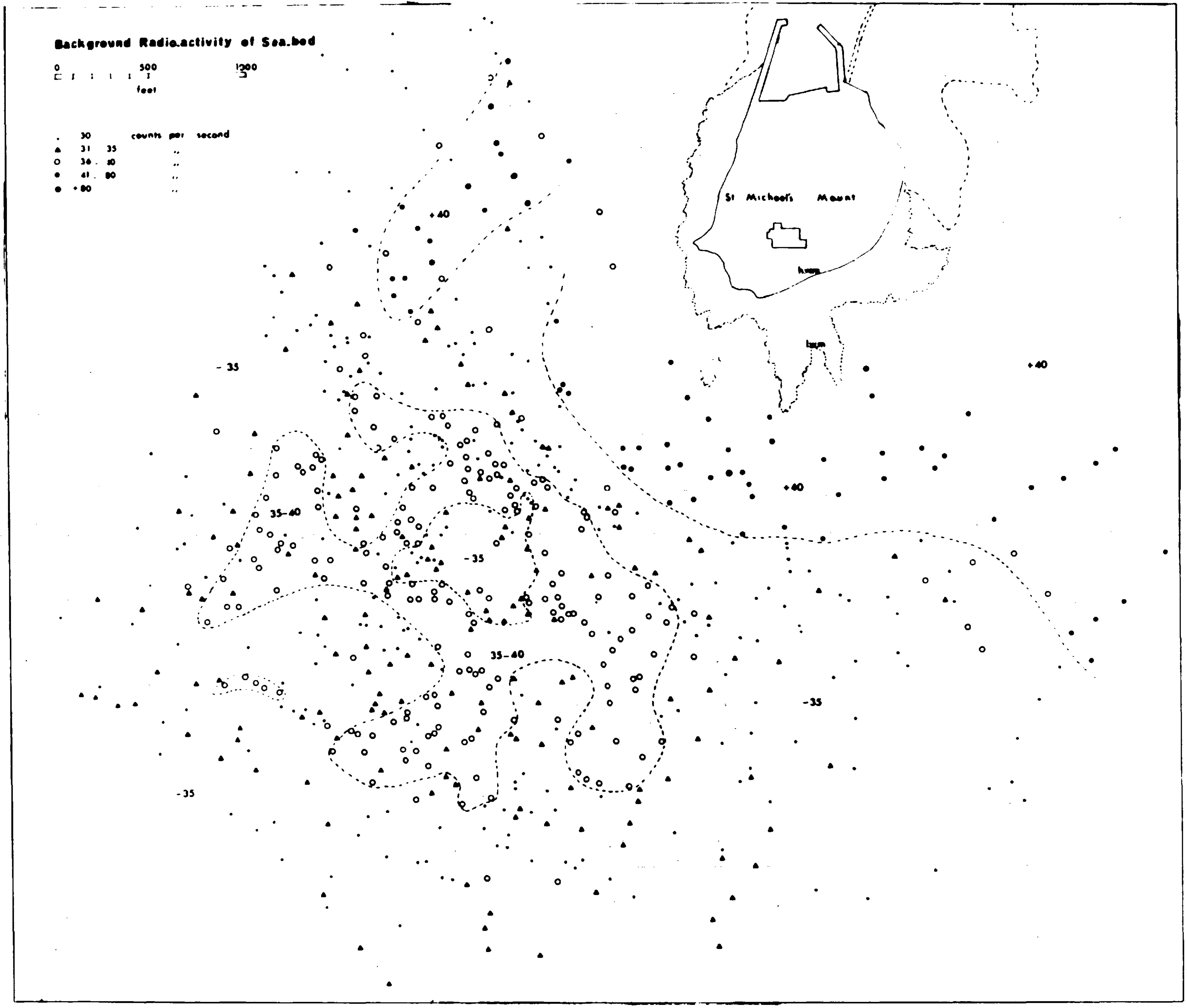
H. Data Collection

Data was obtained by means of a sodium iodide scintillation counter, which was frequently lowered onto the bottom of the sea while sailing along traverses. When weather conditions permitted, the detector was dragged over the bottom giving a continuous reading. Later in the survey, it was felt necessary to obtain a gamma spectrum of the measured activity in some selected locations as high background values at St. Michaels Mount could not be distinguished from the actual tracer. The apparatus used to measure the gamma spectrum comprised of a PIP 400 Victoreen Multi-channel Analyser, an interface unit to allow an ADDO-X printer to work from the PIP 400, a Telsec recorder and a translation amplifier. All the above required 230 V A.C. 50 c/s supply and a small generator was used to produce this. The standard electronics and scintillation counter were used for detection. The pulses from the detector were tapped off as they entered the pulse forming unit, amplified and inverted by the translation amplifier before being registered on the PIP analyser. Equipment was kindly made available to the writer by the A.E.R.E. and Mr. T.V. Parsons joined the field operations to supervise measurements with these expensive and delicate instruments.

Positioning was made by means of sextants using outstanding coastal features as bearing marks.

As no **transport** occurred during the first two days, the next survey took place one week later. From then onwards, readings were taken with 3-4 week intervals depending on weather conditions. In all, 4 groups of data have been obtained each consisting of several hundred measurements.

FIG 2,9


Background Radio.activity of Sea.bed
0
500
1000
feet
• 30 counts per second
▲ 31 35 ,,
○ 36 - 40 ,,
● 41 - 80 ,,
● +80 ,,
St Michael's Mount
hwm
lwm
+40
-35
35-40
-35
+40
+40
-35
35-40
-35

I. Presentation and Discussion of Data

1. Background radioactivity

The activity of the tracer will be superimposed on the natural activity. In order, therefore, to compare data, it is essential that the natural activity is deducted from the total activity. Secondly, to compare results of different sets of data, one must adjust each set for the loss in activity with time as determined by the half-life of ^{182}Ta. Background was established by joining all measurements with an activity below 40 counts/sec (Fig. 2,9). During the pre-tracing period, it became apparent from a background survey that the natural activity of the sand in this area ranged from 26-38 counts/sec, while rocks had an activity in excess of 50 counts/sec. Accordingly, it was decided to take 40 counts/sec as the upper limit of the natural radioactivity of sand. Most of the data in Fig. 2,9 were collected after the drop of the tracer, and during the survey of the tracer movement. It can be seen that values in the range of 35-40 counts/sec are clustered round the dropping point. It is possible, therefore, that the selected upper limit of background activity is slightly too high. However, rather than creating an optimistic dispersion pattern, it was decided to use this level of background activity (40c/sec) and to present in the figures the locations of 40 c/sec without taking them into any calculations.

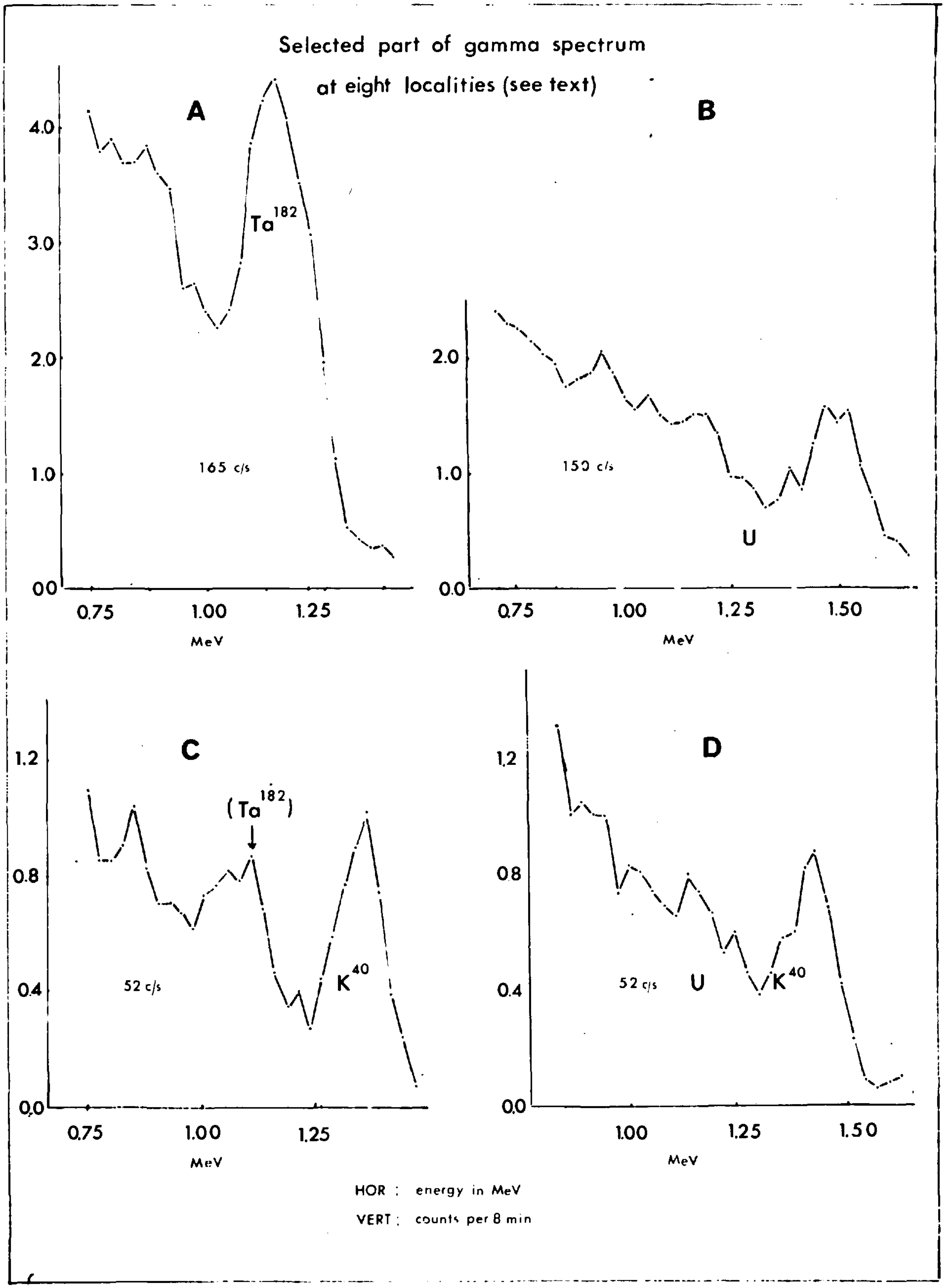

Selected part of gamma spectrum
at eight localities (see text)
A
B
C
D
Ta182
(Ta182)
U
K40
165 c/s
150 c/s
52 c/s
52 c/s
4.0
3.0
2.0
1.0
0.0
1.2
0.8
0.4
0.75
1.00
1.25
1.50
MeV
HOR : energy in MeV
VERT : counts per 8 min

FIG 2,10

Similarly, the area round St. Michaels Mount has been given a background in excess of 40 c/sec without further differentiation. The area was thought to be of less importance from a transport point of view, as rock outcrops and kelp would obstruct transport.

More uncertainty, however, occurred in the area west of the Mount and north of the deposition point, where a rock outcrop of at least 1000 ft in length occurs with a north/easterly strike. The activity in this area was in excess of 50 c/sec, but two traverses from the same location at the southern end of the rocks and taken with a considerable time interval, gave different results. On the other hand, values increased away from the dumping ground. Gamma spectrum analysis in this area showed, however, that the high values are due to outcropping rocks in this area.

2. Gamma spectrum analysis

Eight sites were selected for gamma spectrum determination. The locations are presented in Fig. 2.14. The positions are not very accurate, since during the period of observation there was persistent fog. Positioning was therefore made relative to the Mount. With respect to the diagrams, Fig. 2,10A to H, comparison can be made for the horizontal coordinate only. The vertical coordinate, the number of counts, is dependent on the position of the detector relative to the sea bed which causes variation in the number of pulses registered. Each station was followed by a run of ^{60}Co in order to calibrate the equipment. Nevertheless, small drifts in the calibration of the pulse height analyser occurred, which resulted in variations

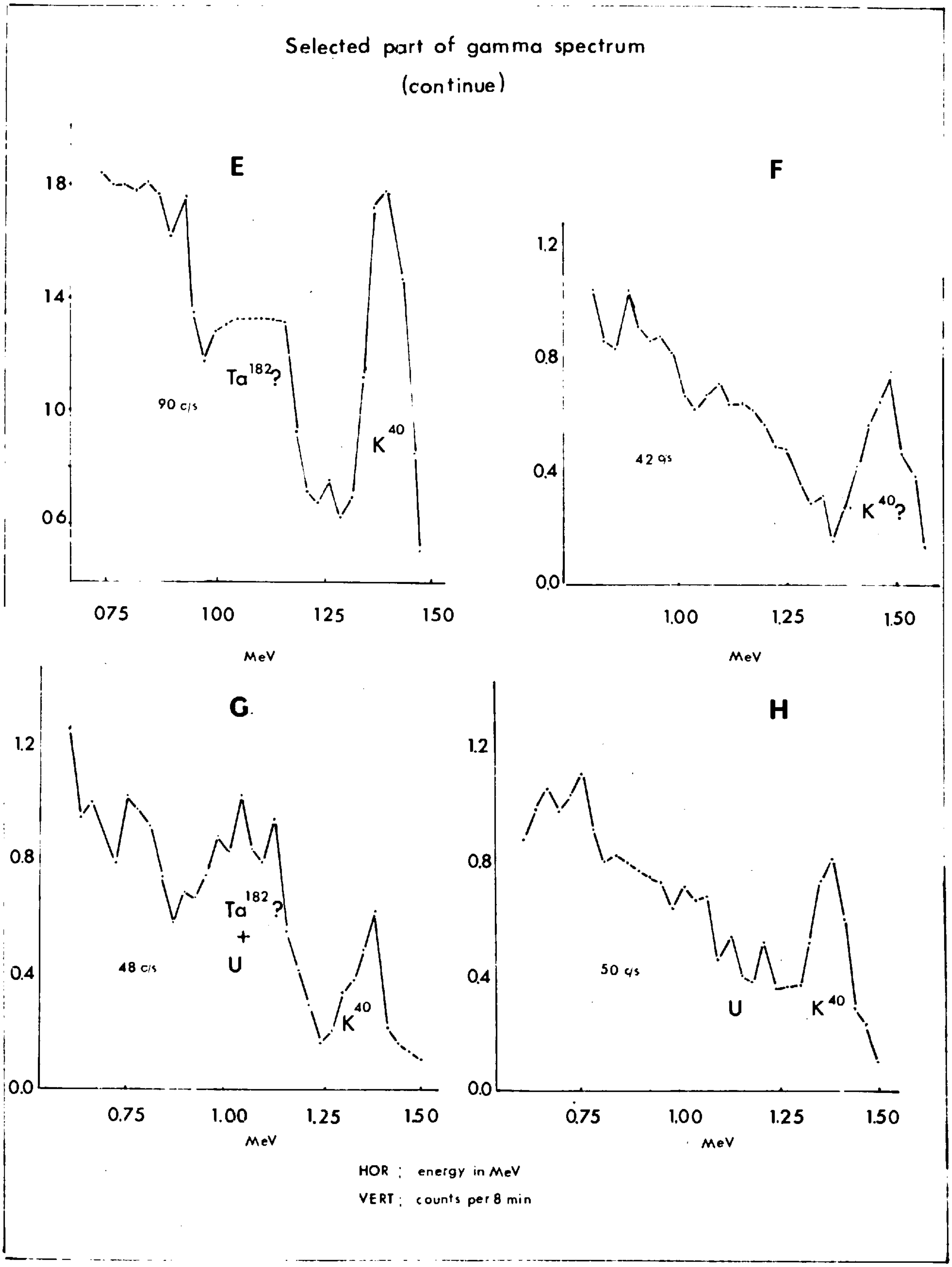

Selected part of gamma spectrum
(continue)
E
18
14
10
06
075
100
125
150
MeV
Ta^{182}?
90 c/s
K^{40}
F
1.2
0.8
0.4
0.0
1.00
1.25
1.50
MeV
42 c/s
K^{40}?
G
1.2
0.8
0.4
0.0
0.75
1.00
1.25
1.50
MeV
Ta^{182}?
+
U
48 c/s
K^{40}
H
1.2
0.8
0.4
0.0
0.75
1.00
1.25
1.50
MeV
50 c/s
U
K^{40}
HOR ; energy in MeV
VERT ; counts per 8 min

FIG 2,10a

in the horizontal scale (compare diagrams F and H).

Figure A represents the bottom near the dumping ground. The energy of ^{182}Ta, approximately 1,2 MeV is well presented. However, the peak is rather wide, which makes its determination in less obvious circumstances rather difficult.

Figure B from near the Mount indicates clearly the presence of uranium and potassium. Peaks are due to pulses from the following energies: 1,09, 1,15, 1,29 and 1,50 MeV. It is apparent from these two diagrams that although a similar counting rate (165 c/s and 150 c/s respectively) this is due to emission from a completely different source.

Figure C located west from the Mount and at the beginning of the high background area has a peak caused by potassium-40 and and ill defined peak which may be due to a little ^{182}Ta although its energy of 1,12 MeV is very close to uranium.

Figure D comes from a location approximately 200 feet further north and has a well defined peak of ^{40}K. The smaller ones are due to traces of uranium.

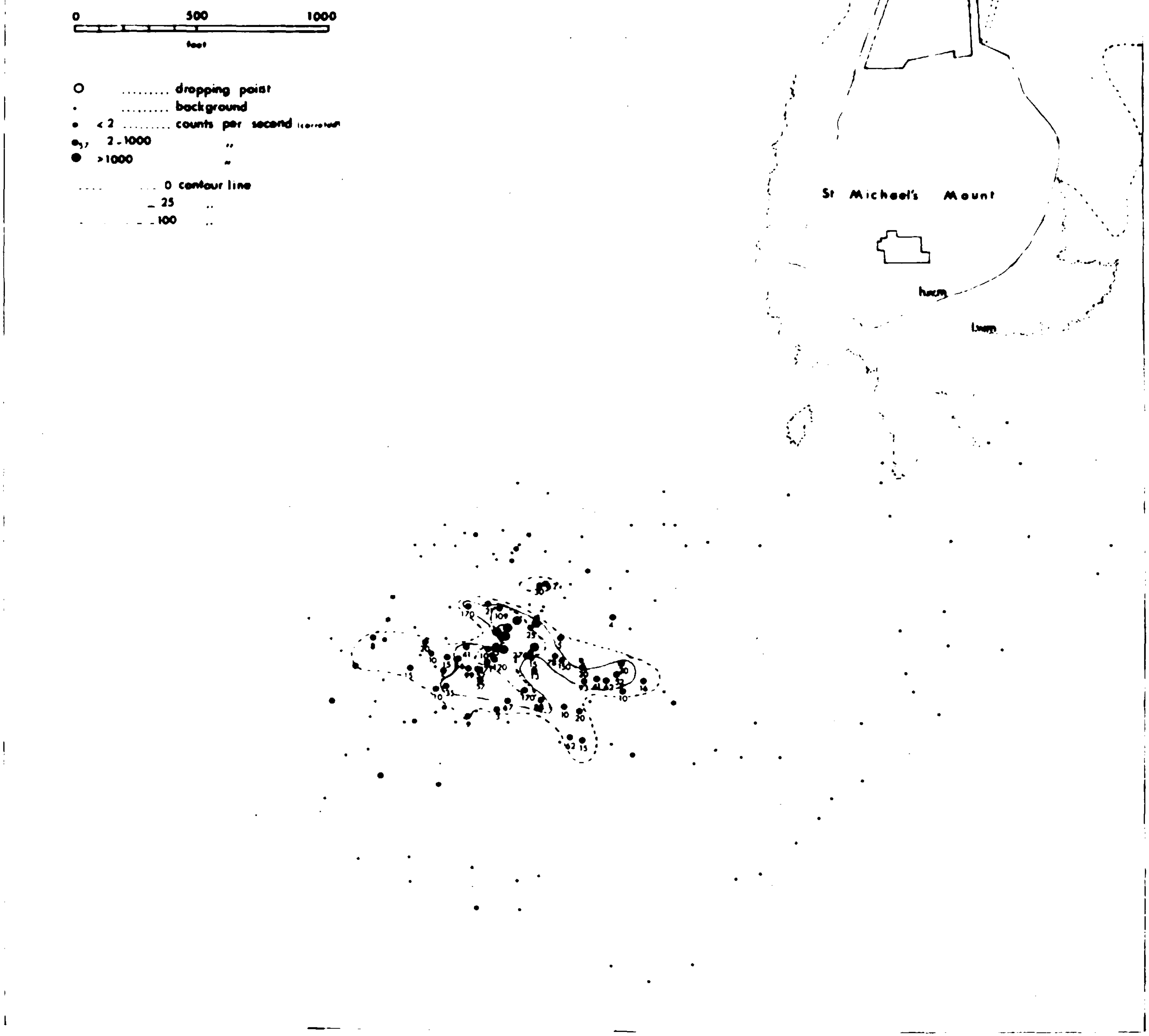
Figure E, representing a locality west of the dumping ground, may contain marginal ^{182}Ta although there is no real peak at the 1,1 to 1,2 range. It is, however, of interest that in this area positive readings occurred at an earlier stage in the tracing survey.

Figure F comes from a locality north of the dumping ground and has no tantalum. The peak at 1,50 MeV is thought to belong to

FIG 2,11

fig 2.11

Dispersion of Tracer after 6 Days



potassium-40. The drift of energy level, also demonstrated by the ^{60}Co must be due to instability in the electronics.

Figure G from the extremity of the eastern tail of the dispersion pattern has again the difficulty in determining whether the peaks belong to tantalum or uranium. It is quite possible that both sources contributed to the counting rate and this becomes more likely if one compares this diagram with figure H which comes from a locality just a little north of the previous one. Peaks in figure H belong to potassium and uranium only.

In conclusion one may say that although the occurrence of uranium obscures positive conclusions, the main problems, i.e. high background values around the Mount and west of it have been solved in so far that they are not due to ^{182}Ta.

3. Dispersion of tracer

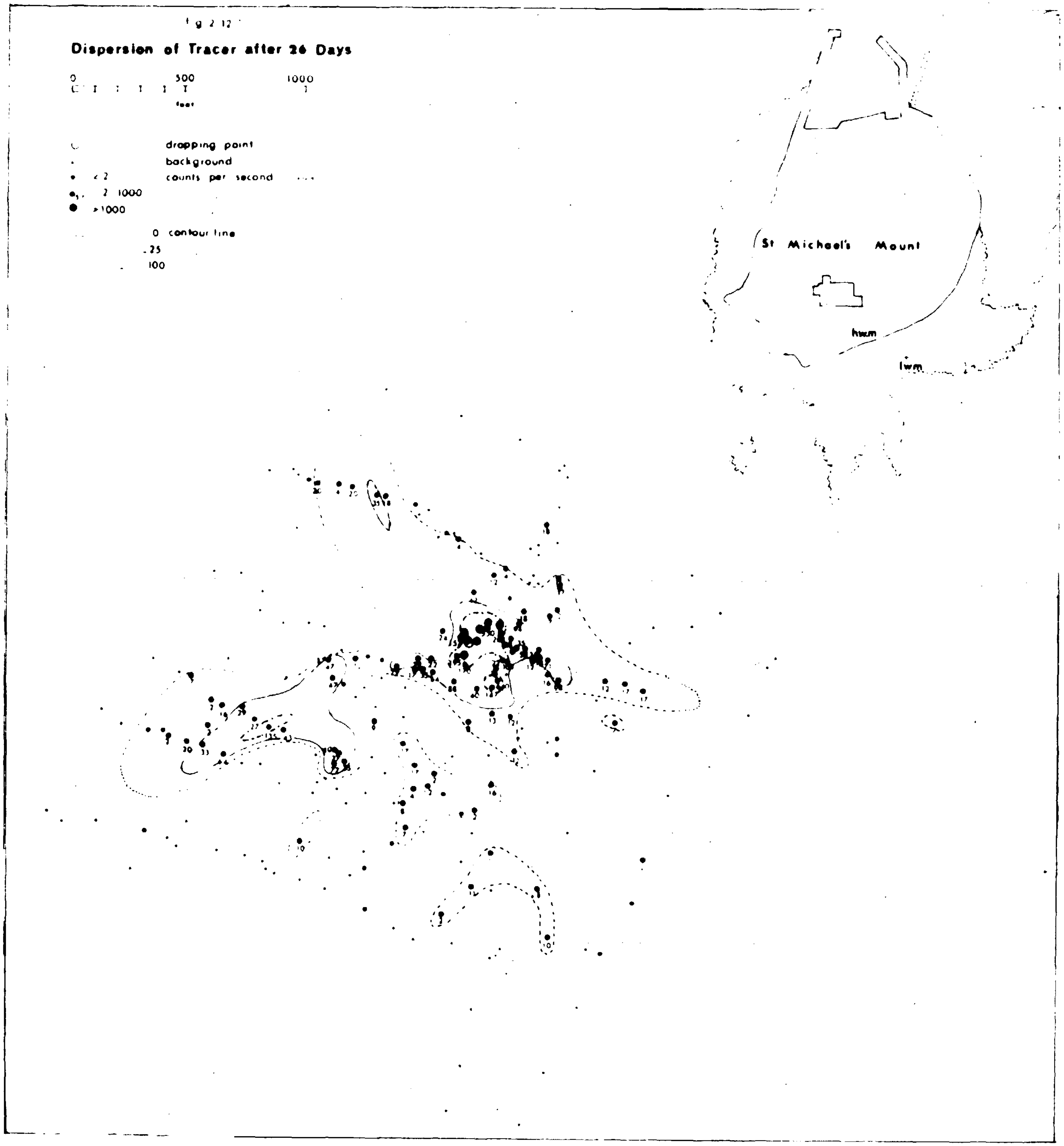
(a) Dispersion pattern after 6 days (Fig. 2,11)

The small dispersion shown by the map, is not believed to be related to the spread of the tracer during dumping. The release occurred three feet above the sea bed, and even with a maximum current of one knot, initial spread would be limited to 100 feet (based on the settling velocity of the particles). Accordingly, the dispersion in east/west direction is considered as genuine.

FIG 2,12

Fig 2.12

Dispersion of Tracer after 26 Days



(b) Dispersion pattern after 26 days (Fig. 2,12)

Transport in south-westerly direction is the most prominent. Discontinous dispersion occurs in southerly direction, while some dispersion appears to take place in northerly direction. However, too few readings were taken in this area to come to any firm conclusion. Easterly transport is continuing slowly.

(c) Dispersion pattern after 83 days (Fig. 2,13)

The main aspect of the map is the general spread in southerly direction, which tends to tail off towards the east. Transport in easterly direction continued more strongly, while dispersion in south-westerly appears to be stagnant.

(d) Dispersion pattern after 142 days (Fig. 2,14)

Transport in easterly direction continues and follows a very narrow path. Dispersion in the other directions appears to be immobile or even decreases, leaving behind isolated patches of positive readings.

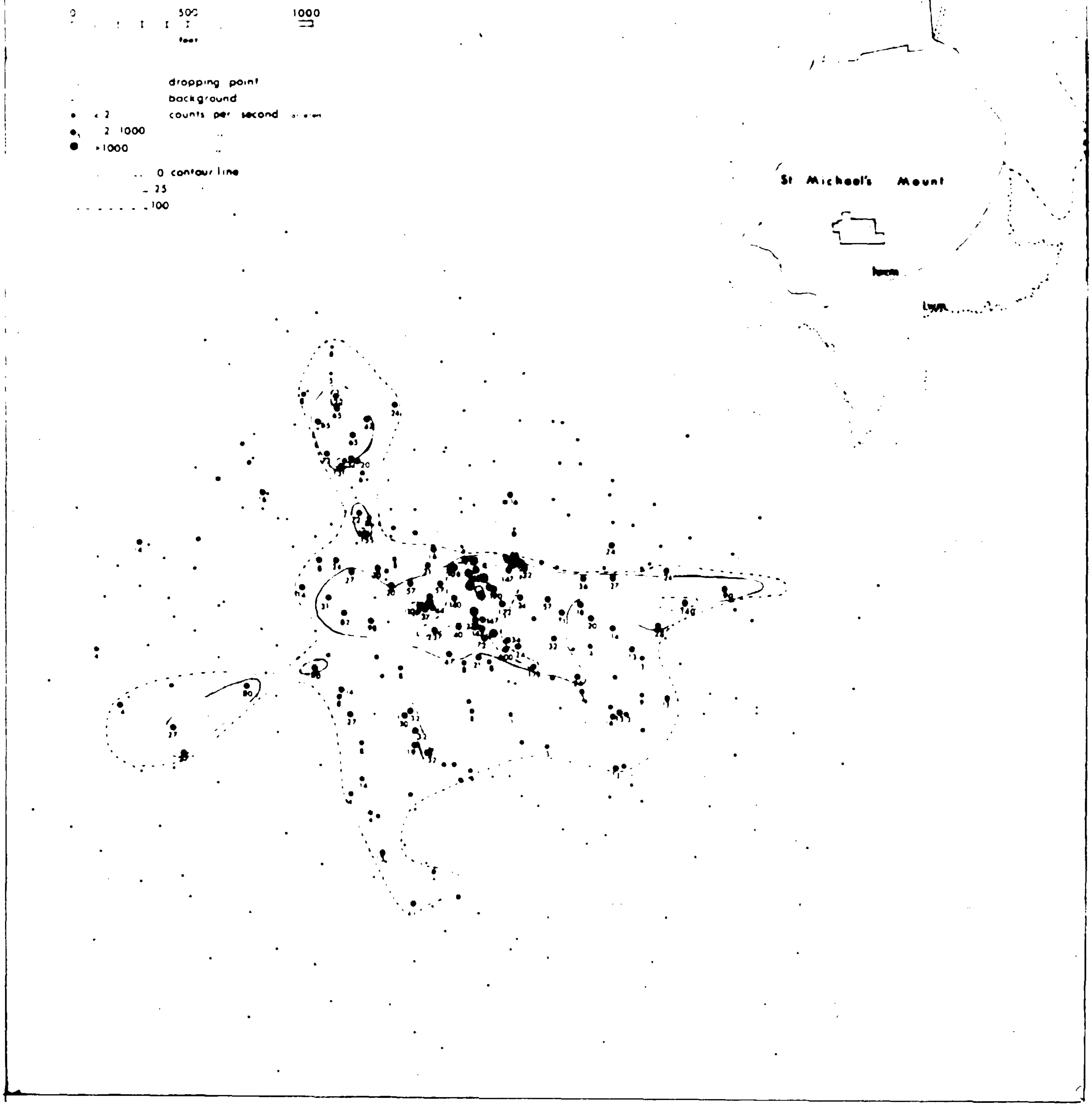
In summary, with respect to all four sets of data, one can say that:

1. There is no dispersion in the north-easterly quarter.
2. There appear to be two major and opposite directions of dispersion, towards the east and towards the south-west. In addition, there are two less defined dispersion directions in southerly and northerly direction.

FIG 2,13

Fig 2.13

Dispersion of Tracer after 83 Days



4. Interpretation

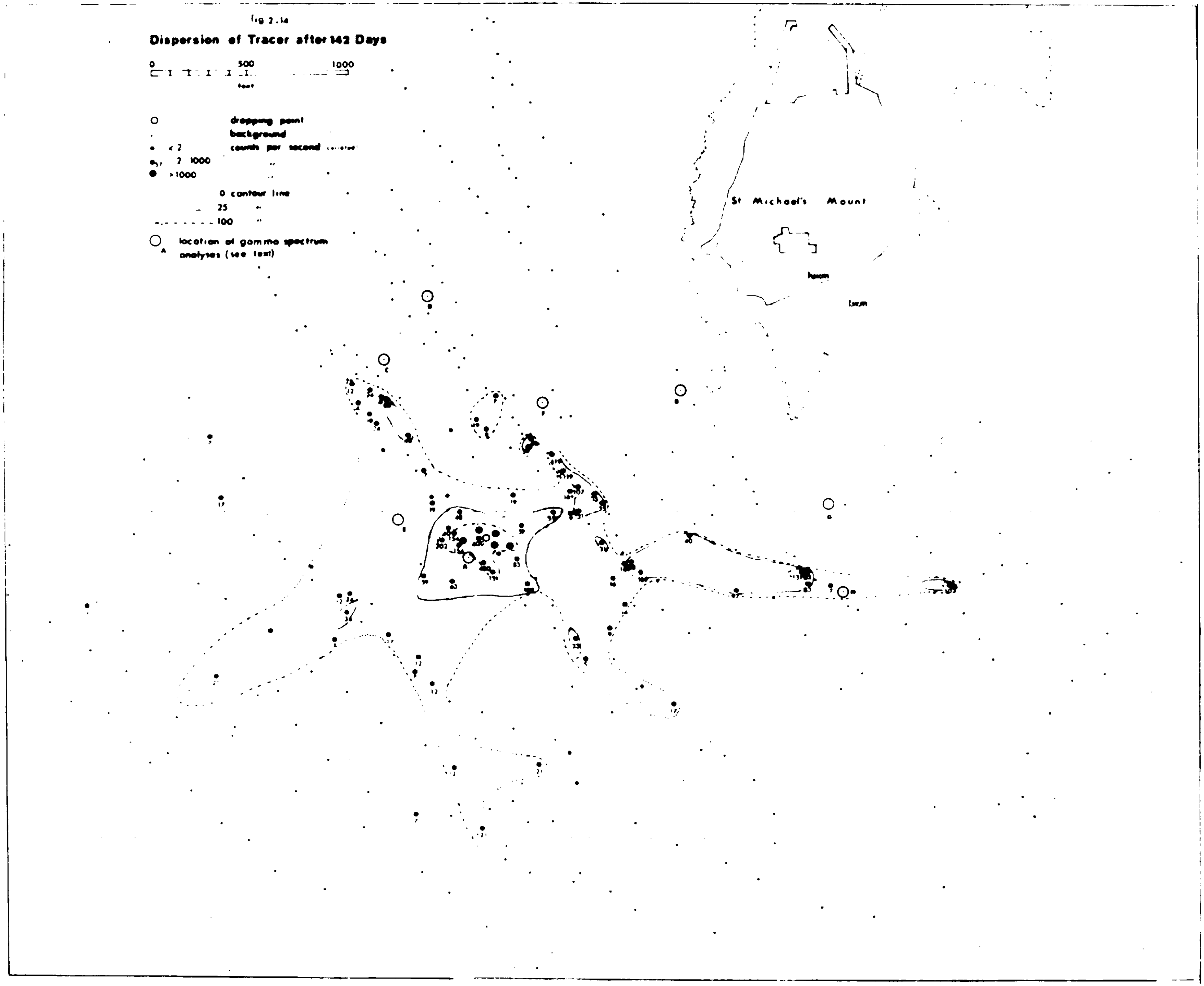
The dispersion in an easterly direction is similar to the direction indicated by the bottom drifters of station 3. Consequently, it is concluded that the main tidal current is responsible for transport in this direction. The fact that the distance covered by the particles is greater than for any other direction, is in agreement with the postulated current strength (Fig. 2,7, Chapter 1). The narrow path as indicated by the tracers is considered to be due to the configuration of the coast i.e. the rocks of the Mount. The main tidal current, coming from the south-west at this location is forced towards the east by the rocks, while in addition, there may well be an additional current from the area west of the Mount, resulting in a very narrow path of maximum current velocity just south of the Mount. It is of interest in this context that the general southerly dispersion tends to be carried towards the east (Fig. 2,13). Two spectrum analyses have been obtained in this area to differentiate between the activity of the submerged rocks and the activity of the tracer (Fig. 2,10G and H).

As mentioned previously, the flood currents are active only during part of the tidal cycle. The following ebbing tide generates currents of lesser strength in a southerly direction. This aspect of the tide is regarded as responsible for the broad dispersion towards the south. The more outstanding

FIG 2,14

Fig 2.14

Dispersion of Tracer after 142 Days



transport in a south-westerly direction is suggested to be caused by the circular eddy current, postulated in the first chapter of this section, which passes the dumping ground on the western side. It is, however, not well understood why the relatively quick dispersion in this direction as shown by Fig. 2,12 is not continued; spread in this direction almost appears to be stagnant, in the subsequent sets of data. Sudden dispersion as the result of heavy weather conditions seems unlikely since the area is protected against winds from the north-east.

The transport in northern direction cannot be related to any tidal current but may well represent the action of waves, especially the heavy ground swell after a storm in the Atlantic, which always washes considerable quantities of kelp ashore.

The quantitative dispersion picture is slightly disappointing. From the tracer, only a maximum of 4% has been transported (Table 2,8) while the total activity measured at the dumping ground was only 25% of the original activity. This can be due to loss of tracer by vertical dispersion, but is most likely caused by the extrme difficulties in bringing the counter on the exact position of release location. Activities in this area varied within a few feet from well over 10,000 c/sec to less than 500 c/sec.

It appears from Table 2,8 that the first three sets of data have a relation between spread and total activity, in so far that the increase in dispersion area is of the same order of magnitude as the increase in transported material. This tendency

Table 2,8 Relation between area of dispersion and total activity

Time after dumping in days	Surface area of dispersion	Percentage material transported
6	0,01 sq. mile	0,5%
26	0,045 sq. mile	2%
83	0,067 sq. mile	3,5%
142	0,08 sq. mile (0.053 sq. mile	4% 3%)

(The calculation of percentage material transported is based on the fact that 1 c/sec = 10^{-9} Curie)

is less obvious for the last set. The area of dispersion and the total activity as presented between brackets, refers to actual measurements, while the first set of figures refer to interpreted results. During the survey on that day, most of the attention was paid to the northern area and too little data was obtained west from the dropping point. However, based on the dispersion of the previous survey, it was felt justified to include this area in the total dispersion pattern.

The relationship between the sets of data indicates that only a small proportion of the tracer is involved in transport. Whether this is a form of sorting in the grain size distribution of the tracer, could not be investigated since the activity at the dumping ground remained too high, while the concentration of tracer outside the dumping ground was too low to recover any tantalite grains. Comparison therefore between transported tracer and "residual" tracer could not be made. The decreasing velocity of dispersion per unit of time may indicate that either further transport diluted the activity to beyond the limits of the detector or that tracer grains were buried.

The limited dispersion of the tracer is mainly due to the complicated current systems at this location. It is possible that dumping towards the east or towards the west would have given a more uni-directional dispersion picture, but this however is no more than speculation. The most important conclusion of the tracer experiment with respect to the present study is that a heavy mineral like tantalite with a particle size of 70 microns or less and therefore cassiterite of similar sizes, is transportable by all currents under the present conditions.

SECTION 3

GEOCHEMISTRY

Introduction

The work of which this thesis is a result, is mainly a detailed research, following the reconnaissance survey in the same area, carried out by P.M. Ong during 1964/65. As marine surveys are relatively expensive, it was decided to concentrate on a limited area rather than to spread the work over the Bay as a whole.

The layout of this section, consequently, will start with the considerations on which the study area was selected, followed by a general discussion on the possible origins of tin and transport of material. Chapter 2 deals with the techniques and the data are presented. Chapter 3 consists of the discussion and interpretation of the data.

CHAPTER 1 GENERAL CONSIDERATIONS

A. Selection and Description of Study Area

During the reconnaissance survey by Ong, data has been obtained covering Mounts Bay as a whole. To clarify the distribution of the tin in the surface sediments, before additional sampling, the bulk of the analytical data has been subject to statistical treatment.

The method used was the so called trend surface analysis which is: "a procedure for separating the relative large scale systematic changes in mapped data from essential non-systematic small scale variations due to local effects" (Krumbein, 1959). This method has been developed by Krumbein and Harris (1957) and was subsequently modified by Krumbein and Faulkner (1960), Axelrod and Benson (1961), Whitten (1962) and Garrett (1965). In this last form it has been applied in the present case.

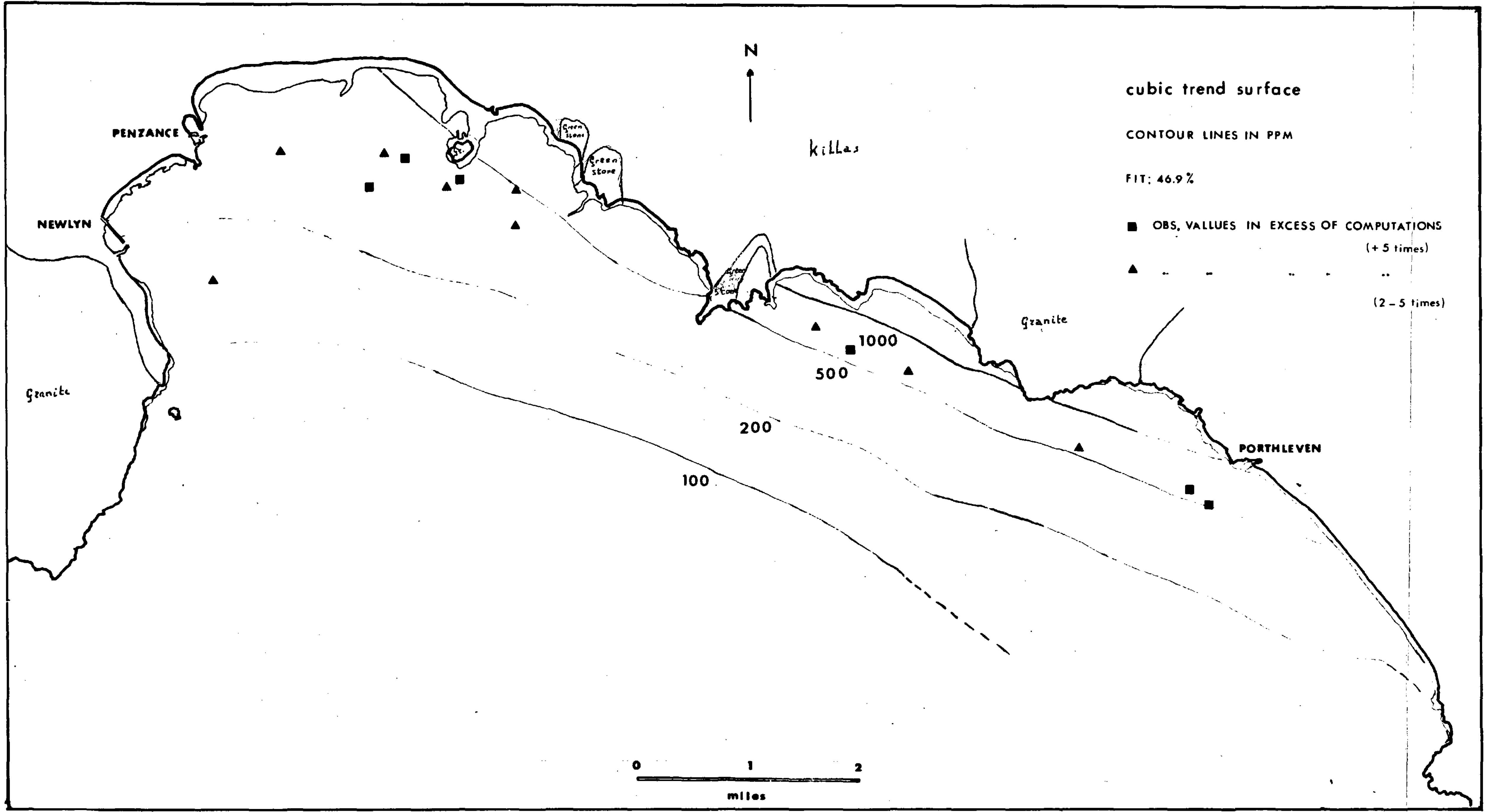
The principle of surface trend analysis is, that on the available data contour lines are computed which are not influenced by the subjectivity of the individual worker. The accuracy or reliability of these contour lines is given by a percentage fit: 50% fit is considered as good. The mathematics of this method are beyond the scope of this thesis and the interested reader is referred to Garrett (1965).

Trend surfaces are linear, quadratic or cubic. The best fit, in this case, is provided by the cubic trend surface, Fig. 3.1. From this figure, the parallelism of the contour lines

FIG 3,1

MOUNTS — BAY

(computed) tin content surface sediment



with the northern coast line stands out clearly, while there is a steady decrease in the tin content of the surface sediments offshore.

The statistical analysis thus reveal some general information regarding the possible sources of the tin; this will be considered later. To select areas of interest, not only are contour lines computed of significance, but also the deviation, positive or negative, of the actual values from the calculated surface. Positive areas of deviation are presented in Fig. 3.1.

Most of the higher values are restricted to a few areas. Those east of Trewavas Head have been discussed by P.M. Ong and are considered to be related to postulated offshore extensions of mineralisation on land. South-west of St. Michaels Mount an area occurs where tin values have been noted as much as 5 times the computed values. Furthermore, anomalies are present in the extreme west of the Bay within the Penzance/Marazion sediment body.

These Penzance/Marazion unconsolidated sediments have by far the most extensive dimensions of all sand bodies. They cover "2/3 of the western half of the bay and have a maximum thickness of 60 feet" (Ong, 1966). The sediments are consistently fine grained, although there is a tendency towards finer grain sizes in off-shore direction. Ong suggests a "slightly bimodal size distribution with a second maximum in the silt/clay fraction". The mean tin content of the 80-mesh undersize fraction is 150 ppm Sn. The lowest values, less than 50 ppm, are found in the southern part of the Penzance sediments. Furthermore, the maximum amount of tin in any given sample is consistently found in the finest fractions.

A third aspect of this area is the fact that the bedrock topography is well pronounced with two main north/south depressions which can be related to the present day river system and consequently are regarded as drowned valleys. In addition, bedrock mineralisation is known to occur in this area.

Finally, from an economic point of view, most of the suitable harbours occur in the western part of Mounts Bay. Consequently, it was decided to select this area for detailed investigations.

B. Considerations of Sources of Tin and Transport of Material

From figure 3,1, the parallelism of the contour lines to the northern coast stand out clearly, while there is a steady decrease in the tin content of the surface sediments towards the open sea. It appears from these data, that in general, the distribution of the tin in the minus 80-mesh of the surface sediments is consistent over the whole bay, irrespective of the fact that the sediments occur as a number of more or less isolated bodies.

Although all the tin in the sediments ultimately is derived from bedrock, a number of direct sources can be considered as follows:

1. Elluvial deposits, related to submarine lodes.
2. Alluvial placers, drowned by a transgressing sea.
3. Tin mineralisation as a minor constituent of the marine rocks.
4. **Terrestrial sources.**

If tin of elluvial origin was mainly responsible for the tin content of the surface sediments, the contour lines of figure 3.1 would suggest a N.W. strike of the lodes with a decreasing frequency towards the open sea. However, the known mineralisation has a N.E. strike (Wherry mine and St. Michaels Mount; Hosking, 1967). Furthermore, based on the genesis of tin in south/west Cornwall, tin mineralisation in general occurs in the vicinity of granites and their thermo-metamorphic aureoles. Consequently, tin being an immobile mineral, one would expect a greater variation in contour lines near the granite outcrops, i.e. the Lands End granite, St. Michaels Mount and the Godolphin granite. However, no such tendency is noticeable: contour lines are parallel to the north coast, irrespective of the rock type exposed.(fig. 3.1)

With respect to the second possibility, it appeared from the geophysical survey, that there are three major submerged valleys in which alluvial placers might be expected. The strike of these valleys is N/S, none of which is reflected in the direction of the contour lines.

The third possibility, tin as minor constituent of submarine rocks, also appears unlikely. As far as rocks are exposed, they always appear to be slates and extremely low in tin (15 to 60 ppm Sn, Ong, 1965). They separate the individual sand bodies and, consequently, if slates are a major source of tin, the immediately adjacent sand would be expected to have a higher tin content than sand which occurs laterally and vertically further away, i.e. in the middle of the sand body. No such parallelism has been observed of contour lines with submarine rock outcrops.

The three mentioned possibilities have in common the reference to sources underlying the present sand bodies. If any of these possibilities were genuine, one would expect an increase in the tin content of the subsurface samples. This is, in general, not the case (see later).

There is, therefore, no evidence that the distribution of the tin content in the 80-mesh undersize of the surface sediments is due to geology or location of submarine mineralisation or drowned placers. Accordingly, the distribution is considered to be dominantly due to transportation from present day terrestrial sources.

Provided this hypothesis is correct, the transport medium responsible for the distribution of the tin in the surface sediments should also have effects on the other components of the sediment. Consequently, one would expect some form of relationship between the tin distribution on the one hand and the distribution of, for instance, quartz (being the dominant constituent of the sediment) on the other hand. On theoretical considerations (Stokes law) there will exist certain specific sizes of grains of different densities, which will be taken together into suspension by a given current. These grains may be called hydraulic equivalents. The concept of hydraulic equivalence has been introduced in sedimentology by Rubbey (1933), followed by Rittenhause (1943) who formulates this idea as follows: "Whatever the hydraulic conditions may be that permit the deposition of a grain of particular physical properties, these conditions will also permit the deposition of other grains of equivalent hydraulic value". Other papers dealing with this concept include Zonneveld (1946), van Andel (1950, 1955) and Taylor (1954).

The relationship between the different components of a sediment will depend in the first place on the grain size distribution of those components in the sediment source. If, for instance, mineral A with grain size (a) is hydraulic equivalent to mineral B with grain size (b), but mineral B only occurs in the source material with grain sizes smaller than (b), and the grain size of mineral A is greater than (a), then in the sediment originating from this source there will not exist any hydraulic equivalence between minerals A and B. This aspect becomes particularly relevant when plural sources have to be considered.

At a given location, the relationship is also determined by the nature of the transport medium at that location. With variation in transport medium, i.e. alterations of hydraulic conditions, a change in the absolute quantities will occur, but the ratio between hydraulic equivalent fractions remains the same. This ratio is called the "relative availability", which is: "... a constant that is common to the stream load and to all the deposits from the stream load regardless of the difference in absolute amount of minerals of the same and other sizes that are deposited under the particular hydraulic conditions existing at different places of deposit" (Rittenhause, 1943). Van Andel in his study of the Rhone delta sediments concludes: "Hence the size distribution of the heavy fraction is controlled by the size distribution of the sand grade of the sediment and thus by the hydraulic conditions."

Another aspect of transport, which may well influence the hydraulic equivalence, is the form in which transport takes place. Suspension, forming the basis of the theory, usually takes place under extreme conditions, whilst normal transport will occur in the form of saltation and rolling. The effect on smaller heavier grains is a concentration in the "valleys" between the ripples (riffle effect), while in addition there also exists a tendency for the finer grains to work their way through the bigger lighter grains (jigging effect). This will effect the relative availability. These and other complications limit the use of hydraulic equivalence and detailed discussion is given in Chapter 3.

CHAPTER 2 FIELD AND LABORATORY TECHNIQUES

A. Sample Collection

The areas selected for detailed examination, were sampled on the basis of traverses. The traverse unit, a 700 foot long hemp rope, was divided into twelve lengths of 50 feet. At each 50 foot mark, a plastic bag was firmly attached. One end was connected with the anchor of the main ship. The procedure then was as follows. After the ship had anchored on the desired location, a 15 foot dinghy was lowered and sailed in the desired direction. The traverse line, stored in the dinghy was automatically unrolled. At the far end a small anchor and a bouy were attached. In the next stage a skin diver went down at the far end and worked his way back to the main ship, filling every sample bag. The dinghy, with a stand-by diver followed slowly. After the traverse was completed, the dinghy returned to collect the traverse line. One worker emptied and cleaned the bags, while a second worker coiled the rope ready for use. When all samples were collected, the dinghy sailed around the main ship and the whole procedure was repeated in the opposite direction. In this way, a continuous traverse of 1400 feet was collected which required two to three hours, according to weather conditions and the skill of the divers and dinghy crew.

A total of 19 traverses have been collected in this way. 5 men were involved in each traverse: 3 divers and two dinghy crew. In addition, a number of cores have been obtained by means of a vibro-corer kindly made available by Mr. Miller of Alpine Geophysics Ass.

B. Sample Location

Prior to any days work, the traverse locations were selected. The desired anchoring point was then established. This was done from the map, by measuring at this point the angles between outstanding coastal features, such as churches. The two obtained angles were set out on sextants. The ship then approached this point slowly, and on the exact location the anchor, with the traverse rope attached, was lowered.

Although it frequently happened in the beginning that the desired point was missed on the first attempt, experience and increasing understanding between skipper and sextant reader improved the technique considerably. After the ship came to a standstill, the traverse was laid out. At the far end a second positioning was made. Plotting on the map was carried out with a station-pointer.

C. Sample Errors

The accuracy of the sample location is dominantly determined by the weather conditions and visibility. Firstly, the anchor will be dragged over a certain distance before it gets a good grip in the sand. Secondly, it is extremely difficult to maintain a straight line when laying out the traverse, especially with strong beam-winds. In the third place, the accuracy of sextant readings in a bouncing dinghy is rather limited. Finally, traverse locations are based on the existing geophysical map, whose accuracy is not known.

With respect to the sample collection itself, some systematic errors are unavoidable. Due to the manouvering of the diver, especially when actually filling the sample bags, stirring occurs, resulting in a possible loss of silt and clay fraction. Samples, therefore, are not wholly representative.

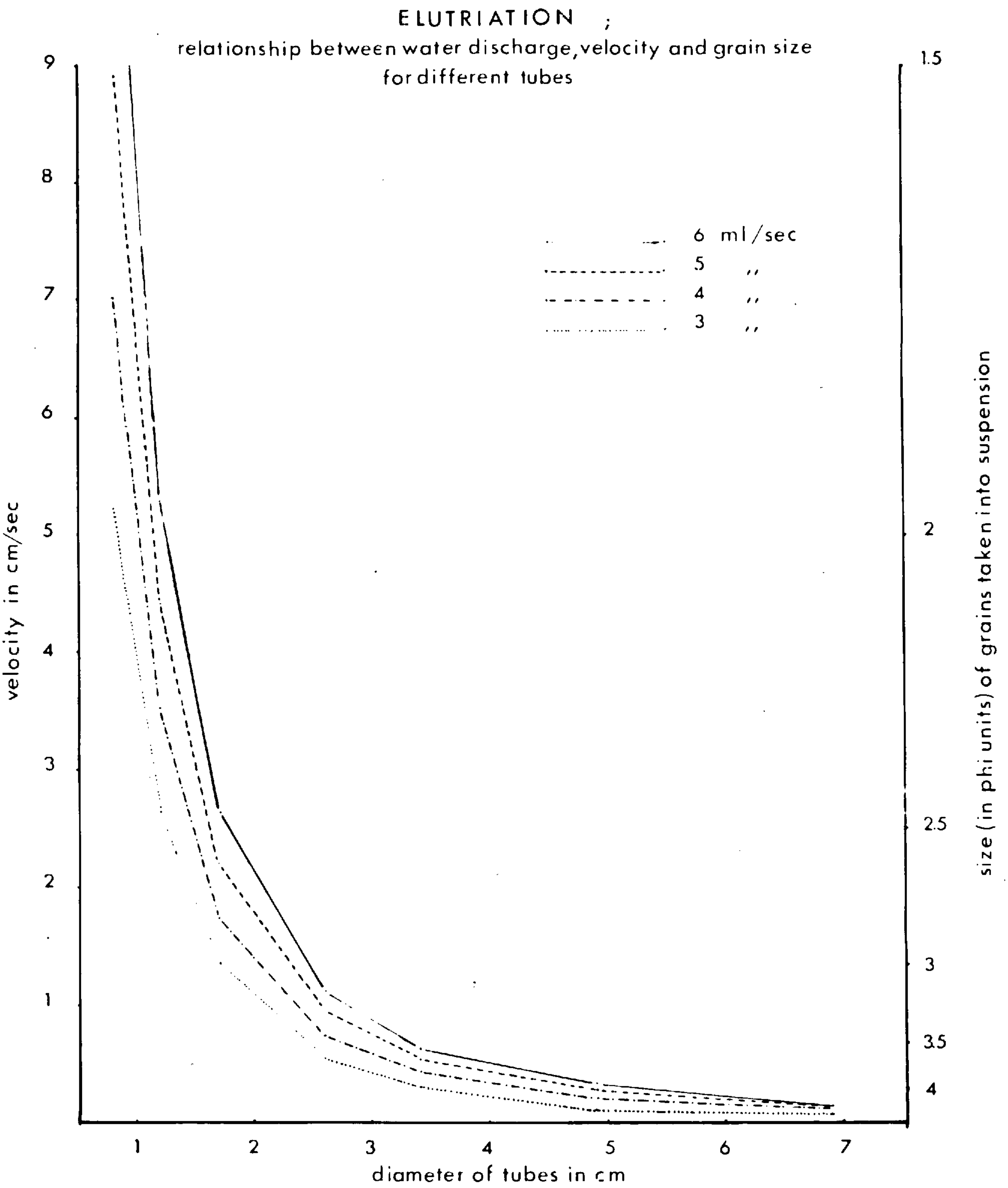
D. Terminology

For the classification of the size fractions, the Wentworth scale (1922) is used, while notations are given in phi units. The phi value is the negative $\log_2$ of the diameter in mm. One phi units is equal to one Wentworth division (Krumbein, 1936). Inman's terminology (1952), using percentile phi 5, 16, 50, 84 and 95 values, has been applied. This is done to obtain a simple tool for statistics, while the results of the different methods in size analysis are easily comparable.

E. Mechanical Size Analysis

1. Dry sieving

All samples have been screened, using a set of nylon screens, with the following apertures: 20, 36, 60, 80 102, 140, and 197 mesh. These correspond to phi values of: 0,25, 1,0, 2,0, 2,25, 2,75, 3,0 and 3,5. No attempt has been made to separate the silt and the clay fractions, as the minus 200-mesh fraction represents, in general, only a very minor constituent of a given sample: from 1 to 5%. In addition, the total minus 80-mesh undersize was



ELUTRIATION ;
relationship between water discharge, velocity and grain size for different tubes

FIG 3,2

obtained, in order to establish the correlation coefficient of its tin content and the tin content of individual fractions. All fractions coarser than 80-mesh have been ground prior to analysis, using ceramic ball-mills.

2. Elutriation

The elutriator has already been described in Section 1. The purpose of applying this method is to obtain information on size distribution based on hydraulic properties of the material concerned, rather than diameter alone.

In order to establish the most effective water supply, resulting in a separation of fractions which can be compared with screening, the diagram in figure 3,2 has been calculated. The computation, using Stokes law, is based on the density of quartz. With the given set of tubes, it was decided to use a water discharge of 5 ml/sec. Size fractions obtained with this discharge are presented in Table 3,1.

Shape of grains is not taken into account. However, it will be appreciated that this factor has a differential effect especially when minerals such as micas are concerned. Furthermore, shape will have an increasing effect towards the finer fractions. In order to establish the **representivity of Table 3,1** the following experiment has been carried out.

Table 3,1 Size fractioning by elutriation, using a water discharge of 5 ml/sec and density of quartz

Diameter of tube in cm.	Max. diameter of grains taken in suspension
0,8 cm	1,4 phi
1,2 "	1,86 "
1,7 "	2,45 "
2,6 "	3,2 "
3,4 "	3,57 "
6,8 "	4,65 "

25 grams of sample 561142 has been elutriated for two hours. After each elutriation, the fractions were weighed and critical phi values were calculated. After this procedure fractions were composited and the sample was homogenised before repeating the elutriation (Table 3,2).

Table 3,2
Table 3,2 Representivity test of elutriation

Percentile diameter	Sample 561142					phi range
	A	B	C	D	E	
phi 5	2,37	2,48	2,48	2,48	2,46	0,11
" 16	2,60	2,61	2,61	2,60	2,60	0,01
" 50	3,08	3,05	3,03	3,02	3,02	0,06
" 84	4,16	4,07	3,71	3,50	3,84	0,66
" 95	4,48	4,45	4,34	3,82	4,37	0,66

From the table it can be seen that the separation is accurate for grain sizes coarser than 3,5 phi (= 90µ, is the finer part of the very fine sand fraction). Below this value, a reliable separation is difficult to obtain and not too much weight should be given to the results.

The inaccuracy in elutriation for the finest fraction is not entirely due to shape: irrgularities in the stirring device and trapped air which decreases the effective weight of the water column are factors which become relatively more significant towards the finer fractions. However, elutriation has provided some useful additional information as will be shown later.

F. HCl Treatment

In order to establish the quantity of shell fragments and its connection with sample location, the carbonate content of a randomly chosen series of samples has been determined. A 50 gram sample was placed in a beaker and 6N HCl was added. The carbonate saturated solution was decanted and the procedure was repeated until no further effervescence occurred. Cleaning with de-ionised water was followed by weighing.

G. Analysis for Tin

All samples have been analysed using the colorimetric method (Stanton and McDonald, 1964). The precision of the analyses was controlled by an incorporated statistical series. If results of the test samples were beyond the acceptable limits (± 25%), analyses were repeated. In addition, selected samples have been analysed on the emission spectrograph, while copper has been determined by atomic adsorption. The efficiency of the colorimetric analysis for tin has been discussed by several authors including Ong (1965).

H. Heavy Mineral Separation

A selected number of samples have been subject to heavy mineral separations using tetra bromethane (sp. gr. 2,9) and clerici (sp. gr. 4,1). 1 gram of sample was used. To speed up separation, most samples have been centrifuged. Recovery of material out of a closed test-tube imposed some difficulties, resulting in a small variation of accuracy.

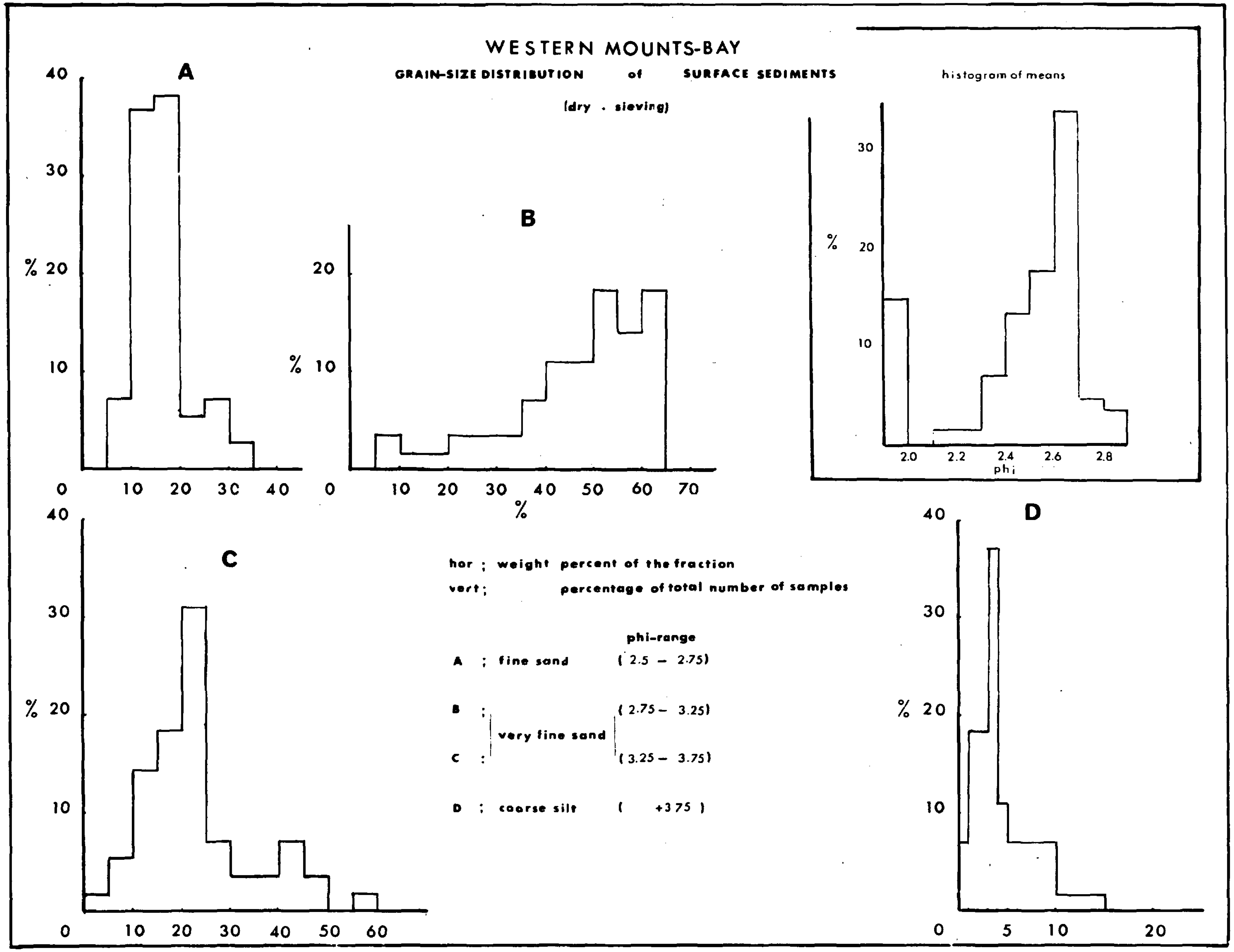
I. Presentation of Geochemical Data

Data will be presented in two different manners; grain size and tin analysis will be followed by a combined presentation of these data on the principle of hydraulic equivalance.

la. Grain size distribution (dry sieving)

As has been said before, all samples have been separated into 8 fractions according to the Wentworth scale. A sub-division has been made into fine and very fine sand as these fractions form the bulk of the sediment. Significant phi values of each sample have been calculated. In order to establish important general tendencies, the histograms of the mean values of samples and the more important individual fractions have been computed (Fig. 3,3).

FIG 3,3


WESTERN MOUNTS-BAY
GRAIN-SIZE DISTRIBUTION of SURFACE SEDIMENTS
(dry . sieving)
A
%
40
30
20
10
0
10
20
30
40
B
%
20
10
0
10
20
30
40
50
60
70
%
histogram of means
%
30
20
10
2.0
2.2
2.4
2.6
2.8
phi
C
%
40
30
20
10
0
10
20
30
40
50
60
D
%
40
30
20
10
0
5
10
20
hor ; weight percent of the fraction
vert ; percentage of total number of samples
phi-range
A ; fine sand (2.5 – 2.75)
B ; very fine sand (2.75 – 3.25)
C ; very fine sand (3.25 – 3.75)
D ; coarse silt (+3.75)

From the inset of this figure, it can be seen that the sediment is very uniform. 95% of the sand (mean plus twice the standard deviation) is well within the fine sand range (2 to 3 phi). In addition, there exists a clear tendency for a second "coarser" population. All samples having a mean value of less than 2,0 phi (coarser sand) belong to traverse 1. Disregarding these samples, which are subject to a different environment as compared to the rest, one may say that sample location appears to have little significance on the grain size distribution of the sediment as a whole. This will be shown in detail below.

Eight fractions have been obtained by screening. However, only the four finest fractions will be discussed at present (Fig. 3,3 A-D). The reason for disregarding the coarser fractions is that they seldom exceed 10 per cent by weight, and they dominantly consist of shell fragments.

Figure 3,3A represents the distribution of the finer part of the fine sand. Its mean value is 11,5% with a standard deviation of 5,2%. Samples exceeding the threshold value for this fraction (mean plus twice the standard deviation = 22%) almost exclusively belong to traverse 1 and form in the diagram a small second population (discussion on individual traverses will be given later).

Figure 3,3B, representing the coarser part of the very fine sand fraction and a small part of the finer part of the fine sand fraction, has a completely different distribution. The histogram is clearly asymetric. The mean value is 46,3% with a standard deviation of 14,7%. All samples, which have less than 30% of this fraction, belong to one traverse located 2,5 miles offshore. Samples of this traverse have more than 20% coarse shell fragments which accounts for the relative deficiency of other fractions. Disregarding these samples, the mean value increases to well over 50%, while the standard deviation decreases. In other words, regardless of location, the bulk of the sediment is confined to very narrow limits.

In Figure 3,3C, the majority of the very fine sand is represented. It has a mean value of 23,5% and a standard deviation of 12%. More than any of the other histograms this one shows the existence of two populations: the first maximum at about 20% and the second one at 45%. All samples which have more than 35 weight per cent of this fraction belong to traverse 2. This traverse is the seaward extension of traverse 1 and also subject to some special conditions.

Finally, in Figure 3,3D, all material finer than 3,5 phi is represented. Its mean value is 3,5% only with a relatively large standard deviation of 2,8%. This is caused by samples of traverse 18. Every sample having more than 5 weight per cent of this fraction belongs to this traverse, and is the only indication of a decrease in grain size in offshore direction, as this traverse is the most southern. However, even in this traverse, 64% of the sediment belongs to the very fine sand fraction.

Not only the surface sediment is extremely uniform. Analysis of the cores, which in some cases reached bedrock, showed that the Penzance/Marazion sediments maintain their uniformity in vertical direction as well. The mean value of two cores of which one foot interval samples have been taken, is 2,79 phi with a standard deviation of only 0,07 phi.

1b. Grain size distribution (elutriation)

As a comparison, half of the samples used for screening have also been separated into fractions by means of elutriation (Fig. 3.4). Once more, the inset of this figure represents the sediment as a whole, while A, B and C are the histograms of the three dominant fractions. The average mean value of the sediment (Fig. 3,4 inset) is 3,00 phi with a standard deviation of 0,33 phi units. This indicates that using this method, the sediment tends to be slightly finer. This is dominantly due to the shell fragments which form, on average, 14% of the sediment. The lower specific gravity and laminar shape of this sediment component, causes this material to settle in equivalent, but finer quartz fractions. However, elutriation also shows the very good sorting of the sediment: 90% falls within one phi unit. Of the six elutriation fractions, only the finer three fractions will be discussed. The other three have negligible quantities and are almost exclusively composed of coarse shell fragments.

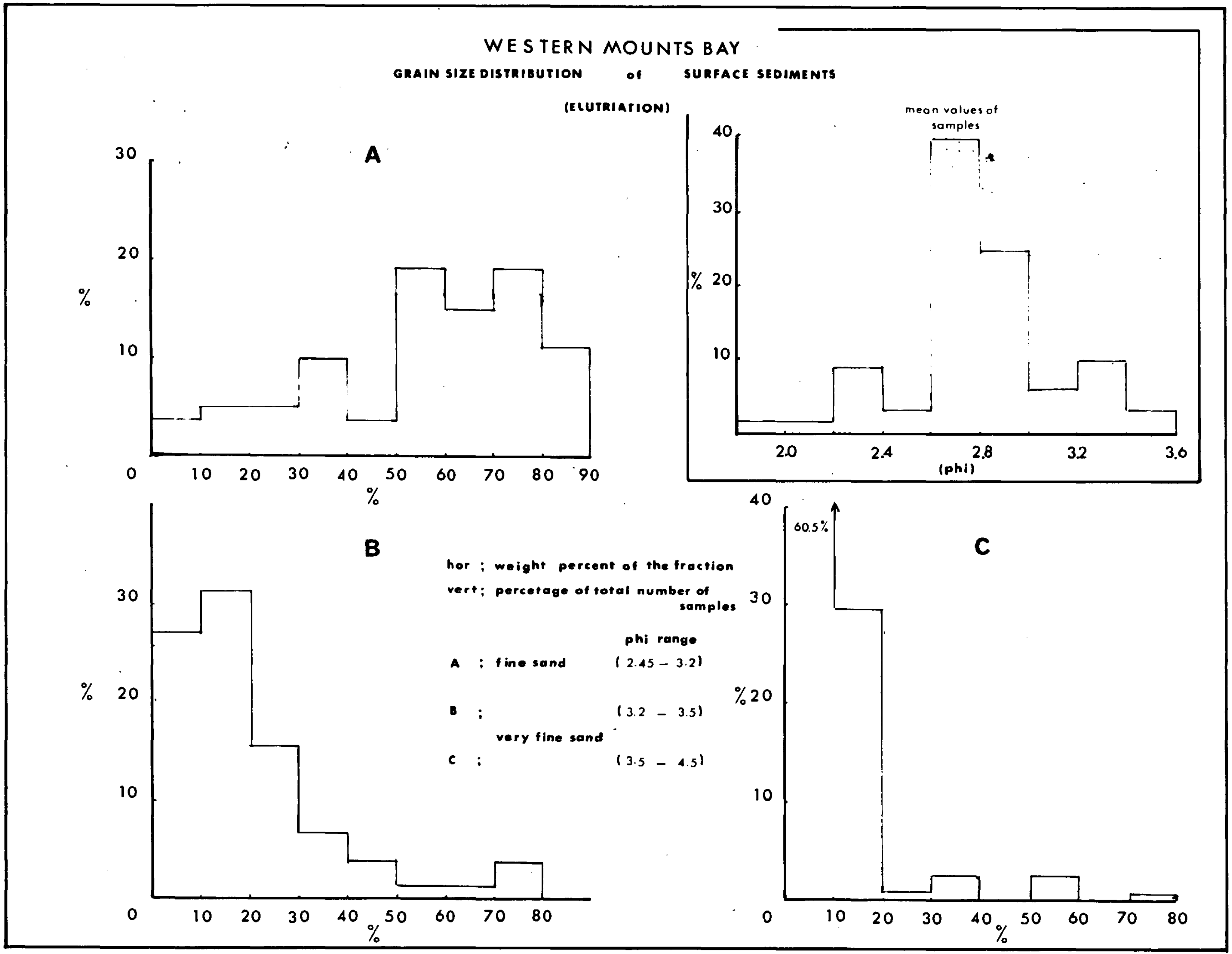
Figure 3,4A represents the histogram of the greater part of the fine sand fraction. This fraction has a mean value of

FIG 3,4

WESTERN MOUNTS BAY

GRAIN SIZE DISTRIBUTION of SURFACE SEDIMENTS

(ELUTRIATION)



54,5% and its standard deviation is 23%. This mean value is 4 to 5 times as great as its comparable dry-sieving fraction. This is partly due, as said before, to the incorporation of shell fragments, which in the case of dry-sieving remain in coarser fractions. However, the main reason for this difference is the fact that in the case of elutriation, 0,8 phi units are covered by this fraction and in the case of screening only 0,5 phi units.

Figure 3,4B, with a mean of 22% and a standard deviation of 18,5% has an indication of a second population. All samples with more than 50 weight per cent of this fraction belong to traverse 2 (compare Fig. 3,3C which, having the same group interval, shows this feature as well).

Figure 3,4C represents the fraction of which the grains have a diameter of smaller than 3,5 phi. Its mean is 11,3% and the standard deviation is 14%. There exists once more a strong comparability with its equivalent screened fraction (Fig. 3,3D): 60% of the samples have less than 10% of this fraction. Samples with a higher weight percentage of this fraction do not clearly belong to one single traverse, but are scattered all over the bay.

From the above data it is clear that the Penzance/Marazion sediments have a very well sorted grain size distribution, regardless of sample locations. The only exception is provided by samples from traverses 1 and 2. However, they represent a different and complicated environment, as they are under the influence of wave action. Discussion on this feature will follow later.

In the discussion on the individual samples and traverses, the terms coarse and fine will be frequently used. It is obvious from the above data that these terms only refer to relative differences.

2. Tin distribution in surface sediments

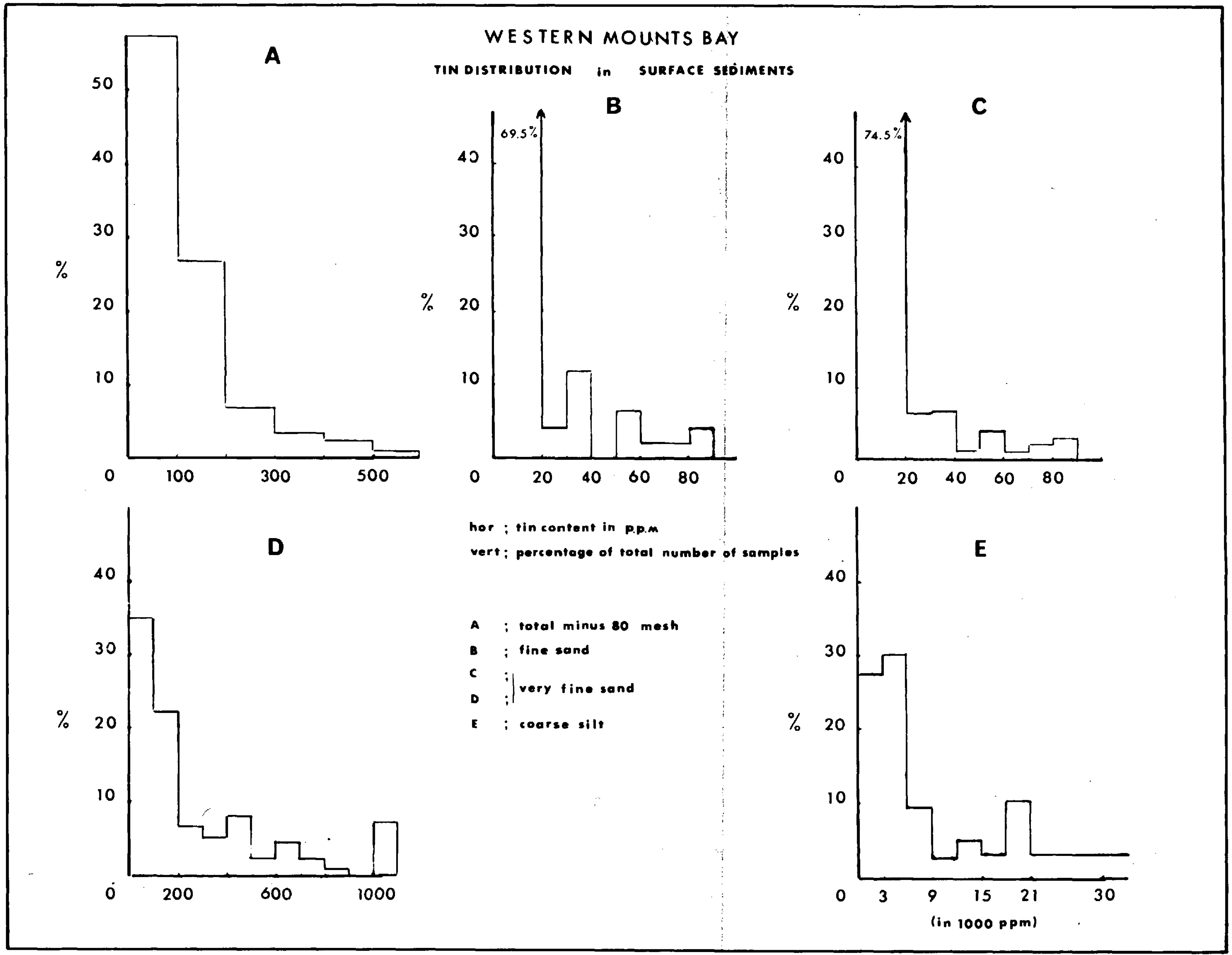
(a) Dry sieving

Fractions coarser than 2,0 phi will not be considered in the following discussion. Analysis of these coarse fractions showed that no significant amounts of tin occurred in them. Apart from individual fractions, the total minus 80-mesh undersize fraction (approx. 2,5 phi) has been analysed as well. The reason for this will be explained below.

In the case of the present study, a plural source of tin has to be considered. It is by no means certain as to whether these sources contribute to the same extent to the tin content of individual fractions of a sample. Hence, the size fraction analysis. It will, however, be appreciated that there are many advantages in analysing one fraction only of a given sample. The minus 80-mesh undersize fraction was selected for this purpose as it (1) represents the bulk of the sample, (2) excludes coarse (mainly shell fragments) material and (3) much of the previous data obtained by Ong refer to this fraction.

Figure 3,5A represents the histogram of the tin content of the total minus 80-mesh fraction. The mean value is 110 ppm Sn,

FIG 3,5



WESTERN MOUNTS BAY

TIN DISTRIBUTION in SURFACE SEDIMENTS

hor ; tin content in p.p.m

vert ; percentage of total number of samples

A ; total minus 80 mesh

B ; fine sand

C ; very fine sand

D ; very fine sand

E ; coarse silt

with a standard deviation of 116 ppm. These results are similar to those obtained by Ong (1965). The histogram is rather asymetric and high values are restricted to the area south-west of St. Michaels Mount.

Figures 3,5B and C represent the tin content of the minus 80 plus 100 mesh fraction and the minus 100 plus 150 mesh fraction (i.e. the range between 2,25 and 3,20 phi). The diagrams will be discussed together as there exists virtually no difference. The bulk of the samples have a tin content of less than 12 ppm Sn. This was the lower limit of detection with the colorimetric procedure. The respective mean values are 26 and 39 ppm Sn and standard deviations of approximately 25 ppm and 49 ppm. These values may well be high for the mean and low for the standard deviation as they are based on samples containing less than 12 ppm tin which are assumed to have 12 ppm. High values for both fractions are restricted to traverse 1 and the area south-west of St. Michaels Mount.

The finer very fine sand, figure 3,5D, has a mean value of 400 ppm Sn, a standard deviation of 700 ppm Sn and there is a clear indication of the existence of two populations, which accounts for the high standard deviation. The population with the higher values once more restricted to the area south-west of the Mount. An interesting feature looking at the sample location, is the fact that samples with high values are often situated near rock outcrops. This will be considered further in the detailed discussion.

Finally, figure 3,5E represents the minus 200-mesh fraction. The analytical results have not been treated statistically because too many samples had tin values greater than the extreme limit of the chemical procedure as employed by the writer. 30% of the samples have more than 1% Sn and 20% have a tin content in excess of 2%. Only in a few cases was the tin content in excess of 2% estimated. In a proportion of these samples, values up to 3% Sn have been found. However, the representivity of analyses of only 0,01 gram of a sample is rather limited. Values of more than 1% occur in the traverses 1, 5, 6, 12 and 14, all but traverse 1 are located south-west of St. Michaels Mount.

The correlation as obtained by computer programming between the tin content in the different fractions is given in Table 3,3.

<u>Table 3,3</u> <u>Correlation coefficient of tin content in different fractions</u>

Fraction	Total minus 80 mesh	80 to 100 mesh	100 to 150 mesh	150 to 200 mesh
total minus 80 mesh	1,00			
80 to 100 mesh	0,15	1,00		
100 to 150 mesh	0,18	0,87	1,00	
150 to 200 mesh	0,68	0,13	0,15	1,00

The best correlation is between the minus 80 plus 100 mesh fraction and the minus 100 plus 150 mesh fraction. This is also noticeable from the diagrams on previous pages. The correlation of the total minus 80 mesh with the individual fractions increases towards finer fractions and becomes significant for the minus 150 plus 200 mesh size. It is possible that there is a good correlation between the total minus 80 mesh and the minus 200 mesh fractions. This, however, is by no means certain. The minus 200 mesh fraction is only a very small proportion of the total minus 80 mesh fraction and accordingly, any variation in the tin content of this fraction will have negligible effect on the variation in the tin content of the 80 mesh undersize, compared with the effect of other fractions. Unfortunately, this matter could not be investigated because of the analytical problems mentioned earlier. Nevertheless, the writer favours the hypothesis that the tin content of the total minus 80 mesh is in the first place a reflection of the tin content of the minus 150 plus 200 mesh fraction.

(b) Elutriation

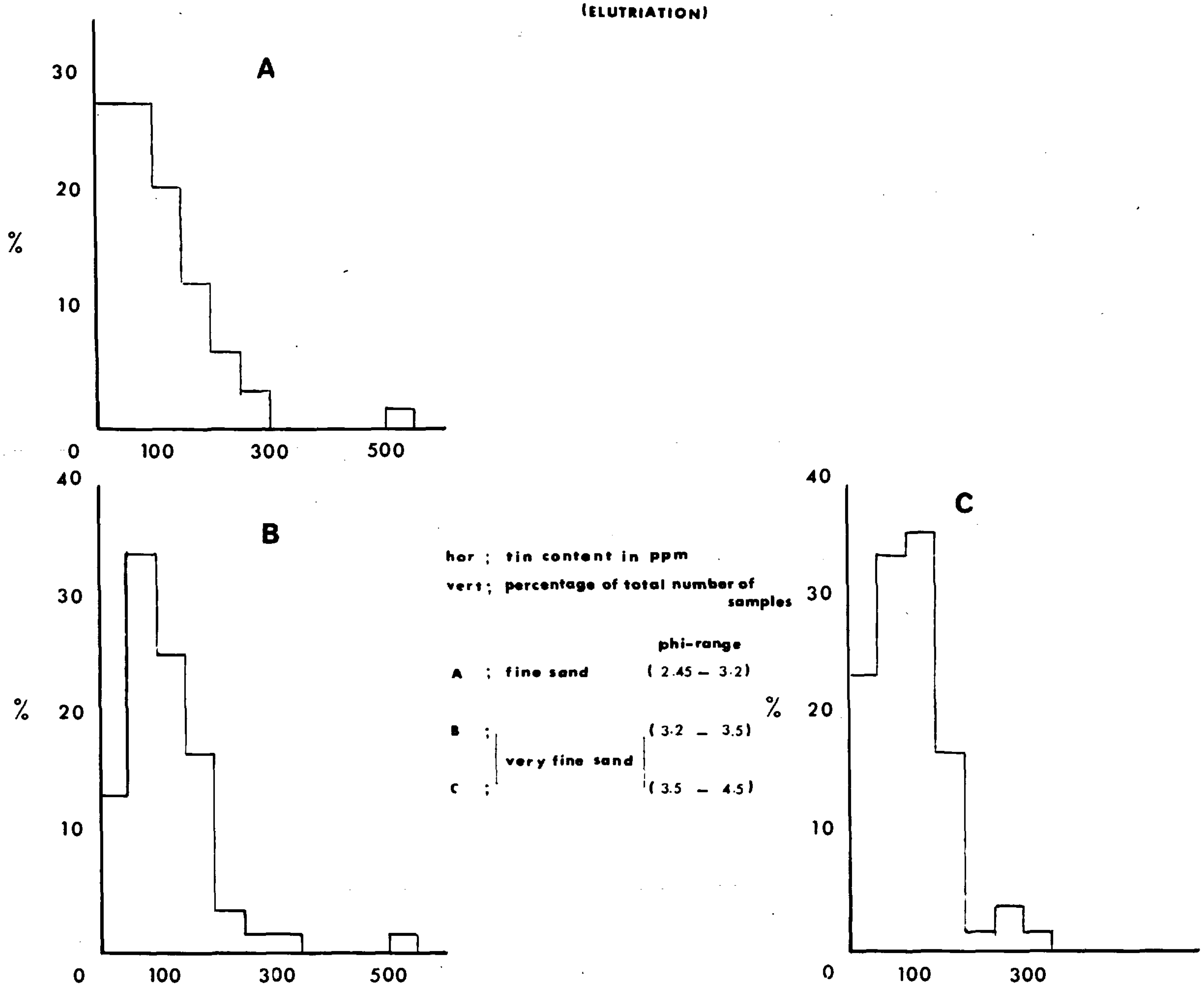
Results of analytical data on elutriation fractions are distinctly different (Fig. 3,6). The mean values of the fine sand (Fig. A) and the very fine sand (Figs. B and C) are 100 ppm Sn, 120 ppm Sn and 115 ppm Sn respectively. Their standard deviations are 90 ppm, 105 ppm and 75 ppm.

FIG 3,6

WESTERN MOUNTS-BAY

TIN DISTRIBUTION of SURFACE SEDIMENTS

(ELUTRIATION)



The fact that the same samples yield greatly different results when treated with screening and elutriation must be explained on the basis of the principle underlying each method.

Screening takes grainsizes into account only, whilst elutriation separates on grainsizes plus density: i.e. hydraulic properties (idealised), the difference being the density.

Differences in the tin content of elutriation fractions are small compared to those between fractions obtained by screening. This indicates, therefore, that smaller, heavier cassiterite grains now occur in coarser, more abundant and hydraulic equivalent light fractions, meaning that the size distribution of heavies is "shifted" to coincide more or less with the grainsize distribution of lights. Differences in the mean tin content of elutriation fractions is virtually non-existent. Consequently, one must assume that:

1. the size frequency distribution of the tin grains is similar to that of the light fraction (ppm is no more than a ratio), and
2. the displacement towards finer sizes of the tin, as indicated by screening, is entirely due to differences in density.

It is of extreme interest to recall the analytical results of the total minus 80 mesh fraction, which had a mean value of 110 ppm Sn and a standard deviation of 116 ppm. This fraction represents the bulk of the sample. Consequently, its tin content is not influenced by size frequency distributions of individual components, and therefore, in support of the above results.

Elutriation is in fact a controlled form of transportation, which may or may not have any resemblence with the actual environment. Nevertheless, the data, suggesting the existence of hydraulic equivalence between tin and quartz, indicates that a similar mechanical process may have been responsible for the distribution of these components in the marine sediments.

Hydraulic equivalence is, in principle, based on Stokes law. Consequently, with the available data on grain size distribution and tin content, one should be able to verify the above hypothesis by simple calculations. This is **illustrated for** two samples in Table 3,4 where, for comparison, the tin content of the fractions obtained by elutriation are also presented.

Table 3,4 Comparison of computed relative availability of tin and elutriation

Size fraction	ppm Sn 1	Weight % of size fraction 2	Weight% of hydro. equivalent fraction 3	Relative availability of Sn in ppm 4	Elutr. in ppm Sn 5
Sample 561005					
-200	24,375	0,9	69,4	316	200
-150 to 200	410	20,7	16,0	273	135
-100 to 150	65	48,7	9,8	322	130
Sample 561154					
-200	5,000	3,7	80,1	230	160
-150 to 200	175	18,1	9,8	260	185
-100 to 150	12	62,0	3,3	224	160

The absolute amount of tin in the different fractions (column 1) shows a tremendous variation. Once expressed as tin content of their hydraulic equivalent fraction (relative availability of tin, column 4) differences, however, almost disappear and compare with the analytical results of elutriation (column 5). The fact that the hydraulic ratios (column 4, Table 3,4) are consistently higher than the elutriation results is probably due to the fact that for the computations, the tin content of the screened samples is regarded as consisting of pure cassiterite grains. The analysed tin, however, may well occur in the form of multimineral grains as well and the gallein method, used for the analysis, attack all forms of tin exposed, whether the grain is monomineralic or multimineralic. The result of this aspect on the computations will be considered later.

In addition the fact must be taken into consideration that the precision of the analysis is only then 25% at the 95% confidence level. This fact superimposed on the analytical errors in the determination of the grain size distributions, will cause variation in the hydraulic ratios.

Despite these shortcomings, it is appreciated from Table 3,4 that expression of results, obtained on a single sample, as relative available tin greatly simplified assessment of the data. Similar results are obtained when the tin contents of a given fraction of different samples are compared. In some cases the differences between the two methods of presentation are spectacular (Table 3,5).

Table 3,5 Comparison of actual and relative tin content of selected samples from traverse 12

Sample No.	ppm Sn	Relative Availability
	minus 200 mesh fraction	
561158	11,000	425
561164	6,500	425
561172	12,500	624

Here, on absolute tin content, both samples 561158 and 561172 would be considered as anomalously high. However, on the basis of relative availability only sample 561172 is anomalous. Sample 561158 has the same relative available tin as all other samples of this traverse.

As will be remembered, the standard deviation of the tin content, obtained by elutriation, is rather great. This, however, is explained by the fact that the tin content decreases considerably in off-shore direction, whilst the sand size distribution remains virtually the same. Although this seems at first to conflict with the concept of hydraulic equivalence, it should be emphasised that the transport of material is extremely complex and will be considered in the next chapter.

CHAPTER 3 DISCUSSION AND INTERPRETATION

A. General

In Chapter 1 of this section, several sources of tin have been considered, which were dismissed as an explanation for the overall tin distribution in the marine sediments of Mounts Bay. For the detailed discussion of the Penzance/Marazion sediments, however, some of these sources may become significant. Similarly, the concept of hydraulic equivalence has been intboduced in that chapter and illustrated in Chapter 2. Both aspects of the previous chapters are considered further here.

Systematic application of Stokes law on the data of the traverses, reveal considerable variation of relative availability. Before considering the results, it is desirable to review the causes of deviation from the basic theory.

The application of Stokes law is based on the assumption that the current velocity required to move particles along the bottom is approximately the same as the settling velocity of these particles in still water (Rubey, 1933). However, this applies only in the region of viscous settling. Inman (1949) suggests that this assumption is only correct for particles of a critical size (0.18 mm diameter in the case of quartz particles). Above this size, the velocity to initiate movement of a particle is less than the settling velocity, which results in transport by rolling. Below the critical size the threshold velocity to move a particle is greater than the settling velocity, resulting in transport by suspension. These considerations will affect relative availability of heavy minerals below the critical size and which are hydraulic equivalent to light particles above this size as will be discussed later. Furthermore, in the region of transport by rolling or saltation, threshold velocity is dependent on the critical drag force. This force is a function of density and size and will be slightly smaller for coarse light grains as compared to the equivalent smaller heavier grains. This results in a decrease in heavy mineral content with distance along the travelled path, and consequently, in a decreasing relative availability.

Apart from these mechanical considerations, which can only be considered qualitatively without much more information on the nature of the bottom etc., the strict applicability of the theory also assumes that all the relevant grainsizes are available in the source material or, in the case of plural sources, complete homgenisation of the material before deposition. The actual calculations can be influenced by sampling errors which could be considerable when a number of divers are being used, and the precision of the analytical results is only better than 25% at the 95% confidence level.

Finally, in the calculations of the relative availability it has been assumed that all the tin occurs as cassiterite grains. In fact, some tin will occur within the mineral lattices of other grains and thus resulting in polymineral grains. The effect of this is a decrease in the density of the tin containing polymineral grain as compared to cassiterite. The hydraulic equivalent light grain of such a polymineral grain therefore will be smaller than the grain sizes used in the computations. The high relative availability resulting from this can be very erratic, as the density of the polymineral grains may vary in their density from 7 to 2,65, according to the amount of tin. Although this will probably be reflected in "micro" variations of the grainsize distribution of the light material, this could not be established by the size fractioning method used. For the minus 200 mesh fraction this will be less important, as the equivalent light fraction includes all material smaller than 100 mesh and forms the bulk of the sample. For the 150 to 200 mesh tin fraction, whose equivalent light fraction is 80 to 100 mesh and which forms only a small proportion of the sample, this can result in high and erratic relative availabilities. This effect will normally be confined to at most one or two of the size fractions. Consequently, anomalous relative availabilities are only considered signficant when they are expressed in all fractions of the same sample.

The combined error due to sampling and analytical procedures and data processing could not be accurately determined. However, it is considered that differences of less than 50% are of doubtful significance and only two-fold differences between pairs of results are taken as definitely significant. Of course, where there is a clear trend reflected by a number of samples, smaller differences are considered as significant.

It will be appreciated, that the concept of hydraulic equivalence in itself is correct, while its application in a number of studies was justified. However, as a prospecting tool, for which it has been used in the present study, it has severe restrictions. Nevertheless it became apparent, after careful examination of the results, that the expression of the data as relative available tin in addition to the plain data, emphasised aspects of the tin distribution in the sediments which were not so obvious from the sample presentation.

Data in Table 3,6 show the mean tin contents and grain-size distribution for each of the traverses and for 3 cores. Locations are given in figure 3,7.

The table can be divided into four groups.

Traverses of group 1 have in common that their relative available tin content is fairly constant in all size fractions and is similar for all traverses. Traverse 14 has rather high values, but this aspect will be considered further in the detailed discussion.

Traverses of group 2 all have outstanding high relative available tin in the 150 to 200 mesh fraction, while in addition they can be divided into two sub groups, based on the relative tin content of the minus 200 mesh fraction; one low and one high.

The third group shows very high values for the 100 to 150 mesh fraction.

The last group, of which core 5 is from outside the study area, exclusively consist of subsurface samples. Absolute as well as relative tin values are of an entirely different magnitude as compared to the other traverses.

The difference in the grainsize distribution between the two sets of samples of group 4 indicate a completely different environment of sedimentation. This is not reflected in the relative availability in the three cores. On the contrary, hydraulic ratios are almost identical.

Samples from cores 33 and 34 (group 4) and the traverses, all come from the Penzance/Marazion sand body. Grain size distribution (last column, Table 3,6) is uniform. Relative tin content in the surface samples is, however, many times greater than for the subsurface samples. Consequently, it can be concluded that the higher surface values indicate a recent increase in the supply of tin, not accompanied by an equivalent change in the supply of sand. This, undoubtedly, is related to the recent mining activities in the catchment area of the bay through which more tin was made available for transport than would have been the case with normal erosion.

Table 3,6 Average values of absolute and relative tin content of traverses (1)

Traverse number		ppm Sn		phi value of traverse
	Minus 200 mesh	minus 150 mesh plus 200 mesh	minus 100 mesh plus 150 mesh	
	Group 1			
1	(15,000) 280	(550) 300	(50) 330	
12	(6,600) 290	(240) 320	(10) 220	2,57
14	(18,000) 500	(400) 670	(20) 410	2,50
(2)14	(18,650) 660	(1430)3250	(30) 480	2,50
9	(3,920) 160	(130) 450	(15) 480	2,70
18	(1,600) 230	(35) 140	(10) 150	2,67
	Group 2			
8	(1,750) 220	(150) 1550	(15) 1400	2,83
11	(3,300) 280	(150) 1875	(10) 80	2,11
16	(1,620) 225	(35) 2350	(15) 650	2,44
2	(8,100) 500	(220) 1500	(25) 800	
5	(20,500) 590	(650) 1920	(16) 550	2,52
10	(3,000) 500	(90) 4470	(10) 340	2,51
	Group 3			
13	(5,500) 260	(75) 340	(10) 1280	2,73
17	(4,400) 160	(120)520	(10) 1500	2,72
	Group 4			
Core 33 and 34	(95) 17	(16) 20		2,72
Core 5	(1,480) 25			0,77

(1) Traverses 15 and 19 are not included in the table as their distribution is irrelevant for this table (see later). Traverse 6 is included in traverse 5.

(2) The second group of data on traverse 14 include all samples, while the first one includes only the non-anomalous samples. The anomalous samples of this traverse are related to nearby mineralisation and in the discussion on this table reference will be made to the first data only.

Two general aspects emerge from the first three groups. Firstly, the relative available tin of the minus 200 mesh fraction remains comparable regardless of the differentiation into groups. There is, however, variation in that traverses 2, 5, 10 and 14 have a relative available tin content double that of the other traverses for this fraction. Three of these traverses (2, 5 and 14) are close to the shore. The second overall aspect of table 3,6 is the fact that all traverses of group 2 and 3 occur within the current eddy postulated on drifter and tracer data in Section 2.

With respect to the first consideration, it will be remembered that the tracer experiment indicated that tantalum and therefore cassiterite is transportable, provided its size is smaller than 200 mesh. This conclusion, together with the constant relative availability of tin for this fraction indicate almost certainly an allochthonous tin source; detrital tin from terrestrial origin. The occurrence of higher values for near-shore traverses has been explained in Chapter 1 and is further support for terrestrial supply.

With respect to the second consideration, more problems arise. The tin content of a single fraction of a given sample is higher than justified by the weight per cent of its equivalent light fraction. This could be due to either of three possibilities.

1. In the source material of the tin of these traverses there is no equal availability of quartz and tin in all sizes.

2. A substantial amount of tin in these fractions occurs in polymineral grains.
3. The current velocity of the eddy is approximating a value where threshold velocity and settling velocity for fine sand coincide.

For the first possibility there is little evidence. Absolute tin content for this fraction is by and large of similar magnitude for all traverses and decreases in offshore direction. Grain size distribution remains the same, but relative availability is high only for certain traverses.

The second possibility is more difficult to assess. In order to verify the suggestion, heavy mineral separations have been carried out on the 150 and 200 mesh fraction of 6 selected samples representing all groups (Table 3,7). It appears from this table that only in the case of traverse 12 and traverse 5 do analytical results conform to this hypothesis. For the first traverse (group 1) tin is concentrated in the plus 4.1 s.g. fraction, while for traverse 5 (group 2) tin occurs in the lighter fractions. The remaining results indicate the existence of tin in the lighter fractions, but this was not expected for traverses 14 and 17, both of which have a relative availability of lower magnitude than traverses 8, 5 and 16. For traverse 14 this may be explained by the fact that for most of its samples a local **elluvial source has** been postulated (see page) while the adjacent sample to no. 1215 does have an abnormal high relative tin content for this fraction. However, for traverse 17 there is no explanation.

Table 3,7 Tin distribution of the 150 to 200 mesh fraction in selected samples,using Tetra Bromethane (s.g. 2,9) and clerici (s.g. 4,1)

Traverse number	Sample number	s.g. of fraction	weight % fraction	ppm Sn	percentage Sn of total
12	561152	>4,1	2,5%	7,810	92,3%
		>2,9	21,4%	900	0,0%(1)
		<2,9	78,6%	18	7,7%
14	561215	>1,4	0,6%	5,800	48,6%
		>2,9	13,8%	500	47,8%
		<2,9	86,2%	3	3,6%
8	561093	>4,1	0,5%	2,300	17,1%
		>2,9	4,8%	810	40,7%
		<2,9	95,2%	30	42,2%
16	561236	>4,1	1,3%	1,660	19,9%
		>2,9	7,2%	1,590	76,2%
		<2,9	92,8%	5	3,9%
5	561052	>4,1	7,8%	407	9,0%
		>2,9	31,0%	1000	90,6%
		<2,9	69,0%	1	0,4%
17	561260	>4,1	0,5%	2,670	3,1%
		>2,9	11,1%	3,710	94,5%
		<2,9	88,9%	11	2,5%

For technical reasons, analysis of the less than 2,9 s.g. fraction included the less than 4,1 s.g. fraction, whose own tin content was later deducted. Consequently, the tin content in absolute weight of the former fraction should be higher than for the latter, provided there is tin in the lighter than 4,1 fraction. For traverse 12 amounts of tin in both fractions are equal, resulting in the zero percentage for the plus 4,1 less than 2,9 s.g. fraction.

It is appreciated that too few traverses have been collected outside the eddy, which makes the discussion inconclusive.

As mentioned previously, traverses with a high relative tin content occur within the boundaries of the eddy current. This current by itself can give no satisfactory explanation. Firstly, there are other traverses in this area which do not show this feature. Secondly, sorting by the current of polymineral grains from a mutual source for all traverses (in and outside the eddy current) would also be reflected in the other components of the sediment, for which there is no evidence. Alternatively, one must postulate an additional source(s) of tin in polymineral grains within the eddy. It seems unlikely that either Marazion River or the mineralisation of St. Michaels Mount are responsible for this form of tin, as other traverses of which the tin content can be related to these sources but which occur outside the eddy do not show these features.

An alluvial source which will influence the western part of the bay more than any other location is Newlyn River. This river drains mineralisation in the Lands End granite, and material discharged by this river will be taken in a northerly to north-westerly direction by the eddy current. However, no information is available as to whether the mode of tin in the Newlyn River is distinctly different from the Marazion River. A second possible source may be submarine mineralisation. However, in the cases where submarine mineralisation is regarded as responsible for the tin content of a traverse, this was reflected in all fractions. Conclusions with respect to the above suggestions will be considered after each traverse has been discussed in detail.

The third possibility with respect to the high relative available tin content in certain fractions is based on the mechanical aspects of transport as outlined in the discussion on the limitations of Stokes law (page 113).

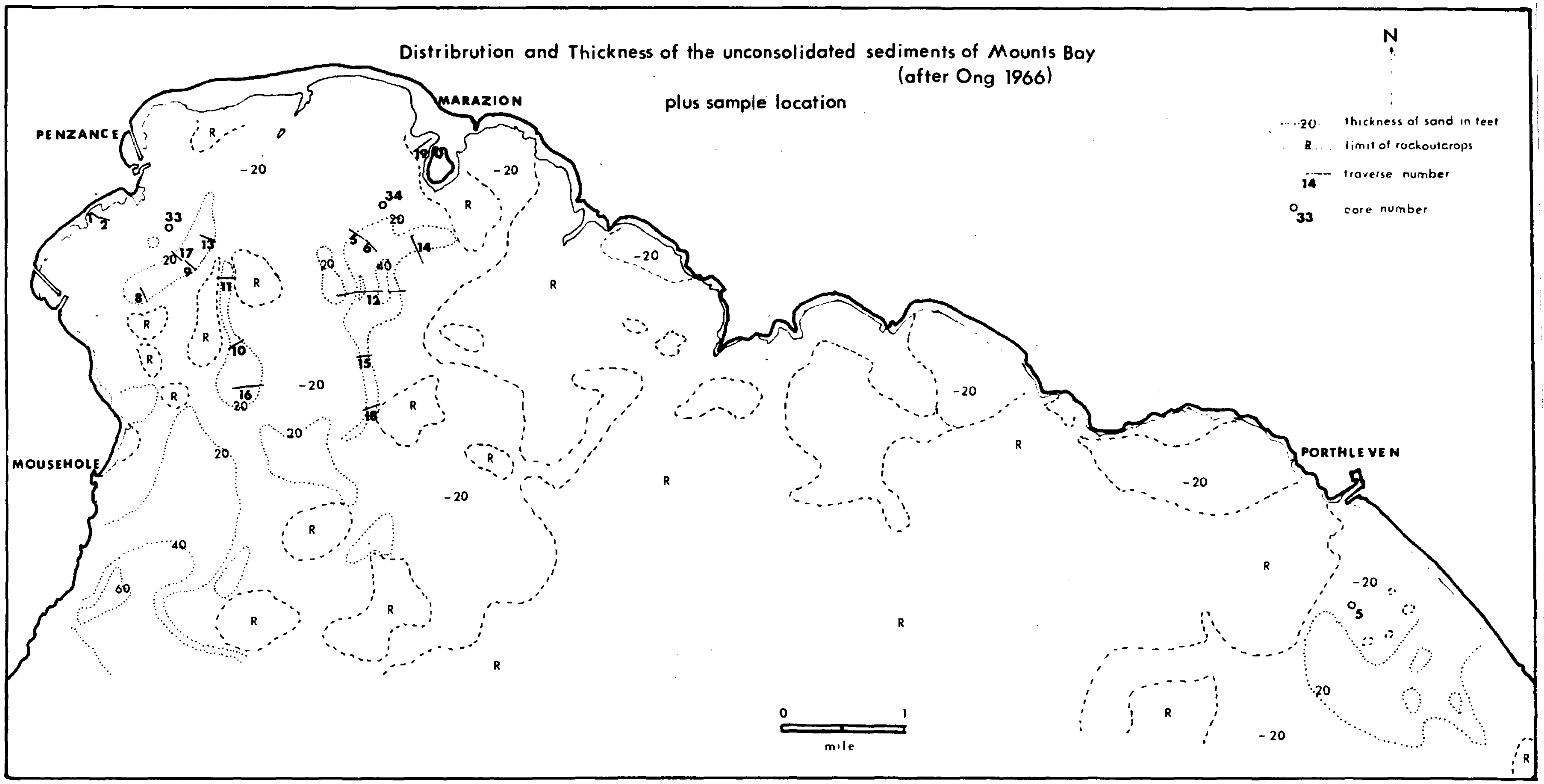
From the discussion on the grain size distribution, it may be remembered that the mean diameter of the sediment was restricted to very narrow limits, while the most frequent diameter was in the order of 2.6 phi (= 0,17 mm). Inman (1949) in his paper on sediments and fluid mechanics, comes to the conclusion that "Grain sizes near 0,18 mm are hydrodynamically unique from all other sizes in that;

1. they are moved by weaker currents than grains smaller or larger than themselves;
2. once moved they do not have as great a tendency to go into suspension as do smaller grains;
3. they are more readily carried into suspension than larger material".

The close agreement between the actual grain size distribution of the sediment and Inman's critical size, seems to suggest that the preponderant current velocity in this part of the bay approximates the value where threshold velocity and settling velocity coincide. A current with slightly higher velocity will initiate movement of particles in the fine sand range (0,25 mm = 80 mesh to 0,125 mm = 120 mesh). Transport of the finer part will be in suspension, while that of the coarse part will be by saltation and rolling. If one considers now tin of 150 to 200 mesh size, which is equivalent to light material of 80 to 100 mesh (0,2 mm to 0,15 mm) and a current velocity slightly above the threshold value for quartz grains of 0,18 mm size, transport of the light material of 150 to 200 mesh size will be transported by suspension, but the tin in that fraction will be transported by saltation like its equivalent coarser light fraction. Consequently, there will occur some form of concentration of tin in the 150 to 200 mesh fraction, resulting in a high relative availability. Tin of minus 200 mesh size will not be affected as all relevant sizes of lights and heavies are transported in the same way; by suspension. Likewise, tin of 100 to 150 mesh size is not affected to the same extent as transport of the relevant sizes will occur predominantly by saltation.

High hydraulic ratios occur in groups 2 and 3 only. Grainsize distribution of the surface sediments on the other hand, remains the same for all the traverses. If the above hypothesis is correct, it seems a discrepancy that anomalous hydraulic ratios are restricted to a limited number of traverses. One can only overcome this problem by assuming that the current affecting the

FIG 3,7



Distribrution and Thickness of the unconsolidated sediments of Mounts Bay (after Ong 1966)

plus sample location

non-anomalous traverses has a slightly higher velocity during its most effective phase as compared with the eddy current velocity. This results in similar transport (suspension or near suspension) for all fractions concerned. Near the critical value a small variation in current velocity may have considerable effects on the mode of transport of particles slightly coarser than the critical size.

Neither of the two possibilities provide a complete satisfactory answer, and it may well be possible that both hypothesis contribute to the high relative availabilities in a specific fraction. More definite conclusions may be obtained if future work is concerned with accurate velocity measurements, studies on the nature of the bottom as well as a study on the mineralogical habits of the tin in the marine sediments.

B. Detailed Discussion on Individual Traverses

A total of 19 traverses have been collected (Fig. 3,7). Their locations have been selected to cover as many features of western Mounts Bay as possible. They include nine traverses over the main submerged valley which occurs S.W. of St. Michaels Mount (traverses 14, 5, 12, 15 and 18). Four traverses have been laid out over the second but less dominant valley which occurs one to two miles west of Penzance (traverses 11, 10 and 16). Another four traverses cover an isolated, thicker sand body in the north-west part of the bay. Three more traverses (1, 2, and 19) represent the sediment influenced by wave action as they occur close to the shore. Two of these (1 and 2) cross a known mineralisation in the vicinity of Penzance Harbour. An additional two traverses were scheduled west of the Mount, but they could not be collected due to bad weather conditions.

Traverse 14 (Fig. 3,8)

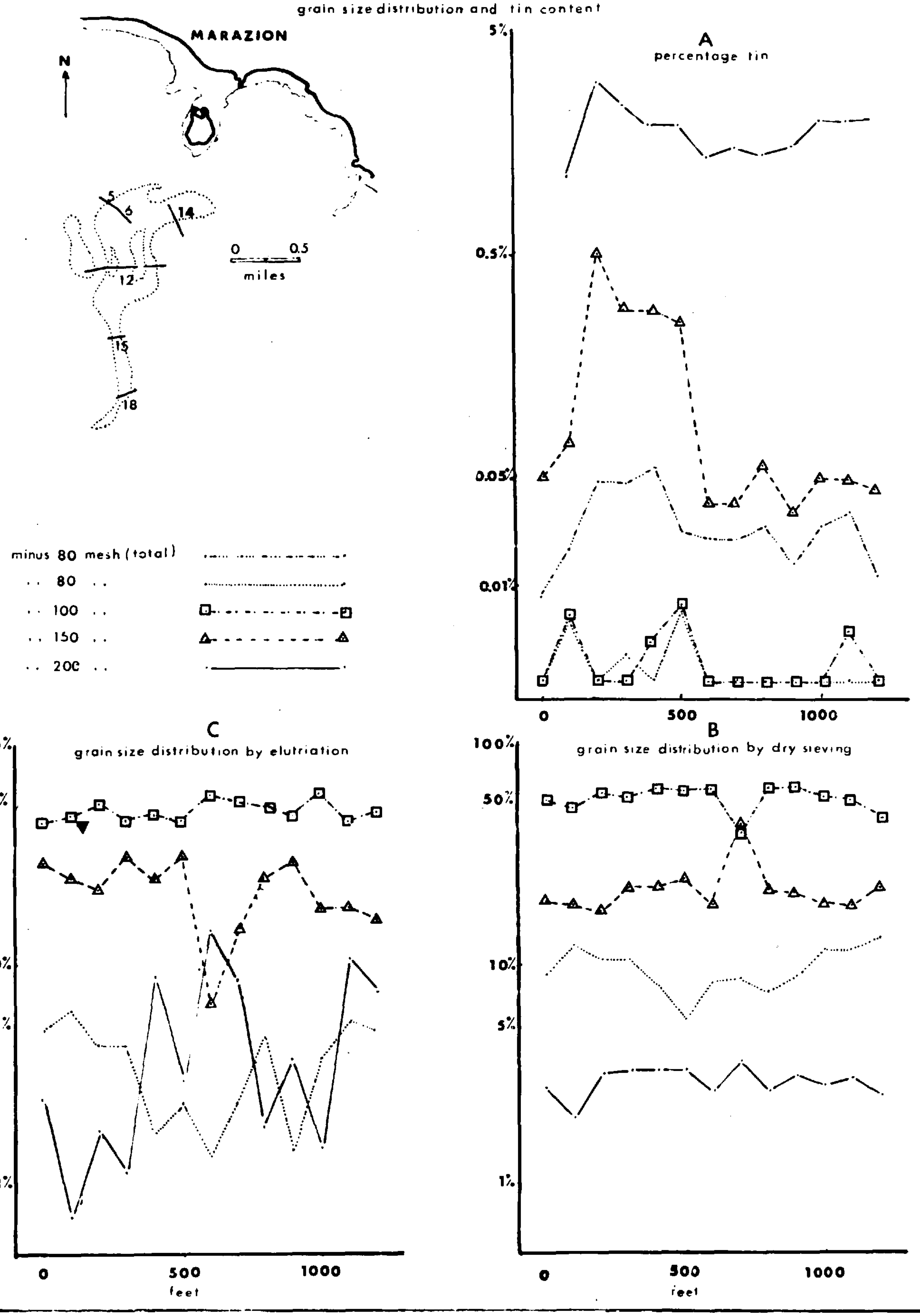
This traverse, together with traverses 5, 12, 15 and 18 cover most of the depression in the bedrock which occurs S.W. of St. Michaels Mount. This valley is approximately 2 miles long, up to 0,5 miles wide and the sediment filling this valley has a thickness ranging from 20 to 40 feet. From its location, it is very likely that the depression is the seaward extension of the Marazion River valley in glacial and post glacial times. It was also noted previously that the tin content of the surface sediments in this area S.W. of the Mount is rather high, considering its location so far from the present shore line. The question therefore arises as to whether there is a connection between tin content and bedrock topography.

Traverse 14 is 1400 feet long and is located 1/2 of a mile south of St. Michaels Mount (Fig. 3,8). Its strike is north west/south east and its N.W. half overlies the submerged valley. Some 200 feet beyond the edge of the valley, a rock outcrop reported by divers, was found to be an elvan dyke approximately 15 feet wide with a N.E. strike.

FIG 3,8

TRAVERSE – 14

grain size distribution and tin content



Grain size distribution, obtained by screening, shows that as a whole there exists little variation along the traverse (Fig. 3,8B). The average mean diameter of the sediment is 2,5 phi with a standard deviation of 0,1 phi. The sand, therefore, is extremely well sorted and falls in the fine sand class (Wentworth). The standard deviation of individual samples is 0,35 ±0,08 phi. Only one sample is relatively coarse and occurs over a small depression. The skewness, a measure of the symmetry of the grain size distribution, showed that samples from either end of the traverse are slightly coarser than elsewhere. However, it is evident that the underlying bedrock topography has no noticeable influence on the grain size distribution of the surface sediments.

Elutriation has also been carried out on samples from this traverse. In view of the limited accuracy, as mentioned previously, broad tendencies will be discussed only. The sand appears to be slightly finer; the average mean diameter is 3,06 phi which is probably due to shell fragments. More important, however, is the fact that negative skewed samples (relatively coarse) are limited to the buried valley. The weight per cent of the finest fraction (circa 200 mesh) is very much less than the circa 150 mesh fraction over the buried valley. Differences between these two fractions decrease towards the south-east of the traverse (Fig. 3,8C). This tendency is not reflected by screening. Consequently, one must assume some sort of difference between the sediment overlying the valley and overlying the plateau. In this context, the tin content of this traverse becomes significant (Fig. 3,8A).

Referring to the 80 mesh under size fraction, it can be seen that higher values are concentrated over the valley. Two of these values are above the threshold value for the bay as a whole. Consequently, one might expect a high tin content for the minus 150 plus 200 mesh fraction. Indeed, high values for this fraction are restricted to the area overlying the valley; four successive samples form a well defined anomaly, 1,5 to 3 times the threshold value for this fraction. Other fractions are also markedly high in their Sn content. The minus 200 mesh fraction has a maximum of three per cent and the two coarsest fractions have maxima just below their respective threshold values.

The consistency of the grain size distribution and the variation in the tin content suggest that no constant hydraulic ratio might be expected. This is confirmed by table 3,8 which represents absolute and relative available tin of the individual samples of the traverse. The average values of this traverse used in table 3,6 excluded anomalous samples and showed fairly constant hydraulic ratios. From table 3,8 it can be seen that this is not the case for the anomalous samples.

Apart from the confirmation of the anomalous tin content over the valley, two more peak values appear at 700 feet in the minus 150 plus 200 mesh fraction. These values are 1,5 times the mean value for the part of the traverse overlying the plateau.

Table 3.8 Absolute and relative available tin of traverse 14

Sample number	minus 200 mesh		minus 150 mesh plus 200 mesh		minus 100 mesh plus 150 mesh	
	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn
561191	11,400	380	450	960	10	150
561193	30,500	1290	700	1300	70	550
561195	25,000	1040	5200	9100	10	160
561197	20,000	790	2750	6080	10	240
561199	20,000	790	2750	7650	45	450
561201	13,750	430	2500	7100	85	2270
561215	15,000	660	335	780	10	330
561213	14,000	440	335	1660	10	160
561211	15,000	570	560	1660	10	220
561209	19,500	340	275	660	10	300
561207	19,200	800	480	760	10	170
561205	20,500	780	445	700	55	660
561203			360	570	10	110

If all the tin along this traverse had been derived from a single, i.e. terrestrial, source it is difficult to explain the difference in the tin content, but not in the grain size distribution at the two ends of the traverse. Considering the thickness of the sediment beneath the N.S. half, which is in excess of 20 feet, it seems unlikely that the tin content of this part of the traverse is reflecting an underlying relic alluvial placer.

In discussing an alternative interpretation of the data, it is worth noting that maxima in tin content of successively finer fractions are slightly replaced towards the north-western part of the traverse (Fig. 3,8A). Decreasing mobility towards coarser sizes, would suggest a source in the vicinity of the maximum of the minus 100 plus 150 mesh fraction.

The occurrence of an elvan dyke, some 200 feet further S.E. along the traverse may be significant. None of the samples adjacent to this dyke, however, show an increased tin content, although there exists a small but marked anomaly in the relative available tin of the minus 150 plus 200 mesh fraction. The real distance between elvan dyke and anomalous samples may be, however, much shorter. Firstly the traverse cuts the dyke obliquely and secondly, the dip of the dyke is unknown. This also could result in a shorter direct distance between suboutcropping rock and traverse location. It is, therefore, not entirely impossible that the displacement of maxima is related to grainsize variation in the primary source, the traverse representing an oblique cross section.

The fact that the succession of maxima occurs over the sediment filled valley, may well be in support of the postulated eluvial source. If one imagines the mineralisation situated on the valley slope, its dispersion pattern will be down slope, with the maximum migration for the finest grains. If one has simultaneous deposition of material in the valley, the dispersion will not be limited to the valley slope and bottom alone, but also to the "new" valley floor, with the finest grains the furthest away from the mineralisation. In this way, one gets a "fingering" effect depending on the speed of sedimentation. The distribution as found with the traverse, may well represent such a "tongue". The above suggestions should be verified with subsurface samples. Unfortunately, they could not be obtained during coring. It is evident from the dicussion that many questions remain and if further research is carried out, this location should have a high priority.

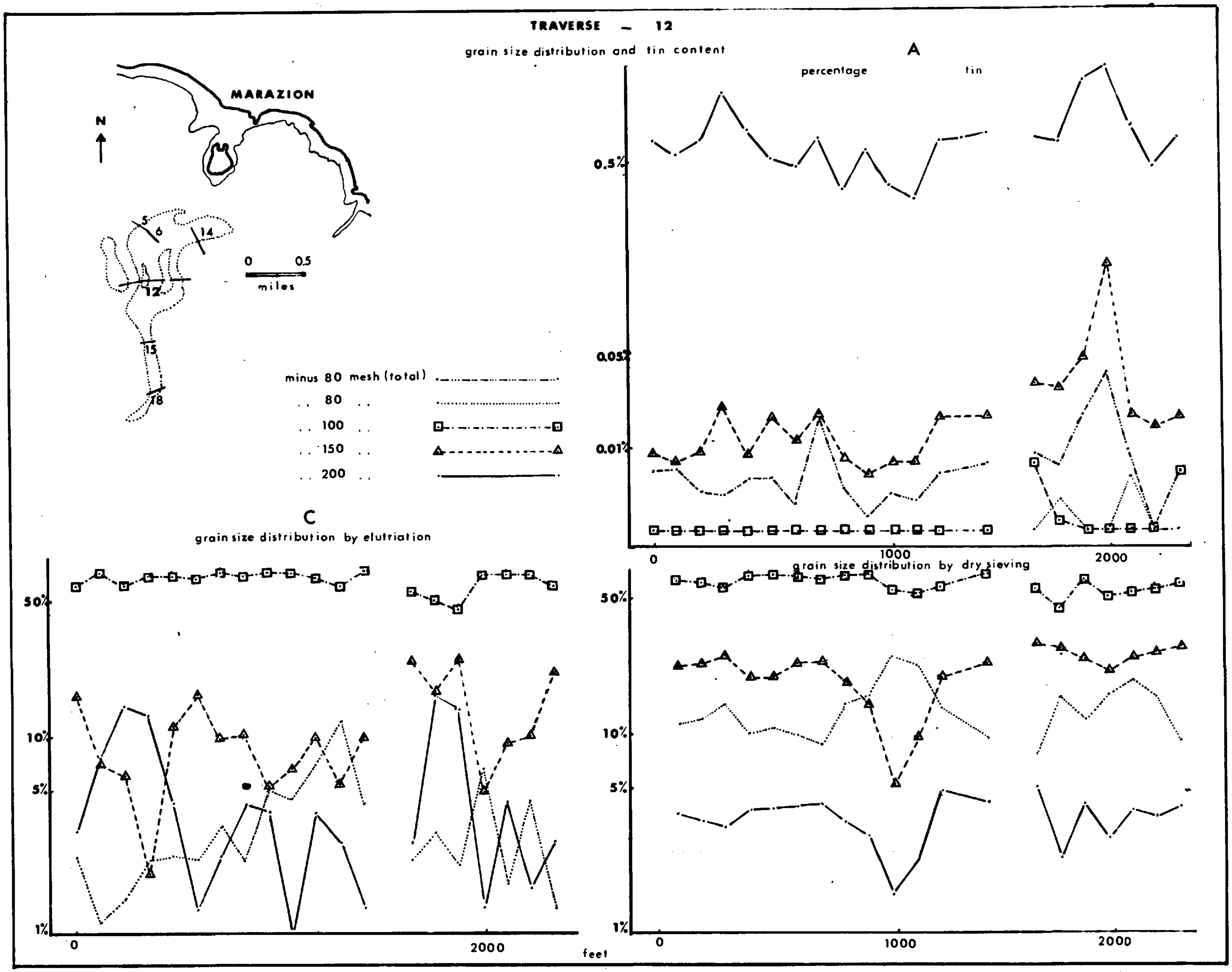
The results of traverse 14 have been considered in isolation. However, the data presented below on traverse 12 have considerable relevance in any discussion on the nature and strike of the postulated eluvial source of tin.

Traverse 12

Traverse 12 is located one mile south-west of St. Michaels Mount and approximately 0,5 miles further along the drowned valley (Fig. 3,9). The strike of the traverse is E"W and has a length of 0,5 miles. The traverse is not continuous. Due to difficulties in manouvering the 75 foot long ship, it was impossible to drop the anchor at the end of the first sampling section.

The bedrock topography covered by this traverse has three depressions. The eastern two converge just south of the traverse location, whilst the third one is more or less isolated. The maximum thickness of the sediment is 40 feet.

FIG 3,9



Grainsize distribution as obtained by screening shows in general similar results to traverse 14. The average mean diameter is 2,57 phi with a standard deviation of 0,1 phi, compared to 2,5 and 0,1 phi respectively on traverse 14. The mean of the standard deviations of individual samples is 0,32 phi ± 0,07. Like the previous traverse, the sand is very well sorted indeed. In the middle of the traverse, however, a group of samples occur which are relatively coarse; more than 0,3 phi units less than the mean. They are located over the middle and deepest bedrock depression.

The grainsize distribution obtained by elutriation shows the sand to be slightly finer; 2,8 phi for the mean diameter and a standard deviation of 0,25 phi. There exists a tendency for coarser samples towards the middle of the traverse as well, although none of them is anomalous. An interesting feature revealed by elutriation is the common minimum in weight per cent of the two finest fractions 300 feet from the eastern end of the traverse (Fig. 3,9C). This is not demonstrated by the screened data. Consequently, using the same arguments as for traverse 14, one may expect at this location a higher percentage of heavy minerals and possibly a higher tin content than elsewhere along the traverse..

The tin content of individual fractions is by and large far less than the comparable fractions of traverse 14 (Fig. 3,9A). The absolute and relative tin content are given in Table 3,9.

Table 3.9 Absolute and relative available tin of traverse12

Sample number	minus 200 mesh		minus 150 mesh plus 200 mesh		minus 100 mesh plus 150 mesh	
E	ppm Sn	rel.av. Sn	ppm Sn	rel.av.Sn	ppm Sn	rel.av.Sn
561164	6,500	425	175	470	10	210
561162	5,000	200	85	170	10	270
561160	6,000	240	100	190	10	190
561158	11,000	425	210	370	10	190
561156	7,000	325	100	200	10	270
561154	5,000	230	175	260	10	220
561152	4,500	210	130	300	10	270
561150	6,500	320	175	460	10	190
561149	3,000	120	90	110	10	230
561147	5,500	200	65	60	10	160
561145	3,600	80	85	18	10	60
561143	3,250	160	85	220	10	280
561141	6,300	400	175	250	10	135
561166	4,500	200	160	350	10	210
561168	7,600	390	175	340	10	180
561170	15,000	580	1600	2120	10	200
561172	12,500	620	450	600	10	140
561174	6,000	270	260	490	15	160
561176	6,500	300	275	810	85	1050??
W						

The overall lower results are due, as stated previously, to its location with respect to the present shore line, and therefore with the source of terrestrial tin. Relative availability of tin is far more regular than for traverse 14, indicating that the tin distribution between the different fractions is dominantly caused by transport.

Three interesting aspects emerge from the computations. In the first place, there appears to be a "deficiency" in the tin content of all fractions in the coarser samples of the middle of the traverse. Relative availability decreases as low as 82, 18 and 60 for the minus 200 mesh, the minus 150 plus 200 mesh and the minus 100 plus 150 mesh fractions, respectively. Secondly, at the eastern end of the traverse, high relative availability occurs, which is restricted to the two finest fractions. Thirdly, the last sample of the traverse shows anomalous relative tin content for the two coarsest fractions.

The deficiency in relative available tin (sample 561145, Table 3,9) is difficult to explain. As mentioned the sediment at this location tends to be slightly coarser as compared with the other samples. This could be due to either of two features: (a) the samples represent a different horizon of the sediment as compared to the other samples of the traverse or (b) the hydraulic conditions at this location are different. The first assumption is not supported by any change in depth according to the divers. Furthermore, the absolute tin content does not change drastically, which could be expected on the basis of comparing surface with sub-surface material (Table 3,6). The writer therefore rejects this first hypothesis. An immediate problem in accepting the second hypothesis is that the theory of constant hydraulic ratios does not seem to apply to these samples. However, relative availability decreases in all fractions, indicating that there still exists a hydraulic relation in the samples themselves, although the absolute amount of tin is less than would be expected on the basis of the occurrence of greater quantities of coarser light material.

The conclusion, therefore, is that there exists an additional supply of hydraulic equivalent light materials only, diluting the relative tin content in the sediment of which these samples are taken. This then could be the effect of the incoming tidal current, the path of which is independently postulated in section 2 and which crosses traverse 12 more or less at this location.

One could make several objections against this interpretation:

(a) If this current exists, its direction is opposite the direction of the tin supply, consequently there should be little or no tin at all.

(b) It is difficult to visualise an active current restricted to a relatively small zone.

(c) If this current exists, and is responsible for the supply of coarser hydraulic equivalent light material, then it should also remove finer light fractions, resulting in an increased absolute tin content for these fractions. This is not the case.

Regarding the first two objections, it will be appreciated that the tidal current is only active during part of the tidal cycle. Furthermore, the current may occur over the whole traverse but relatively stronger over the discussed area. There is no completely satisfactory explanation for the absence of any significant increase in the absolute tin content of the finest fraction. However, it should be emphasised that the terms coarse and fine are qualitative and only refer to "coarser fine" and "finer fine" sand.

The second aspect of table 3,9, the high relative available tin in the samples 561170 and 561172 is directly reflected in the absolute tin content of the samples. As will be remembered, this was predicted from comparing grainsize distribution obtained with screening and elutriation. It is of extreme interest that at this location an elvan dyke was reported as well. When this dyke is projected along its north-easterly strike, it joins the elvan dyke of traverse 14. Accordingly, it is concluded that this elvan dyke is probably responsible for the anomalous tin contents in traverses 12 and 14. The reason, then that the anomaly in traverse 12 is less wide, is due to the fact that the traverse crosses the rock outcrop more at right angles, while the elvan dyke occurs well away from the depression in the bedrock. The magnitude of the anomaly is also lower, as less tin from terrestrial sources contributes to the total tin content of the samples. This is expressed in the overall lower relative availability.

The third aspect of the table, the higher tin content in the coarser fraction at the eastern end of the traverse, cannot be satisfactorily explained without additional information.

Traverses 15 and 18

Discussion on these two traverses will be limited, as neither the grain size distribution nor the tin tenor of the traverses reveals special features.

Traverse 15 is located 1,5 miles S.S.W. of St. Michaels Mount (Fig. 3,10). The drowned valley at this location is approximately 500 feet wide and is covered by the traverse which is 700 feet long. The sediment is characterised by abundant shell fragments, which in the minus 36 mesh undersize fraction account for more than 20% of the material compared to less than 10% for the rest of the bay. Although all traverses have shell fragments, they are restricted to the coarser fractions. The minus 80 mesh undersize fraction is almost shell free, while the minus 60 plus 80 mesh fraction has a little. As these coarse fractions are not under consideration for reasons outlined before, shell content will only be mentioned when it forms a major component of the sample.

The shell fragments give the samples of this traverse a coarse appearance with an average diameter of 1,47 phi and a very

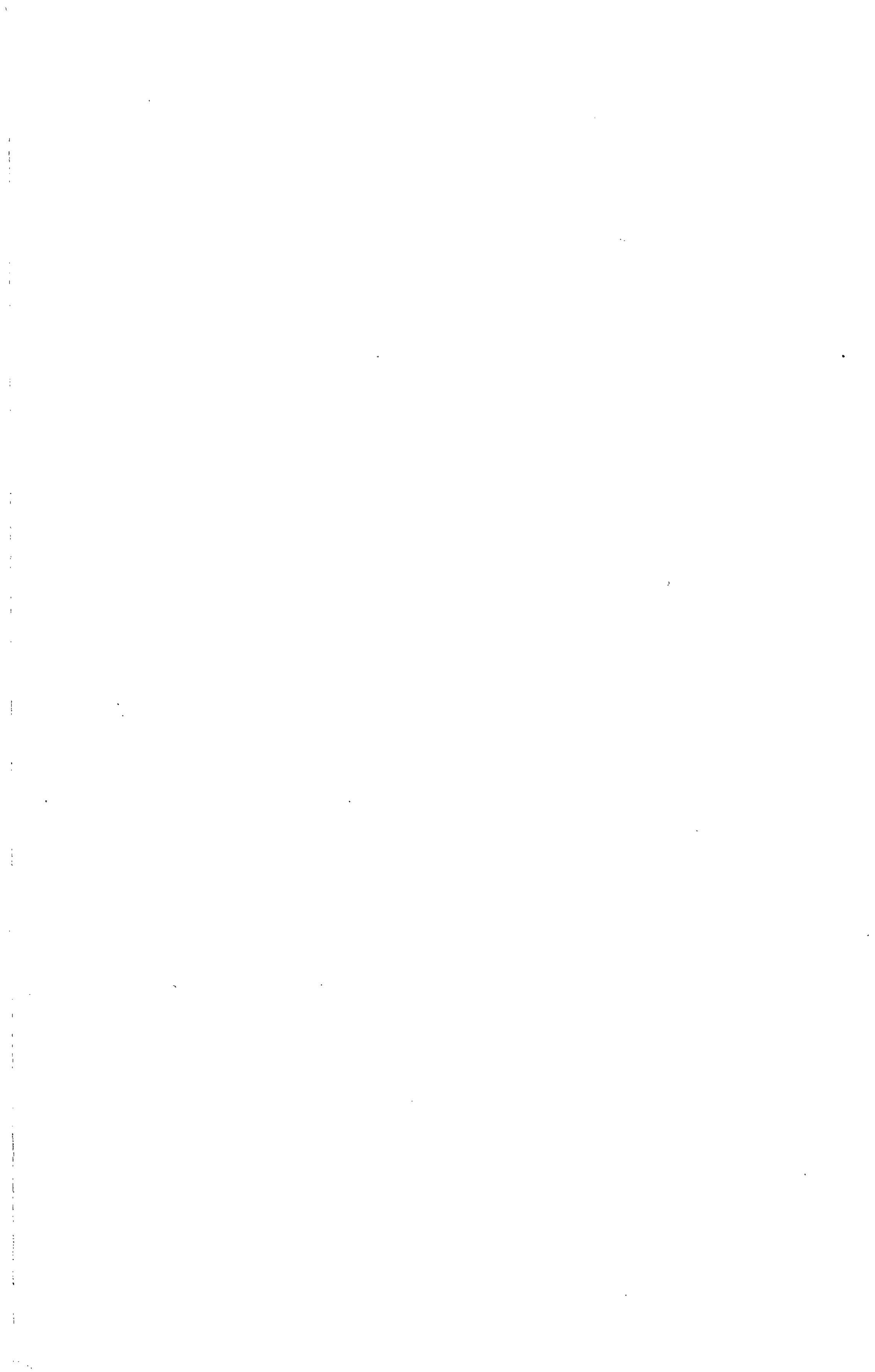
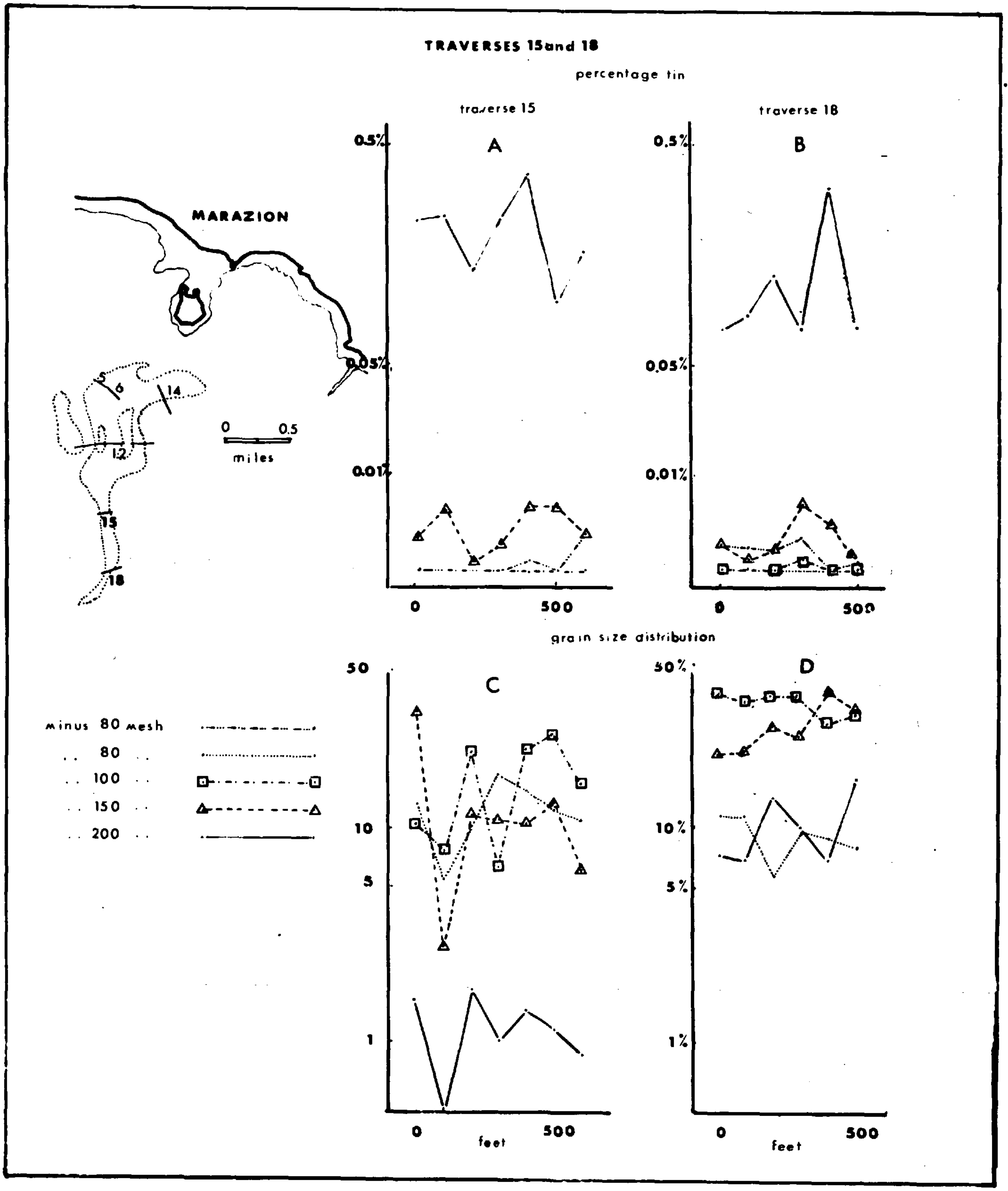


FIg 3,10


TRAVERSES 15and 18
percentage tin
traverse 15
traverse 18
A
B
0.5%
0.05%
0.01%
0
500
MARAZION
5
6
14
12
15
18
0
0.5
miles
grain size distribution
C
D
50
10
5
1
50%
10%
5%
1%
0
500
feet
minus 80 mesh
.. 80 ..
.. 100 ..
.. 150 ..
.. 200 ..

unsorted nature; standard deviation is 1,08 phi. Elutriation has been carried out on a number of samples. The average mean diameter of 2,34 phi clearly illustrates the effect of the low density of the shells. The tin content of the samples is low. Relative availability has not been calculated.

Traverse 18 is also 700 feet long and was laid out over the most southerly part of the buried valley. Its distance to St. Michaels Mount is approximately 2 miles. Shell fragments occur but not to the same extent as in the previous traverse.

Traverse 18 is marked by an increased quantity of fine material as compared to all the other traverses; the minus 200 mesh fraction has an average of 13 weight per cent. Nevertheless, the average diameter of the sediment remains almost the same; 2,67 phi.

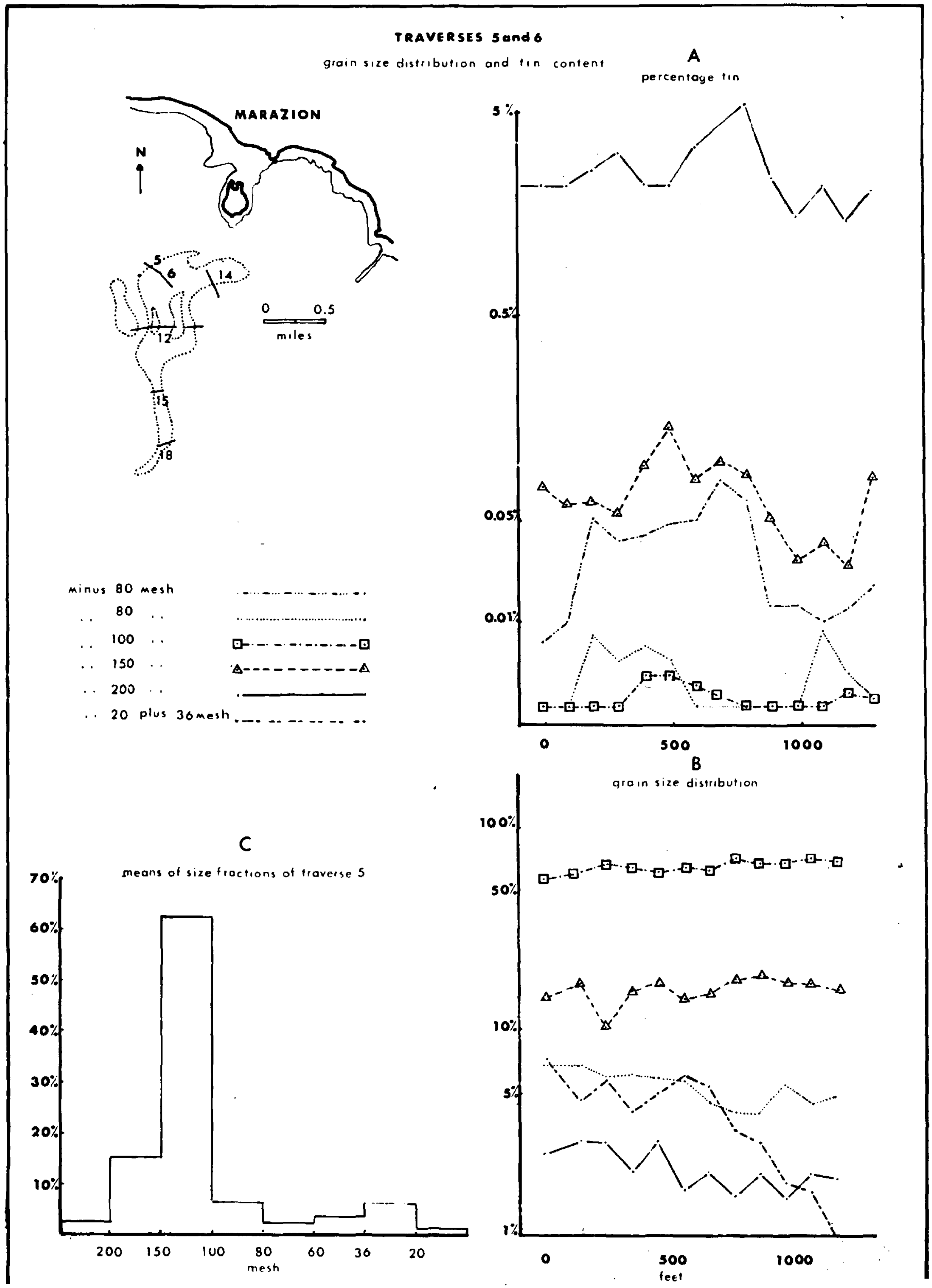
The tin content of the traverse is similar to that of traverse 15. Hydraulic ratios, which could be computed in this case, are constant. The average values for the minus 200 mesh fraction, the 150 to 200 mesh fraction and the 100 to 150 mesh fraction are 230, 140 and 150, respectively. These values are in agreement with the results of the other traverses. For the minus 200 mesh fraction relative available tin is of the same order of magnitude as elsewhere in the bay, while for the two other fractions this relative available tin is much lower, being farthest away from the shore.

Traverses 5 and 6

These traverses together form the third major traverse over the drowned valley (Fig. 3,11). It is 1300 feet long and is located approximately $\frac{3}{4}$ of a mile S.W. of the Mount. The strike is more or less north/west-south/east. The average mean diameter of the samples, obtained by screening, is 2,52 phi and has the same dimensions as for traverses 12 and 14. The standard deviation is greater and has a value of 0,15 phi. This great variation is entirely due to the combination of the coarser samples of traverse 5 (N.W. part) with the finer samples from traverse 6 (S.E. part, Fig. 3,11B). Sorting of individual samples is good; the mean standard deviation is 0,27 phi. Samples from traverse 5 tend to be slightly less sorted than for traverse 6. This feature is further emphasised by the first and second skewness, both of which are negative and indicating an asymetrical distribution towards coarser sizes (Fig. 3,11C). The size distribution does not appear to have any relation with the contour lines of the bedrock depression.

The tin content of this traverse is in general high. Within the traverse it is higher for the north-western part, and it reaches a maximum towards the middle of the sample series. In terms of relative available tin content, the data give a rather inconsistent distribution (Table 3,10) and samples and fractions can not be compared with each other.

FIG 3,11


TRAVERSES 5 and 6

grain size distribution and tin content

In Section 2 an eddy current was postulated, to which reference was made in the general discussion at the beginning of this chapter. This current crosses the traverse near or at its north-western end. South-east of the traverse location the main tidal current is postulated to exist which has an opposite direction. It seems likely, therefore, that the eddy current decreases in transport capacity in south-easterly direction along the traverse, which results in finer and better sorted sediment towards traverse 6.

Table 3,10 Absolute and relative tin content of traverses 5 and 6

Sample number	minus 200 mesh		minus 150 mesh plus 200 mesh		minus 100 mesh plus 150 mesh	
	ppm Sn	rel.av.Sn	ppm Sn	rel.av.Sn	ppm Sn	rel.av.Sn
			Traverse 5			
561041	20,000	690	700	1510	10	210
561042	20,000	770	550	1420	10	280
561044	23,000	830	600	1040	10	320
561046	28,000	800	500	1280	10	270
561048	20,000	430	875	2420	35	1020
561050	20,000	760	1375	4100	35	890
561052	30,000	870	750	2340	25	460
			Traverse 6			
561053	20,000	450	850	2830	15	540
561061	14,000	250	250	1090	10	610
561059	20,000	540	310	1370	10	450
561057	13,000	230	225	700	20	760
561055	18,500	470	770	2950	15	660

The decrease in the relative available tin of the minus 200 mesh fraction towards the south-east is caused by the increase of the proportion of equivalent light material (Fig. 3,11B) without an increase in absolute tin content. Maintaining hydraulic equivalence as a working basis, one must therefore conclude that the tin content of this fraction in the north-western part represents a form of concentration. This observation can be interpreted in either of two ways:

1. in this part of the traverse there is too little light material of minus 200 mesh size, or
2. for this part of the traverse there is an additional source of tin in this size.

The first interpretation seems illogical as there is already a higher weight per cent of the minus 200 mesh fraction for traverse 5 as compared to traverse 6, while the amount of light material required to dilute the tin content sufficiently, would result in a much smaller average diameter of sediment for traverse 5 than for any of the other traverses.

The second interpretation will be considered later as there is additional supporting evidence.

The tin content of the 150 to 200 mesh fraction, which occurs to a substantial amount as polymineral grains (Table 3,7) resulting in an overall high hydraulic ratio, decreases as well in south-easterly direction. This is considered to be due to the form of transport of the fractions concerned. Light material of

150 to 200 mesh size is easier transported near the north-western side as reflected by the increasing proportion of this size in south-easterly direction. The heavy mineral content of this fraction as well as the equivalent light material are not as easily transported and their quantity decreases towards traverse 6 (Fig. 3,11A, B). Relative availability is and should remain of comparable magnitude. The outstanding values of samples 1048 to 1053 will be discussed later.

For the 100 to 150 mesh fraction relative available tin increases in south-westerly direction, while differences between this fraction and the minus 200 mesh fraction decrease in that direction. The lower results for traverse 5 are due to the greater proportion of equivalent light material in the samples as expressed by the larger mean diameter of the sand. The tin content for this fraction appears therefore too low. However, variation in analytical results will especially affect this fraction which makes a discussion difficult. Far more important are the high relative availabilities for the samples 1048 and 1050.

For the 150 to 200 mesh fraction these samples have high relative and absolute tin content as well, while the adjacent samples for this fraction (1052 and 1053) have a similar tendency. For the minus 200 mesh fraction relative available as well as absolute tin reaches a maximum in sample

1052, while it has been concluded previously that for the whole of traverse 5 values must be considered as high. Maxima in the successive fractions are displaced from coarse to fine in south-easterly direction.

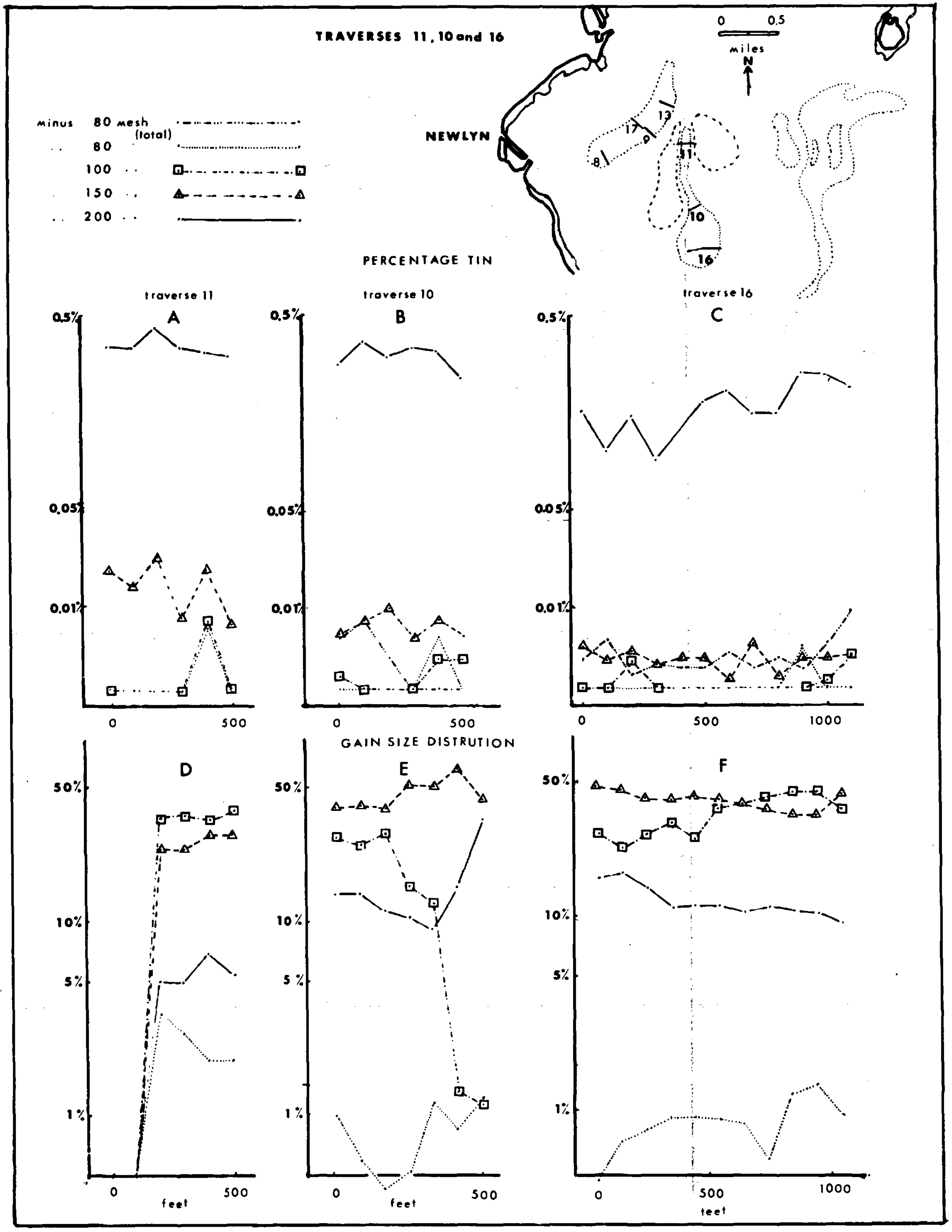
Accordingly, it is concluded that for these traverses there exist as well an additional local source of tin, which is probably located to the north of the traverse. Two aspects may support this conclusion. Firstly, Ong (1966) has found an anomalous high tin content in a sample just north of the traverse location. Secondly, just north of the traverses rocks occur, found during the tracer experiment. Their background radioactivity is as high as the rocks of St. Michaels Mount and may, therefore, have a granitic composition. Their strike is north-easterly and they are about 600 to 800 feet long.

The combination of variable currents, variable grain size distribution, tin as cassiterite and in polymineral grains as well as plural sources make any interpretation extremely difficult and if further work is carried out in Mounts Bay, the area south-west of the Mount should have the highest priority.

Traverses 11, 10 and 16

A second, less pronounced valley occurs more to the west of the Penzance/Marazion sand body. From its location (Fig. 3,12) it appears that this valley may be related to the Newlyn River.

FIG 3,12


TRAVERSES 11, 10 and 16

This relationship should be seen in the form of a tributary valley, rather than the main valley, which occurs more to the south-west. Three traverses have been laid out over this valley, all of which have been subject to screening and tin analysis. As the tin content of the traverses has certain features in common, the size distribution of individual traverses will be discussed first, followed by a combined discussion on the tin distribution.

Traverse 11, the most northerly one (Fig. 3,12), is 500 feet long. Both extremities are located on rock outcrops which appear to be slates. The sediment is characterised by an increasing amount of coarse shell fragments towards the western side of the traverse, resulting in very little material finer than 80 mesh in the last couple of samples. On average, the shell fragments count for more than 50% of these samples. It is of interest that divers reported not only a depression as compared to the level of the rock outcrops, but also a distinct drop in temperature. Apart from shell fragments, which give the samples of this traverse a coarse and unsorted nature, angular slate fragments occur in many samples.

The average mean diameter of the sediment is 2,11 phi (excluding the most westerly samples) while the average standard deviation is 0,5 phi units.

Traverse 10 is located approximately 0,5 miles further in an offshore direction. Its total length is 700 feet. Contrary to traverse 11, its shell content is much lower and comparable to the rest of the bay (circa 15%). The size distribution and sorting is also of the same order of magnitude as for other traverses. The average mean diameter is 2,51 phi with a standard deviation of 0,26 phi units. The most easterly sample of this traverse is extremely fine; the weight per cent of the minus 200 mesh fraction is 42,2% which makes this sample by far the finest of the bay. As this sample stands on its own, no conclusions can be based on this features.

Traverse 16, located another 1500 feet further towards the south, is 1100 feet long. There exists a slight but persisent tendency towards coarser sand in an easterly direction (Fig. 3,12C). Nevertheless, the sediment as a whole has a similar mean diameter and standard deviation to the other traverses; 2,44 phi and 0,28 respectively.

Regarding the tin distribution, figure 3,12A, B and C show a distinct decrease in tin content in an offshore direction. This could be expected with the overall terrestrial origin for tin in the surface sediments. The hydraulic ratios, however, vary considerably from fraction to fraction as well as from traverse to traverse (Table 3,11). Within fractions of a given traverse, relative availabilities compare well (not presented in the table).

Table 3,11 Average absolute and relative tin content of traverses 11, 10 and 16

Traverse number	minus 200 mesh		minus 150 mesh plus 200 mesh		minus 100 mesh plus 150 mesh	
	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn
11	3,300	280	160	1,875	10	80
10	3,000	500	90	4,470	10	340
16	1,620	225	35	2,350	15	650

Samples 561133, 561135 and 561111 have not been included in the table. The first two (traverse 11) because too little material was available for weight per cent determination, while the third one (traverse 10) has so much fine material that it should be further subdivided to obtain accurate results.

In terms of relative availability, the tin content of the minus 200 mesh fraction of traverses 11 and 16 is in close agreement with the previous traverses. The relative tin content for this fraction in traverse 10, however, is twice as high and it compares only with the traverses located close to the shore. The high relative available tin content for the 150 to 200 mesh fraction has already been explained to some extent by table 3,7, where analytical results indicated that for traverse 16 a substantial amount of the tin occurred in the fractions lighter than 4,1 s.g. Although no analyses have been carried out on the same fraction of the other traverses, similar results are obtained by calculations. If one takes for instance traverse 10 and decreases the relative availability of the 150 to 200 mesh fraction to the level of the other fractions of this traverse, i.e. by a factor of 10 (450 instead of 4470) the absolute amount of tin is 10 ppm. The actual amount measured is 90 ppm Sn. Consequently, pure cassiterite seems to form 11% of the total tin content in this fraction. However, this does not explain the great variation in results for this fraction in different traverses. A certain variation may be due to the fact that the density of the polymineral grains may vary which affect the calculations accordingly, but the difference between, for instance, traverse 11 and 10 is almost three-fold. In addition, higher values for traverses 10 and 16 may be caused by the eddy current on the way as outlined in the general discussion (concentration of tin in this fraction due to the different form of transport of material smaller and greater than 0,18 mm). The path of this current is postulated to occur near traverse 10. However, there is no real satisfactory explanation for this feature. Local sources can be disregarded as anomalous values occur in one fraction only, while the absolute tin content is low and constant for the traverses (Fig. 3,12).

Traverses 17 and 9

These traverses, which are co-linear, occur approximately 0,5 miles south-east of Penzance. The sediment over which **they** are laid out, forms a more or less isolated body in excess of 20 feet thick.

Only 9 selected samples have been used for grain size analysis. They indicate that the sediment once more is extremely uniform. The average mean diameter is 2,72 phi with a standard deviation of only 0,01 phi. Variation from sample to sample is negligible as well; the individual standard deviations are 0,28 ± 0,01.

Absolute and relative tin content of the samples used for screening are presented in Table 3,12.

Table 3,12 Absolute and relative tin content of traverses 17 and 9

Sample number	minus 200 mesh		minus 150 mesh plus 200 mesh		minus 100 mesh plus 150 mesh	
	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn
			Traverse 17			
561268	4,000	190	110	550	10	1,560
561266	5,500	200	110	500	10	1,030
561260	4,650	110	180	700	20	1,780
561256	3,500	140	80	330	10	1,580
			Traverse 9			
561097	5,600	150	135	330	10	270
561099	3,500	140	125	330	10	400
561101	3,250	180	185	700	10	594
561105	4,000	200	135	500	10	770
561109	3,250	150	85	380	10	400

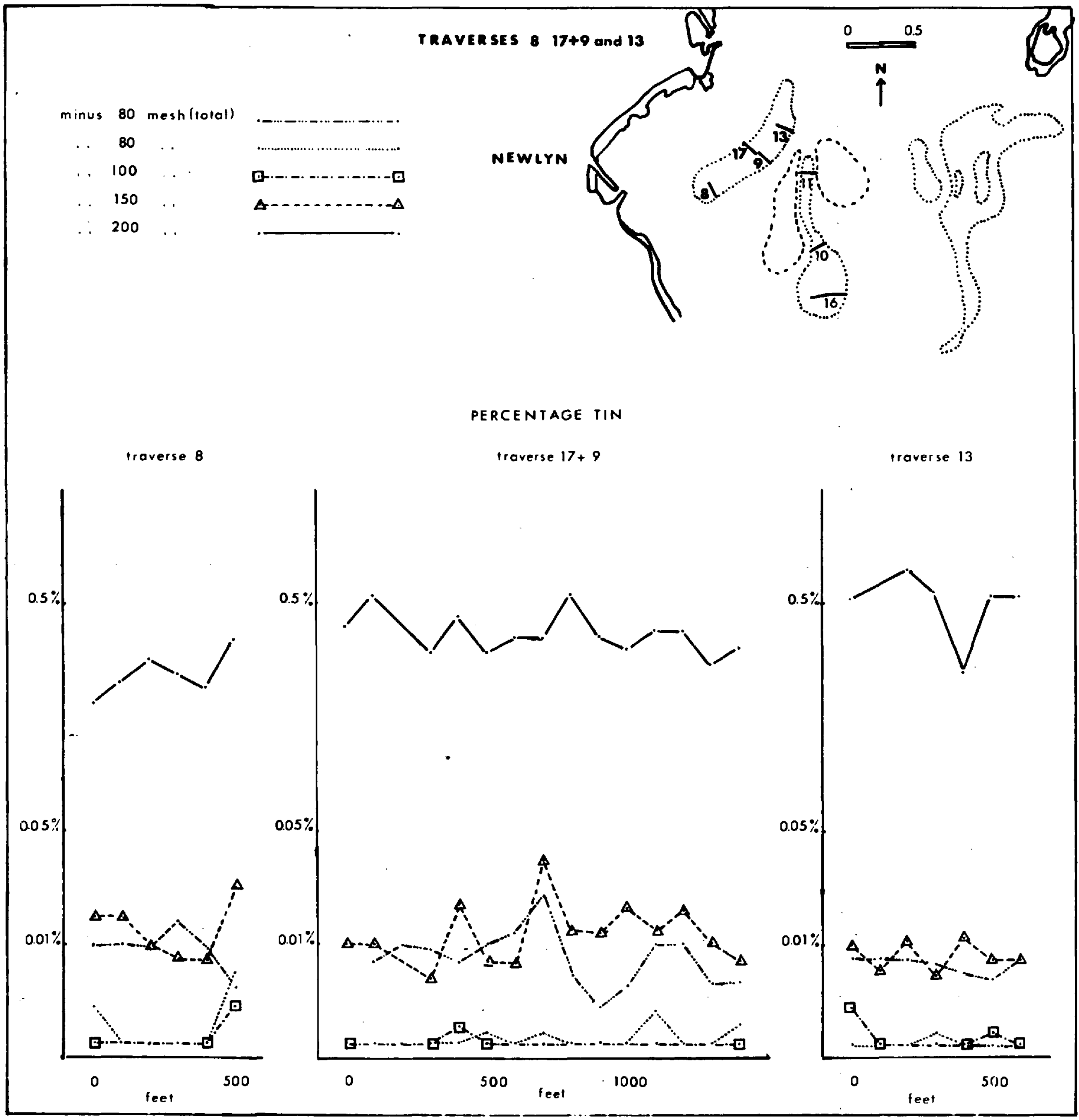
As can be seen from the table, relative availability for the minus 200 mesh fraction remains constant. Furthermore, it is lower than any of the other traverses. Based on the previous discussions, it is therefore concluded that the tin of this size is from terrestrial origin, while its distance from the source is greater than for the other traverses, in or outside the eddy system. The only source which can possibly affect all traverses is Marazion River (see discussion on traverses 8 and 13).

The relative tin content of 150 to 200 mesh fraction is higher than for the previous size fraction. The explanation for this has been given in the discussion on tables 3,6 and 3,7.

The relative available tin in the coarsest fraction is rather puzzling. Although values for traverse 17 are probably due to a large percentage of tin in non-cassiterite form, the far lower results of traverse 9, which forms no more than an extension of traverse 17, are not understood. Even with an additional source affecting traverse 17 only, one would expect a gradual decrease rather than a sharp distinction in the relative amount of tin. Grain size distribution of the light material of both traverses remains the same.

It should, however, be emphasised that a small variation in ppm content and weight per cent determination of the light fractions causes appreciable variation in the relative availability as compared to other fractions.

FIG 3,13


TRAVERSES 8 17+9 and 13
minus 80 mesh (total)
. . 80 . .
. . 100 . .
. . 150 . .
. . 200 . .
NEWLYN
0 0.5
N
8
17
9
13
11
10
16
PERCENTAGE TIN
traverse 8
traverse 17+ 9
traverse 13
0.5%
0.05%
0.01%
0
500
1000
feet

Traverses 8 and 13 (Fig. 3,13)

Both traverses are 600 feet long and are located on the extremities of the same sand body as traverses 17 and 19. The grain size distribution for traverse 8 is slightly finer (average diameter is 2,83 phi) than for traverse 13 or 17 and 9 (average diameter of 2,73 phi). Sorting in individual samples, however, is equally good, as both standard deviations are similar; 0,30 and 0,28 respectively.

Absolute tin content is of the same order of magnitude as for the other two traverses over this sand body, but relative tin content varies (Table 3,13).

Table 3,13 Average, absolute and relative tin content of traverses 8 and 13

Traverse number	minus 200 mesh		minus 150 mesh plus 200 mesh		minus 100 mesh plus 150 mesh	
	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn
8	1,750	220	150	1,150	15	1,400
13	5,500	260	75	340	10	1,280

(data is based on selected number of samples only)

The above data is in agreement with results of the previous traverse within the eddy. For the minus 200 mesh fraction the relative tin content is the same, although the absolute tin content of traverse 13 is three times as high as for traverse 8.

The high relative available tin for the 150 to 200 mesh fraction of traverse 8 is due to the substantial amount of tin in polymineral grains (table 3,7). Nevertheless, it is not completely understood why the same fraction for traverse 13, which afterall also occurs in the eddy, does not show a similar tendency.

Before discussing the 100 to 150 fraction it is of interest to note that, with respect to traverses113, 17 and 9 and 8 relative tin of the minus 200 mesh decreases from traverse 13 via traverses 17 and 9 to traverse 8. This indicates probably a source for this size of tin north from traverse 13. For the 150 to 200 mesh the reverse is true, and is emphasised by the relative tin of this fraction. Consequently, it appears that for this size there is an additional source in the south to south-west. The fact that relative tin decreases far quicker than the absolute tin may indicate that the decrease in tin is dominantly caused by a decrease in the proportion of tin in polymineral grains.

A second explanation which may be partly responsible or serve as an alternative, is concentration in this fraction by the current. This will be less towards traverse 13, as this traverse is located more towards the centre of the postulated current path. Results of the 100 to 150 mesh fraction once more suggest a substantial amount of tin in polymineral mode for these fractions, although this is not tested by heavy mineral separation.

The low results of traverse 9 become even less understandable with the results of traverses 8 and 13.

It is of interest that high values for this fraction are restricted to the most westerly traverses and may also point towards a source of polymineral grains in this direction. Further discussion on this suggestion will follow after the discussion on traverses 1 and 2 which have relevant evidence.

Traverses 1 and 2

Discussion on these traverses has been postponed until now, as they form by far the most complicated ones. However, conclusions based on data of these traverses are relevant to all the previous traverses.

The traverses are co-linear and located close to the shore, with right angles to the Penzance promenade (Fig. 3,14). Its total length is 1500 feet and includes 30 sample locations, ranging from the low water mark to a depth of 15 feet. The main purpose of this traverse is to establish the dispersion pattern of tin in relation to a known mineralisation. Parallel to, and ± 500 feet from the low water mark, an elvan dyke occurs which has been mined for tin as early as the late 18th century. The richness of this mine is illustrated by the fact that up to 1830, when the mine collapsed, the total output was in the order of £70,000 (Russel, 1939). Re-examining of the elvan dyke is presently undertaken by Amalgamated Roadstone.

Located so close to the shore, the area under consideration is subject to a number of mechanical processes, affecting the size distribution of the sediment. They can be divided into (i) wave action, and (ii) tidal action.

Wave action can be further divided into a number of idealised individual processes; waves in deep waters, waves in shallow water (solitary waves) and breaking waves. Apart from "primary" wave action, a "secondary" action will be induced by reflection against the promenade wall and the rock outcrops which flank the traverse. Although tidal action will be discussed later, it may be mentioned here that one of the effects, the rise and fall of water level, will result in a continuous variation in wave action location.

The action of a wave, described in terms of wave length L, wave height H, and wave period T, has been expressed in simple, idealised mathematical functions (King, 1961, Sheppard, 1963). However, the whole sequence of wave action is extremely complex. Most workers, therefore, have approached near shore processes from an experimental point of view (Ingle, 1966). Consequently, it is proposed to limit the discussion to broad lines only.

A wave is in principle a mass of water, in which the individual water particles perform an orbital movement. The orbital diameter of this movement, which tends to be open (i.e. a spiral rather than a circle) in the direction of the wave propagation, is equal to the wave height at the surface. It decreases exponentially with distance below the surface and becomes zero at a depth equal to the wave length. Being open circles, there is a net horizontal movement of which the velocity depends on the orbital diameter and wave period. The above process is called the effect of a deep water wave. (Deep, intermediate and shallow in this context are commonly defined in terms of the ratio of water depth versus wave length; deep water wave is $\frac{H}{L} > \frac{1}{4}$, intermediate wave is $\frac{1}{20} < \frac{H}{L} < \frac{1}{4}$ and shallow wave $\frac{H}{L} < \frac{1}{20}$)

While advancing, the wave reaches water of intermediate depth and eventually enters into shallow water. During this process, wave period and to a certain extent, the energy, remain constant. Wave length and height however, change. The waves alter into a so called solitary wave, and wave height becomes a significant proportion of the total water depth. The orbital movement changes from an open circle to an ellipse, with the largest diameter horizontal.

The maximum horizontal velocity at the bottom is half the horizontal component of the orbital velocity at the surface. The acceleration landwards takes place with the passage of the crest, while the rough shows a slight reverse flow to compensate the water mass which is transported onto the shore. Finally, when depth of water is equal to wave height, the orbital velocity becomes equal to the wave phase velocity, the crest advances faster than the lower part and the wave forms a breaker.

The main interest for the purpose of this study is the resulting bottom velocity of the above processes. In deep water, the wave induced current is a function of orbital velocity and wave phase velocity. In the intermediate and shallow depths however, this Stokes relation does not hold anymore. It has been shown, both experimentally (Bagnold, 1947; Russel and Osario, 1957) and theoretically (Longuet-Higging, 1953) that in this depth range the forward movement is restricted to the surface and bottom, whilst a reverse flow exists in between. Provided the wave dimensions are known, it is possible to calculate the actual resulting bottom velocity which has an inshore direction. However, a series of "secondary" wave actions will have a compensating effect.

In the vicinity of the Wherry mine, waves approaching the coast, will be reflected against the Wherry rock at least at low tide, resulting in an adjustment of the orbital movement and consequently of the induced currents. The effect of the reflection depends, apart from wave dimensions, on the angle of the wave train approach.

Secondly, there is the effect of the Penzance promenade wall. Apart from low tide itself, the waves reach the promenade wall before they break. If the wave orthogonal is at right angles to the shore, little energy will be lost during reflection, and the reflected wave will interact with the primary wave. This will form a clapotis (standing wave) resulting in no more than a rise and fall of the wave crest. If, however, there does occur a loss of energy (i.e. the water is too shallow for perfect reflection), the smaller reflected waves pass through the primary ones, and obstruct the currents induced by the primary wave. When the orthogonal is not at right angles to the wall, a diagonal crest pattern develops. It will be appreciated that the resulting bottom velocity is difficult to establish.

A third effect of wave action is the so called rip-current. Accumulation of a water mass through wave action will induce a longshore current, which periodically results in a seaward directed current; the rip-current. As mentioned earlier, the area under consideration is flanked by rock outcrops. The only location for a rip-current is along the line of the traverse. Because of the configuration of the rocks and bottom, longshore currents induced by waves can be largely ignored. Any rip-current will develop mainly as a result of waves breaking over the outer rocks (the elvan dyke) and only be able to return to the sea via the channel between the rock outcrops.

The force of the rip-current is considered to be proportional to the stage of the tidal cycle. At low tide, few waves break over the rocks, resulting in a small rip-current, while at high tide great quantities of water flow over the rocks. The significance of this current probably decreases sharply when it leaves its predestinated path between the rocks and is able to disperse. To clarify the effect of all these processes, it is useful to consider the situation within a wave of given dimensions at various stages of the tide.

For this purpose, a wave with a length of 60 feet and height of 4 feet will be chosen. It is also assumed that the wave orthogonal is at right angles to the shore, in order to avoid complexity of reflection patterns. At neap tide, the wave will effect the bottom at a depth of half a wave length i.e. 30 feet. The orbital diameter at the bottom is only 4 per cent of the wave height. At a depth of 15 feet (intermediate depth) the orbital diameter is still only 20 per cent of the weight height. From now on the wave drift current will increase noticeably with decreasing depth and at 10 feet the onshore velocity of the bottom current will be in the order of 0,25 ft/sec. In the meantime, being in the intermediate and shallow zone, a reverse flow between top and bottom will come into existence.

At a certain location, the inshore current will be met by the offshore rip-current and the former ceases to exist. Bringing into account the tide, the whole process will be shifted inshore as water depth is the main criterium. However, the location where inshore and offshore currents meet each other will still be the same; the rip-current gains in strength during the incoming tide. With the outgoing tide the rip-current will have a decreased significance, but may be compensated for by the ebb itself. In other words, regardless of the state of the tide, there is a fixed location where opposite currents will meet. The net effect will be determined by the phase of the tidal cycle.

It will be appreciated that the above discussion is essentially an over simplification of a complex process. However, it enables an interpretation to be made of the grain size distribution and tin dispersion of traverses 1 and 2.

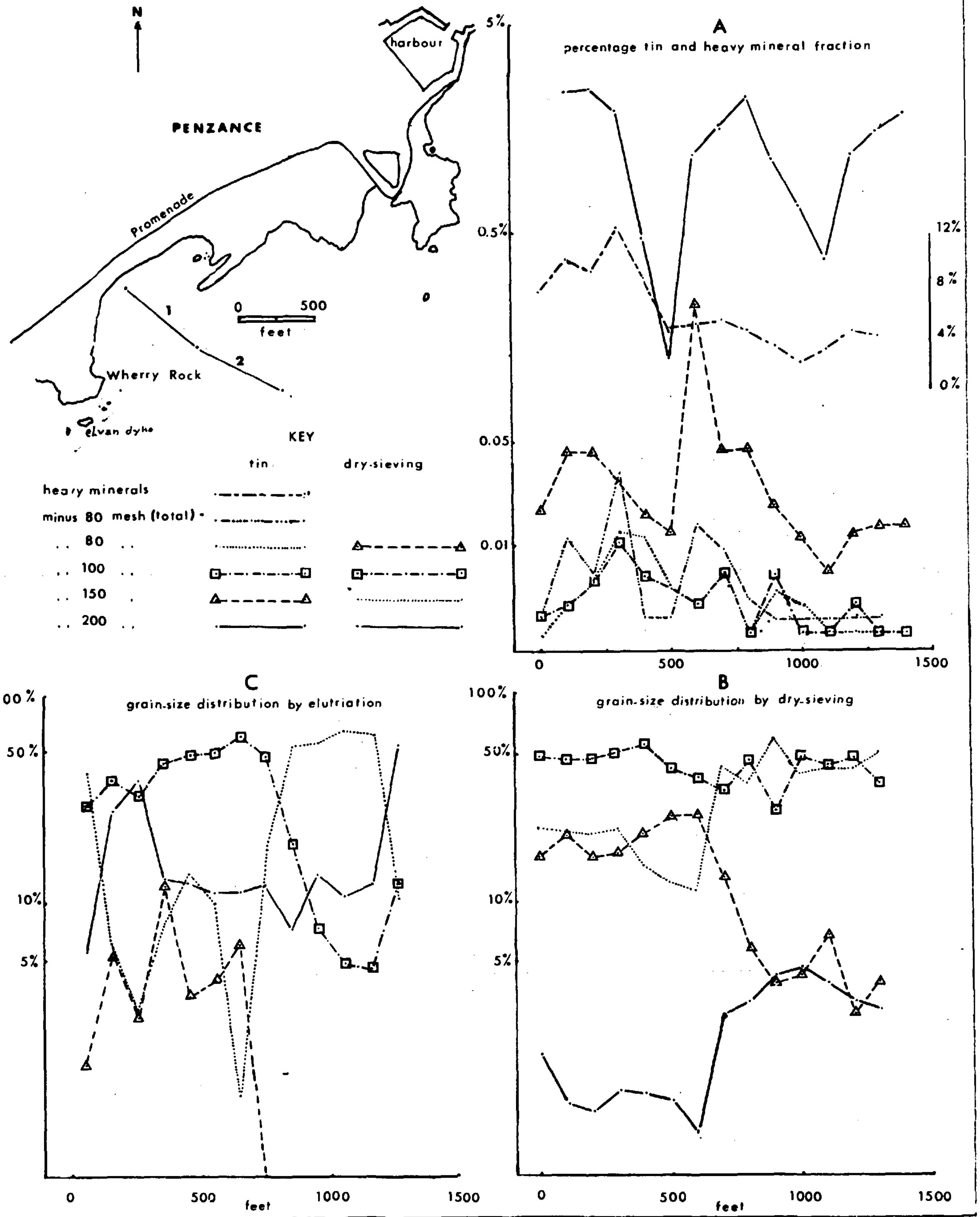
Grain size distribution as obtained by screening is presented in figure 3,14B. Towards the sea (from left to right), the weight per cent of the coarsest fractions increases gradually up to 600 feet. At the same time, the quantity of all other fractions decreases. Comparing the mean diameter of successive samples, there exists a clear tendency towards coarser sediment. This feature reaches a maximum at 600 feet where the sample has a mean value of 2,13 phi. This is the coarsest of all surface samples collected in western Mounts Bay (neglecting samples distorted by shell fragments) and is well above the threshold for the bay as a whole.

The next sample, beyond 600 feet, has a mean value of 2,73 phi. In other words, there is a difference of more than half a Wentworth division between these two samples. The weight percentage of the two finest fractions increases from 6,8% to 47,8%. The dominance of these two fractions is maintained and increases even to 78% at 1000 feet, where the sample has a mean diameter of 2,83 phi. This is anomalously fine for the bay. Beyond 1000 feet the amount of the fine fractions decreases slowly.

FIG 3,14

TRAVERSES 1 and 2 ; WHERRY MINE

grain-size distribution and tin content.



The interpretation is as follows. The offshore rip-current which gains in strength on its way out, is able to transport more and more material, leaving behind increasingly coarser material. At 600 feet, which is just outside the line connecting the most offshore rock outcrops, it meets the incoming wave drift current, disperses and discharges part of its transported material. From there on, the finest material will be carried further by the reverse flow at intermediate depths. However, the deeper the water the less significant this current and fine material settles. The effects of this latter current on this location depends on the state of the tide. Consequently, the area over which fine material is deposited is a wide zone rather than a fixed location.

At first sight, the tin distribution along this traverse appears to be rather inconsistent. The total 80 mesh undersize fraction shows two peak values, one at 300 feet from the beginning of the traverse and the other at 600 feet, separated by two samples with very low values. The minus 150 plus 200 mesh fraction only shows one peak of 2,250 ppm Sn which is well above the threshold for this fraction. On the other hand, there does not exist an anomalous feature at 300 feet, as would be expected on the basis of the 80 mesh undersize fraction. The two coarsest fractions on the other hand, are distinctly higher at this location compared to the rest of the bay. The minus 200 mesh fraction has a peak value of 3 per cent at 800 feet. More distinct, however, are the two "negative" anomalies at 400 and 1000 feet.

Calculations of the hydraulic ratios of the tin in individual fractions (Table 3,14) on the other hand shows a more regular distribution. With respect to the minus 200 mesh fraction, relative availability of the samples 1003, 1005, 1007, 1025 and 1027 is of the same order of magnitude as most other traverses. This indicates that the absolute tin content of these fractions conforms to the size distribution of the sediment. The relative tin content of the samples 1013, 1015 and 1017, on the other hand, show that the absolute tin content in the minus 200 mesh fraction of these samples is too high in terms of hydraulic equivalence. The two "negative" anomalies remain, although the one at 1000 feet decreases in significance.

The minus 150 mesh plus 200 mesh fraction is even more interesting. The tin distribution for the first four samples is normal, followed by a deficiency as in the minus 200 mesh fraction. The peak value of sample 561013 decreases considerably, while the following four samples show that their absolute tin content has to be considered as anomalously high with respect to the distribution of the light material. The last samples have a high relative availability as well.

The minus 100 mesh plus 150 mesh fraction has a similar distribution; a deficiency at 500 feet and an anomaly between 700 and 900 feet. The last four samples are also somewhat high.

Table 3.14 Absolute and relative tin content of traverses 1 and 2

Sample number	minus 200 mesh		minus 150 mesh plus 200 mesh		minus 100 mesh plus 150 mesh		feet from 561001
	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	
561001	23,000	340	175	230	25	320	
561003	23,000	340	410	210	35	200	
561005	24,375	310	410	270	65	320	200
561007	20,000	320	310	390	100	710	
561009	4,375	75	175	135	65	500	400
561011	1,250	25	135	70	50	160	
561013	12,000	160	2250	850	35	86	600
561015	21,500	750	410	1330	70	1300	
561017	30,000	1070	450	2930	12	300	800
561019	10,400	500	200	3000	65	1280	
561021	6,750	360	130	1330	10	450	1000
561023	3,800	175	70	430	10	720	
561025	12,500	420	135	2160	10	890	1200
561027	15,000	475	150	1380	10	650	

In summary, one can say that by computing the hydraulic ratios, some order is brought about in the tin data. It emphasises a common minimum, while anomalous values are brought together and eliminates to a certain extent the scattering as shown by the absolute data.

The constant hydraulic ratio of the first four samples in all fractions indicates that the distribution of the tin is similar to the size distribution of the light material. The following two samples maintain a constant hydraulic ratio although the relative availability is much lower. This is a similar situation as for traverse 12. However, it is impossible to apply the same explanation as for that traverse. Additional supply of light material is contradicted by the postulated current which increases in velocity in an offshore direction, as reflected by the coarser material. Therefore the only possible source of such material should be located further inshore from the samples 561009 and 561011. Removal of light material would result in an increased relative availability for the first four samples. This is not the case. Fractional removal of tin by direct transport seems very unlikely. Consequently, the only alternative that remains is fractional removal by vertical dispersion. For the whole traverse this is the best location for such a process, as the rip-current velocity varies constantly with the tide. It may be significant that the relative availability is the least for the minus 200 mesh fraction, which in consequence of its size may filter through easier than the coarser fractions.

From sample 561013 onwards, the relative tin availability increases for all fractions, with a maximum at approximately 800 feet (sample 561017). The increase is not of the same order of magnitude for individual fractions. Consequently, there is no hydraulic equivalence between the fractions, and one has to postulate an additional source of tin at this location. Alluvial placers can be disregarded as no river has ever discharged at this point. Elluvial supply seems to be the alternative, for which the Wherry mine is the best evidence. Beyond the 800 foot sample, relative availability decreases for the minus 200 mesh fraction to values similar to the inshore part of the traverse. For the minus 100 plus 150 mesh fraction this decrease is not so marked but is still apparent. The relative available tin of the minus 150 plus 200 mesh fraction, however, remains high and irregular.

As will be remembered, there is an overall offshore movement of sediment along this part of the traverse, induced by the rip-current and wave action at intermediate depths, while a less significant inshore bottom movement exists outside the 600 feet mark. Consequently, material introduced at the postulated source point will disperse, dominantly in an offshore direction. Not knowing the availability of tin in the source material, it is no surprise that the relative available tin from fraction to fraction is all but constant at and near the postulated point of introduction. It is, however, surprising that no constant hydraulic ratio exists within a given fraction. The environment of this traverse afterall is clearly affected by an active transport system, as expressed by the grain size distribution of the light material and the relative availability of the minus 200 mesh. The latter, while slightly higher than for the inshore part of the traverse, regains a constant value very soon beyond the postulated point of introduction.

If one compares, for instance the 150 to 200 mesh fraction of samples 1003, 1005, 1015 and 1017 their absolute tin content remains constant. The relative availability of tin, however, is far greater for samples 1015 and 1017 as compared to 1003 and 1005. It appears, therefore, that the ratio of cassiterite versus tin in polymineral grains increases towards samples 1015 and 1017. It is of interest that the heavy mineral content of the 80 mesh undersize for sample 1003 is twice as much as for sample 1015, which seems to support the suggestion that more tin occurs in lighter fractions for the offshore part of the traverse.

Accordingly, it is concluded that the high and inconsistent relative availability in samples of the seaward extension of the traverse is largely due to the introduction into the sediment of tin of another nature than cassiterite. The mineralogical aspects of the multimineral grains and the effect of varying tin content on density, which is held responsible for the great variation of hydraulic ratios, is a research project in its own right and largely beyond the scope of this thesis. If any further research is carried out, this aspect should get the highest priority.

It is very unfortunate, that the traverses have not been extended further offshore. In the first place, it would have been interesting to study the changes with distance from the source. Secondly, the effect of the longshore eddy current would have been extremely relevant to the results of the previous traverses. The similarity in problems of traverse 2 and other traverses within the eddy suggests a common solution. Whether or not this is true, is not known. Far more detailed sampling is essential, while investigations also should include a closer examination of the river sediments.

Traverse 19

In order to compare the results and discussion of traverses 1 and 2 with samples of similar physical environment, but without the complications of an elluvial source of tin, an additional traverse has been laid out. The location of this traverse was determined by the fact that the sediment should be affected by wave action, whilst in addition it should also be favourable for the existence of a rip-current. The only possible location within the study area is provided by St. Michaels Mount and the adjacent Hogus rock (Fig. 3,15).

Wave generated longshore currents on this particular stretch of shore line, have in general a south-easterly direction as indicated by bottom drifters (Section 2). Consequently, a rip-current will be generated during part of the tidal cycle when the causeway to the Mount is emerged. The existence of a rip-current is not only determined by wave train direction and the causeway, but also by the Hogus rock. During a few hours, before and after low tide, the beach behind the rock falls dry and any current ceases to exist. It is not possible to estimate precisely over what period of time conditions for the formation of an offshore current are present, but this will be in the order of a few hours every tidal cycle. A second difference in the environment of this particular location as compared to traverses 1 and 2, is the well developed beach profile, which enables the waves to perform a normal sequence; deep water waves, shallow water waves and breaker zone. Only at spring tides will waves be reflected against the wall protecting Marazion village.

The aim of this traverse, however, is to check the results of the previous traverses. It was, therefore, decided to avoid the complicated processes of breaking waves, by locating the traverse outside the zone of breaking waves at low tide. The total length of the traverse is 1000 feet. The sample interval is 50 feet. Due to frequent rock outcrops on the bottom it was impossible to obtain a continuous series. The depth varies from 6 to 19 feet at low tide.

With respect to grain size distribution, a similar tendency seems to exist regarding the sequence coarse to fine sand as for traverses 1 and 2. The mean diameter of the sediment increases in an offshore direction (phi values decrease) followed by a series of samples with smaller mean diameters (phi values increase). The change occurs near the 500 foot mark from the beginning of the traverse. This feature, however, is far less outstanding as compared to the previous traverses; the maximum

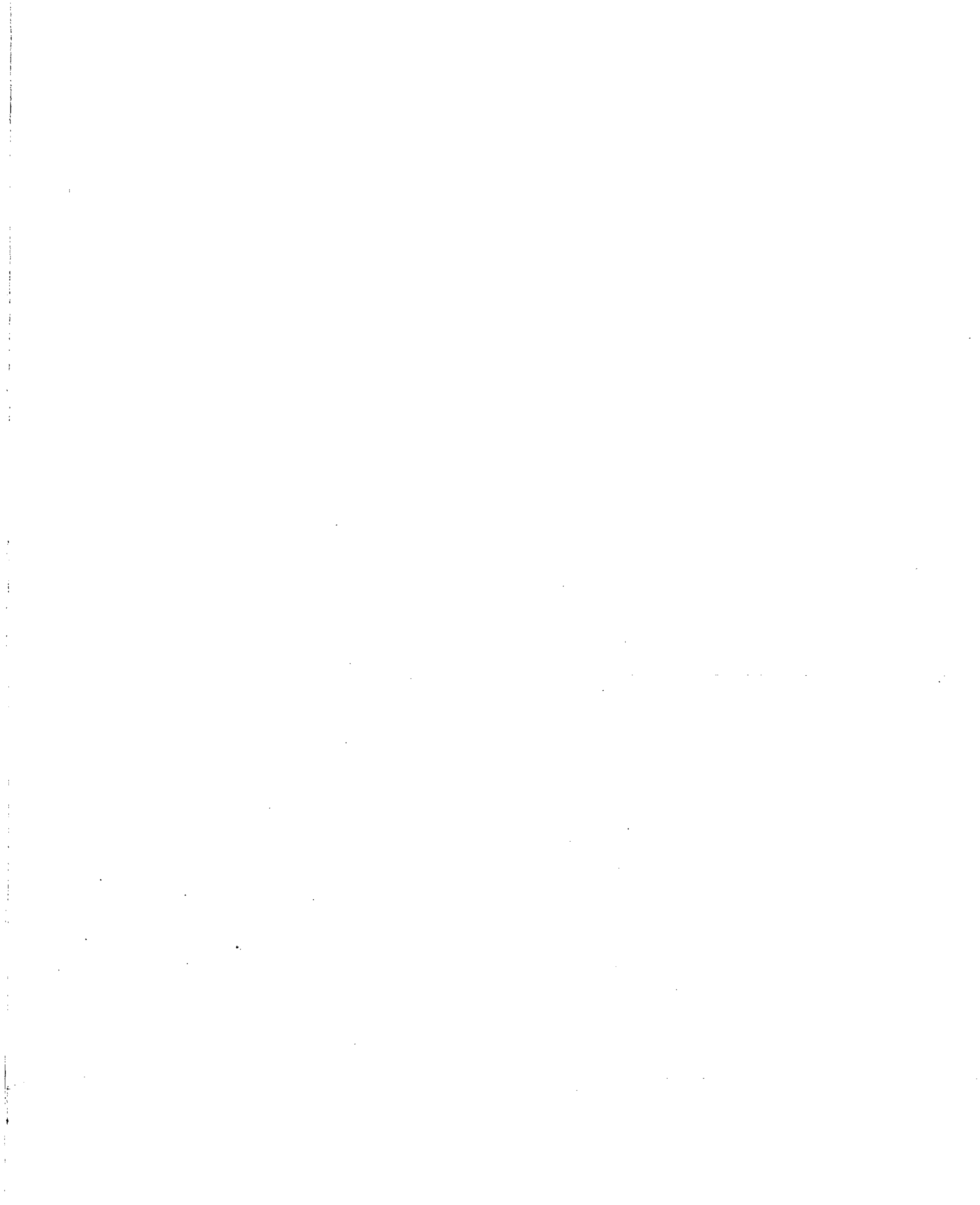
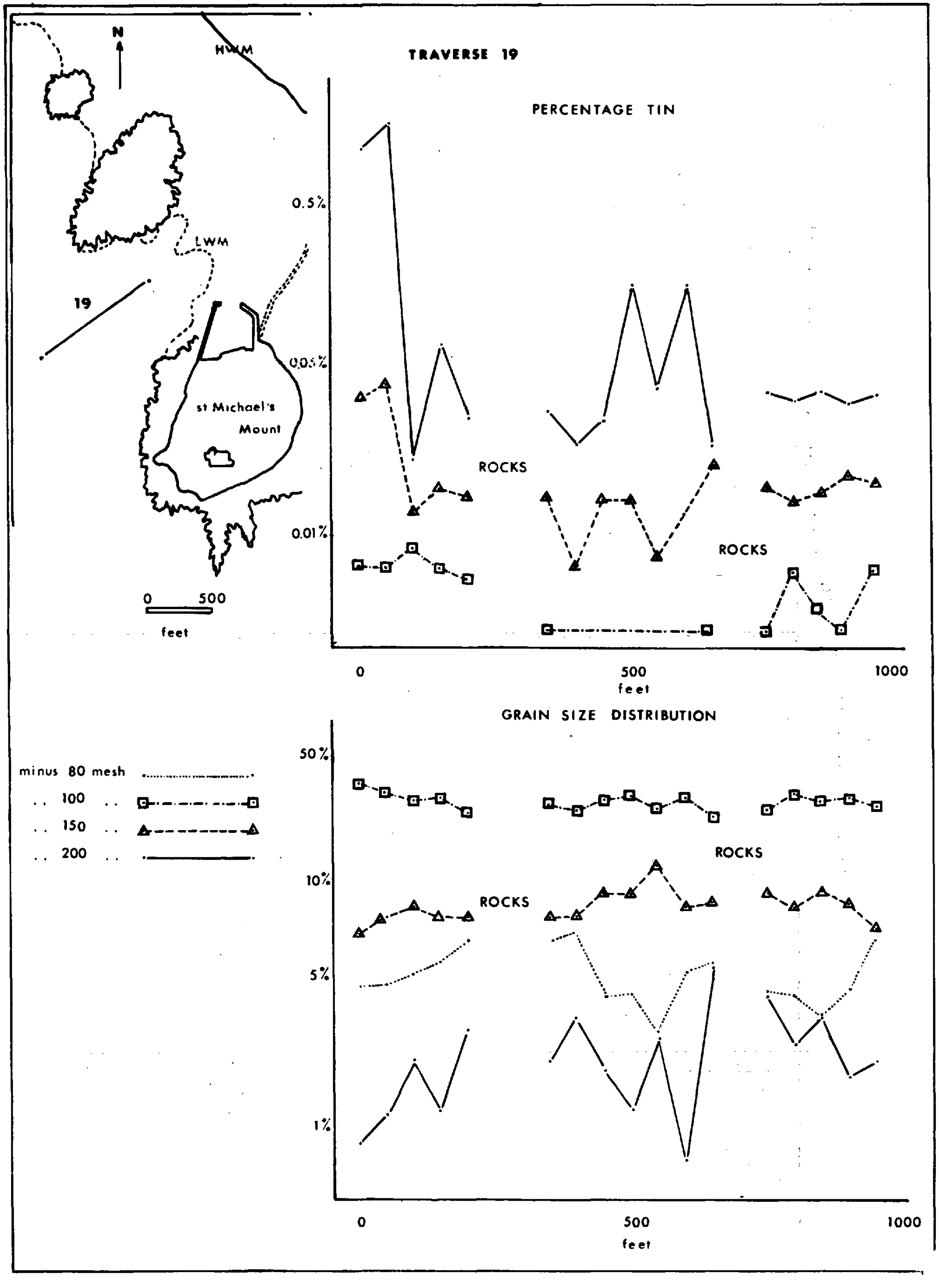


FIG 3,15



TRAVERSE 19
N
HWM
LWM
19
St Michael's Mount
0 500
feet
PERCENTAGE TIN
0.5%
0.05%
0.01%
ROCKS
ROCKS
0
500
feet
1000
GRAIN SIZE DISTRIBUTION
50%
10%
5%
1%
ROCKS
ROCKS
0
500
feet
1000
minus 80 mesh
.. 100 ..
.. 150 ..
.. 200 ..

differences between coarse and fine sand are in the order of 0,15 phi units. The mean diameter for the traverse as a whole is 2,68 phi. To interprete the results, a similar line of arguing is used as for traverses 1 and 2.

At high tide, the bottom movement, determined by wave dimensions, will be inshore. No rip-current exists as the causeway to St. Michaels Mount is submerged, although it may still provide some sort of barrier to the development of longshore currents. With outgoing tide, the effect of the waves on the bottom will increase (the water becomes shallower) but at the same time a rip-current will be generated whose significance increases with emergence of the causeway.

The inshore movement by wave induced currents will be countered by the rip-current. Similar to the previous traverse, there will exist a point where the offshore current disperses. This will occur on that location where the predetermined path of this current ceases to exist, i.e. somewhere along the line connecting the seaward side of Hogus with the nearest point of the Mount.

At low tide, no rip-current exists, and the movement at the bottom once more is inshore. The net result of the three variables; waves, tide and rip-current is far less predictable and more gradual than for traverses 1 and 2. This explains that there is not a sharp distinction between coarser and finer sand along the traverse. Furthermore, submarine rock outcrops will obstruct the effect of bottom currents on the sediment. Although less conclusive, it appears that processes explaining the grain size distribution of traverses 1 and 2 are valid as well for this traverse.

The tin distribution along this traverse (Fig. 3,15A) shows, in the first place, that for the minus 200 mesh fraction absolute tin values are at least 10 times lower than the other traverses. The other fractions appear to have a "normal" tin content. There is no evidence that the "deficiency" is explained by assuming an offshore transport for this fraction only, (for instance by means of the eddy current) as this would also affect the equivalent light fraction for which no apparent deficiency exists. More likely, low results are due to dilution by an increased quantity of light material of the same size, for which this traverse has a relatively large proportion. All these processes are mechanical ones. One may therefore expect that the relative amount of tin remains within comparable limits. This is extremely well illustrated by table 3,15.

Two very satisfying results emerge from this table. In the first place, high absolute tin contents for the minus 200 mesh fraction disappear completely in terms of relative tin. Secondly, for the two coarser fractions there exists a more or less common minimum. This latter feature occurs at approximately

Table 3.15 Absolute and relative tin content of traverse 19

Sample number	minus 200 mesh ppm Sn	rel.av. Sn	minus 150 mesh plus 200 mesh ppm Sn	rel.av. Sn	minus 100 mesh plus 150 mesh ppm Sn	rel.av. Sn	Distance in feet
561719	9,000	174	650	1135	65	6425	
561718	12,000	316	800	1618	10	573	
561717	300	15	155	300	35	1875	100
561716	1,200	33	210	360	65	2050	
561715	550	40	185	250	135	1400	200
561712	600	40	185	250	10	150	
561711	380	30	65	80	10	170	400
561710	600	20	175	540	10	790	
561709	2,250	50	175	520	10	600	500
561708	750	43	75	460	10	1380	
561707	2,750	48	160	310	10	400	600
561706	400	66	300	600	65	930	
561704	750	67	220	630	50	1100	
561703	700	35	175	440	65	6260	800
561702	750	50	200	790	85	6600	
561701	675	25	250	600	65	3000	900
561700	750	38	240	210	65	830	offshore

400 feet from the beginning of the traverse, which is also the location where the line connecting Hogus and the Mount crosses the traverse. As will be remembered, it was postulated that at this location the rip-current reaches its maximum after which it disperses, and discharges its carried load. The common minimum for the coarsest fractions at 400 feet and the apparent high in the

absolute tin content for the finest fraction at 500 feet are entirely sedimentological features, confirming similar results on traverses 1 and 2.

The relative availability of the minus 100 plus 150 mesh fraction is very erratic and is higher for the offshore part of the traverse. Once more, there are two possible explanations; tin could occur in the form of polymineral grains, or there is a concentration of tin in this fraction due to the difference in transport of the equal and equivalent light sizes. The first possibility lacks support in that the feature is restricted to parts of the traverse only, while differences are very great.

Concentration by currents appears more likely. Velocity of currents, either induced by waves or rip-current varies and reaches maximum values somewhere in the middle of the traverse. The decrease in velocity in offshore direction may possibly reach critical values where difference in transport of tin of 100 to 150 mesh and lights of the same size is optimal. This results in a concentration of tin as compared to that part of the traverse where transport of tin and lights of same sizes occur more in similar ways. The far more constant values for the 150 to 200 mesh tin fraction may support the above interpretation in that they indicate that current velocities for the whole traverse are high enough to transport this finer size and its relevant light fractions in the same way.

Finally, there are samples 561719 and 1718. The absolute, as well as the relative tin content, is of a completely different order of magnitude as the rest of the traverse. The grain size distribution of these samples on the other hand remains the same and compares to the other samples of the traverse. It may be possible that the samples represent a lense of heavy minerals similar to lenses encountered at beaches. This concentration at beaches is the result of wave action. Advancing waves transport material by suspension onto the beach, especially during storms and returning waves carry material by rolling, leaving behind some heavies and resulting in an impoverishment in heavies at the location where the material is picked up. However, these are beach processes, where there is an alternative to and fro movement. The samples under consideration on the other hand, occur outside the low water mark. Transport by waves increases in inshore direction and there is, therefore, no reason why transported material should be discharged at the location of the samples, since they occur outside the breaker zone.

Deposition as the result of the counter action of the rip-current may be active during part of the tidal cycle but this feature is more likely to happen where the rip-current disperses, i.e. further offshore as indicated by the grain size distribution. In addition one would expect gradual variation rather than abrupt differences. The concentration of tin in samples 1718 and 1719 as a result of present day processes seems therefore unlikely. It is, however, not entirely impossible that the tin in these samples represent a lense of heavy minerals of a foreshore beach in a very recent past. The sea level is known to have been a little lower at the turn of the century, while the depth at the inshore part of the traverse is not more than several feet.

Vertical distribution of tin

Through the generosity of Alphine Geophysics Ass., the writer was able to examine some cores from western Mounts Bay. Due to shortage of time, only three cores could be fully analysed. Two of them come from within the study area, while the third one collected near Porthleven, will serve as a comparison.

Cores 33 and 34

Core 33 is 16 feet long and samples have been taken with 1 foot intervals, with an additional sample 2,5 feet from the bottom where the sediment changed from sand to very fine sand with a thin pebble layer in between. It appears from this core, at least as far as the top 12 feet are concerned, that the Penzance/Marazion sand body is very uniform, not only laterally but also vertically. The average diameter of the top 12 feet is 2,79 phi with a standard deviation of only 0,07 phi units. Although these results are supported by samples from core 34 (average diameter of 2,65 phi), it is appreciated that two cores are not necessarily representative of probable vertical distribution, but they do provide, nevertheless, some indications.

The change of environment at 13,5 feet from the surface as indicated by the very coarse layer (mean diameter of 0,80 phi), is difficult to interprete without further information. The coarse granules are rounded to well rounded and occur at the base of the marine sediment column. It may, therefore, represent a fossil beach. If this is the case, transgression must have taken place very rapidly as the layer is thin; 1 inch, and situated on top of a very fine sand layer.

Material, forming the last two feet of the core and which occurs underneath the silt layer is of a different nature. Material is more angular and includes rock fragments. It may indicate that bedrock is not far below, but more information in the form of deeper cores and more closely spaced is essential to come to any reliable interpretation of these bottom samples.

The tin content of the samples is far less than that of the surface samples and is limited to the minus 200 mesh fractions only, at least as far as the top 13 feet are concerned. The very top samples have been ignored as the vibration during coring as well as the transport of the cores has distorted the top few inches. There appears to be an enrichment in the tin content of the minus 200 mesh fraction 9 feet below the surface. This is, however, not clearly emphasised by the relative availability which is only slightly higher. Consequently, the value of 550 ppm tin in the samples is regarded as the result of the environment of deposition.

From 9 to 13,5 feet below the surface, there is hardly any tin at all.

The coarse layer at 13,5 feet remains low for the minus 200 mesh fraction, but the coarser fractions have detectable tin.

In terms of relative available tin values are fairly constant with the exception of the 100 to 150 mesh fraction. The tin content of the last two samples increases towards coarser fractions, and reaches a maximum in the 80 to 100 mesh fraction. Values for the last sample in terms of absolute and relative tin content are consistently higher than for the penultimate sample. It is, however, impossible to say as to whether this is a form of concentration at the bottom, as one does not know if this sample represents the bottom. The only small variation in the relative tin content of the four finest fractions of the last sample, on the other hand, may indicate an environment in which hydraulic equivalence was maintained, but more data is needed to make any valid suggestion, as to what these results mean.

Core 34 recovered 8 feet of sediment. Its grain size distribution, as stated before, is similar to that of core 33. Tin content also of the same order of magnitude. The sample 6 feet below the surface has a rather high relative tin content for the 150 to 200 mesh fraction, but as neither the sample above or below has any tin in this fraction no significance should be attached to this result.

By far the most important implication of the analysis on the core samples is that the tin content of the surface samples is many times higher than for the subsurface sediments. With the size distribution of the sediment remaining the same, this is the best evidence in favour of an additional and recent supply of tin

Table 3,16 Absolute and relative tin content of tin containing fractions of core 33

	Fraction							
feet below surface	minus 200 mesh	150 to 200 mesh	100 to 150 mesh	80 to 100 mesh	60 to 80mesh	36 to 60 mesh	mean diameter in phi	
1	<20 (8)						2,94	fine sand
2	<20 (7)						2,95	
3	340 (27)						2,79	
4	90 (10)						2,87	
5	30 (6)						2,93	
6	75 (5)						2,79	
7	40 (6)						2,89	
8	250 (18)						2,72	
9	550 (33)						2,69	
10	<20 (8)						2,71	
11	<20 (10)						2,79	
12	<20 (10)						2,79	
13	<20 (4)						2,66	
13,5	<20 (17)	30 (23)	35 (60)	20 (9)	30 (10)		0,80	ganules
14	35 (13)						3,27	very fine sand
15	<20 (29)			210 (70)	105 (23)		1,65	very coarse sand
16	30 (130)	75 (70)	135 (130)	325(110)	250 (40)	35 (11)	1,50	
			Core 34					
1	<10 (9)	60 (11)						
2	225 (18)	50 (18)						
3	15 (7)	- -						
4	<10 (6)	- -						
5	<10 (2)	- -						
6	110 (5)	35 (60)						
7	100 (3)	- -						
8	175 (8)	35 (36)						

(phi values of the coarse samples refer to the minus 20 mesh undersize fraction only) which, no doubt, is related to the mining days of the catchment area. Ong (1966) noted for two cores of 4 feet, collected just north-east of Penlee Point (east of Newlyn), a similar tendency. His data, which refer to the minus 80 mesh only, indicate, however, a less spectacular decrease.

Core 5

This core represents sediment in the vicinity of Porthleven. It is 11 feet long and much coarser than cores 33 and 34 (last column, table 3,17). In addition, grain size distribution varies considerably from sample to sample. From the top to 5 feet below the surface, samples increase in diameter over more than two Wentworth divisions. For the next 5 feet average grain size diameter remains constant, followed by finer sand which increases downwards in diameter as well. The boundary between coarse and fine sand (samples 1509 and 1510) is very sharp. Material is very well rounded, and within a sample it is well sorted. It seems, therefore, likely that the sediment represents a beach deposit in an earlier stage of the transgression.

The tin content of samples of this core varies considerably, as can be seen from table 3,17. In terms of relative tin content it appears that there exists little hydraulic equivalence between the tin and the light material. This may be the result of the particular conditions of the environment. Some material carried onto the beach by the waves may remain trapped in the pores of coarser material although the backwash may have enough potential to carry that material in an offshore direction. This will result in a concentration of heavy minerals as indicated by the high relative availability, especially in the coarsest sample (561504). This process of concentration will be the least effective for the **finest** particles, as is demonstrated by the data on the minus 200 mesh fraction (Table 3,17).

In addition, it may well be possible that the appropriate grain sizes of tin to match the size distribution of the light material was not always present in the source of material of the tin during the various stages of deposition. An indication to this affect may be provided by the very low relative available tin in the 80 to 100 mesh fraction of samples 561507 and 1508. Of interest is the fact that no real concentration occurs on the boundary from coarse to fine material (sample 1509 and 1510) but that some form of placer formation appears near the coarsest sample. This is especially reflected in absolute as well as relative tin content for the 100 to 150 mesh fraction.

Comparison with cores 33 and 34 can be made for the minus 200 mesh fraction only, since it is the only fraction which is tin containing for all cores. From tables 3,16 and 3,17 it can be seen that the majority of the samples have a relative tin content of the same order of magnitude, although there is a great variation in the absolute tin content. This feature is regarded as further evidence in favour of the concept of hydraulic equivalence, since the conditions under which the sediment of core 5 is deposited

Table 3,17 Absolute and relative tin content of core 5

feet below surface	sample number	200 mesh		150 to 200 mesh		100 to 120 mesh		80 to 100 mesh		mean diameter in phi
		ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	ppm Sn	rel.av. Sn	
1	561500	2,750	65	135	50	35	270	60	200	1,90
2	561501	6,000	150	185	75	85	550	45	180	2,30
3	561502	325	20	110	60	110	420	100	30	0,53
4	561503			750	20	4120	2400	1100	50	0,33
5	561504	2,250	10	650	650	1500	2500	350	20	0,11
6	561506			325	40	225	190			0,40
7	561507			500	170	680	100	325	4	0,25
8	561508	3,250	160	450	150	650	180	550	8	0,26
9	561509	200	25	800	340	600	310	165	10	0,46
10	561510	200	10	75	35	75	190			1,86
11	561511	1,160	20	75	40	175	375			1,53

are different from the environment of deposition of cores 33 and 34. The three higher results for this fraction in core 5 are considered to reflect processes of concentration as discussed above.

Raised beaches

The last group of sediments to be discussed briefly are the raised beaches. As mentioned in the chapter dealing with the general geology, Cornwall is characterised by a series of marine platforms at different levels. Fossil beaches immediately fringing Mounts Bay are dominantly present in the form of the "10 foot" beach and, to a far lesser extent, the "40 foot" beach. In addition, a beach deposit has been reported situated on top of the head near Marazion (Robson, 1944). The writer was not able to locate this beach, possibly due to erosion of the soft cliffs.

The 10 foot raised beach can be seen in a number of places all relatively sheltered by cliffs and rocks, which offered a protection for the head from erosion. A good exposure occurs approximately one mile east of Marazion. Under a cliff called the Creep, fossil beach material can be found even trapped in rock fissures. Another excellent example of this marine deposit is located 0,5 miles south of Mousehole, where a fracture zone in the granites enabled the sea to form a small cove. Big boulders occur in a matrix of head. Other localities where this beach can be found occur at Prah Sands and east of Porthleven near Loo bar.

Samples have been taken from the Creep and near Mousehole. The thickness of the 10 foot raised beach at the Creep is difficult to establish as it is partly covered by the recent beach. The three feet exposed have been sampled with half a foot interval. The sediment consists of very well rounded particles, whose average diameter is in the order of 3 to 4 mm. Material is very well sorted.

Fine fractions (minus 60 mesh) are largely absent. This comes as no surprise, considering the location near a steep cliff forming more or less a spearhead in the coast line. Consequently, grain size analysis with respect to fine material could not be obtained, and tin analyses are presented only (Table 3,18).

Table 3,18 Tin content of raised beach near Marazion (in ppm)

Sample number	-200	100 to 200	60 to 100	36 to 60	20 to 36	10 to 20	mesh
560936	240	210	1060	75	<25	75	
560937	175	120	130	<25	75	285	
560938	30	50	140	<25	125	75	
560939	125	75	480	225	<25	75	
560940	<25	100	960	140	65	75	
560941	85	175	350	125	<25	75	
560942	75	125	450	<25	85	<25	

From the table it can be seen that the fossil beach has a fair amount of tin not only confined to the smallest sizes; the maximum amount occurs, with the exception of sample 937, always in the minus 60 plus 100 mesh fraction. It seems not unlikely that this tin content represents a similar sort of concentration as happens in the backshore of present day beaches as has been discussed previously. Whether or not this beach and some of the subsurface sediments in the bay are contemporaneous is not known, but they have in common that they were formed prior to human activities. In the marine sediments, tin occurred only in the minus 200 mesh fraction: in the beach tin is dominantly confined to the coarser fractions, illustrating once more the feasibility of transportation of tin of this very fine size. Of great interest is the fact that the last sample of core 33 has a similar distribution of the tin; a maximum in the minus 80 mesh fraction. It is not known if this sample 561586 also represents a fossil beach, although it seems unlikely as the particles are angular.

The source of tin in the beaches is a matter of speculation. One may assume that the overall tidal system has little changed since Cornwall got its final geographical outlay. Consequently, tin is most probably derived from the west. The nearest known mineralisation in that direction occurs on the Mount. It would be of extreme interest to find out as to whether the mineralogical nature of the tin present in the beaches reflects that of the tin of St. Michaels Mount. This was largely beyond the scope of the present thesis.

The second beach sampled occurs south of Mousehole. Its exposure is no more than 15 feet wide and forms a small cove in the granite. The beach deposit is characterised by rounded granite boulders of several feet diameter. They occur on a platform of fractured and weathered granite. The matrix consists of angular and rounded material some of which undoubtedly has been derived from the head, which lies on top. A man-made tunnel occurs on the side, whose roof consists of the same material. Due to cementation little material could be collected. Four samples, 5 feet apart, have been taken of which sample 561291 represents the roof of the tunnel (Table 3,19).

Results are of the same order of magnitude as the previous ones, with a maximum in the tin content for the 80 to 100 fraction. Furthermore, data indicate that the tin content is slightly higher for the sample taken from the tunnel. A little higher up the tunnel, just before a roof fall, a quartz vein appears. No samples could be taken at this point.

Table 3,19 Tin content (in ppm) of Mousehole raised beach

Sample number	-200	-150 +200	-100 +150	-80 +100	-60 +80 mesh
561291	145	155	225	520	80
561300	85	200	65	240	-
561308	-	35	55	65	35
561318	65	100	35	110	110

The history of this tunnel could not be traced, but it is quite possible that there is a connection with some ancient prospecting.

The writer does not think that the tin of this raised beach has come from very far. First of all, water depth increases immediately beyond the cliffs to well over 100 feet. Secondly, there is a very little sandy material amongst the components of the beach material, while thirdly, currents passing this part of the coast line come from the south, i.e. from the open sea.

It is of interest that in terms of absolute tin content both beaches reach their maximum in the same fraction, although they are more than 7 miles away from each other and most likely have received their tin from completely different sources. Whether this feature will persist in terms of relative tin content which would increase its importance significantly, could not be determined as too little material has been collected to separate out sufficient quantities of the fine light materials.

Distribution of copper in some selected samples

Copper has been determined in 34 samples representing all traverses. They include the majority of samples from traverses 1 and 2. In addition, samples from raised beaches have been analysed. Results refer to the 150 to 200 mesh fraction and the 100 to 150 mesh fraction only, since insufficient material of the minus 200 mesh fraction remained after tin analysis.

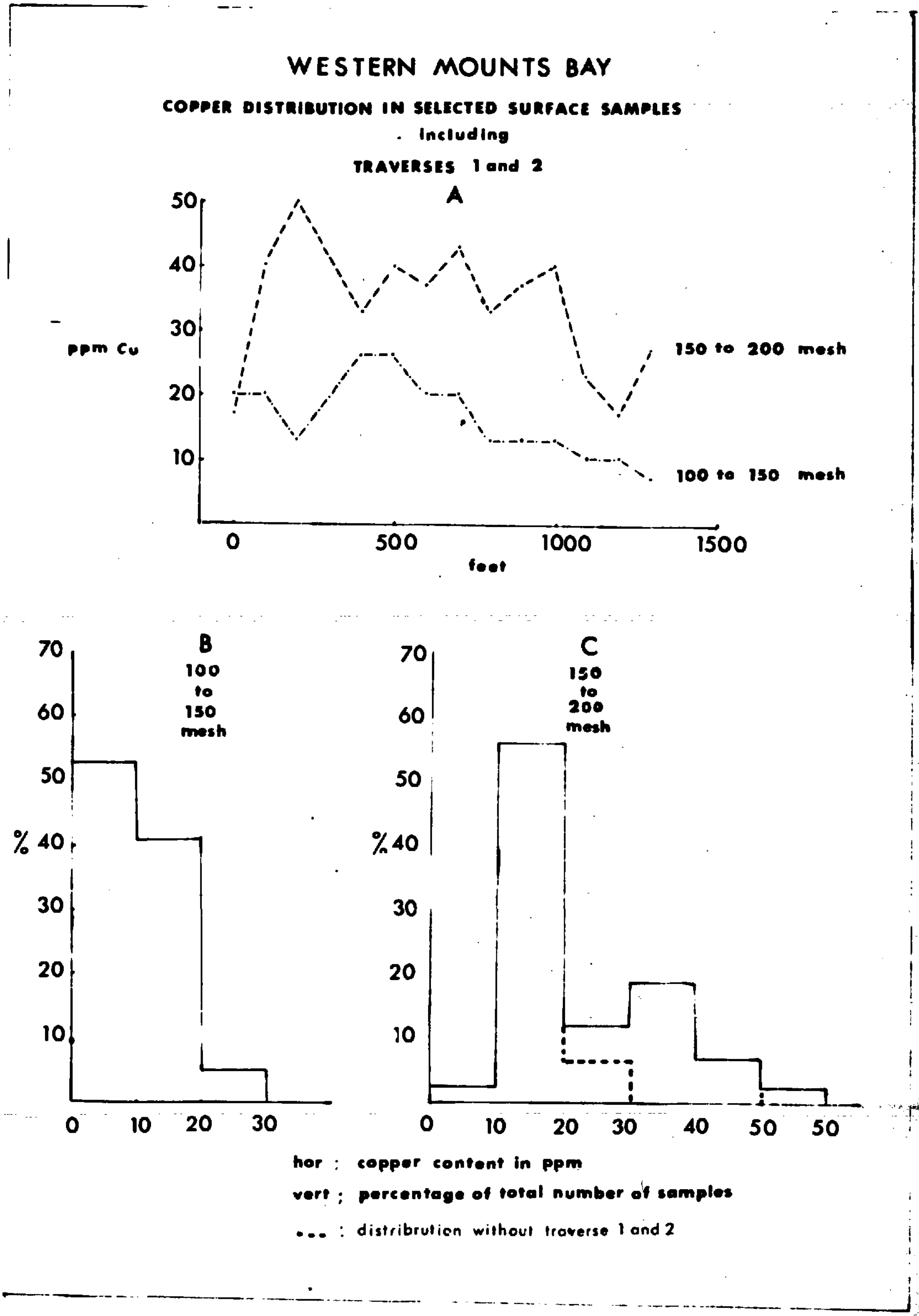

WESTERN MOUNTS BAY
COPPER DISTRIBUTION IN SELECTED SURFACE SAMPLES
. including
TRAVERSES 1 and 2
A
ppm Cu
50
40
30
20
10
0
500
1000
1500
feet
150 to 200 mesh
100 to 150 mesh
B
100 to 150 mesh
70
60
50
% 40
30
20
10
0
10
20
30
C
150 to 200 mesh
70
60
50
% 40
30
20
10
0
10
20
30
40
50
50
hor : copper content in ppm
vert ; percentage of total number of samples
... : distribrution without traverse 1 and 2

FIG 3,16

No attempt has been made to interprete the results on the basis of hydraulic equivalence, since copper sulfide (s.g. 4,1) or copper oxide (s.g. 5,6) require a completely different grain size distribution analysis for computations for which no time was available.

Histograms of the copper distribution of the marine surface sediments are presented in figures 3,16B and C. The histogram of the 150 to 200 mesh fraction (Fig. 3,16C) clearly shows the existence of two populations. The higher values are formed by 10 samples from traverses 1 and 2, one sample of traverse 12 (561171) and one other sample from traverse 14 (561216). This latter sample has a value of 90 ppm Cu and has by far the highest copper content of all samples. The sample of traverse 12 occurs at the same location as the tin anomaly on this traverse, while the sample of traverse 14 occurs at the location where the tin content of the 100 to 150 mesh fraction reaches a maximum.

Samples of the 100 to 150 mesh fraction (Fig. 3,16B) which have a Cu content of more than 20 ppm belong to traverse 1 only (samples 561009 and 1011). The location of these high values is not exactly the same as the location of the high tin values for this traverse, but they occur in the same general vicinity (compare Fig. 3,1 and Fig. 3,14). Likewise, the high copper value of the 150 to 200 mesh fraction for this traverse does not coincide with the location of maximum tin values. However, it became apparent from the discussion on the tin distribution of this traverse that absolute maxima are not necessarily real anomalies, and the only conclusion one can make is that the copper content of traverses 1 and 2 is definitely higher than for most samples.

It cannot be a coincidence, that high or anomalously high values in the copper content of the sediment occur near known or postulated mineralisations of the bedrock, especially since Sn and Cu often are associated in Cornwall. There is no reason to assume differences in thepH of the freely moving seawater in so small an area. Consequently, the copper analytical results are regarded as further evidence in favour of the postulated mineralisation south of St. Michaels Mount.

For the Marazion raised beach, data is essentially the same as for the marine sediments, with the exception of the minus 200 mesh fraction of sample 560936 (Table 3,20).

The copper content of the Mousehole raised beach is significantly higher. As with tin, values are in general higher in the sample taken from the roof of the tunnel. It is of interest that the mean copper content of the minus 150 plus 200 mesh fraction (37 ppm Cu) of this raised beach is identical to the mean copper content of the same fraction of traverses 1 and 2 (37 ppm Cu).

Table 3.20 Copper content of Marazion and Mousehole raised beaches

Sample number	-200	-150 +200	-100 +150	-80 +60	-60 +80	mesh
560936	62	6	15	19	13	Marazion
560942	6	19	13	13	10	
561291	82	46	39	29	23	Mousehole
561300	85	36	29	19	23	
561308	79	36	36	32	26	
561318	56	29	26	23	15	

Data on the copper content of the samples is very incomplete. Nevertheless they show that a detailed examination may well reveal some very interesting information

Summary and General Conclusions

Based on:

1. the high tin content of the rivers draining into the bay;
2. the capability of the rivers to discharge tin into the bay;
3. the parallelism with the northern coast line of the contour lines of decreasing tin content in offshore direction of the submarine sediments; and
4. the substantial difference in the tin content of surface sediments as compared to subsurface sediments.

It is postulated that a dominant proportion of the tin in the surface sediments had an allocthonous origin, while its dispersion in the marine sediments was the result of marine transport. Since the processes of marine environment will affect all components of the sediment, it was assumed that this would result in a relation between them. This relationship should, in theory, be a constant ratio between two or more components of the sediment, since it is the result of a transport medium affecting a certain grain of a given density in a similar way as another grain of different density.

In calculating the ratio between the tin distribution and the size distribution of the sediment, it appeared that:

1. for tin of minus 200 mesh size, which includes the majority of the tin in any given sample and whose equivalent size of light material forms more than 80 per cent of the sediment, the ratio remains, by and large, constant, irrespective of the absolute tin content or sample location;
2. the ratio for tin of 150 and 200 mesh and tin of 100 to 150 mesh remained of the same order of magnitude only in a number of cases. In most samples the tin content of these fractions was "too high" as compared to the tin content of the minus 200 mesh fraction.

Two factors which can act separately or together may cause this "concentration". These are:

(a) A proportion of the tin in these fractions occurs as part of polymineral grains. This results in high computed hydraulic ratios.

(b) Concentration of tin in these fractions is the result of differential transport. This feature is optimal when current velocity reaches values where the settling velocity of a particle and the velocity required to initiate movement of this particle are equal. The plausibility of a current velocity in this region is demonstrated by the very well sorted sediment, whose mean diameter conforms to the critical size related to this velocity.

High hydraulic ratios for the coarser fractions seem to occur more frequently in samples from the western traverses. Grain size distribution for all samples remains by and large the same. Accordingly, it is concluded that for these fractions there exists an additional source of tin for this part of the bay, which may be the Newlyn River. This source, however, is less significant than supply from Marazion River, as is indicated by the absolute tin content of the samples. Transport of tin from the postulated source takes place by the eddy current, which in itself may cause additional concentration of tin in these fractions.

The most important conclusion is that by presenting the data in two ways; as absolute tin content and as relative tin content, a better understanding is obtained of the dispersion of tin in the marine sediments. If high absolute tin content remains high for <u>all</u> fractions in terms of relative tin content at the same or closely related locations, a local source has to be postulated. This is demonstrated by traverses 1 and 2, 12, 14 and possibly 5 and 6. If on the other hand, high absolute tin content does not persist, in terms of relative tin content, in all fractions, the concentration of tin is due to sedimentological processes. This is demonstrated by traverses 1 and 2 and 19.

SUMMARY AND GENERAL CONCLUSIONS

Section 1

1. Placer deposits, alluvial as well as residual, are known to occur in the catchment area of St. Michaels Mount.
2. Alluvial placer deposits may be expected in the drowned valleys.
3. The tin content of a soil profile near Rosepeath indicates the possible extension of mineralisations which have been mined on either side of the river.
4. The contribution of primary mineralisation to the tin content of **stream sediments** is difficult to establish since the tin content of the present day river sediments is dominantly the result of contamination from mining activity.
5. The stream sediments of Marazion River are coarse angular and not well sorted. The most dominant components are quartz and feldspar.
6. The tin content of the stream sediments of Marazion River which predate mining activity is confined to the minus 80 mesh fraction. The tin content of stream sediments which are contemporaneous to and later than the mining activity is many times higher and tin occurs in all fractions.
7. Tracer techniques are an essential help for the study of sediment transport in natural environments.

8. The use of fluorescent hues does not affect the hydraulic properties of the sediment and transport of tracers is representative of the sediment as a whole.

9. Variation of stream velocity of Marazion River is the result of variation in daily rainfall.

10. Transport of stream sediments of Marazion River is fast for all fractions irrespective of river characteristics.

11. Transport of medium sand and smaller sizes takes place by suspension and is able to reach the beach.

12. Transport of sediment coarser than medium sand takes place by rolling.

13. With high stream velocities all material is transported by suspension.

14. Sorting between successive fractions is not well developed.

15. Heavy minerals are transported in similar ways as their hydraulic equivalent light fractions and heavy minerals of fine sizes and smaller are able to reach the marine environment.

Section 2

1. The current systems in Mounts Bay are isolated from the main current system along the south-west coast of Britain.

2. Current velocities in Mounts Bay vary between 0,1 and 1 knot.

3. Bottom drifters give information on current directions only.

4. Recovery of drifters was in the order of 50 per cent.

5. A higher rate of recovery occurs with strong winds which generate bigger waves with stronger inshore wave induced currents.

6. Currents in Mounts Bay are tidal and have an overall clockwise direction.

7. Currents west of St. Michaels Mount are inshore with a tendency of an easterly drift and are wave induced.

8. Currents south of St. Michaels Mount have an easterly to south-easterly direction parallel to the coast line.

9. Currents in the eastern part of the bay also follow the coast line but appear to be stronger.

10. Currents in the western part of the bay are northerly and form a circular eddy current within the triangle formed by Mousehole/Penzance/St. Michaels Mount.

11. Surface current directions in the middle of this eddy are low and erratic.

12. Individual beaches and coves are not isolated from the main current system.

13 Variation in radio-active background values in western Mounts Bay roughly coincide with the postulated current direction.

14. The application of radio-active tracers showed that heavy minerals are transported in the marine environment by all currents, provided its grain size is 70 microns or smaller.

15. Only a small proportion of the tracer has been transported during the period of observation.

16. Gamma spectrum analyses in the natural environment have only qualitative significance and give valuable information with respect to the **nature** of the radio-active source.

17. Heavy minerals of 70 microns or less whose equivalent light fraction forms the bulk of the Penzance marine sediments are transportable by all currents; the main tidal current in easterly direction, the eddy current in south-westerly direction, the ebbing tidal current in southerly direction and wave induced inshore currents.

Section 3

1. The tin content of the unconsolidated marine sediments of Mounts Bay decreases in an offshore direction, while contour lines are parallel to the northern coast line.

2. Areas with anomalously high tin content occur south of St. Michaels Mount and east of Trewavas Head.

3. Size fractioning by elutriation has a limited reliability especially for fractions finer than 150 mesh.

4. The unconsolidated sediments of the Penzance/Marazion sand body are uniform and well sorted in 95 per cent of the sand and has a mean diameter in the 2 to 3 phi range (fine sand).

5. Decreasing grain size distribution in offshore direction is apparent in a limited number of samples only.

6. The tin content of the minus 80 mesh undersize fraction is dominantly a reflection of the tin content of the 150 to 200 mesh fraction.

7. The tin content of the marine sediments is confined to the smallest sizes.

8. The tin content of the surface sediments has high to anomalous values for all fractions in the area south of St. Michaels Mount.

9. The tin content of the size fractions obtained by elutriation remains fairly constant from fraction to fraction and has far lower values than the corresponding fractions obtained by screening.

10. The tin distribution as obtained by elutriation suggests that the size distribution of tin particles is similar to the size distribution of the sand but displaced towards finer sizes.

11. Presentation of the data on the basis of hydraulic equivalence indicates that a major proportion of the tin of the marine sediments (tin of minus 200 mesh size) has a constant ratio with respect to its equivalent light fraction. This suggests that tin of this size has been subject to transport.

12. Variations in the hydraulic ratios for the 150 to 200 mesh fraction and the 100 to 150 mesh fraction are suggested to be due to the occurrence of tin in polymineral grains and

to concentration as the result of selective transport.

13. High relative available tin for all fractions at the same location is due to supply from a local source.

14. It is postulated that the tin content of traverse 14 is partly the reflection of an elluvial source.

15. The tin content of traverse 12 is the result of supply of tin of an allochthonous source. In addition, it reflects the existence of an elluvial source while a deficiency in the tin content indicates supply of light material only.

16. The tin content of traverses 5 and 6 is suggested to be partly related to supply from an elluvial source.

17. The tin content of the western traverses suggests an additional source of tin of polymineral grains. The significance of this source is restricted to a limited area.

18. The distribution of tin and sand of traverses 1, 2 and 19 is the result of wave action. In addition, the tin content of traverses 1 and 2 reflects the existence of bedrock mineralisation

19. The tin content of subsurface samples is confined to the minus 200 mesh fraction and values are many times lower as compared to surface material.

20. Raised beaches have tin content in all fractions with a maximum in the minus 60 to 100 mesh fraction.

21. High copper content of the sediments coincides with high tin content.

Recommendations for Future Studies

1. The contribution of bedrock mineralisation and mining activity to the tin content of the stream sediments should be studied. This could be done by comparing stream sediments of different age while in addition, a study should be made of the mineralogical habitus.
2. Comparable work should be carried out in the Marazion and Newlyn rivers.
3. Transport of rivers should be studied in different seasons using a number of fluorescent dyes for individual fractions. In addition, flume experiments using natural material and simulating the actual environment are desirable to obtain an understanding of the form of transport of material.
4. Detailed studies on the variation of natural radioactivity with respect to its possible connection with transport patterns should be carried out.
5. It is desirable that transport of material in the marine environment is studied at different locations using a number of tracers simultaneously to obtain information on the selective transport.

6. Studies of transport should be accompanied by accurate measurements of current velocities, wave dimensions, nature of bottom, etc.

7. The mineralogy of tin in the marine sediments should be studied and its relation to possible sources.

8. The concept of hydraulic equivalence should be checked by controlled experiments, making allowance for tin in grains of different density, by separating the sediment in fractions of smaller size interval, by applying the concept on other components of the sediments especially copper.

9. The area south of St. Michaels Mount should be subject to detailed surface sampling with a number of critically chosen cores reaching

10. The tin content of subsurface samples should be studied in detail.

11. The eastern part of the bay should be subject to similar investigations.

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