DETAILED GRAIN SIZE ANALYSIS OF RECENT MARINE SEDIMENTS AND POST-GLACIAL HISTORY OF PORT AU PORT BAY, WEST NEWFOUNDLAND

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DETAILED GRAIN SIZE ANALYSIS OF RECENT MARINE SEDIMENTS AND POST-GLACIAL HISTORY OF PORT AU PORT BAY, WEST NEWFOUNDLAND

by

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ABSTRACT

Grain size analysis of about 130 bottom grab samples taken from the recent marine sediments of Port au Port Bay have led to the distinction of three sediment types with different, although characteristic, cumulative grain size distribution curves. The three types encountered are: 1) unimodal sands found in areas of high wave and tidal current energies, 2) bimodal silts and clays deposited in the low energy basin areas, and 3) bimodal gravels in areas of medium to high energies. The coarse component of Type No. 3 is often a residual deposit from a time of even higher energy associated with the lower post-glacial sea level.

Based on this analysis, it is proposed that the characteristic "break" to the finer grades in many fine sand and silty sediments is due to the inherent scarcity in the natural environment of material with diameters between 10 and 40 microns. This size range represents the gap between a <u>fine sand</u> and a <u>clay</u> population, each of which is representative of a different mode of formation. This is in opposition to many workers who believe that this "break" is due to a different mode of transport.

A correlation between particle diameter and mode of transport is nevertheless attempted. It is based on the

assumption that tidal currents do not affect the areas of the bay below the deepest sill which, in turn, is deduced from studies of the faunal distribution and the physical oceanographic properties. Deposition in the basin areas, then, is thought to be from suspension only with the maximum particle diameter in these sediments, after removal of the ice-rafted fraction, being around 0.125 mm.

The sea level at the time of the last ice retreat from Port au Port Bay (around 13500 yrs. B.P.) was at the "marine limit", more than 100 feet above the present datum. Isostatic recovery of the land area, as a result of glacial unloading, was apparently occurring faster than the accompanying eustatic rise of the sea, a consequence of the returning glacial meltwaters. Following the ice withdrawal sea level fell rapidly until the isostatic component had diminished to a rate equal to that of the eustatic rise, when the lowest post-glacial sea level was registered. This lowest level calculated from the grain size variations within one of the basin cores was around -35 and -45 feet from the present datum. This is in close agreement with the lowest level calculated from the difference between the theoretical rebound curve and the world-wide eustatic curve. Subsequently, with a further decrease in the isostatic rebound rate, the eustatic component was greater and slow submergence of the land area took place.

The "Marjorie and Muriel"; the boat used for all the offshore sampling carried out in Port au Port Bay.

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CHAPTER I

INTRODUCTION

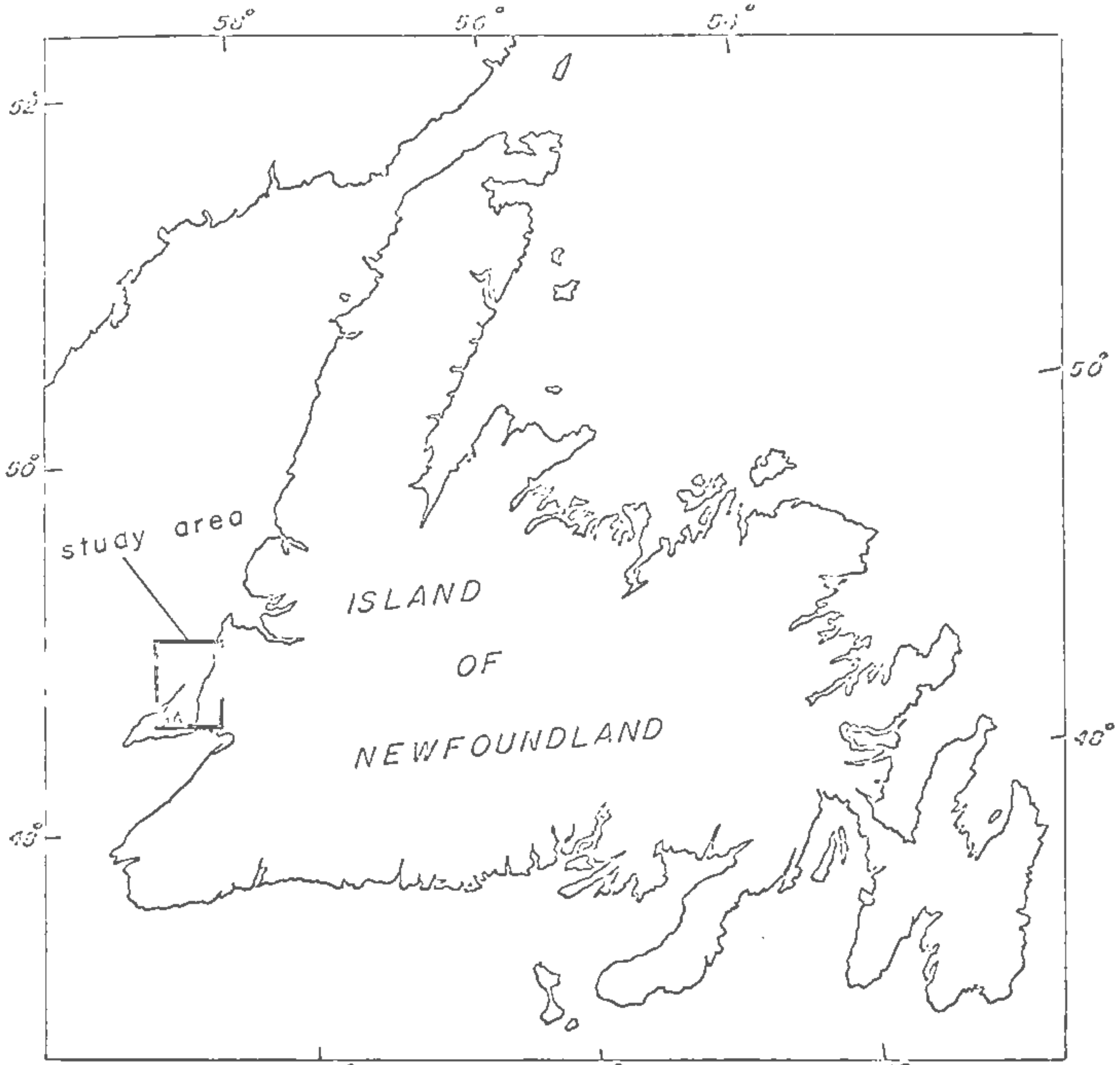
General Statement

Apart from a chiefly descriptive study of twelve core samples of bottom sediments in the innermost part of St. Georges Bay made by Dorothy Carroll (1963) and data on hydrographic charts little was known about the nature of the recent marine deposits in the nearshore areas around west Newfoundland when the author began his work in the Port au Port Bay area (Figure 1) in the summer of 1966. He set out to make a comprehensive collection of the recent sediments from the bottom of the bay, the beaches, the raised post-glacial outwash deposits and from the bedrock outcrops along the shores. As well, bottom water samples from the bay were collected.

Subsequent analysis of this material in the laboratory was expected to permit the author, not only to compile a detailed facies distribution map, but also to understand the modes of transport of the bottom sediments and to elucidate the post-glacial geological history of the area. This necessitated, primarily, the detailed grain size analysis of all the sediment samples collected in the study

FIGURE 1

Index Map showing the location of the study area on the west coast of Newfoundland.



INDEX MAP

area. A limiting factor of the correlation of the size distribution data with the transporting energies is the scarcity of measured bottom and surface tidal current velocities within the bay. Nevertheless, because of the fjord nature of the bay, a number of basins with their bottoms isolated from active tidal currents seem to exist. This isolation of an environment in which only one mode of transport (suspension) is thought to persist enabled a number of deductions to be made. Physical oceanographic data was essential, here, in order to establish the exchange phenomena in the basins.

An obvious offshoot of a size analysis study of this sort is the mineralogical and lithological analysis of the samples. The mineralogical composition of the marine sediments and raised outwash deposits in the bay is instructive in two principal ways: 1) it may elucidate the source of the sediments, which are in large part from glacial deposits, and may thus give some indication as to the last direction of ice movement and 2) the stability of the mineral suite present will indicate to some extent the amount of reworking undergone which is undoubtedly associated (to an unknown degree) with the post-glacial sea level fluctuation.

Cursory examination indicated that one would have needed much better control (higher sampling density) of the drift deposits within the whole Port au Port Bay drainage basin in order to carry out 1) as mentioned above. Because of the time factor involved complete mineralogical identifications (as per 2)) of the grains comprising the various size fractions in the bottom sediment samples were not made. Even so, an attempt was made to summarize the general character of the mineralogy of the bottom samples.

Complications arising from the existence of residual deposits in the bay necessitated a more detailed study of the Quaternary geology and post-glacial history than was originally anticipated.

Acknowledgements

The author would like to express his sincere thanks to his supervisor, Dr. W. D. Brückner, for his intensive involvement in all of the problems encountered by the author while carrying out and writing up this study.

As well, the author is very grateful to Dr. B. R. Pelletier of the Bedford Institute for his continued interest and for providing considerable financial support.

During the initial stages of the investigation, associated with the collection of the samples, the author was enthusiastically assisted by Russell Crosbie. The skipper of the "Marjorie and Muriel" Jack O'Brien and the crew, Gordon Gallant and Ray Hackett, were at all times most helpful and cooperative. The late Professor H. D. Lilly of Memorial University was invaluable during the diving phase of the field work. The British Newfoundland Exploration Company and The Mines Branch, Province of Newfoundland, are to be thanked for the loan of a compressor and wet suits respectively.

During the subsequent laboratory analysis the extremely conscientious work of Paul Thompson and George Horan is greatly appreciated. The author is indebted to Rex Gibbons for the computer work carried out in the early stages of the study. Likewise, he is grateful to Mrs. Kathy Langhus for punching up much of the data in the latter stages. The foraminiferal identifications made by Grant Bartlett are, as well, appreciated. Art Coote at the Bedford Institute is to be thanked for the loan of a dissolved-oxygen determination apparatus and for running salinities on the water samples collected. The G.S.C. radiocarbon dating laboratory and particularly Dr. Wes Blake, Jr. are to be thanked for age determinations on three samples of shell material collected in the thesis area.

I. A. Brookes, Dr. H.B.S. Cooke, D. R. Grant and V. K. Prest all contributed to the author's understanding of the Quaternary geology and post-glacial history of the study area. Likewise, correspondence with R. K. Stevens with reference to the chapter on Geology aided the author in its writing. Discussion with C. K. Singh, I. S. Koh and S. B. Misra at Memorial University and Dr. R. Gees,

A. K. Lyall and M. R. Gregory at Dalhousie University along with many others have helped the author to consolidate various ideas with respect to the chapter on Sedimentology. The author alone is, nevertheless, responsible for any apparent error of fact or interpretation.

The Geology Departments at Memorial and at Dalhousie are to be thanked for their financial support for the years 1965-68 and 1968-69 respectively. As well much financial support was received from Dr. Brückner's National Research Council operating grant.

The members of the drafting and photography laboratories at the Bedford Institute were very helpful in advising the author and reproducing the figures of this thesis.

The author is indebted to his typist Mrs. Jeanette Connolly for continuously transforming a scribbled draft into a thesis.

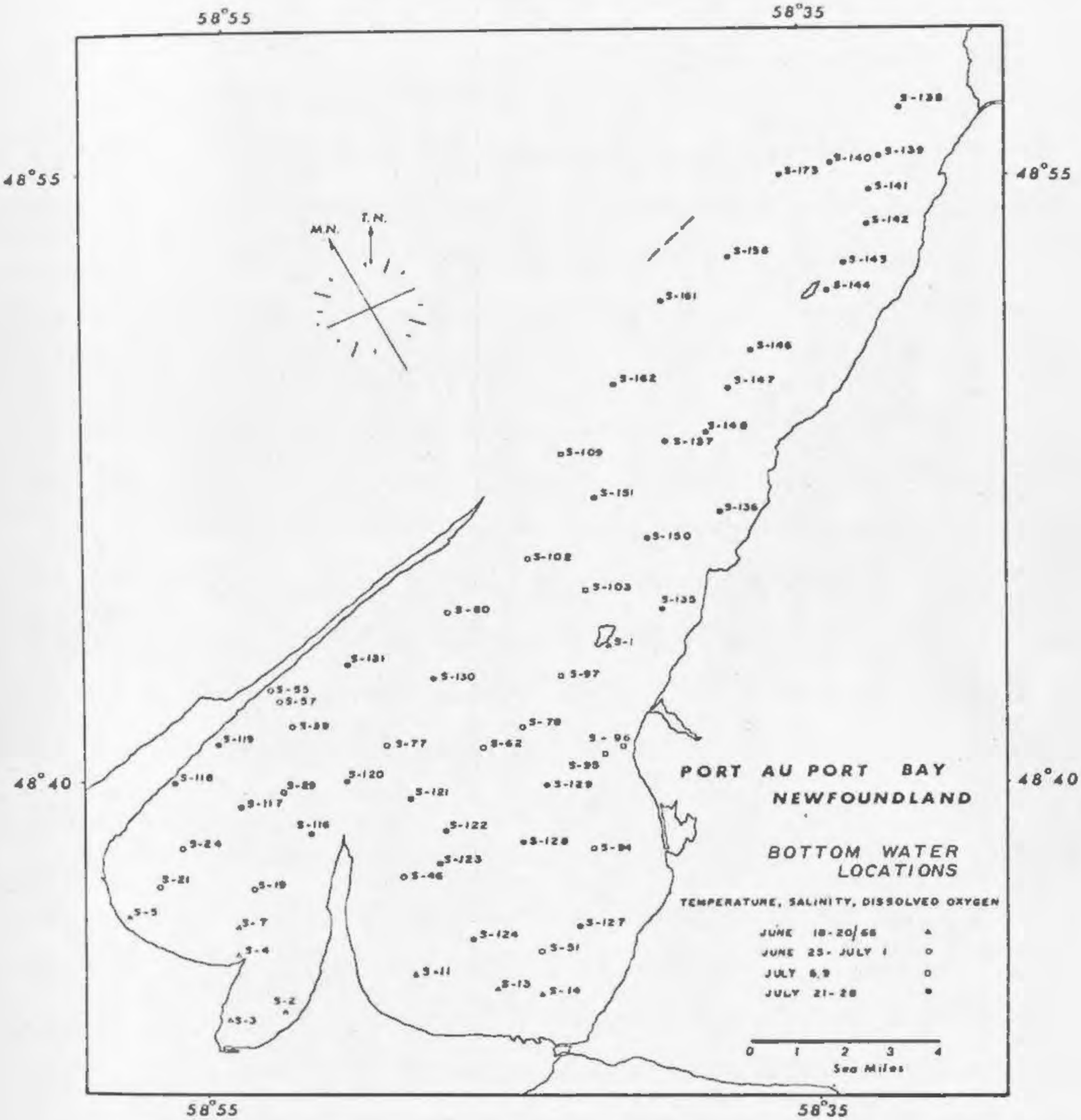
He would also like to express appreciation to his wife Deirdre who has for such a long time put up with and encouraged the author with this work.

CHAPTER II

PHYSICAL OCEANOGRAPHY

The investigations dealt with in this section are confined to four properties of the bottom waters of Port au Port Bay: salinity, temperature, density and dissolved-oxygen content.

The survey carried out was of a reconnaissance nature; it included samples from about 60 stations (Figure 2), which were collected between late June and late July, 1966. The samples were taken from the lowermost 5 feet of water at each locality using a Nansen reversing water bottle (Sverdrup, Johnson and Fleming, 1942). The salinities were measured, at the Bedford Institute of Oceanography, after the completion of the cruise, by the electrical conductivity method (Brown and Hamon, 1961). The temperatures were recorded with a protected reversing thermometer (Sverdrup, Johnson and Fleming, 1942). Due to the rough nature of the survey, the standard corrections to be made (LaFond, 1951), based on the auxiliary temperature readings (maximum ΔT was 5°C), were thought to be insignificant. The densities (σ_T) were calculated from the salinity and temperature observations using the Nomogram for "Sigma-T" (LaFond,


58°55
58°35
48°55
48°40
T.N.
M.N.
PORT AU PORT BAY
NEWFOUNDLAND
BOTTOM WATER
LOCATIONS
TEMPERATURE, SALINITY, DISSOLVED OXYGEN
JUNE 18-20/68
JUNE 25- JULY 1
JULY 6,9
JULY 21-28
0 1 2 3 4
Sea Miles

1951). The remaining property, dissolved oxygen, was determined on board ship, as the water samples were retrieved, using the standard titration method (Strickland and Parsons, 1960).

A critical study of the data obtained revealed that the bottom configuration of the bay (see Figure 12), as well as the duration of the cruise, were of marked influence. As the basins of the study area are separated by sills that largely control the water circulation, an evaluation of all data from the bay together would result in misleading conclusions; the individual basins had, therefore, to be considered separately. During the period when the samples were taken, the water properties changed fairly rapidly so that the interpretation of data that were obtained in time intervals longer than about one week suffered from the uncertainty of whether differences recorded at different depths were actually related to depth or were the results of changes with time. Only once were all depths sampled adequately within a short time period (July 21-28).

On the following pages, the distribution of the four properties determined will be discussed one by one, and in each case separately for the East Basin, West Basin and the combined Fox and Serpentine Basins (Figure 12). The data on which the following discussion is based are shown in Appendix A.

Salinity

In Figure 3 the salinity values found in the bottom samples of the three basin areas on different days are plotted against depth.

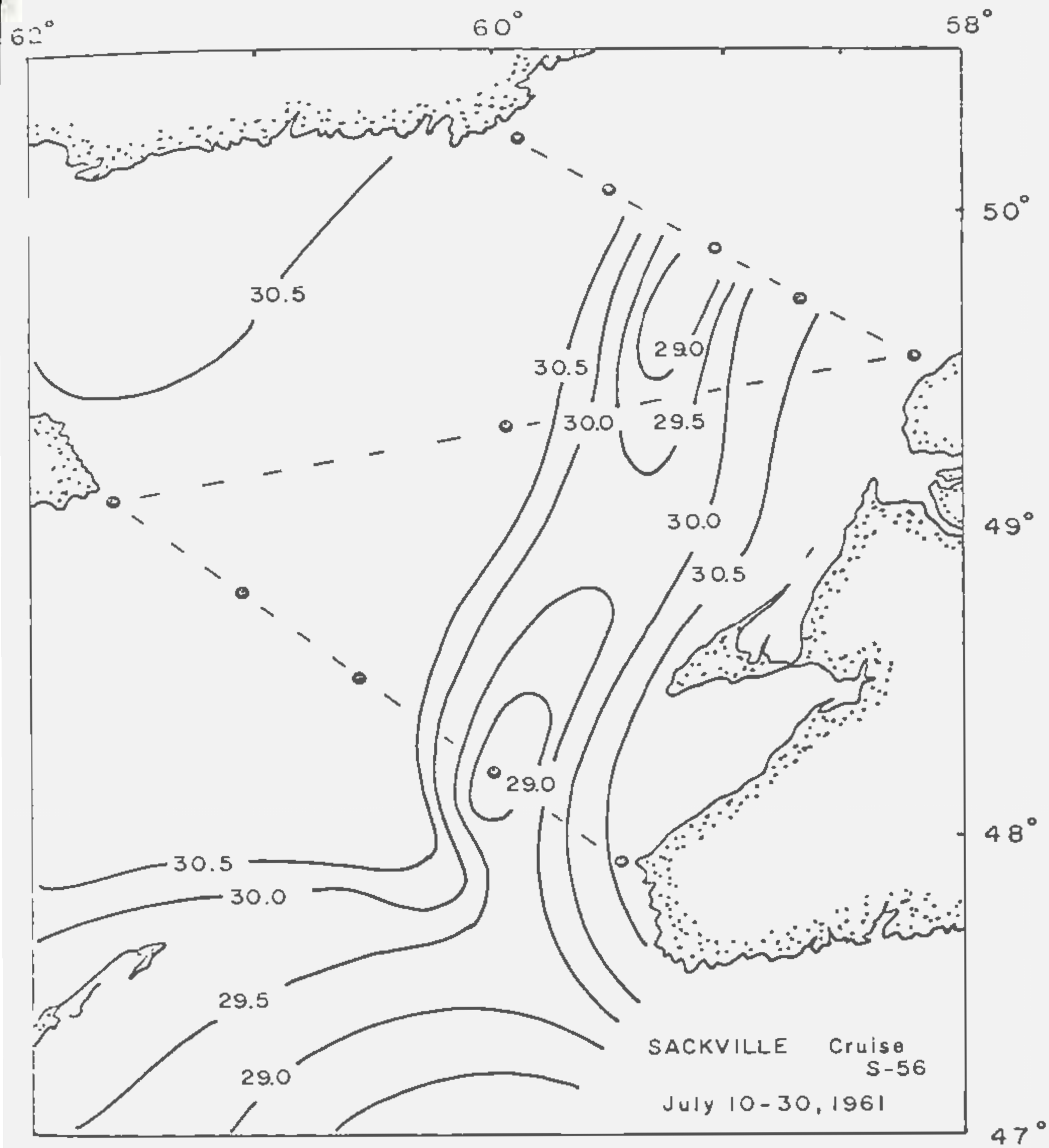
In the upper layer of water (0-60 feet) in the Fox-Serpentine Basins the salinity decreased markedly as the summer progressed, and minimum values of 31.2-31.3 $^{0}/oo$ were recorded in late July. In the other two basins a similar but slight, though probably significant, decrease was noted with time, leading to minimum values of about 31.6 $^{0}/oo$.

The general decrease of salinity in the upper layer through the summer is probably due to the influx from the land of fresh water supplied by precipitation and run-off, as this should be felt during the warmer season of the year in contrast to the colder season when the precipitation remains locked up on land as snow and ice. From the beginning of melting in the spring time, the surface waters would be diluted progressively, and summer precipitation would keep this process going.

The markedly lower salinity in the Fox-Serpentine Basins might be related to the fresh water emptied into the sea by the Serpentine River, although this is not believed to be the chief cause of the discrepancy. It should be mentioned that a number of the shallower samples included

in this discussion under the Fox and Serpentine Basins heading, are in fact located in the Bar Flats physiographic region (Figure 12). This being the case, one might then expect these upper waters of the Fox and Serpentine Basins to be similar to the adjacent part of the Gulf, as much tidal interchange takes place between these waters. Figure 4 (F.R.B. Oceanographic Atlas, 1961) shows the surface salinity distribution for the eastern Gulf in July, 1961. A low salinity band located just off the west coast of Newfoundland seems to be the dominant feature. If this band of low salinity is truly characteristic for the mid-summer months, and in fact considerable exchange and mixing of this Gulf water with the Bar Flats area and the Fox-Serpentine Basins occurs, then the salinity in the latter region would be considerably less than in adjacent areas (East and West Basins) which had much less contact with this Gulf water.

In the East and the Fox-Serpentine Basins a well defined halocline exists, below which salinities rise to values of 32.0-32.0 $^{o}/oo$ in the deepest parts of the basins. The bottom waters at these depths seem to undergo little salinity change during the summer, with the summer salinities presumably little changed from those of the winter. The depth of the halocline coincides with the depth of the deepest sill in both cases, which may indicate



SURFACE SALINITY

from F.R.B. Oceanographic Atlas

that the sills are a significant feature in the development of the haloclines. In West Basin, however, the deepest sill seems to have no effect on the vertical salinity distribution. This problem will be discussed more fully below.

Temperature

Figure 5 shows the temperature distribution in depth and time for the three basins studied. The change with time is very obvious in the upper layer of all three basins. Slightly higher maximum temperatures were found in the Fox-Serpentine Basins, but this difference can probably be attributed to the later date of their observation (July 23-26 compared to July 21 for the other two basins). The warming up recorded, no doubt, reflects the influence of the warm air and increased heat radiation from the sun during the summer season.

In the East and Fox-Serpentine Basins, thermoclines were recorded which, like the haloclines mentioned above, coincide with the deepest sills of these basins. In West Basin no thermocline was noted.

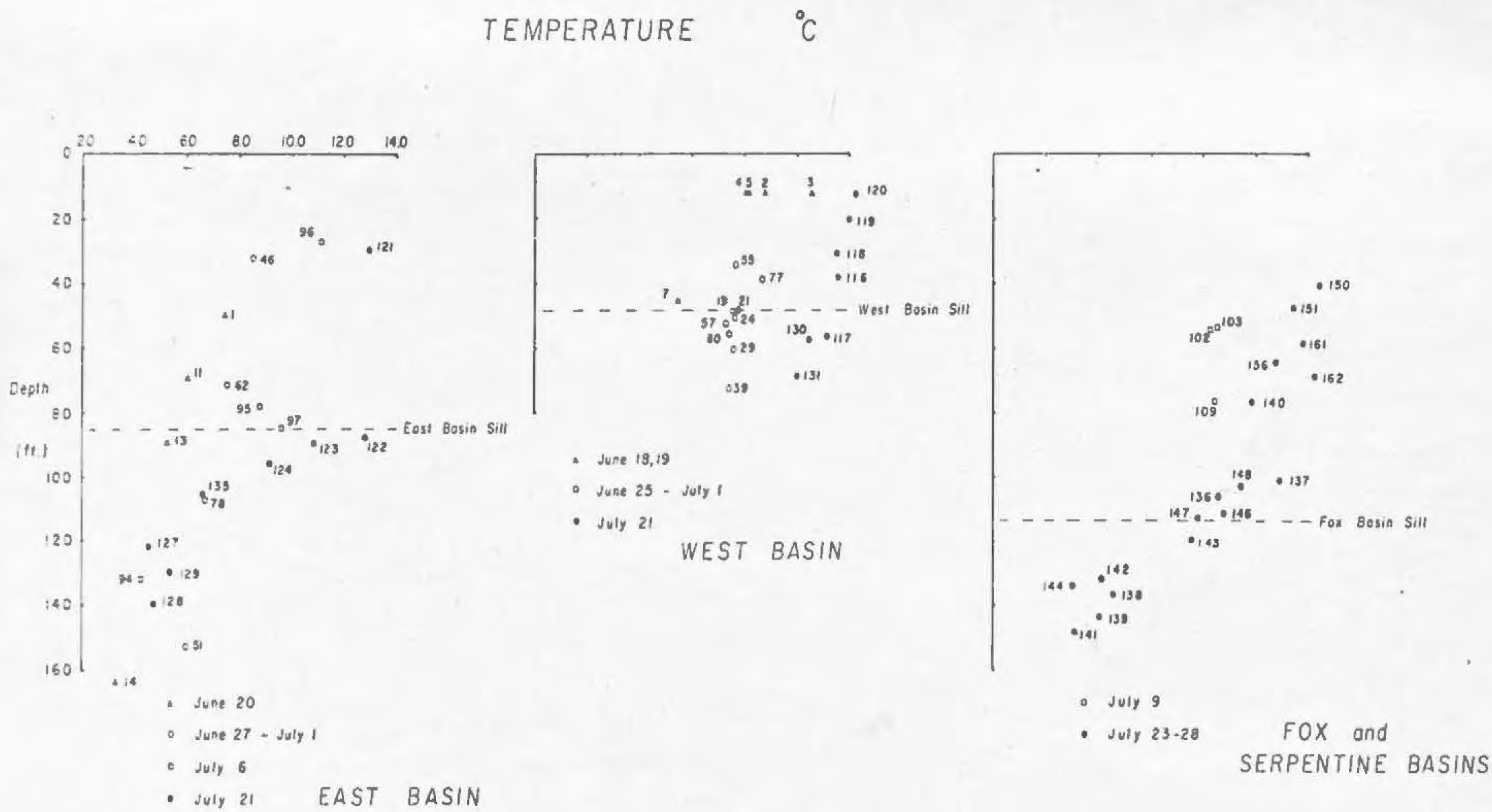
Density

Figure 6 shows the distribution of the densities (σ_t values) in depth and time in the three basins sampled. The densities were fairly similar down to depths of 90 to 110

FIGURE 5

FIGURE 5

Variations of temperature with time and depth in the bottom waters of Port au Port Bay.

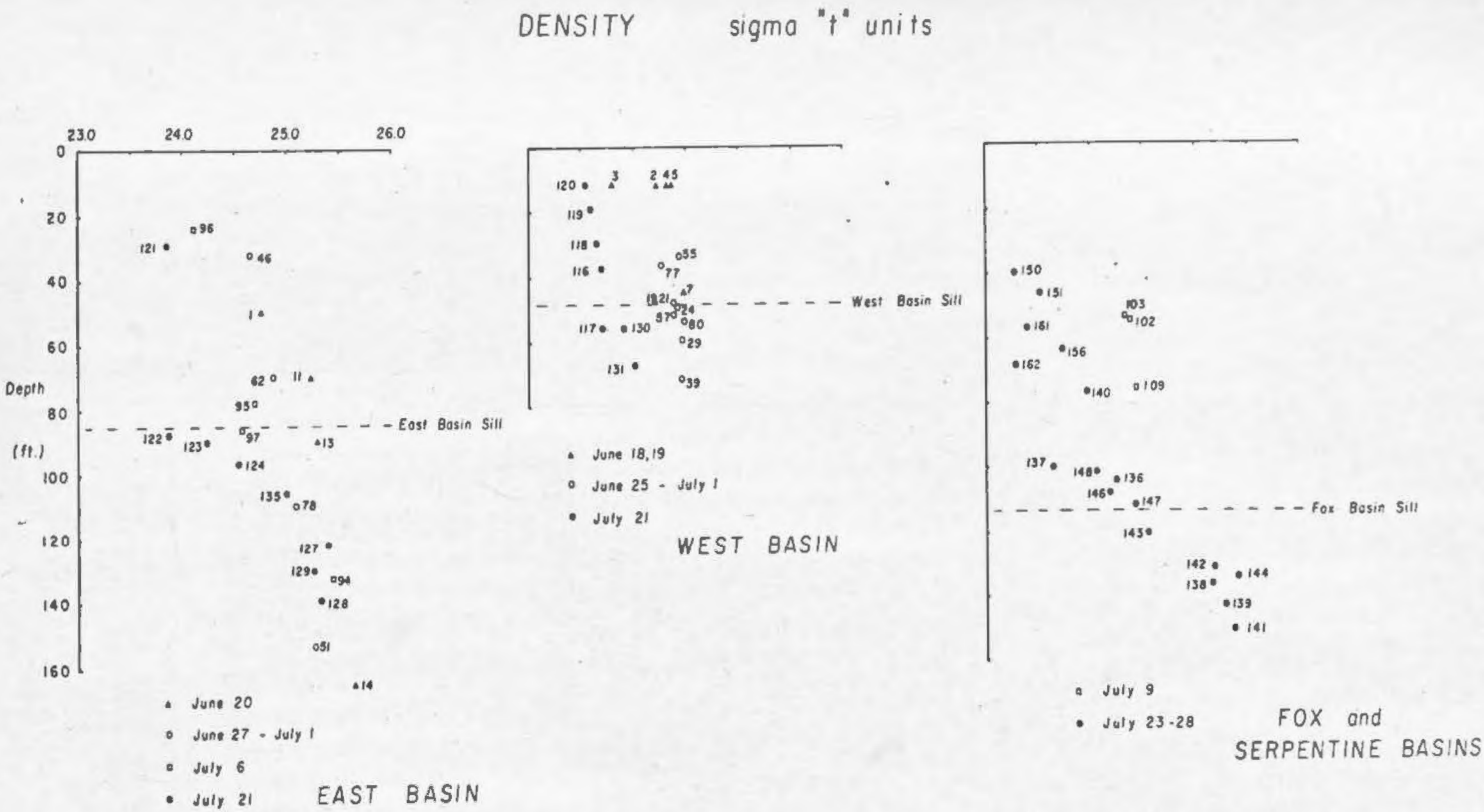


TEMPERATURE °C
0
20
40
60
80
100
120
140
20
40
60
80
100
120
140
160
Depth
(ft.)
East Basin Sill
June 20
June 27 - July 1
July 6
July 21
EAST BASIN
West Basin Sill
June 18,19
June 25 - July 1
July 21
WEST BASIN
Fox Basin Sill
July 9
July 23-28
FOX and
SERPENTINE BASINS

FIGURE 6

FIGURE 6

Variations of density with time and depth in the bottom waters of Port au Port Bay.


DENSITY sigma "t" units
23.0
24.0
25.0
26.0
Depth (ft.)
East Basin Sill
June 20
June 27 - July 1
July 6
July 21
EAST BASIN
West Basin Sill
June 18,19
June 25 - July 1
July 21
WEST BASIN
Fox Basin Sill
July 9
July 23-28
FOX and SERPENTINE BASINS

feet and they decreased significantly in this upper layer as the summer progressed. Below the deepest sills of the East Basin and Fox-Serpentine Basins, the densities converged to reach values of around $25.4\ \sigma_t$ units at the greatest basin depths. In these two basins the summertime density distribution in the upper layer thus appears to have no influence on that in the deeper parts.

Figure 7 shows the density changes with depth in late July for the three basins studied. In both the East and the Fox-Serpentine Basins, a pycnocline can be seen to coincide with the depth of the deepest sill, in analogy to the haloclines and thermoclines mentioned above. In West Basin, however, no pycnocline was recorded, as there were no halocline and thermocline, despite the presence of a sill.

The density distribution in the bottom waters of Port au Port Bay as a whole (corrected to July 21, 1966) is shown by means of contour lines in Figure 8.

An attempt to explain the discrepancies between the thicknesses of the surface layer and the relationship of this layer to the deepest sill for West Basin and the Fox-Serpentine Basins system, will be made.

A general description of the development of the pycnocline is given below:

(1) The winter values of salinity, temperature, and

FIGURE 7

FIGURE 7

Variations of density with depth in the bottom waters of Port au Port Bay, for late July 1966.

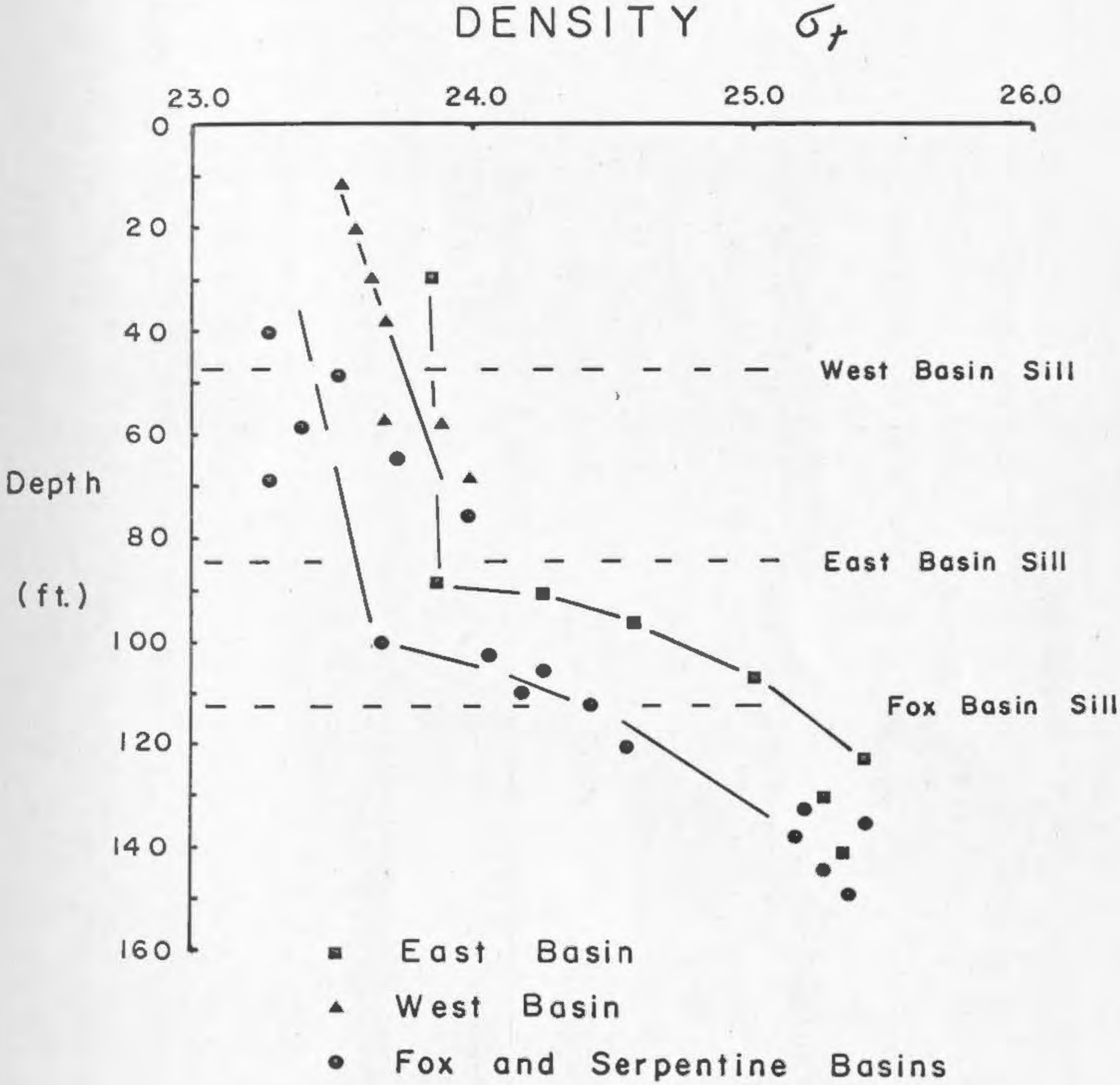
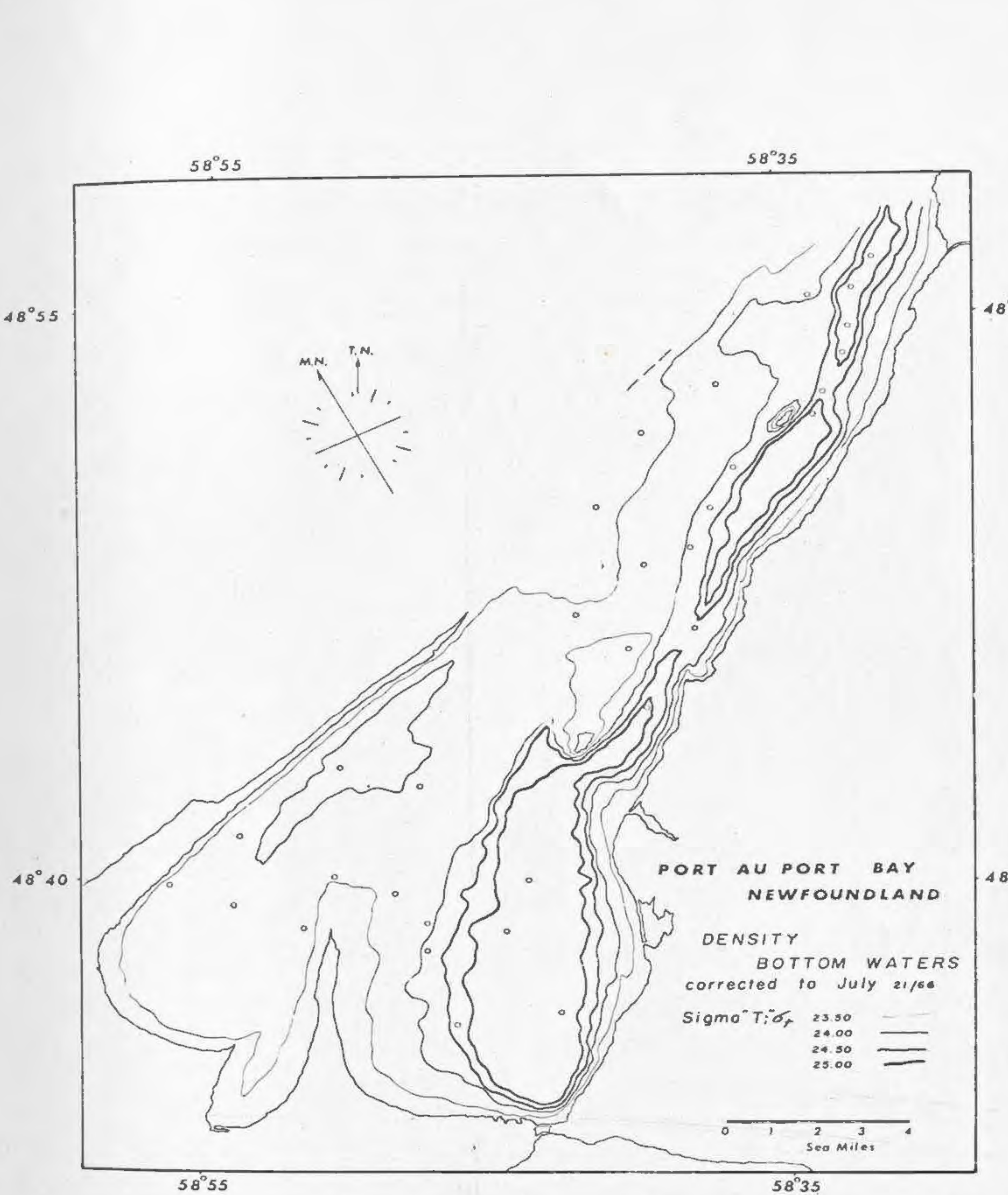

DENSITY σ_t
23.0
24.0
25.0
26.0
0
20
40
60
80
100
120
140
160
Depth
(ft.)
West Basin Sill
East Basin Sill
Fox Basin Sill
East Basin
West Basin
Fox and Serpentine Basins

FIGURE 8

FIGURE 8

Distribution of bottom water densities in Port au Port Bay for late July 1966.

o = the locations of the bottom water samples taken in late July.


58°55
58°35
48°55
48°55
48°40
48°40
M.N.
T.N.
PORT AU PORT BAY
NEWFOUNDLAND
DENSITY
BOTTOM WATERS
corrected to July 21/66
Sigma T; σ_t
23.50
24.00
24.50
25.00
0 1 2 3 4
Sea Miles
58°55
58°35

density are similar at all depths in Port au Port Bay and the adjacent part of the Gulf of St. Lawrence.

(2) During the warmer season of the year, influx of fresh water from the land and rain falling directly into the sea lowers the salinity of the uppermost layer of water, while higher atmospheric temperatures and increased heat radiation from the sun raise its temperature. The density changes correspondingly, as it depends on the two other properties.

(3) Water agitation caused by wind waves and tidal currents tends to mix the uppermost layer of water so affected with the water beneath it, thus gradually increasing the thickness of the water layer undergoing summer changes.

(4) With a growing contrast between the densities of the upper layer and those of the deeper waters the amount of mixing decreases, and a pycnocline develops at a near-constant depth.

Because of the intimate association of the bay waters, at every ebb and flood tide, with those of the adjacent parts of the eastern Gulf, the properties of this Gulf water mass would seem to have a considerable effect in the development of the water properties inside Port au Port Bay.

Lauzier et al. (1957) have done a study on the water properties of the surface layer in the Gulf of St. Lawrence and have found the isothermal layer to be about 10 to 15 meters thick during the mid-summer months. If the temperature and salinity are effectively defined by conditions at the surface (i.e., increased air temperature and fresh water influx), then the thickness of this less dense surface layer is proportional to 1) the amount of agitation the water undergoes at the surface and 2) the relative density difference at any given time between this surface layer and the underlying water. The greater the density contrast ($\Delta \sigma_T$) between these layers, the thinner will be the corresponding surface layer, for a given agitation condition.

The surface temperatures as well as the average wave action effects in the eastern Gulf can be assumed to differ little from those existing in Port au Port Bay. The salinities, as we have seen, may be considerably less in the Gulf during the summer and, consequently, the surface density here may be considerably less than the surface density within the bay. The actual density contrast ($\Delta \sigma_T$), then, in the Gulf, is greater than in the bay, and for any given wind and wave conditions the isothermal layer will be considerably thinner in the eastern Gulf. This may explain the discrepancy between the thickness of the surface isothermal layer in the Gulf, which is $\simeq$ 10 to 15 meters thick and the much thicker layer in West Bay ($\simeq$ 25 meters).

Because of the ineffectiveness of the sill in controlling the thickness of this surface layer in West Bay, tidal currents can be presumed, here, to be of little significance in the formation of this layer.

Nevertheless, the coincidence of the pycnoclines (also the haloclines and thermoclines) with the corresponding deepest sills in the East and Fox-Serpentine Basins is evidence for the possible contribution of the tidal currents in these areas in determining the thickness of the surface layer.

The mechanism by which the sill controls the maximum depth of the surface layer is complicated and dependent upon the network of tidal currents which flow in and out of the bay during the flood and ebb tides.

Figures 9 and 10 are the ebb and flood tidal current vectors in Port au Port Bay as deduced from the Canadian Hydrographic chart 4659 and the Newfoundland Pilot (1966). These figures are drawn from very scanty data, but are an attempt, at least, to show the basic tidal circulation in Port au Port Bay and approximate tidal current velocities.

Basically, eastern Gulf water enters the Serpentine Basin from the north during the ebb tides (Figure 9). It has a low density upper layer $\simeq 35$ to 50 feet thick. When entering the bay, dense water is moving at a much shallower depth than water of the same density inside the bay. Mixing

FIGURE 9

Generalized vectors of Ebb tidal current flow inside Port au Port Bay.

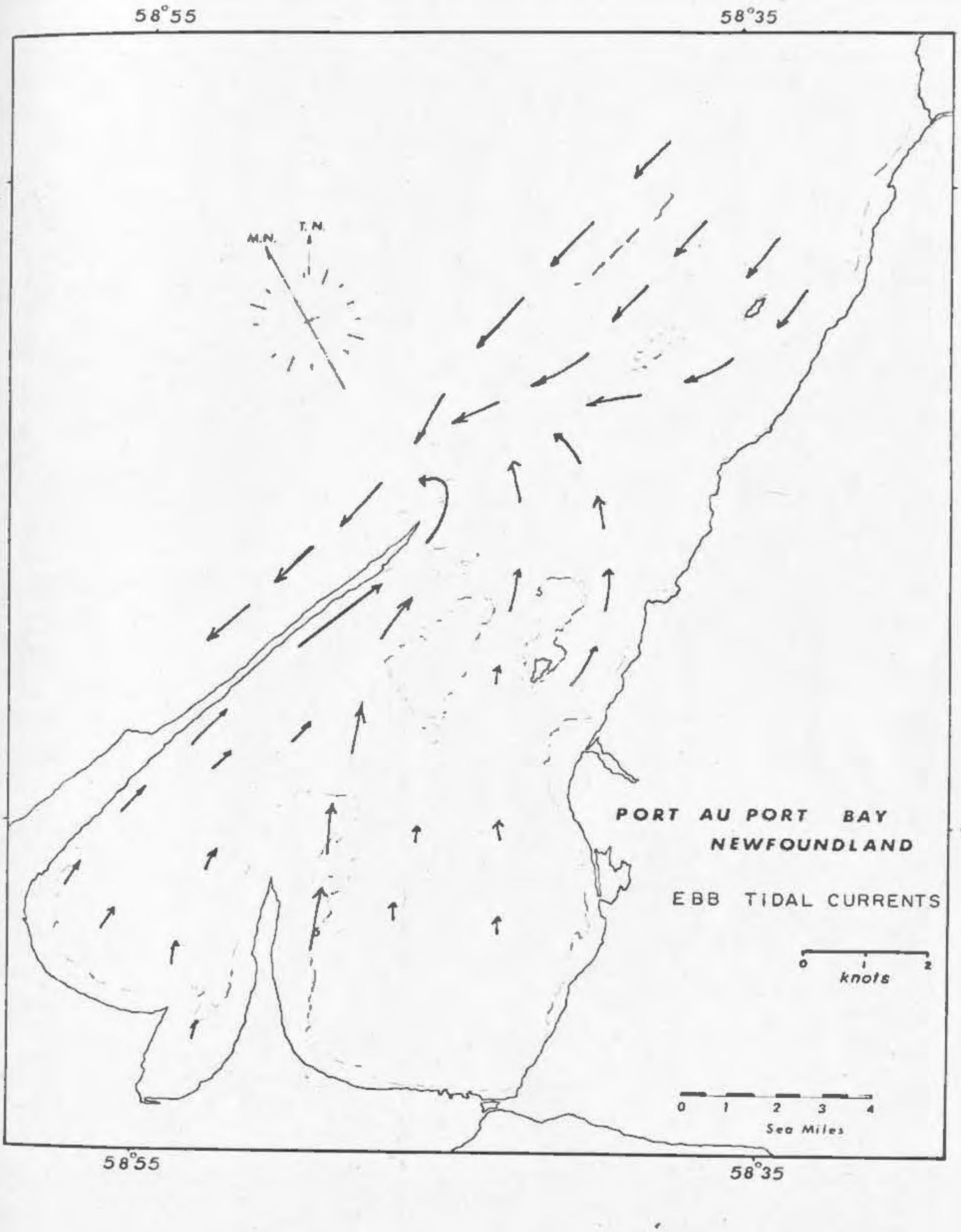
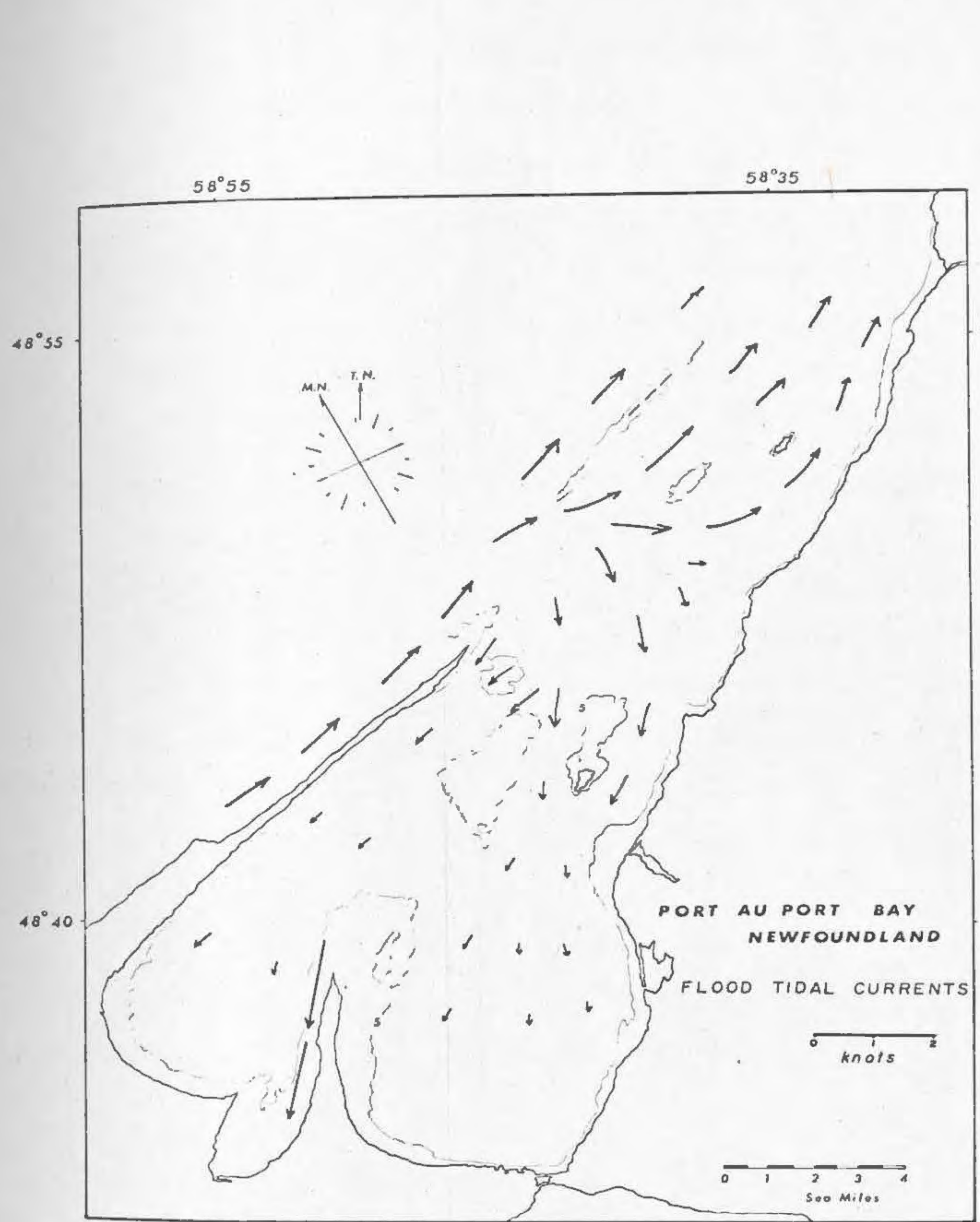

58°55
58°35
48°55
48°55
M.N.
T.N.
48°40
48°40
PORT AU PORT BAY
NEWFOUNDLAND
EBB TIDAL CURRENTS
0 1 2
knots
0 1 2 3 4
Sea Miles
58°55
58°35

FIGURE 10

FIGURE 10

Generalized vectors of Flood tidal current flow inside Port au Port Bay.


58°55
58°35
48°55
48°55
M.N.
T.N.
48°40
48°40
PORT AU PORT BAY
NEWFOUNDLAND
FLOOD TIDAL CURRENTS
0 1 2
knots
0 1 2 3 4
Sea Miles
58°55
58°35

will occur with the incoming denser water displacing the less dense water in the bay. During the ebb tide, water is flowing out of East Bay, which would seem to exclude the entrance into it of any Gulf water. During flood tides (Figure 10) only, water from the Bar Flats area is thought to enter East Bay. Gulf water flowing over the Bar Flats is mixed to the extent that it becomes isothermal, hence even during the flood tides it is unlikely that any dense water enters East Bay. Perhaps a bottom counter-current exists by which denser water may be brought into East Bay during the ebb tide cycle. Any outflow from these basins can take place only to depths less than the deepest sill depth and would explain the coincidence of the bottom of the surface layer with the sill. Only the Bar Flats water enters West Bay and hence enables the uninhibited development of the surface layer by wave action.

With the onset of winter conditions, towards the end of the year, the contrast between the properties of the upper layer of water and those of the deeper waters would gradually decrease and finally disappear in the Gulf as well as in Port au Port Bay.

Dissolved-Oxygen Content

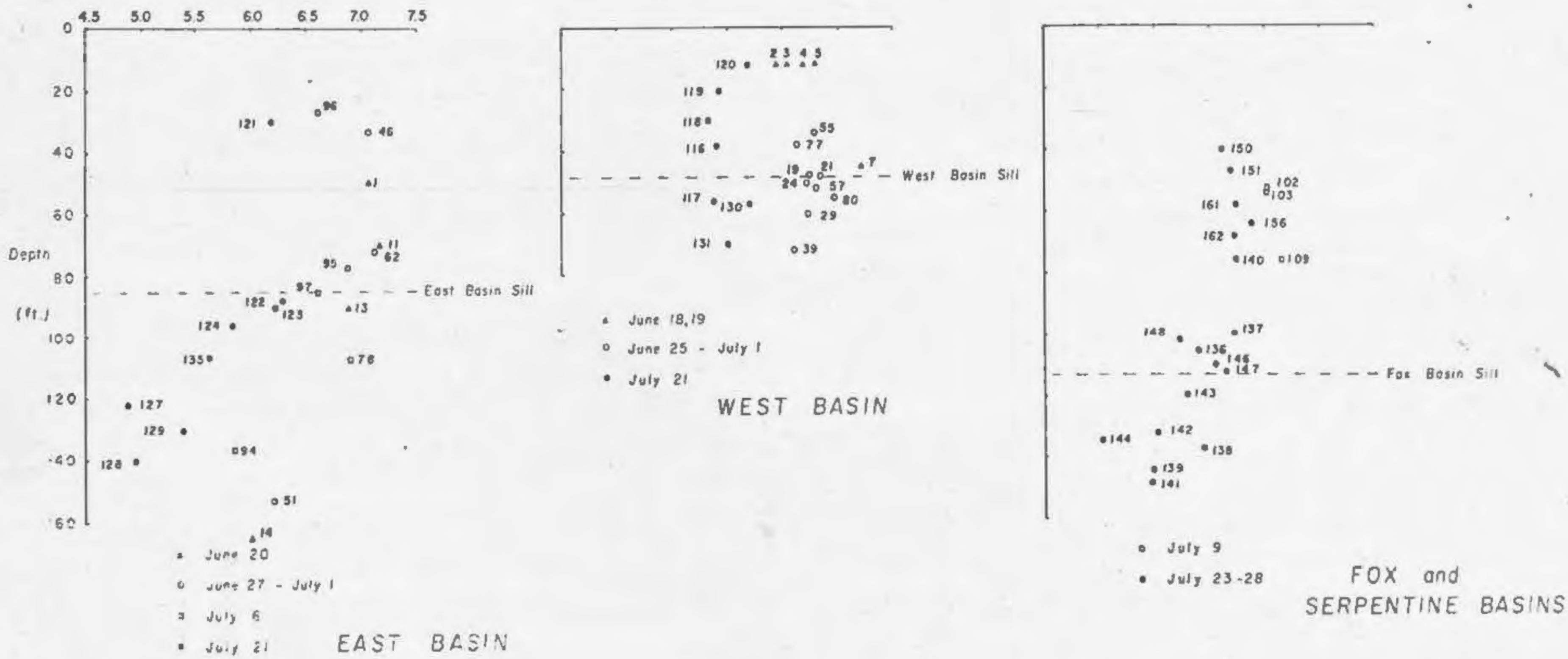
Figure 11 shows the distribution of dissolved oxygen in depth and time in the three basins studied. In the East and West Basins, the amounts of dissolved oxygen decreased

FIGURE 11

FIGURE 11

Variations of dissolved oxygen with time and depth in the bottom waters of Port au Port Bay.

DISSOLVED OXYGEN CONTENT ml./litre



appreciably at all depths as the summer progressed. Three measurements made early in the summer at moderate depths in the Fox-Serpentine Basins indicate that the same development was taking place there, though, in the absence of early summer observations at greater depths, this cannot be confirmed for the deeper waters of that area. The late-July data of the three diagrams reveal that the dissolved oxyten contents were very similar (around 6 ml./l.) throughout the waters of the upper layer, whereas in the deeper waters (below the deepest sill of the East and Fox-Serpentine Basins) a marked decrease of dissolved oxygen with increasing depth was noted (minimum values around 5 ml./l.).

The gradual decrease of dissolved oxygen during the summer can almost certainly be attributed to flourishing organic activity and accompanying decay of the organic matter produced. However, in the upper layer, agitated by waves and tides, oxygen from the atmosphere can partially replace the oxygen withdrawn by the processes of organic growth and decay, while in the deeper waters such replacement is much slower or does not take place at all during the warmer part of the year.

ADDENDUM

It has recently (January 1970) been pointed out to the author by Mr. Don Peer (personal communication) that because of the temperature change associated with the above discussed dissolved oxygen values, the actual changes observed may not in fact be meaningful. It is instructive instead to calculate the percent oxygen saturation values for these stations. This may be done using a nomogram in which the saturated oxygen values for any given combination of temperature and salinity are given. The percent saturation can then be calculated by dividing the observed value by the value representing saturation. This was done for a number of groups of samples observable in Figure 11.

The surface layer is characterised by two main groups visible best in the West Basin section where late June and late July dissolved oxygen values are $\simeq 6$ and $\simeq 7$ ml./l. respectively. These changes are, nevertheless, associated with a considerable temperature change, 10°C to 14°C. The corresponding percent saturation values for the two groups work out to greater than 100% in both cases. Supersaturation occurs in all of these surface layers and is ample evidence of continued oxygenation and mixing during the summer months. In these surface waters photosynthesis is evidently occurring at a greater rate than is respiration of the organisms.

On the contrary, in East Basin the bottom waters show a distinct dissolved oxygen change with time, accompanied by little change in the temperature and salinity. The calculated percent saturation values for late June and late

July are around 85% and 60% respectively. It is evident that, at least during the summer months, there is a progressive depletion of the percent oxygen saturation of the basin bottom waters with time. Presumeably, when the surface temperatures drop with the oncoming of winter and the water column becomes somewhat unstable, exchange can take place. The minimum values of percent oxygen saturation are not known, as bottom water samples were not obtained on a year round basis. Nevertheless, they must certainly continue to decrease until exchange does in fact take place. In all probability the rate of decrease per month of the percent oxygen saturation values is not likely to be equal to the decrease observed from late June to late July ($85-60/85 * 100 \simeq 30\%$). It is possible, although by no means proven, that the percent oxygen saturation values may decrease to values low enough to be restrictive on much of the bottom fauna. This may explain to some extent why, apparently, no evidence of living organisms was found in the basin sediments of Port au Port Bay.

The author has observed many samples collected from Hudson's Bay in which the texture of the bottom sediments was very similar to that of the sediments in the basins of Port au Port Bay. In the Hudson Bay sediments a prolific fauna was observed; worms and shrimps being the main inhabitants.

It is instructive to point out, here, some preliminary results from investigations made by some members of the Bedford Institute in the Bedford Basin-Halifax Harbour area. Bedford Basin is a fiord basin very similar in physical dimensions to Port au Port Bay. The fauna observed in the basin portion of Bedford Basin as determined from two preliminary samples by Don Peer, Bedford Institute (personal communication) is deficient in biomass and has very little species diversity. Out of the 25 or 30 species which might be expected in fine sediment of this nature, only one species (*Spiochaetoperus* sp.), a Polychaete worm, exists. This worm is a filter feeder living in a tube and does not burrow through the sediment as do some other kinds. This species possesses a tough chitinous tube which is resistant to decomposition and would be very evident in any bottom samples. This particular worm is apparently absent in Port au Port Bay. In intermediate depths, where the bottom is still below that of the deepest sill in Bedford Basin, two more organisms are found. They are another worm (Family HESIONIDAE *Podarke* sp.?) and a tube-inhabiting sea anemone. Benthonic foraminifera have been found to exist (at least at the time of sampling) in the deepest parts of Bedford Basin (M.R. Gregory, personal communication). As will be discussed later in more detail, foraminifera are apparently absent, as with *Spiochaetoperus* in the basin areas of Port au Port Bay.

Because exchange in the basin is irregular and has been observed to occur only twice in 1968 (Dr. R. Loucks, personal communication) it is possible that low percent oxygen saturation may have, in fact, existed in the basin immediately prior to the exchange. The author proposes that the scarcity of fauna in Bedford Basin may be associated with this low percent oxygen saturation condition.

West Basin has been described as having uniform water properties from top to bottom, at least during June and July. One should then expect to find significant differences in the bottom fauna between this bay and those where the water column is composed of two distinct masses (East Bay and Fox-Serpentine Basins). These expected differences do not seem to exist and may indicate a differentiation in West Bay between the surface and bottom waters at a later time of the year. In fact, if the temperature profile for West Bay is examined more carefully (Figure 5) the bottom waters are somewhat cooler than the surface waters in late July which may be the beginning of the differentiation of the water mass in this bay.

The implications of the above conclusion are important when attempting to interpret the physical nature and mode of transport of the bottom sediments in these basin areas.

CHAPTER III

GEOLOGICAL EVOLUTION OF PORT AU PORT BAY

The bedrock geology of the area under study is very complicated. Rocks from the pre-Cambrian to the Carboniferous age are present, although many breaks in this record exist. Sedimentary rocks predominate, but volcanic rocks and intrusive rocks also occur. (See map No. 1.)

These rocks belong mainly to two different and contrasting sequences of Cambro-Ordovician age: a "carbonate sequence" representative of shallow water conditions, and a "clastic sequence" with greywackes and volcanics representing the facies of a rapidly subsiding basin (Williams, 1964, and Rodgers and Neale, 1963).

The carbonate sequence comprises, from bottom to top (1) the Kippens, March Point and Petit Jardin Formations, which are known or assumed to belong to the Cambrian, (2) the St. George Group of Lower Ordovician age, and (3) the Table Head Group of Middle Ordovician age.

Neither the Cambrian rocks of this sequence nor the crystalline Pre-Cambrian rocks of Grenville age that underlie them outcrop in the area under study itself, but occur nearby to the east and southeast.

The clastic sequence has been called the Humber Arm Group by Schuchert and Dunbar (1934) or the Humber Arm Terrane by Rodgers and Neale (1963) in the type section along Humber Arm and comprises, from bottom to top, the Summerside Formation (red and green shale, sandstone, some pebbly beds), the Irishtown Formation (black and brown shale, quartzite, some conglomerate), the Cooks Brook Formation (black shale, platy limestone, limestone breccias), the Middle Arm Point Formation (green and black shale, dolomite, chert and sandstone beds), and Blow-me-down Brook Formation (greywacke, some pebble beds, shale). The uppermost unit of the Humber Arm sequence is composed of basalts, the ultra-basic and other intrusive masses of the Bay of Islands Igneous complex (Brückner, 1966). Though fossils are very scarce in the Humber Arm rocks, identification of graptolites from scattered localities indicate a Cambro-Ordovician age, i.e., roughly the same age as that of the carbonate sequence (Cummings, 1967). Of the Humber Arm rocks, the Cooks Brook, Middle Arm Point and Blow-me-down Brook Formations are found in the study area with the volcanic and intrusive rocks interbedded with sediments in the north-eastern part.

The rocks of the carbonate sequence are only moderately deformed whereas those of the clastic sequence are very strongly disturbed. These disturbed rocks have been found to overlie shale belonging to the top of the carbonate sequence (Middle Ordovician). The main outcrop area in which this feature may be observed is about one mile north of the town of Port au Port on the eastern side of Port au Port Bay (Map No. 1).

The fact that (1) old rocks of the clastic sequence overlie younger rocks of the carbonate sequence, (2) there exists a strong contrast in lithology and hence depositional environment between the two sequences, and (3) there exists a contrast in their styles of deformation has led Rodgers and Neale (1963) to propose the existence of a "klippe" in western Newfoundland. The general sequence of events is that, during the Taconic orogeny, uplift in the central mobile zone of Williams (1964) caused the clastic sequence to slide to the west and come to rest as a "klippe" on top of the shallow water deposits of the contemporaneous carbonate sequence. Brückner (1966) has emphasized the existence of so-called "zones of chaotic structure" between successive "klippe" slices and between the "klippe" itself and the underlying autochthonous rocks, which he attributes in part to differential tectonic movement, but mainly to nappe movement over zones where thick deposits of surficial material had accumulated as a result of a lengthy period of subaerial denudation. The paleo-geographic significance of this will be dealt with below.

As said earlier, during the early Paleozoic, shallow water stable shelf environments prevailed in the study area. Generally speaking, the Lower and Middle Ordovician St. George and Table Head Groups are composed of carbonates with the periodic occurrence of interbedded shales. Possibly, the shales are an indication of conditions unfavorable for carbonate sedimentation. One unit of interest is a limestone breccia which is the uppermost unit in the Table Head Group. Exposures can be seen at (1) Round Head near Lourdes, (2) South Head just north of Piccadilly, and (3) on the east side of Port au Port Bay, 1 mile north of the Gravels (Map No. 2). These breccias are thought to be the result partly of landslides falling from cliffs (fault scarps?) into the sea and partly by submarine slumping (Brückner, personal communication). They are possibly related to faulting and other crustal adjustment of the stable shelf area in response to Taconic orogenic activity.

As previously stated, structural deformation in the two sequences present in Port au Port Bay varies considerably. It is proposed that the autochthonous rocks remained relatively untouched during the Taconic orogeny except for the platform adjustments mentioned above. Before emplacement of the allochthonous "klippe" rocks, local uplift and consequent erosion may have caused some relief to be developed in the carbonate rocks, as is evidenced by the patchy distribution of the uppermost Table Head breccia horizon. With the emplacement of the "klippe" these erosional depressions were filled.

In Middle Ordovician times, then, subaerial erosion took place on the allochthonous and autochthonous terranes with subsequent production of the "zones of chaotic structure". Because of the difference in the resistance of these units, erosion after emplacement of the "klippe" tended to accentuate the autochthonous (resistant) terrane as high points in the landscape. The crushed and deformed shale-rich allochthonous sequence succumbed more quickly and formed the low areas.

With the deposition of the Long Point rocks in post "klippe" times, the initiation of the neo-autochthonous phase had begun. On the west side of West Bay the Long Point Formation unconformably overlies erosional remnants of "klippe" rocks (Rodgers, 1965). Further west, near the town of Mainland, Stevens (1967) believes that it lies conformably on the Cambro-Ordovician autochthonous sequence. There, a transitional unit between the Table Head Group and the Long Point Formation rocks which is in composition very similar to the Humber Arm rocks of the "klippe" and was tentatively included in the klippe mass by Rodgers and Neale (1963), is interpreted by Stevens as a conformable sequence. This would seem to indicate that the Middle

Ordovician shoreline, immediately following the "klippe" emplacement, was slightly east of the Mainland area (Map No. 2), yet west of the areas where erosion of the "klippe" rocks is known to have taken place. In fact, the Long Point shoreline may have had considerable indentations (10 to 20 miles) but it was probably not far from the present outcrop of the basal unit of the Long Point Formation at Long Point when deposition of this unit took place in late middle Ordovician times. This basal unit can be followed north-eastward for twelve miles to the tip of Long Point where it disappears below sea level, but it can be traced on the hydrographic chart as a drowned ridge for thirteen more miles. In this submerged segment it reaches sea level only at one spot near its termination at the Long Ledge (The Ledges). The Long Point rocks are overlain by the Clam Bank Formation rocks which are dated around Siluro-Devonian times. The nature of the contact is not known as it is not visible (Rodgers, 1965). This neo-autochthonous sequence of rocks has undergone very little deformation as has the older autochthonous sequence. The Acadian orogeny apparently had little effect in the Port au Port area. Further north and east of the study area (Humber Arm area) and yet still west of the Central Mobile zone of the Appalachian orogenic belt, St. George-Table Head rocks, as well as the Cambrian sediments beneath them are found to be completely recrystallized. Perhaps this was an effect of the thermal metamorphism from large batholithic intrusions which were emplaced during the Acadian orogeny.

Yet to be explained, is the actual origin of the deformation, mild as it is, of the autochthonous sequences of the Port au Port Bay area. The deformation takes the shape of gently undulating folds, gentle monoclines and northeasterly striking normal faults. Earliest evidence of uplift is the breccia unit of the uppermost Table Head Group. Other evidence are the erosional depressions in the carbonate rocks, in which some of the "klippe" rocks are now found. This episode of differential uplift (and faulting?), however, is not necessarily the cause of the folding in the lower autochthonous sequence. Because of the possible conformity of the Long Point Group with the underlying Humber Arm type rocks near Mainland and the definite conformity of these rocks with the underlying Table Head Group, deformation in this area is thought to have occurred after the deposition of the Long Point Group; that is, sometime after the Early Devonian. Carboniferous rocks in Port au Port Bay overlie the Cambro-Ordovician carbonates with an angular unconformity. This, then, dates the folding in the autochthonous sequences as post Early Devonian and pre-Carboniferous. It may have been a fringe effect of the more violent tectonic events of Acadian times that took place further east.

It is likely that the faulting within the autochthonous terrane, as well, is pre-Carboniferous in age. It is certainly post "klippe", as offsetting of some of the "klippe" rocks by these faults is observed. A good example of this is present in the Piccadilly Bay area. Rodgers (1965) concludes that overturning in the Clam Bank Formation occurred in pre-Carboniferous times, as judged by the undisturbed attitude of the nearest Carboniferous remnant. The parallelism of the autochthonous fold axes and fault planes indicates a probable contemporaneous deformation during the Acadian orogenic cycle.

Although the deformational trends in the Carboniferous rocks are very similar to the Acadian ones in western Newfoundland, it is believed that the normal faulting noted in the Carboniferous sequences was not as active in the Port au Port area, as it was further southeast in the Codroy Valley area.

Very often, the Carboniferous rocks are found in erosive depressions or canyons in the Table Head rocks. This indicates that preceding the deposition of these Carboniferous sediments, an erosional landscape very similar to what we see now existed. At the Aguathuna Quarry shallow water marine Carboniferous sediments with brachiopod shells can be found preserved in what must have been a cave or sink hole in the Table Head rocks in Ordovician times. At Lead Cove, Belman's Cove, and various other small coves in the Table Head rocks along the south shore of Port au Port Bay, somewhat deformed Carboniferous rocks are found. At first glance down-faulting of the Table Head rocks in Carboniferous times with subsequent preservation of the down-faulted Carboniferous material seems the most likely answer. From detailed mapping of the upper units of the St. George Group rocks, between the Aguathuna Quarry and the Gravels, the author has found that considerable relative displacement (up to 50') between the two sides of a cove may exist. As well, although these apparently down-faulted Carboniferous rocks do exist, many pockets of Carboniferous sediments unaffected by faulting exist along the sides of the coves. It would seem that the coves existed in pre-Carboniferous times, probably developing along Acadian faulted zones. The subsequent deformation observed may be interpreted as due to slumping of the Carboniferous sediments accompanying or following solution of underlying Lower Carboniferous gypsum deposits (Brückner, personal communication).

Certainly, in Carboniferous times, large scale downwarping with accompanying deposition of sediment occurred in (a) the southern Gulf of St. Lawrence and (b) the Fundy Geosynclinal Trough, which runs from western Cape Breton Island to western Newfoundland. The Port au Port area is not thought to have participated in this downwarping. As pointed out by Cummings (1967) the Port au Port Peninsula and the west coast of Newfoundland proper were regions of relative stability throughout the Paleozoic era.

Twenhofel and MacClintock (1940) have proposed three peneplain surfaces for the west coast region of Newfoundland, with the highest level being at around 2000 feet. It is possible that Carboniferous and Triassic sediments covered the present west coast region and the Gulf to this upper level (Brückner, personal communication). With Tertiary uplift and subsequent erosion and dissection of the land surface, most of this Carboniferous material would have been eroded and transported out of the Gulf to the continental shelves. Large thicknesses of Carboniferous sediments are found only in the trough areas.

Let us recapitulate these developments with emphasis on the geomorphological events. In early Paleozoic times the Port au Port Peninsula was part of a relatively stable platform region receiving shallow water sediments. Before emplacement of the "klippe" slices in the area local uplifting had enabled erosion to form a landscape of low relief. The "klippe" material slid unto this landscape and both autochthonous and "klippe" rocks were then subject to further subaerial erosion.

The Long Point-Clam Bank Formations were deposited upon an already dissected terrane of "klippe" slices and autochthonous carbonate rocks. After deposition of these neo-autochthonous units, associated with a transgression of the sea, further local uplifting (Acadian) and consequent regression of the sea permitted the renewal of erosion enabling the resistant basal member of the Long Point Formation and much of the St. George-Table Head Groups to become apparently differentially elevated. Possibly, blanketing by Carboniferous sediments to a thickness of up to 2000 feet occurred, with uplifting in the Mesozoic and Cenozoic eras later enabling erosion of most of this Carboniferous material to take place. S.C.U.B.A. diving investigations on various shoal areas in Port au Port Bay (Map No. 1) showed them to be composed of either (a) the St. George-Table Head rocks or (b) the sandstone or volcanic units of the Humber Arm sequence. These are the most resistant rock units in the bay, along with the ridge-forming Long Point Formation. It is the differential resistance against erosion of these various units and the shaly material of the "klippe" that is responsible for the present-day existence and shape of Port au Port Bay.

For a more detailed description of various aspects of the geology of Port au Port Bay, the reader may consult the following other publications: (1) Cooper (1936), (2) Kindle and Whittington (1958), (3) Lilly (1963), (4) Riley (1962), (5) Smith (1958), (6) Stevens (1965), (7) Sullivan (1940), and (8) Walthier (1949).

CHAPTER IV

GEOMORPHOLOGY AND QUATERNARY GEOLOGY

This chapter is composed of two main sections: the physiography and relief features of the Port au Port Bay region and the Quaternary (mainly post-glacial) geology of the coastal areas surrounding Port au Port Bay.

I. Physiography and Relief Features of the Port au Port Bay Region

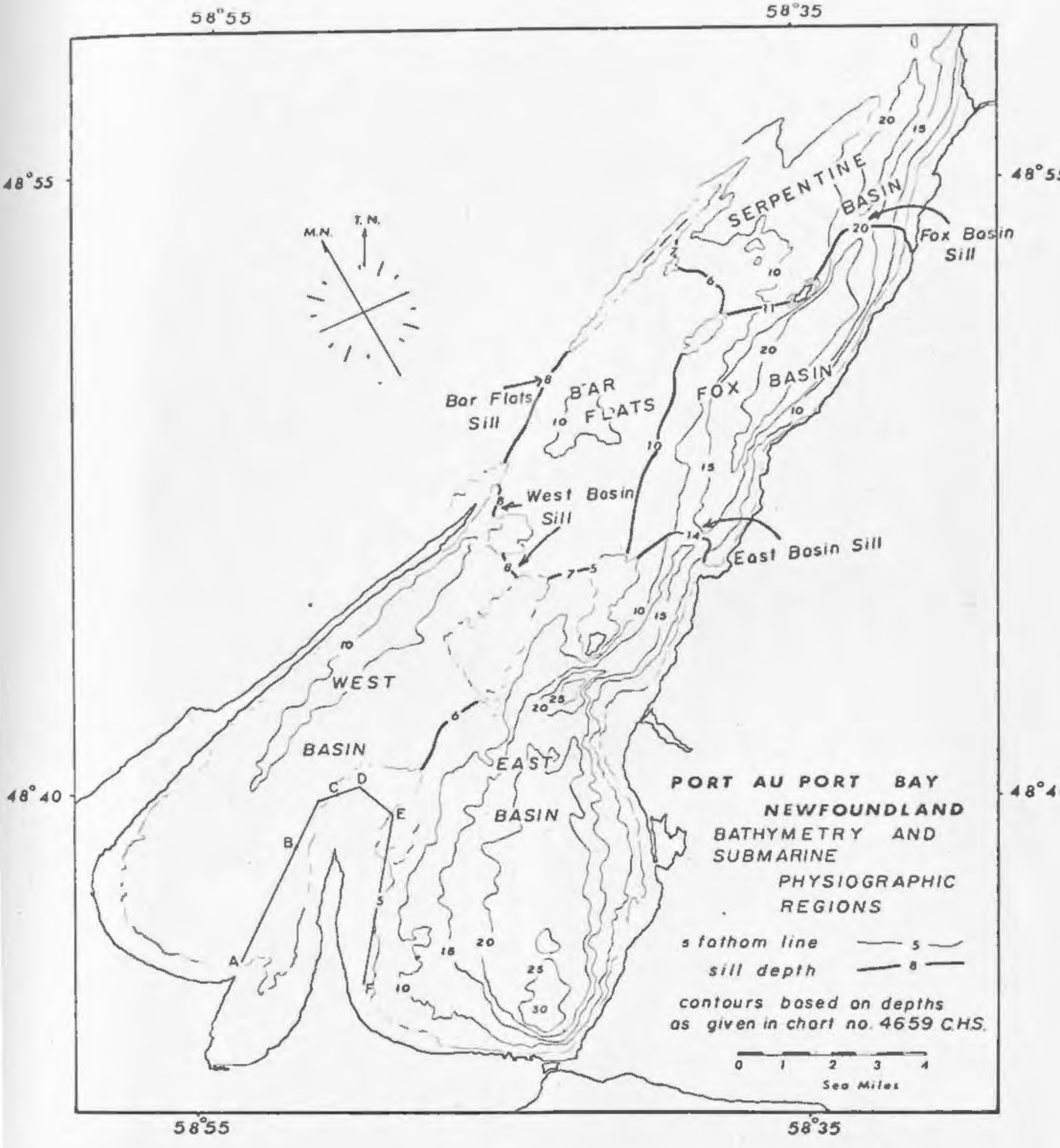
The land bordering Port au Port Bay to the west and south (the Long Point and the Port au Port Peninsula proper) has a low to moderate relief. The slopes of the Port au Port Peninsula rise gently southwestwards and southwards to elevations of between 600 and 800 feet, with summits at 766, 1060 and 1160 feet (Map No. 2). The land to the east of the bay has a more impressive relief, as Table Mountain east of Port au Port Bay has a crest elevation of about 1200 feet, and the Lewis Hills north of the Fox Island River reach heights from 1800 to over 2600 feet (including the highest point of Newfoundland with 2672 feet). The Port au Port Peninsula and Table Mountain are dissected only moderately where in the Lewis Hills there are valleys of considerable depth and steepness (Map No. 2).

The relief of the bottom of Port au Port Bay is very subdued even in comparison with the gentle slopes of the Port au Port Peninsula. Figure 12 shows the bathymetry and physiographic regions of Port au Port Bay. Four main basins are shown, with those along the eastern shore being the deepest. A depth of 30 fathoms, found in the centre of East Bay, is the deepest point in the whole Port au Port Bay system. The network of sills is also shown in Figure 12, with the deepest sill connecting each basin being given the name of that bay. In the area adjacent to Port au Port Bay, the Gulf of St. Lawrence is similarly shallow, having depths generally between 20 and 30 fathoms. A gentle slope towards greater depths begins some 20 miles offshore. The marked contrast between the relief of the Lewis Hills area, east of Port au Port Bay, and that of the floor of the bay and the adjacent area of the Gulf is shown in Figure 13.

Although Quaternary deposits are present at many places on land, and an almost continuous blanket of such post-glacial deposits covers the sea floor in the study area, it is the nature of the bedrock (see Chapter III) and its differential resistance against erosion which have determined the shape of the major physiographic features of the region. Long Point on the northwest side of Port au Port Bay is a cuesta with a crest in resistant carbonate rocks which dip towards the Gulf (Long Point Formation).

FIGURE 12

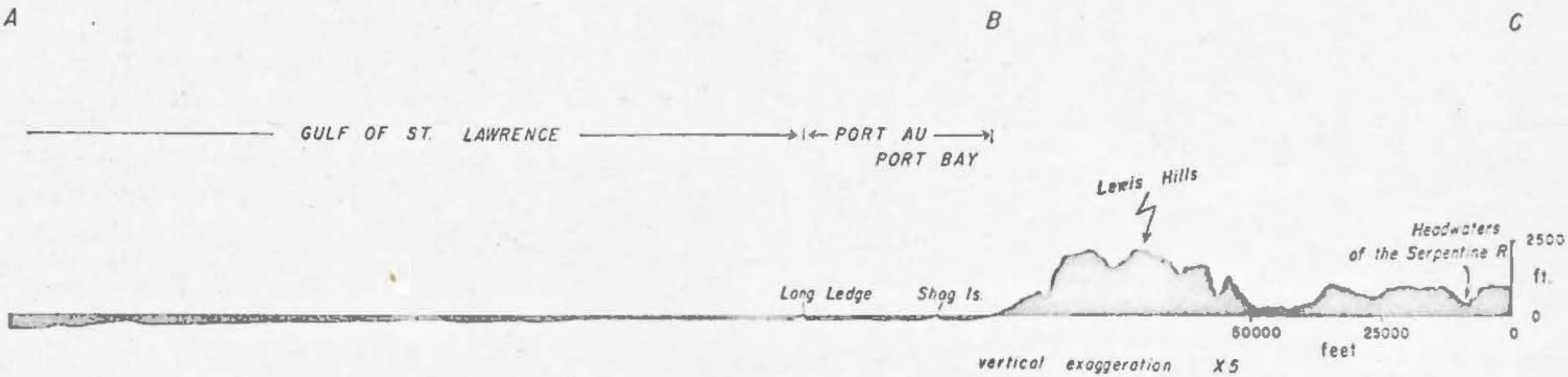
Bathymetry and submarine physiographic regions of Port au Port Bay.



58°55
58°35
48°55
48°40
M.N.
T.N.
SERPENTINE BASIN
Fox Basin Sill
Bar Flats Sill
BAR FLATS
FOX BASIN
West Basin Sill
East Basin Sill
WEST BASIN
EAST BASIN
A
B
C
D
E
F
PORT AU PORT BAY
NEWFOUNDLAND
BATHYMETRY AND SUBMARINE PHYSIOGRAPHIC REGIONS
5 fathom line
sill depth
contours based on depths as given in chart no. 4659 C.H.S.
0 1 2 3 4
Sea Miles

FIGURE 13

A profile of the elevations of the sea bottom and land surface from the Lewis Hills to the Gulf of St. Lawrence, demonstrating the relative relief between the land and sea bottom. See Map No. 2 for location of profile.


A
B
C
GULF OF ST. LAWRENCE
PORT AU PORT BAY
Lewis Hills
Headwaters of the Serpentine R.
2500 ft.
0
Long Ledge
Shag Is.
50000
25000
0
feet
vertical exaggeration X 5

The higher areas to the south and southeast of the bay also consist of resistant carbonate rocks, which dip generally towards the bay (St. George and Table Head Groups). The Lewis Hills to the northeast are composed mainly of very resistant volcanic and intrusive rocks (upper part of the Humber Arm Terrane). The low areas close to the shoreline, however, from Rocky Point to South Head (West Bay), around Shoal Point, and from Broad Cove to Black Point (East Bay), are underlain by shale-rich sequences which offer little resistance to erosion (mainly sedimentary formations of the Humber Arm Terrane). It seems justified to assume that most of Port au Port Bay and in particular the basin areas are composed of the same weakly resistant formations.

Erosional relief modifications dating from post-glacial times have generally been small in Newfoundland (Brückner, 1969). In contrast to this, the erosive effects of the Pleistocene ice sheets have been much greater; glacially rounded land forms are present at many places in the surroundings of Port au Port Bay, U-shaped valleys can be noted (Plate 1), and the irregular relief of the bay floor with its basins and sills is typical of glacial excavation (Figure 12). As the Pleistocene ice sheets of eastern North America are known to have covered the continental shelves off Newfoundland and Nova Scotia, it is logical to assume that the floor of the Gulf of St.

N

S

Plate No. 1

Glacially-rounded hills and U-shaped valley modified by post-glacial solifluction and talus development. Raised terraces (maximum elevation 160-180 ft.) at several levels undergoing recent erosion by stream incision and wave attack; Joe's Brook on the northeast coast of Port au Port Bay.

The locations of this plate and those following are marked on Map No. 3.

Lawrence was also subjected to considerable glacier erosion.

Although a substantial volume of bedrock has obviously been eroded by the Pleistocene ice sheets, throughout the area under consideration, this volume can only have been a comparatively small portion of the total volume of rock that was removed in order to bring about the great relief contrast now in evidence. Twenhofel and MacClintock (1940) have demonstrated that evidence of preglacial erosive planation by terrestrial agents is widespread in Newfoundland. They have stated that in the western part of the island remnants of such planation surfaces are present at elevations of 500 to 1000 feet, 1300 to 1700 feet, and 2000 to 2600 feet. Brookes (1964) even believes that ten planation surfaces can be discerned. The remnants of planation surfaces at several levels are proof that several sequences of uplift, dissection, and planation have occurred in preglacial (i.e., Tertiary and Mesozoic) times. During the formation of each of these planed surfaces, enormous masses of bedrock were eroded.

It is tempting to assume that the bedrock "layer" between the level of the lowest erosion surface of Twenhofel and MacClintock (1940) and a level approximately corresponding to the depth of the vast shallows of the Gulf of St. Lawrence (Magdalen shallows, 20-40 fathoms) was subjected to dissection and planation during a younger (late Tertiary) episode of terrestrial denudation; in this case, a base level of erosion 100 to 200 feet below the present sea level would have to be postulated. Alternatively, continuous coastal erosion by the sea may be thought of as having developed an enormous wave-cut platform in the Gulf, though the relatively slow progress of sea encroachment on bedrock coasts would seem to make this alternative less probable. Large stretches of the southern Gulf are underlain by poorly to moderately consolidated Carboniferous sediments of mainly subhorizontal attitude. The remnants of such rocks exposed on or near the Port au Port Peninsula indicate that they have been present in the past, possibly covering the whole of Port au Port Bay and the adjacent part of the Gulf. The horizontality of these rocks together with their low resistance against erosion have certainly favoured the progress of erosional lowering and planation of the areas concerned, whatever the agents may have been.

II. Quaternary Geology along the Coast of Port au Port Bay

Along the shoreline of Port au Port Bay, exposures of bedrock alternate with exposures of Quaternary deposits.

The most extensive bedrock exposures are found along Long Point on the western coast and north of Fox Island River on the eastern coast. Exposures of smaller dimensions are present to the west and south of South Head and on the southeast side of Piccadilly Bay (West Bay) as well as between Boswarlos and Black Point (East Bay). (See Map No. 3.)

Most bedrock exposures along the shore exhibit wave-cut cliffs and at the foot of these cliffs wave-cut platforms of varying widths are present at many places (Plate 2).

On bedrock outcrops beyond the reach of present and past wave effects, features of glacial erosion can usually be noted, such as roches moutonnées, smaller-scale rounding and polishing, glacial grooving (Plate 3), and striations (Plate 4). The development of these features ceased when the glacier melted in the study area; they can therefore be attributed to the final stages, or even years, of the Wisconsin glaciation. Glacial striae in two or three diverging directions (Plate 5) visible on the same outcrop indicate that the direction of ice flow changed once or twice at these places during the latest stages of the classical Wisconsin glaciation. (See also MacClintock and Twenhofel, 1940.) In the carbonate rocks of the area, corrosion features have generally developed at those places where rock surfaces were exposed to rain during a part or all of post-glacial time.

The Quaternary deposits present along the coast can be divided into (1) glacial deposits, (2) raised terraces, W

E

Plate No. 2

Modern, wide, wave-cut platform cutting an almost vertical sandstone sequence of the Humber Arm terrane; located at Broad Cove on the northeast side of Port au Port Bay.

Plate No. 3

Aerial photograph of N-S glacial grooving on the northwest side of Table Mountain. Scale of the photograph is 5000 feet per inch, indicating a length, although discontinuous, of up to 10000 feet for some grooves. They are found only on the northern slope indicating movement from that direction. Glacial striae (Plate 4) found in one of the grooves confirm this.

Note the angular discordance between the grooves and the outcropping bedrock of the St. George Group dolomitic siltstones. Also of interest, on the lower side of the photo, is the westwardmost exposure of the large Bay St. George outwash sequence; named "The Gravels".

Photo is from the courtesy of the National Air Photo Library in Ottawa (No. A-12156-126).

N

S

Plate No. 4.

Glacial striations on a rock surface (St. George dolomites) found within one of the glacial grooves seen in Plate No. 3. The striation direction is, in almost all instances, parallel to that of the grooving.

Plate No. 5

Glacial striations in two directions can be seen. This exposure occurs in the St. George Group dolomites, and is found just north of the Isthmus in the extreme southeast corner of Port au Port Bay.

Note the oblique section of a Cryptozoan reef exposed by the excavating action of the ice.

(3) modern deposits, and (4) other post-glacial deposits.

(1) Glacial deposits in situ comprise blankets and patches of till as well as individual erratic blocks and stones resting on bedrock surfaces. Till can be seen to cover the bedrock in many of the coastal exposures. As well, till underlies many of the raised terrace deposits. Plate 6 shows a typical exposure of the till blanket on Shoal Point (Map No. 3). Isolated erratic blocks and stones are found in varying numbers at places where till blankets were either not deposited or where they have been eroded and differentially sorted after their deposition. Much of the erratic material and pebbles in the till consist of crystalline rocks, which outcrop to the east of the study area (Indian Head Range and Long Range Mountains). This indicates that the last glacier advance in the region in late Wisconsin times moved westward (MacClintock and Twenhofel, 1940).

Till material has participated, at places, in solifluction and slumping (Plate 1), and erratics undercut by erosive agents have fallen onto wave-cut platforms, beaches, and into streams.

From the presence of glacial deposits and their remnants on the land around Port au Port Bay, it may be inferred with some confidence that the area of the bay itself was also covered by glacier ice, which agrees with

N

S

Plate No. 6

Basal till overlain by roots of trees and subsequent peat layers; located on the west side of Shoal Point.

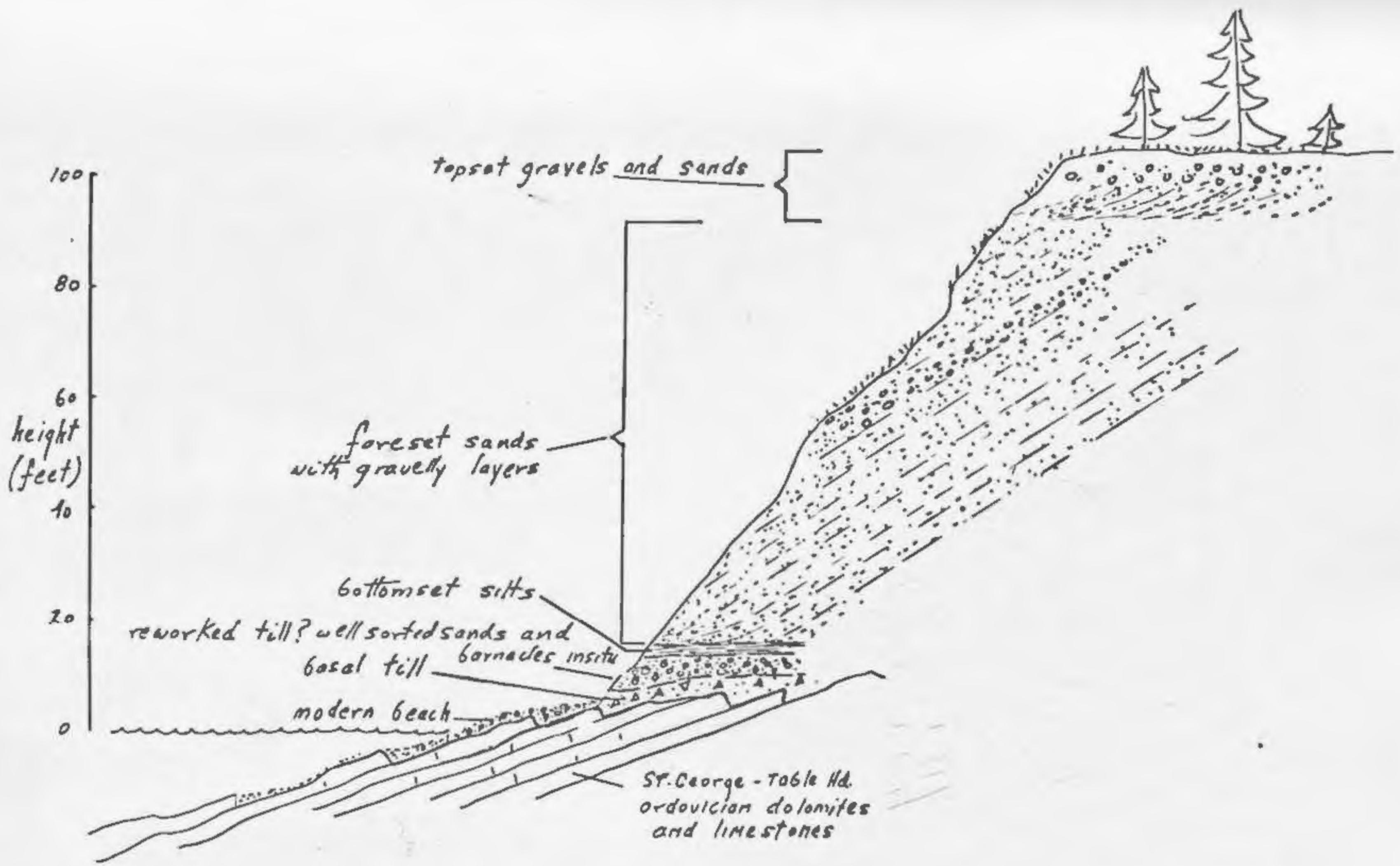
the conclusion reached above on the basis of the bay floor morphology.

(2) The main areas with <u>raised terraces</u> around Port au Port Bay are marked in Map No. 3. They are found at the mouth of the valleys of the Serpentine River, Rope Cove Brook, Molly Ann Brook, Deadmans Brook, Joe's Brook, Lewis Brook, and in Broad Cove where three small streams enter. Further south but still on the east side of the bay, the Fox Island River outwash fan can be observed. At the Isthmus below the town of Port au Port, a large outwash delta sequence called "The Gravels" is visible. This occurrence is essentially the westernmost exposure of an outwash sequence which is almost continuous along the coast of St. George's Bay from the town of Port au Port eastwards to Stephenville and Stephenville Crossing and from there southwards for about 50 miles to Highlands (Map No. 2). These terrace deposits have already been studied by MacClintock and Twenhofel (1940), by Flint (1940), and recently by Brookes (1969), who has mapped them in much detail. Returning to Port au Port Bay, other minor outwash terraces can be seen at Smelt Brook on the west side of Piccadilly Bay and from Harry's Brook to just north of Victors Brook on the southwestern side of West Bay.

Most of the above terraces consist, from the base upwards, of a till deposit which is in turn overlain by thinly laminated silts, inclined sands and gravels, and horizontally bedded gravels which are respectively the bottomset, foreset, and topset beds of a delta sequence. Often this ideal sequence is modified by the presence of other material. At Tea Cove in West Bay the bottomset(?) are composed of clay material instead of silt, and locally stones in varying numbers are embedded in this clay. The transportation of these stones to their places of deposition can be explained best by ice-rafting. Figure 14 shows a schematic section of the terrace about 200 yards east of the Isthmus at Port au Port. The stratigraphy of this section is very similar to the general one described above, except that between the till horizon and the bottomset silts a pebbly layer about 1 foot thick exists. Fossil barnacles are found in place (Plate 7) on the uppermost pebbles of this bed. The matrix of this pebble deposit is a very well sorted sand (mean size $\simeq$ 0.3 mm.) and would seem to imply a high energy of formation (i.e., to rework the till, remove the fines, and redistribute the sandy material, the size of which would be related to the prevailing energy). Kame deposits underlying the bottomset beds of the delta sequence occur between Romaines Brook and Blanche Brook at Stephenville and indicate that, locally, glacier ice was still present when the deltas developed (MacClintock and Twenhofel, 1940).

FIGURE 14

Diagrammatic sketch of the section of post-glacial deposits at the Isthmus, town of Port au Port.



SCHEMATIC SECTION of POST – WISCONSIN deposits at the Isthmus, town of Port au Port

Plate No. 7

Reworked till of Figure 14; well-rounded pebbles in a matrix of well-sorted sands, overlain by the bottomset silts of the delta sequence.

Note the barnacles in their growth position, with the silt actually infilling the cavities.

It is obvious, even to the casual observer, that terrace surfaces are present at different elevations (Plate 8). The highest terraces vary considerably in height from one part of the bay to another. The highest terrace observed in the area is at about 160 feet above datum and is found between Joe's Brook and Lewis Brook on the north-east side of Port au Port Bay (Plate 8). The terrace at the Isthmus is about 100 feet high (Plate 9). At Romaines Brook, a record of five distinct terrace levels is preserved at heights of about 100 feet, 30 feet, 20 to 24 feet, 8 to 10 feet, and 5 feet (barometer). Many well-developed terraces at 25 to 30 feet exist in the area (i.e., at Fox Island River, Plate 10; at Broad Cove, Plate 11; and at Rocky Point, Plate 12). At Fox Island River and Broad Cove topsets can be seen overlying foresets and would seem to furnish a fairly accurate value of a higher sea level. The well-developed raised beach at Rocky Point may indicate a stillstand at this 30 foot level.

It is pertinent to mention here that the highest terraces found at a given point do not in fact represent the marine limit or the maximum extent of marine incursion. Brookes (1969) has found the marine limit at the Isthmus to be around 120 feet above datum. Likewise, at Abraham's Cove he has found the marine limit (a raised beach) to be around 145' while a well-developed terrace at only 80 feet exists.

N  S

Plate No. 8

This plate shows many of the terrace sets seen in Plate No. 1, from further out to sea where, on the far right (south), a good example of a lower regressional terrace can be discerned.

E

W

Plate No. 9

A view looking south at the 100 foot terrace at the Isthmus. Photo taken in mid March/68 shows local ice which has frozen unto the shore at high tide.

In the foreground a bed of Cryptozoan mounds included in the St. George Group sequence can be seen.

W  E

Plate No. 10

Remnant of the Fox Island River outwash sequence with well-developed topset and foreset beds. Elevation of the top is about 25 feet above the present datum; near Point au Mal on the east side of Port au Port Bay.

N

S

Plate No. 11

The 30 foot terrace in unconsolidated material at Broad Cove. Gently dipping foresets are visible in the section exposed.

S

N

Plate No. 12

Well bedded fossil beach deposit with shells, about 30 feet above the present datum; located at Rocky Pt. on the west side of Port au Port Bay.

<u>Terraces</u>, in fact, are thought to represent a period of stillstand when grading to a given sea level by existing streams can occur. On the contrary, as will be seen in more detail below, the <u>marine limit</u> is dependent upon the time of deglaciation and is generally not a time of relative stability between the land and the sea.

Whereas the uppermost terraces appear to consist almost entirely of material derived directly from the glacial drift that was deposited by the dying ice sheet and hence are outwash deposits in the strict sense, the lower terraces, which developed during and after some stream incision into the upper terraces, are made up mainly of detritus eroded from the latter. As delta surfaces (or, more precisely, the bases of their topset beds) are related to sea level, it must be concluded that, after the time when sea level stood as high as the highest terraces, time intervals during which sea level dropped causing stream incision alternated with time intervals when sea level was stable (or perhaps slightly rising?) permitting alluviation to proceed.

Flint (1940) has shown that the raised outwash terraces of west Newfoundland can be correlated with raised platforms in bedrock cut by wave attack at the same elevations. Along the coast of Port au Port Bay remnants of such raised platforms are not common. Long Point is the best example, with an almost level surface at 50 to 60 feet above the present sea level which can be attributed to levelling by the strong waves generated on the Gulf of St. Lawrence when the sea was temporarily stable at that elevation. On the northwest side of Long Point, well-developed platform remnants are present also at 25 to 30 feet above sea level. Likewise, at Black Point and at Broad Cove (Plate 13) bedrock surfaces at about 30 feet exist. At Broad Cove the terrace at 25 to 30 feet is underlain by vertically dipping Humber Arm sandstones on the west and outwash material in the cove itself further east. Shoal Point appears to have a gently north dipping erosion surface beneath its peat cover (Plate 6). On its east side a fossil beach sand overlies this till (in some places Humber Arm shales are present instead of till) and is evidence enough to propose that the surface underlying the peat on Shoal Point is a wave beveled surface.

(3) Among the modern deposits existing along the coast of Port au Port Bay the most obvious are the beaches. Their distribution is shown in Map No. 3. Generally, beaches are present along those stretches of the coast where unconsolidated Quaternary deposits are exposed to the attack of the sea and hence continuously provide a fresh supply of loose debris from which beaches can be maintained. At those stretches where bedrock cliffs border the sea, beaches are normally absent as the rate of bedrock breakdown is very

W

E

Plate No. 13

Bedrock cliff at Broad Cove Pt. forming the westernmost extent of a 25 to 30 foot terrace, which to the east is composed solely of unconsolidated material (Plate No. 11). Photograph taken from a recent wave cut platform (very similar to that seen in Plate No. 2 and located only 200 to 300 yds. southwest of it).

slow if compared with that of the unconsolidated materials. The lack of beaches is particularly apparent along the southeast side of Long Point (north of Tea Cove), along the south coast of East Bay from Aguathuna to Black Point (though with a break at the Isthmus of Port au Port), and from Broad Cove northward to Lewis Brook on the east coast of the bay. Apart from Shoal Point where till is the source of the beach material (Plate 6), all major beaches are related to areas with raised outwash material (Map No. 3). This is particularly clear in the stretch from the Serpentine River to Lewis Brook, in the area around Fox Island River, at the Isthmus of Port au Port, and along the coast of West Bay from South Head to Tea Cove. (What is said here about the sources of the beach material likewise applies, of course, to the offshore deposits of Port au Port Bay.) In general, long-shore transport does not seem to have a major influence on the formation of the beaches in the study area, except at the mouth of Fox Island River and at the lagoon of Point au Mal where extended south-pointing sandy spits are present.

The beach sands themselves are quite immature, presumably a result of the slow transgression of the sea (discussed later in this chapter). The maturity of these beach sands is deduced primarily 1) from grain roundness, which is angular to sub-angular, and 2) from the heavy mineral assemblage. The heavy mineral suite in the beach sands is composed principally of illmenite, magnetite, olivine, hypersthene, augite, diopside and various amphiboles where an ultra-basic source is present and of garnets, tourmaline, biotite, apatite, pyroxenes and amphiboles where acidic sources exist. The heavy mineral assemblage present at any given point is almost identical to that present in the raised outwash deposit from which it was derived. This suite, likewise, is little changed from the original till and/or bedrock source.

All beaches situated at comparatively sheltered localities consist of sands having median grain diameters between 0.3 and 0.5 mm. Major pebbly to bouldery beaches are present only in two areas on the east coast of Port au Port Bay: south of the Serpentine River to Lewis Brook, with a few stretches of sand in between south of Rope Cove and just north of Deadman's Brook, and at the Isthmus of Port au Port (Map No. 3). Apparently, the power of the waves breaking at these localities is so great that most of the sand furnished by the source is removed from the beach and deposited at some distance offshore. At the northern locality the increased wave power in operation seems to be that of the swell on the Gulf of St. Lawrence, as it can enter the bay to the north and south of The Ledges and reach the coast with its full strength. At the

Isthmus locality, fairly strong waves may arrive when northwesterly winds are blowing across East Bay, which has a fetch of about 10 sea miles in that direction.

Contributing as well to the existence of boulder and pebble beaches is the offshore slope. Where the slope of the bottom is steep right up to the shore, any large waves impinging on the shoreline will break almost on the beach will full energy available for the transportation and removal of the sand-size material. On the contrary, in areas with a very gentle offshore shope (head of West Bay, east and west side of Shoal Point) any large waves running onshore will break offshore with the result that their full impact will not be felt right on the beach. In this manner sandy beaches may be maintained in areas of very gentle offshore slopes, almost irrespective of wave magnitudes.

Modern deposits other than beaches comprise products of mass wasting as well as lagoonal and peat deposits. Where raised terraces (or till) border the sea, steep slopes barely in gravitational equilibrium are maintained under the influence of wave attack, rain fall, wind, gravity, and internal cohesion. At these places, small-scale slumping occurs from time to time, and patches of scree and miniature alluvial cones are forming; but sea attack generally removes these ephemeral deposits as fast as they are developing. Lagoonal deposits are present mainly at the mouth of Fox Island River, southwest of Point au Mal, and at the Isthmus of Port au Port. They comprise silts and muds, commonly including varying amounts of organic matter. Peat is found adjacent to lagoons as well as in other flattish areas. The surface of Shoal Point is the largest area of the latter kind (Map No. 3).

(4) For the sake of completeness, two types of post-glacial deposit must still be mentioned, which belong neither to the raised terraces nor to the strictly modern deposits. The first of these are surficial blankets of debris on slopes and valley floors, which have developed by solifluction (Plate 1). They are composed mainly of till material and may still overlie undisturbed till. This type of mass-wasting takes place upon surficial melting of sloping permanently frozen ground. As permafrost is no longer present in the study area, the solifluction blankets have probably developed in the early part of the post-glacial period.

The second type of deposit to be reported here is the kind of landslide known as slumping. Such landslides of bedrock material are present on the western side of the Lewis Hills. A huge, complex body of this nature lies to the north of Bluff Head; a smaller, simpler one has formed to the south of that mountain. The chaotic internal character of these landslide masses is well visible in recent exposures at the coast.

Chronology of Quaternary Events in Port au Port Bay

The detailed nature of the sea level fluctuations in the study area is not yet known. Recently, with the advent of radiocarbon dating (C^{14}) an absolute chronology has been attempted. The stratigraphy of the adjacent areas as given by Flint (1940) and MacClintock and Twenhofel (1940) is excellent, and the sequence of events they propose is very similar to that established on the basis of the radiocarbon dates. At the time of writing, 5 radiocarbon dates from shell material collected in post-glacial deposits of the study area are available. Brookes (1969) has obtained dates from two samples taken in the Abraham's Cove area (Map No. 2): one (G.S.C.-968) at about 20 feet above sea level in (bottomset?) clays dating 13600 $\pm$ 180 yrs. B.P. and the other (G.S.C.-1074) at 5 to 10 feet below the uppermost marine feature dating 13700 $\pm$ 230 yrs. B.P. The level of this uppermost marine feature (about $\pm$ 145 feet) is the so-called "marine limit" for the Abraham's Cove area. The similarity of the dates for the basal marine clays and for the beach deposit near the marine limit, at this locality, seem to indicate that the formation of the outwash deposit was synchronous with the formation of the marine limit in the area. The absence of any lower older marine features indicates that the highest developed feature was synchronous with the deglaciation of the area. This coincidence of the time of the first marine incursion (deglaciation) with the marine limit implies that during the process of deglaciation the land surface was rising relative to that of the sea. Apparently, then, at deglaciation, the isostatic rebound of the crust as a result of removal of the ice mass was considerably greater than the eustatic rise of the sea resulting from the addition of glacier meltwater.

The author (Lowden and Blake, in press, and Brookes, 1969) has obtained three radiocarbon dates. One sample (G.S.C.-937) was dated at 13200 ± 200 yrs. B. P. (from shells, mostly Mya truncata Linné in stony marine clays about 10 feet above sea level at Tea Cove on the western side of West Bay). If a parallelism may be drawn here between the Tea Cove and Abraham's Cove situation, then the date for the deposition of the clays at Tea Cove, although at an elevation well below the marine limit, is probably the date of deglaciation of the area. Brookes (1969) has noted marine features up to a height of about 70 feet in this area (although not yet established as the marine limit). The discrepancy in the highest observed marine features between these two areas might be accounted for by the different deglaciation times. Between the times of deglaciation of the two areas (13600 yrs. B. P. and 13200 yrs. B. P.) rebound to the extent of about 75 feet (145'-70') had occurred. The other two dates obtained will be discussed in detail below.

It seems, then, that at the time of the recession of the glaciers from the Port au Port Bay area isostatic rebound of the land areas was the dominant mechanism in force. Because of this, the upper limit of marine incursion is not represented by a terrace, but simply by a line of washed boulders (Brookes, 1969). The sea, then, was at its highest position with respect to the land, in the Port au Port area, at the time of deglaciation. Before, at the time of and after deglaciation the land was rising at a faster rate than was the sea, therefore, a relative rapid sea level drop occurred. How, then, during this regressional phase, could terraces have developed? Presumably during this phase, even for short periods of time, the isostatic rebound rate and the eustatic rise must have been somewhat similar. An explanation is given as follows: Once large-scale melting had begun over wide areas, the response of the crust to deglaciation seems to be quite rapid (Andrews, 1968). Possibly, the response to a glaciation (Robinsons Head Drift readvance, MacClintock and Twenhofel, 1940) is just as rapid, only in the reverse sense. It is proposed that a readvance of the ice, although short termed and much more localised in extent than the universal retreat, might cause a rapid reduction in the isostatic rebound rate. With the subsequent retreat of this local ice mass isostatic rates would again exceed greatly the eustatic rates and the sea level would resume its rapid drop. Acting simultaneously with this isostatic phenomenon would be the relatively synchronous worldwide eustatic fluctuations as a result of even small changes in glacier regimes. Depending upon the time involved for the crust to react to glacial loading, crustal rebound rates may decrease in response to a re-advance by the time the advance has in fact stopped and glacier retreat has begun. In this way a decrease in the rebound rates coupled with a surge in the eustatic component may enable a stability of adjacent land and sea bodies to persist long enough for terrace development.

Nevertheless, it has become increasingly apparent that, in fact, the formation of terraces may not be at a time of sea level stability. These outwash terraces can form in an exceedingly short time if the sediment is available and the transporting capacity of the streams is adequate. Andrews (1969), among others, proposes that a climatic change, presumably to a more humid one causing increased stream discharge, is one of the paramount reasons for the development of an outwash terrace at a given time.

It is necessary, here, to point out that very often shoreline features in bedrock (wave-cut platforms) are found at the same elevation as the outwash delta surfaces. This being the case, sea level stability must have existed for some time. Nevertheless, in the study area these platforms are found mainly in the shale-rich rocks of the Humber Arm terrane which are undoubtedly weak when speaking in terms of resistivity to storm wave action.

Discounting these short term equalities, eventually the isostatic rate of uplift decreased to equal the rate of eustatic rise of sea level. This was the time of maximum emergence which was subsequently followed by a gradual submergence of the land when eustatic encroachment finally exceeded the isostatic rise. The author (1969) has found the level of maximum emergence to be around 35 to 45 feet below the present sea level. A core (S-89) taken in West Bay contains a coarse sandy horizon which is inconsistent with material being deposited at the present time in the bay. Given certain assumptions for the past, based on the present day conditions, that no tidal currents ran over the bottom of West Bay and that wave activity was not significantly different from what it is today, then the depth of water needed for storm wave action to have transported this coarse material by traction can be calculated. By subtracting this depth (35 to 45 feet) from the present depth of the sandy layer ($\simeq$ 80 feet) the probable position of the lowest post-glacial sea level in Port au Port Bay is found to be between -35 and -45 feet. The above estimate coincides with that estimate arrived at by subtracting from the calculated theoretical uplift curve, using a relaxation time of about 2000 years (Andrews, 1968), the world-wide eustatic sea level curve as given by Shepard (1963).

The time of maximum emergence, deduced from these two curves, is given when the rates of sea level rise are synchronous and is between 8000 and 10000 years B.P. A radiocarbon date (G.S.C.-1203) on shelly material from this sandy zone gives an age of 5760 ± 210 yrs. B.P. This is thought to be, at least, a minimum age for the time of maximum emergence. It is unfortunate that, in order to obtain enough material (5 grams) for a C^{14} determination, the mixing of datable material from the core S-89 with similar material from core S-88, although at the same apparent stratigraphic position, was necessary. This is perhaps the source for the discrepancy between the theoretical date and that actually found. On the other hand, the C^{14} date may very well be correct, with a short term eustatic drop having caused the lowest sea level to be registered at this time.

An anomalous occurrence yet to be discussed is the deposit of well-rounded pebbles with well-sorted interstitial sands underlying the bottomset silts at the Barnacle occurrence (Plate 7) described above. The barnacles from this zone have recently been dated giving an age of 13400 ± 290 (G.S.C.-1187). This date, coinciding with that of the time of high sea levels in the area, necessitates that tidal currents were sufficiently strong to rework the basal till.

CHAPTER V

SEDIMENTOLOGY

Field Work

Field work for this thesis was done during the months of June, July, and August, 1966. For most of the work at sea and along the shore, a Cape Ann type boat having a length of about 55 feet was used (Frontispiece). Some coastal stretches were approached by road.

Bottom sampling of the area under investigation included grab samples and cores. The grab samples were recovered with a hand winch and the heavier coring equipment was lifted with a gasoline winch. A Dietz-Lafond snapper was used for obtaining the bottom grabs. Upon collection, the grab samples were put into polyethelene bags and labelled. The cores were taken by means of a Kullenberg piston corer, with a driving weight of 150 pounds and with a 6 foot or 12 foot, 1 3/4 inch inside diameter pipe. The cores were preserved in the original plexiglass core liners.

Initially, the bottom sampling was carried out on a grid-like pattern but this rigid approach was abandoned in favour of sampling in conjunction with echo soundings and bottom topography, so that adequate representation of the different bottom facies was obtained. Generally, a grab sampling interval of one mile was attempted, with the result that about 200 samples were collected (Figure 15). The coring interval chosen was much greater, as the time required to obtain one core was much longer than that needed for one grab. As well, a few cores are generally adequate for the reconstruction of the sedimentary history in one depositional basin. Most success in the coring operations was achieved in the basins where fine grained deposits of considerable thickness exist. Attempts to core in the sand deposits of the sill areas between the basins gave only poor results. In all, about 25 cores were collected, which had an average length of eight feet, but in fact ranged from one foot to 12 feet in length.

Positioning of the locations of these marine samples was done principally with a sextant. The three-point plot method using prominent topographic and man-made (church, radar station) features on shore provided adequate fixing of the boat location to within $\pm$100 meters.

About 40 samples were taken from the recent shoreline beaches and about 100 samples from post-Wisconsin or post-glacial raised terrace deposits were also obtained (Figure 15).

FIGURE 15

Bottom grab, core, beach and raised outwash (Pleistocene) sampling locations, prefixed respectively S.,S.,B, and P.


58°55
58°35
48°55
48°40
M.N.
T.N.
PORT AU PORT BAY
NEWFOUNDLAND
SEDIMENT SAMPLE
LOCATION
GRAB
CORE
GRAB and CORE
BEACH
PLEISTOCENE
0 1 2 3 4
Sea Miles

Laboratory Work

The present thesis is based essentially on a detailed granulometric study of the bottom grab samples only. Preliminary studies of heavy minerals and foraminifera were also made and the results will be used as a supplement to the grain size data (where applicable).

To start, each grab sample was soaked in water for at least 24 hours. The portion to be analysed was obtained by taking a small handful (after mixing) from the complete grab sample. This crude procedure proved to be adequate as twice or three times repeated analysis of the same samples showed very little discrepancy (Figure 16). The portions obtained in this way were then subjected to wet sieving through a 350 mesh (45 micron) sieve.

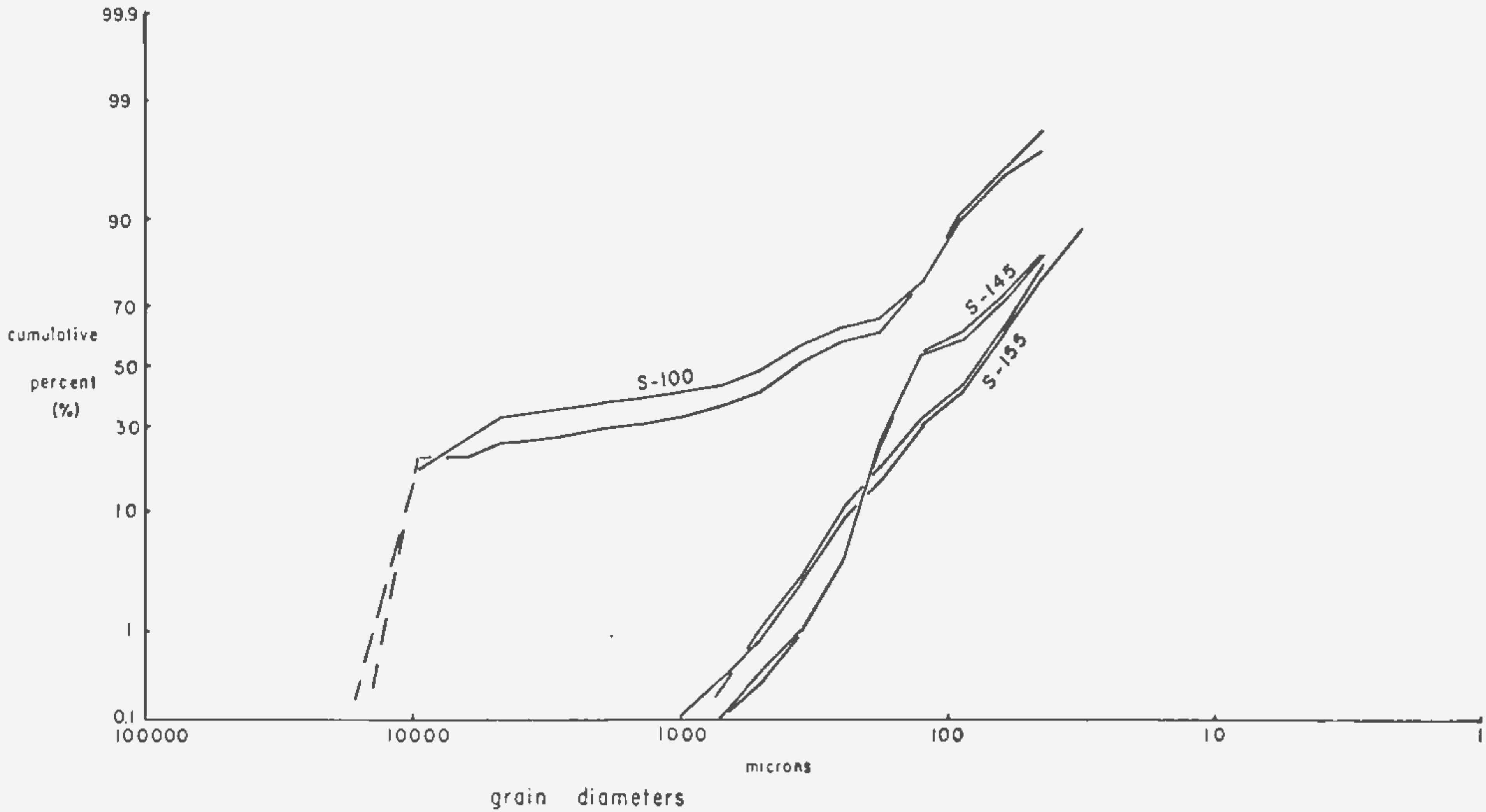
The fractions " coarser than"* 45 microns contained considerable amounts of wood and leaf debris, obviously derived from the forest and grass vegetation beyond the shoreline of the bay. Upon drying, this organic material caused a mat-like bond between the grains and hindered their separation into further fractions by sieving. Treatment with dilute HNO_3, which was tried first, proved to be ineffective in removing the organic material though the carbonate particles were dissolved. It was then found

---

*" Coarser than" in the future to be written as >.
"Finer than" in the future to be written as <.

FIGURE 16

Repeat grain size analysis of three samples located in the study area.



99.9
99
90
70
50
30
10
1
0.1
cumulative
percent
(%)
S-100
S-145
S-155
100000
10000
1000
100
10
1
microns
grain diameters

that repeated decanting from one dish into another separated quickly and effectively the organic material from the clastic material. Concentrates of the organic material were retained and were found to be rich in diatoms, pollen, spores, and foraminifera, apart from the plant debris.

After removal of the organic material, the fractions $>$ 45 microns were dried and subsequently sieved. Hand sieving was used in preference to the Ro-Tap machine, in order to obtain a more complete passage of grains. Between diameters of 45 microns and 2 millimeters (mm.) the sieves used had ½ ϕ intervals; between 2 mm. and ½ inch (12.7 mm.) they had irregular intervals; and for sizes with diameters $>$ ½ inch, ½ inch and 1 inch intervals were used. See Table I for the complete set of sieves used.

The fractions $<$ 45 microns were allowed to settle for about one week, so that the large amounts of water collected during the wet sieving process could be decanted. In the majority of cases, this residue was then dried and weighed.

In some cases, however, an attempt was made to determine the size distribution of the particles $<$ 45 microns more accurately. Hydrometer analysis was considered the optimum method for this purpose because of its speed, which is due to the fact that, although the size distribution of the clays can be worked out, no separation of individual size fractions need be made. Considerable trouble was,

TABLE 1

SIEVE APERTURES USED FOR THE GRANULOMETRIC ANALYSIS OF THE COARSE SILT TO GRAVEL SIZED MATERIAL

Sieve mesh no. A.S.T.M.	Diameter mm.	Diameter Ø units
350	0.045	+4.5
230	0.063	+4.0
170	0.090	+3.5
120	0.125	+3.0
85	0.180	+2.5
60	0.250	+2.0
44	0.355	+1.5
30	0.500	+1.0
22	0.710	+0.5
16	1.000	0
12	1.4	-0.5
8	2.0	-1.0
6	2.8	-1.5
3/16 inch	4.760	
1/4 inch	6.350	
3/8 inch	9.525	
1/2 inch	12.7	
3/4 inch	19.0	
1 inch	25.5	
1½ inches	38.2	
2 inches	51	
3 inches	76	
4 inches	104	

however, encountered in trying to attain complete deflocculation of the fine particles in the suspensions studied. The addition of Calgon (1 gm./1000 ml.) led only to partial success but the addition of 10 cc. of one normal sodium carbonate or sodium oxalate had even less success. High content of organic matter in the sediment seems to be the chief cause for flocculation, as samples that were collected below the surface layer of 3-5 cm. thickness, where all the organic material had probably been oxidized, needed no dispersing agent. With many samples the flocculation could not be decreased at all, and hence the size analysis of the material less than 45 microns in diameter is completely unreliable. In these cases, the fine fraction was merely treated as a whole and weighed as such. Any samples shown in the figures of this thesis, with size distribution data given for particles $<$ 45 microns, are samples in which coagulation was small or absent. Only 10-15 samples, out of about 50 tried, could be dispersed to an adequate degree.

Once the weight of each size fraction had been obtained, the weight percentages were calculated and corresponding cumulative curves were drawn on logarithmic-probability paper.

Heavy mineral separations, using bromoform of specific gravity $\simeq$ 2.85, were generally made of the 45 to 63 micron and 63 to 90 micron fractions only, but, in some cases, of all the size fractions. The heavy concentrates were then mounted on slides for microscopic study.

In order to obtain significant concentrations of foraminifera much larger portions of the samples were needed than those fractions obtained in the sieve analysis. The concentration of the foraminifera was achieved by means of heavy liquids. Contrary to the heavy mineral separation, these liquids were used to float the forams. Mixtures of bromoform and carbontetrachloride (specific gravity, 1.62) giving a fluid with a density around 2.7 gm/cm^3 and pure carbontetrachloride were applied successively.

Grain Size Distributions

The object of this section is to discuss the relationship of the grain size distribution of the samples collected in Port au Port Bay to the main factors responsible for these distributions, i.e., present wave action, present tidal currents, and source material. This is not a simple matter, as a cursory examination of the size distribution data obtained reveals that they can be correlated only in part with the energies in operation today.

For the detailed examination of the grain size distributions a choice had to be made between two methods, the first, using particular grain size parameters only, and the second, using cumulative curves.

Folk (1966) has discussed in detail the development and refinement of grain size parameters used for the description and environmental interpretation of clastic sediments. He has also mentioned the advantages and disadvantages of the method of statistical moment measures over graphical methods in the calculation of these size parameters. The parameters generally used in grain size analysis are the mean diameter, standard deviation, skewness and kurtosis. The grain size distribution of a sediment can certainly be described by means of this set of four, so-called, scores each corresponding to one of the four parameters. These scores, when juggled around and plotted one against the other, can be used to compare a large number of samples. This is the principle of the much used bivariant analysis of Friedman (1961, 1962, 1967) who used it to differentiate between beach, dune and river sands and of the quadrivariant analysis of Folk and Ward (1957).

Another method of presenting size distribution data is the construction of cumulative curves of each sample. This is a more qualitative approach than the one described above but it permits direct comparison of different samples with respect to all sizes. The main drawback of this method is that simultaneous comparison of many samples is more difficult.

Klovan (1966) has used the "Factor Analysis" statistical method in an attempt to pair end member grain size distributions with a given depositional environment.

Tanner (1958) and Spencer (1963) have advanced a modified approach by plotting the cumulative curves on logarithmic-probability paper and dividing these into various components. The size frequency data of many well sorted sands, when plotted on a logarithmic scale, give a Gaussian or normal distribution (Udden, 1914). Thus, when the cumulative curves of well sorted sands are plotted on logarithmic-probability paper, straight lines result. From this, the assumption can be made that a sediment in equilibrium with its depositional environment is represented by a straight line on logarithmic-probability paper; that is, its grain size distribution is log-normal. A non log-normal curve, then, can be broken up into a number of log-normal components, each component contributing a certain percentage to the total curve, with each component having a certain mean and certain standard deviation. In this respect, one possible explanation for composite curves of this type may be due to sediment components each representing a different energy level.

One of the purposes of this study was to determine in detail the nature and cause of this non log-normality in many of the bottom samples. It would seem that the grain size parameters calculated for such a composite sample would give ambiguous results when attempting to correlate these parameters to the prevailing energies.

Samples were collected from three distinct environments: 1) the floor of the bay, 2) the beaches, and 3) the raised terraces. As the sediment samples taken from the raised terraces have no bearing on the energy systems in force at present, their cumulative curves will not be scrutinized in detail as will the others. The grain size distributions of the raised terrace deposits collectively are important, nevertheless, because they are the main source for the beaches and hence the ultimate source for the sediments in Port au Port Bay. The beach sediments have been described sufficiently for our purposes in Chapter IV.

Three fundamental types of cumulative curves were found in the marine sediments of Port au Port Bay.

The first type is the unimodal curve in which the sediments are thought to be generally in equilibrium with the environment. These unimodal sediments are usually medium to fine grained sands and are found in areas of high energy (beach or tidal channel environment) where reworking takes place almost daily.

The second type comprises positively skewed fine grained sands. Sediments of the second type seem to be present in areas where active reworking is not taking place, thus representing essentially areas of sediment accumulation.

The actual division between the types of cumulative curves is somewhat arbitrary, especially between Types 1 and 2. The finest sediment of Type 1 is positively skewed and virtually equivalent to the coarsest sediment of Type 2. In fact, in Type 1 samples the "fine tail" composes generally $< 1\%$ of the total sample whereas in the Type 2 samples the fine tail is usually considerably greater than 1% of the total sample.

The third type of cumulative curves covers a wide range of sizes, from coarse gravels to clays. The gravels are thought to belong mainly to two kinds: a) residual gravels and b) contemporary (active) gravels. Often a well-sorted medium to fine grained sand mode is found accompanying this gravel material.

This division of the bottom sediments into types is based essentially on visual distinction, and represents a somewhat crude equivalent to the factor analysis distinction.

Cumulative Curves Type No. 1

The curves of this type closely approach a straight line, i.e., the sediments concerned are unimodal or nearly so. Sediments possessing this property are well-sorted and can be interpreted as having formed in equilibrium with one dominant depositional regime (Udden, 1914).

The samples of the study area belonging to Type No. 1 are listed in Table 2. Those samples of which cumulative curves are plotted in Figure 17 are underlined in the table.

As the straight part dominates in all curves shown, and in fact in all samples listed in Table 2, it is assumed that the sediments concerned were laid down in equilibrium with the strength of the transporting agent governing at the places concerned, i.e., with wave action for S-28 and S-105 and with tidal currents at the other locations. Hardly any of the cumulative curves are perfectly straight, however, but they have "hooks" or "tails" either at one end or at the other, and in many cases at both ends, so that they are more or less obviously S-shaped. The magnitude of the tails may differ considerably from sample to sample. The presence of these tails means that the sediments contain a surplus of coarse and/or fine particles over the amounts belonging to an ideal, log-normal grain size distribution. The reasons for such departures require some discussion as several possible explanations come to mind. The tails are thought to be connected with properties of the particles involved such as their shapes, their specific gravities, their travelling habits, and their sorting and relative abundance in the source areas. As well, the variations and strength of the transporting agent and the type of depositional environment must be considered.

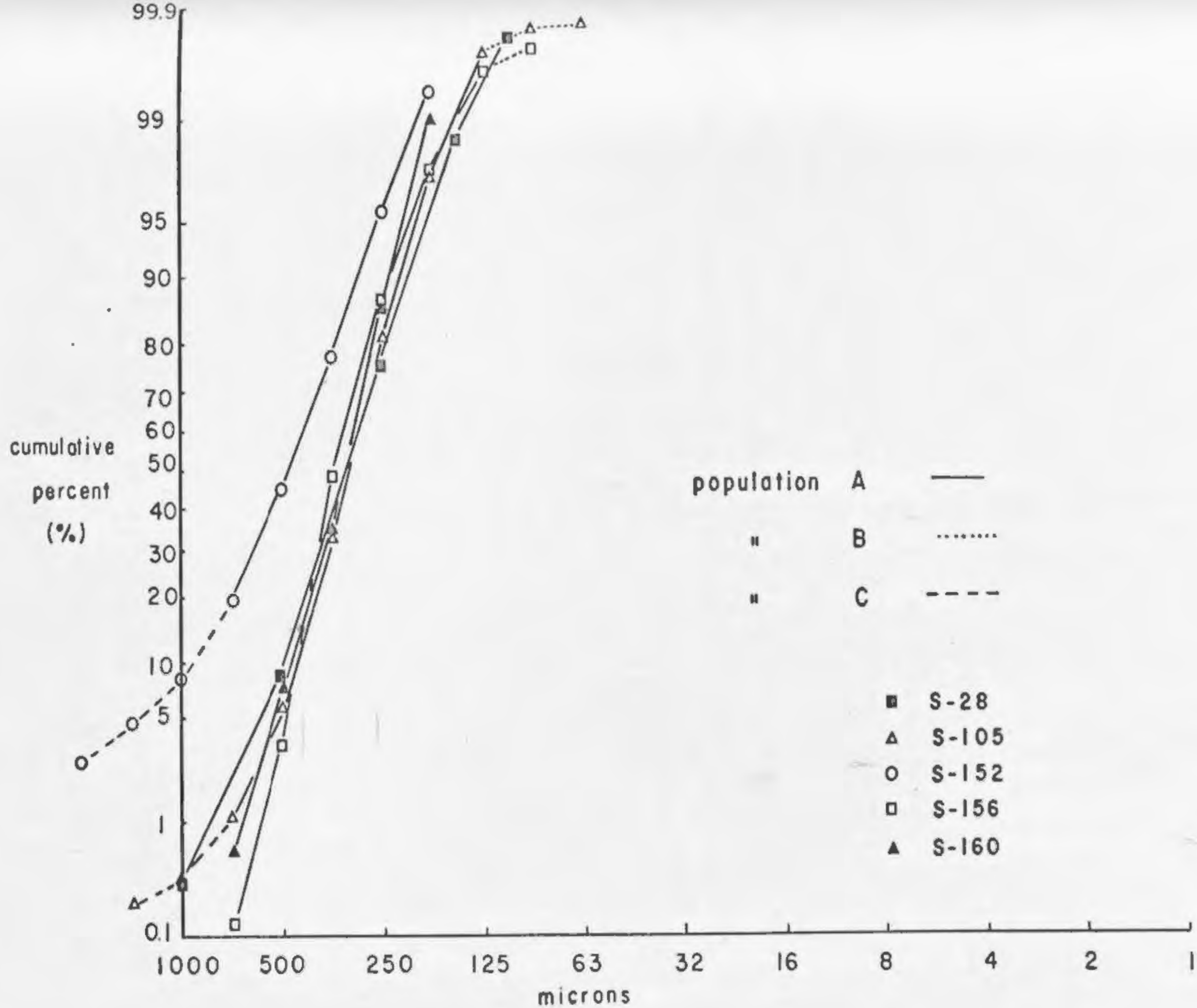
TABLE 2

CUMULATIVE CURVE TYPE NO. 1 SAMPLES

West Bay		Bar Flats	
Sample No.	Depth (ft.)	Sample No.	Depth (ft.)
S-28	12	S-105	25
		S-108	40
		S-151	47
		S-152	50
		S-156	64
		S-157	32
		S-160	40
		S-170	36

FIGURE 17

Grain size distribution (cumulative curves) of some cumulative curve type No. 1 samples.



cumulative curve Type No. 1

Much has been written recently by Moss (1962, 1963) on the physical nature of sand and pebble deposits. A summary of his findings, here, will help to elucidate the processes responsible for deposition of the unimodal (and other) sediments, and the relationships of the coarse and fine tails to the main sediment.

He states that all sandy sediment deposits are composed of a combination of three fundamental populations, A, B, and C. The resulting deposits may be composed either of A alone, AB, AC, or ABC. A is the main component of the sediment and is characteristically well sorted. Populations B and C are the fine and coarse tails of the cumulative distribution respectively. Figure 17 shows examples of each of these combinations:

A	S-160, S-28
AB	S-156
AC	S-152
ABC	S-105

Moss's explanation for the formation of these various composite sediments will be given here in brief.

To begin, if it is assumed that a well-sorted population A exists on the bottom of a marine channel in response to the prevailing fluid energies, then, as proposed by Moss, optimum transport and movement of these grains will occur by saltation. Surface creep, that is, rolling and sliding, is minimal for grains of similar dimensions because equidimensional grains will fit nicely into the relief of the bottom deposit and thus escape most of the impact from the moving fluid. On the contrary, if grains of considerable magnitude larger (2X to 5X) than the bottom deposit exist, impact pressure and torque from the moving fluid will cause rolling over the bottom. In this way, it is possible to have coarser grains than found in population A moved with population A. The deposit thus formed would be typical of an AC population mixture. This is an example of different modes of transport enabling different sizes to be transported in the same energy system.

It is worthwhile to notice that a sediment may consist solely of population A or population A and C with no fine tail whatsoever. This is in keeping with the mode of transport of either of these deposits; that is, dominantly saltation of the bed load which would effectively prevent the deposition of any finer material in the interstices. Beach deposits are commonly of the A or AC type. In shallow marine areas where strong tidal currents are present, bottom sediments of the AC type are most prevalent, but those composed of population A alone are not uncommon.

Of some importance, here, may be the relative abundance of certain sizes in the source areas. If an area of very high energy existed where only much finer sediment than capable of being transported in that environment was available, then one might expect only this finer sediment to be found. As well, because of the high energies available, any coarser material encountered would likewise be mobilized. In this manner, one might conceivably obtain a sediment which, in fact, is much finer than the transporting capacity at that point but which, nevertheless, might contain a representative coarse tail. This is legitimate reasoning but seems not to be applicable in the study area as the overall size distribution of all the sand size material in the raised terraces gives almost equal frequency of occurrence to all grain diameters between 0.125 mm. and 1.000 mm.

Three remaining factors which may possibly contribute to the existence of a coarse tail are (1) differences in particle shape, (2) differences in particle density, and (3) ice rafting.

(1) With reference to particle shape, disk-like particles of a certain diameter have the same settling velocity as sphere-like particles of a smaller diameter (Krumbein, 1942), and both can hence be transported and laid down together by a current of sufficient strength. In Port au Port Bay, flaky rock fragments derived from sedimentary strata outcropping along the shores and/or from till material eroded by the glacier from rocks of the same kind make up a large portion of the sediment

fractions > 0.5 mm. These rock flakes might therefore be invoked to explain the coarse tails of the cumulative curves. A quick calculation reveals, however, that the thickness of the coarse flakes must be as small as 1/100 of their diameter if they are to be transported by a current along with the fine-grained fractions ($d \simeq 0.100$-0.200 mm.) and this is clearly not the case.

(2) Specific gravity probably does not play an important role either, as the range in densities of the dominant sediment constituents in Port au Port Bay is much too small. If two roughly spherical grains with specific gravities of 2.7 and 5.0 respectively travel with equal velocities, the ratio between their diameters is about 1.4, which is insufficient to explain the presence of the coarse tails.

(3) Ice-rafting is generally recognized by the presence of odd pebbles in fine-grained sediment (e.g., single large pebbles embedded in strata of well-sorted sand or basinal silt and clay). Many workers in Arctic regions have encountered this phenomenon: Leslie (1963) in Hudson's Bay, Grant (1964) in Baffin Bay, and Marlowe (1964) in the Prince Gustaf Adolf Sea. In many cases, the ice-rafted material has travelled hundreds of miles before it was freed from the ice and it likely represents a lithologically exotic component at the place of its deposition. In the writer's study area, no Arctic ice has ever been observed

in recent years (personal communication--Ice Operation Officer, Department of Transport, Government of Canada). In fact, in most of Port au Port Bay the ice forms locally and upon partial melting drifts away into the Gulf of St. Lawrence as pan ice. Even the pack ice of the Gulf rarely enters the bay. However, ice formed locally can reach thicknesses of 3 to 4 feet and can freeze solidly onto the shore whether beach or bedrock, as was observed by the writer in March, 1968 (Plate 14). A number of small ice pieces were seen on that occasion, which contained well-sorted beach material. It is possible, therefore, that such frozen-in beach material is dropped frequently from melting pan ice within the confines of Port au Port Bay and may be a chief cause of the coarse tail found in many bay samples. One might think that the ice-rafted material would constitute a separate well-sorted population in the bay samples because it was picked up by the ice as a well-sorted beach sand, but the grains are not likely released from the ice all at the same time and this must largely obliterate their previous sorting. Examination of a core taken in the centre of West Bay far away from the shores (core No. 89) confirmed this concept. The core of silt and clay which included scattered granules had periodic zones in which the concentration of this coarse material was quite high, although still in a silt clay

Plate No. 14

Small ice cake with minor amounts of sand and gravel sprinkled on its surface. This material was probably transported to this site by slumping and solifluction (associated with spring melting) of the outwash material along the exposed cliff face of the raised outwash terraces; located on the extreme southeast corner of Port au Port Bay.

matrix, which can only be interpreted as ice-rafted material. These coarse zones are not the same as the sandy layer discussed in Chapter IV. A size analysis of this material produced a coarse tail with no dominant mode, identical to the tails present in many grab samples. Ice-rafting, then, is possibly a major reason for the coarse tails of many unimodal sands in Port au Port Bay, and likewise, also, for the coarse tails of the positively skewed fine sands (cumulative curve Type No. 2) which will be discussed below.

Let us examine now the mechanism by which the population B or fine tail may form. A decrease in velocity in an area where the population A is saltating and the population C is moving by surface creep will cause the deposition of the coarse tail and most of population A. The bed load will be effectively immobile, with only the scattered grain from population A saltating where local turbulence is developed. This is typical of the environment associated with the formation of ripple marks. Now, because the bed load is relatively immobile, although moving steadily in one direction, interstitial areas are voids into which fines may become trapped or settle out. In particular, tidal currents which oscillate from a maximum velocity to zero, although having low velocities only for short periods of time, provide an environment for momentary settling of suspended and saltating fine material between the coarser grains.

Cumulative Curve Type No. 2

The samples comprising this type are the finest grained found in the study area. They are present in all the basin areas and in many nearshore areas where active reworking is not taking place. The coarsest member belonging to this type is virtually unimodal, but as one progresses to the finer sizes the unimodality disappears and a distinct bi-modality appears with the samples possessing a definite skew to the finer sizes.

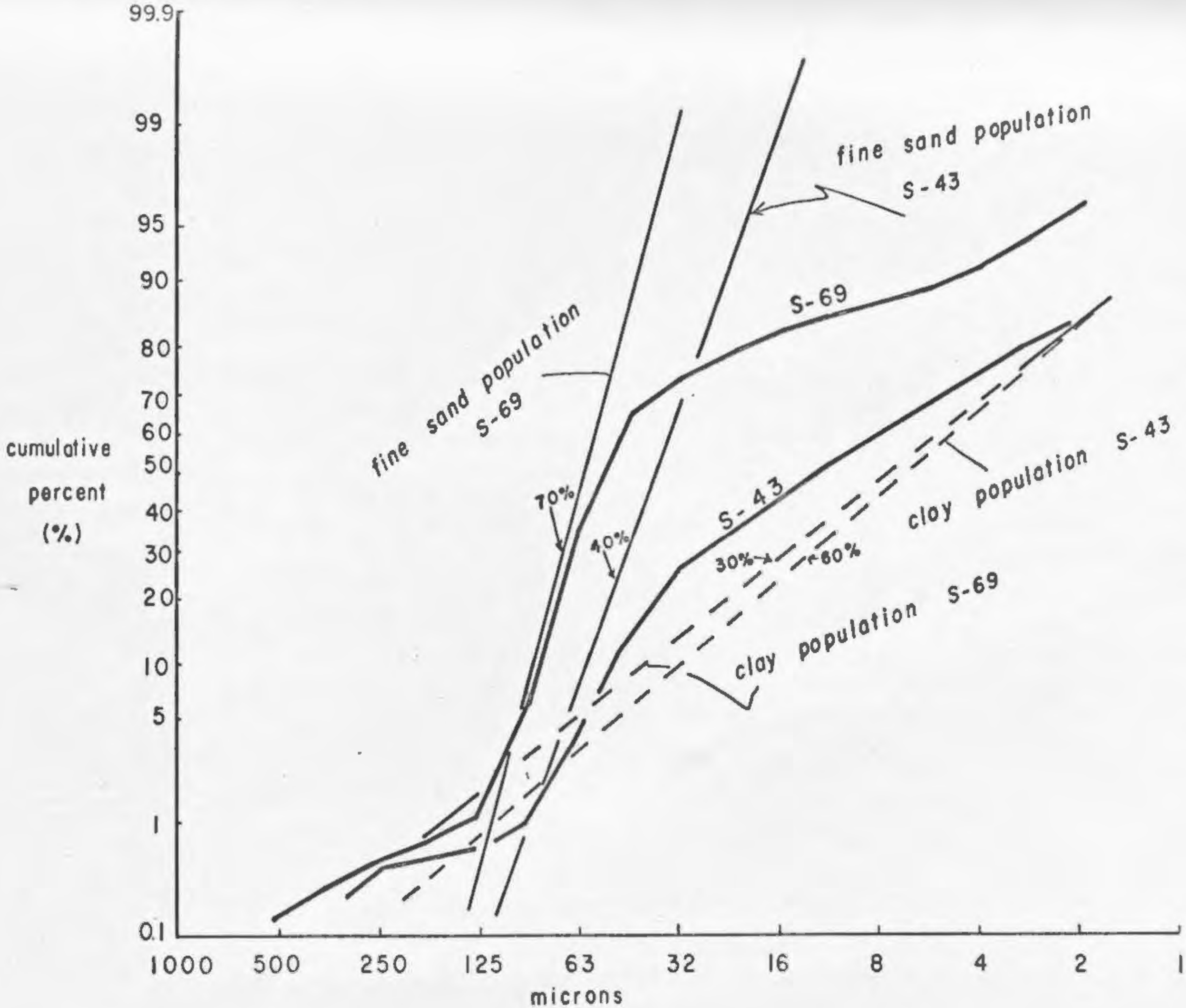
Using the "Method of Differences" as defined by Tanner (1959) these sediments are generally found to be composed of two populations: 1) a well-sorted fine sand or coarse silt (median diameter $\simeq$ 0.180 mm. to 0.045 mm.) and 2) a relatively poorly-sorted clay (median diameter $\simeq$ 0.010 mm. to 0.006 mm.) (Figure 18).

Table 3 is a list of all the samples analysed which represent the Type No. 2 cumulative curve. Those under-lined are shown in Figures 19, 20, and 21.

From cursory examination of the cumulative curves from any of the basins a uniformity in the transition from the fine sand population to the clay population seems to exist. If this break or transition from one population to

FIGURE 18

The basic components (populations) of cumulative curve type No. 2.



grain diameter

TABLE 3

CUMULATIVE CURVE TYPE NO. 2 SAMPLES

East Basin

Nearshore and Shallow Water		Basin	
Sample No.	Depth (ft)	Sample No.	Depth (ft)
S-1	50	S-14	165
S-12	72	S-43	182
S-13	90	S-52	147
S-15	12	S-62	72
S-45	15	S-64	86
S-65	12	S-67	84
S-71	48	S-79	72
S-96	24	S-92	70
S-125	14	S-93	88
S-126	10	S-97	85
		S-98	88
		S-132	106
		S-133	123

West Basin

S-2	12	S-6	45
S-3	12	S-26	50
S-31	20	S-29	60
S-37	16	S-39	72
		S-60	60
		S-69	72
		S-70	48
		S-76	54
		S-80	59
		S-81	72
		S-86	50
		S-89	70
		S-134	76

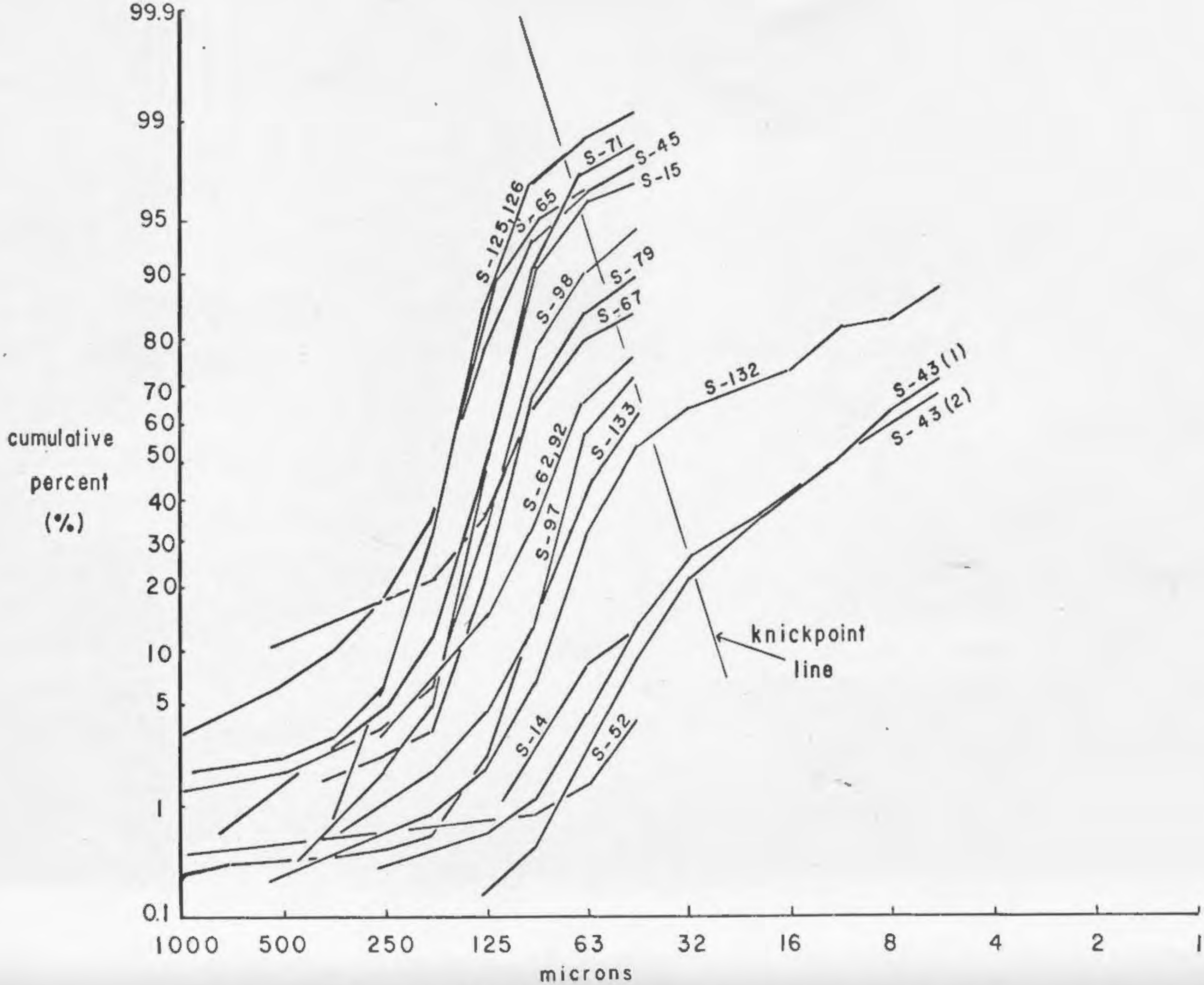
TABLE 3 (Contd)

Fox-Serpentine Basins

Nearshore and Shallow Water		Basin	
Sample No.	Depth (ft)	Sample No.	Depth (ft)
S-107	54	S-111	140
S-159	70	S-112	114
S-178	36	S-114	130
S-179	42	S-115	145
S-180	40	S-145	153
S-182	50	S-146	110
		S-147	112
		S-153	88
		S-154	134
		S-155	154
		S-172	145

FIGURE 19

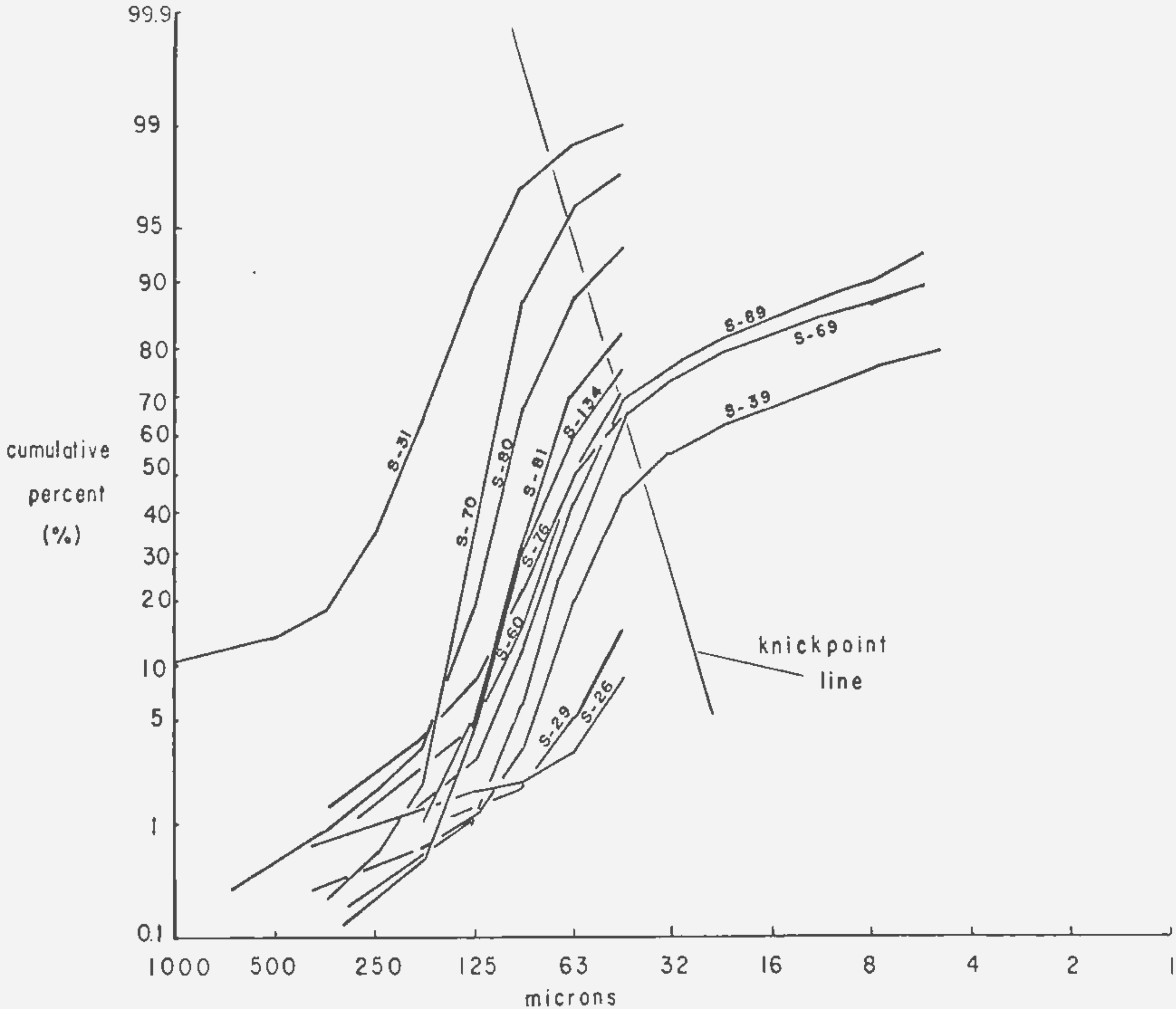
Grain size distribution (cumulative curves) of the Cumulative curve type No. 2 samples in East Basin.



EAST BAY cumulative curve Type No. 2

FIGURE 20

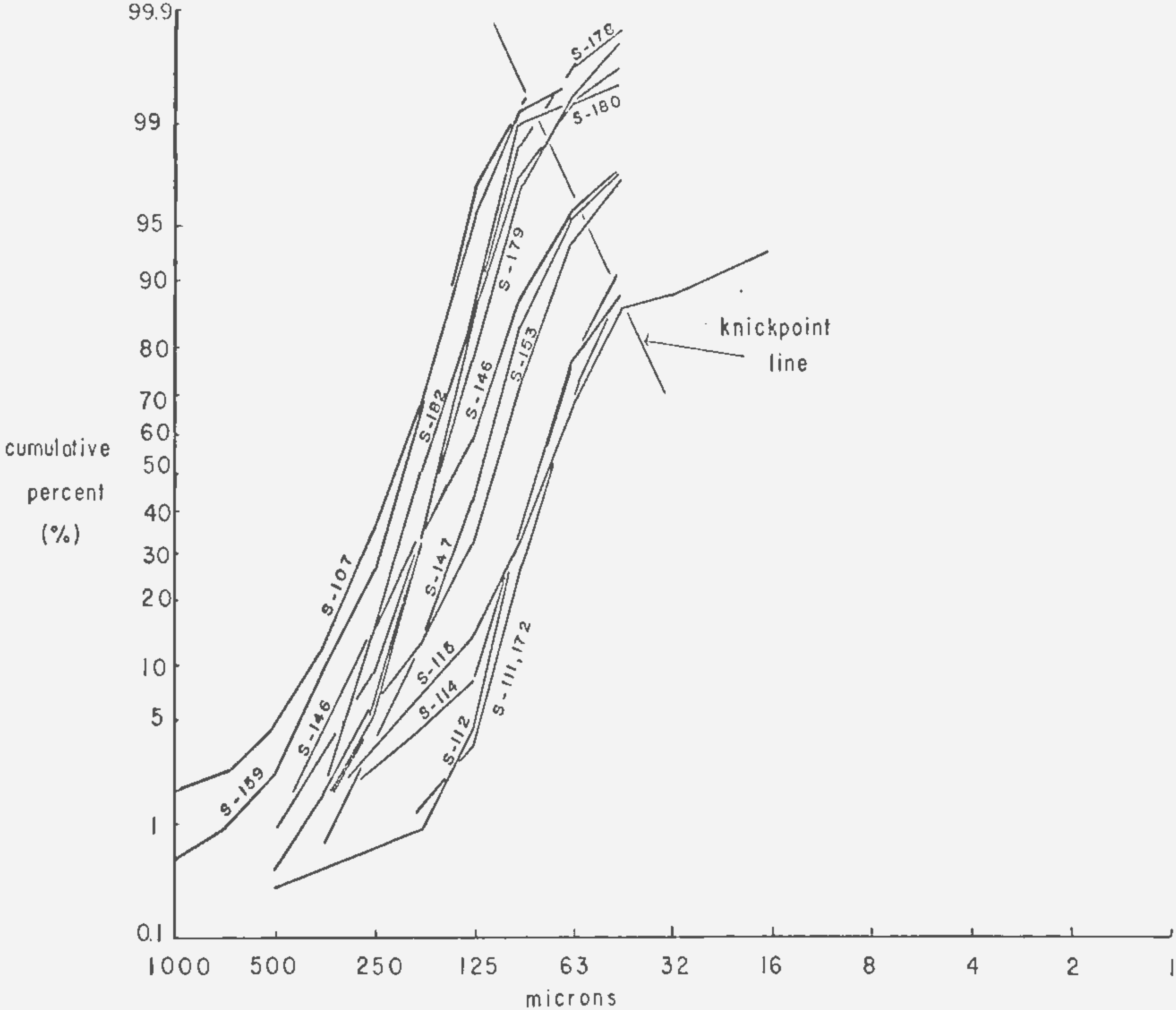
Grain size distribution (cumulative curves) of the cumulative curve type No. 2 samples in West Basin.



WEST BAY cumulotive curve Type No. 2

FIGURE 21

Grain size distribution (cumulative curves) of the cumulative curve type No. 2 samples in Fox Basin.



FOX BASIN

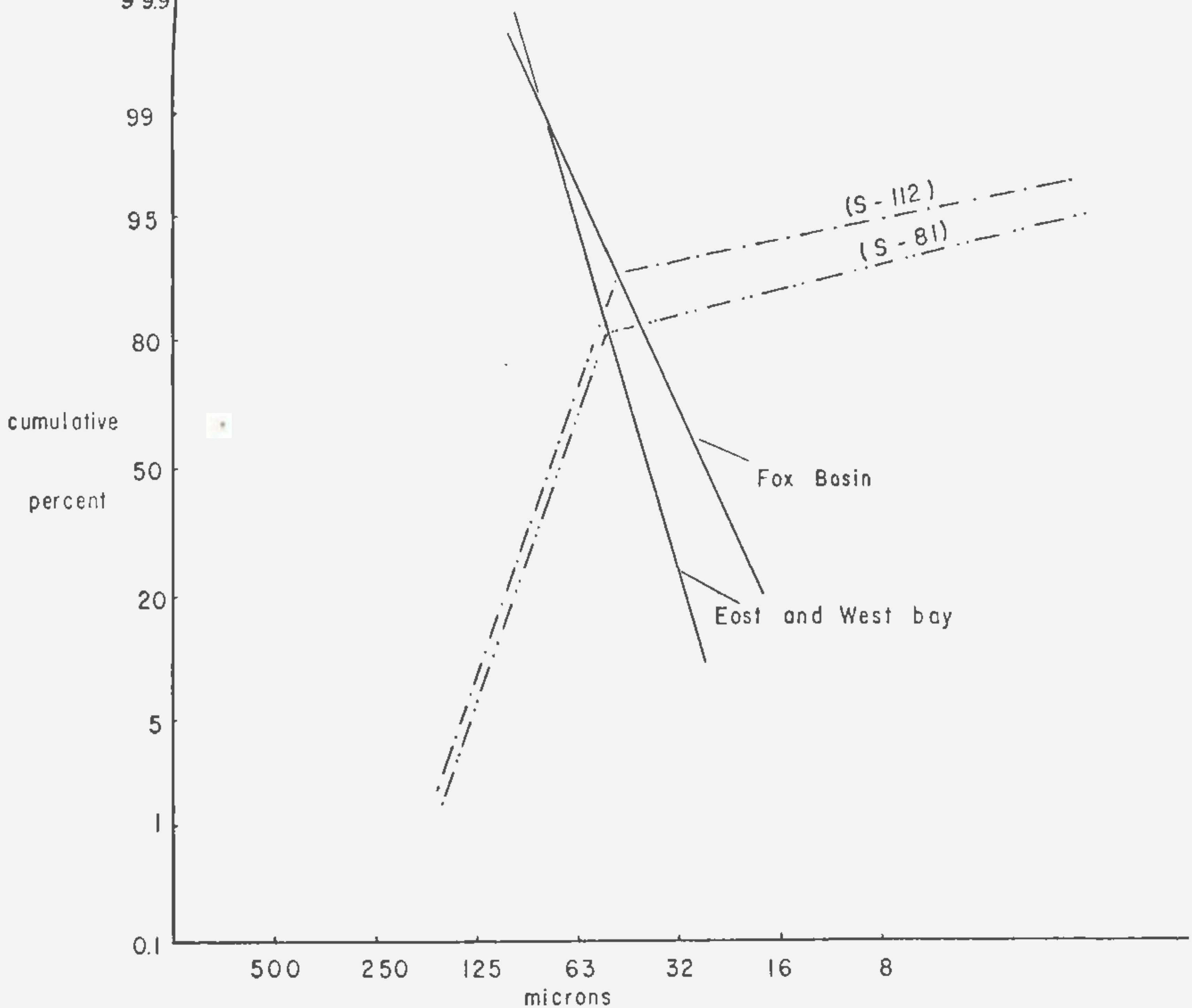
cumulative curve Type No. 2

the other is called the "knick-point" then the line joining all the knick-points of samples from one basin of deposition can be called the "knick-point" line (Figure 19, 20, and 21). It is somewhat arbitrary as to where the maximum change in slope or knick-point occurs but it can, nevertheless, be located quite easily. In the coarser samples the fine sand population is the dominant component of the sediment and in the finer samples the clay population is the dominant component.

It is noteworthy that the knick-point lines from different depositional basins do not coincide (Figure 22). The meaning of this fact is that, even though two identical fine sand components exist, they are found with different percentages of the clay population. If, because the coarser fractions of the samples are identical (the fine sand populations), it can be assumed that very similar energy conditions at deposition existed, then the relative concentration of the clay population, with respect to the fine sand population, must vary from one basin to the next. This is exemplified in Figure 22 where two samples (S-112 from Fox Basin and S-81 from West Basin) have identical fine sand components but with S-112 having 10% less clay than S-81. This implies that the relative concentration of the clay population in the West Basin area is higher than in the Fox Basin area. This seems reasonable as many

FIGURE 22

Plot of knick-point lines for all basins of Port au Port Bay with representative cumulative curves.



KNICKPOINT CURVES

cliff sections of raised marine clays and clay-rich tills exist along the eastern side of West Bay in contrast to the Fox Basin shoreline where little clay-rich material is present. At the same time there is an ample supply of sand size material in both areas.

The reason for a particular slope for any one given knick-point line is found in the interaction of four factors; i.e., the size distribution and relative concentration of the two contributing fine sand and clay populations. As mentioned above, the grain size distribution of the fine sand population is thought to be sensitive to energy conditions and would thus become finer with a decrease in average transport velocity. Contrary to the behaviour of the fine sand population, the size distribution of the clay population is relatively constant (Figure 18). With this given decrease in energy conditions, the relative amount of the fine sand material transported will drop. Because of the complementary relationship of the relative abundances of the two contributing populations, when, due to a decreasing energy regime, the contribution of the fine sand component decreases, the percentage contribution of the clay population must necessarily increase. Apparently, in this case, the lateral shift of the fine sand population to the fine sizes is proportionally greater than the downward shift (increasing percentage contribution) of the clay population, with the result that the break from the fine sand to the clay population (knick-point) occurs at progressively finer sizes as the flow regime decreases.

At this point, it must be mentioned that the basis for all this previous discussion has been the non-coincidence of the knick-point lines from one depositional area to another. As we have seen, the plotting of these lines can be quite subjective. This is justification for attempting before continuing to find a more objective method of locating the knick-point line or at least indicating that, in fact, a difference in relative concentrations of the two components does exist.

The samples under investigation are composed of a mixture of two populations: 1) a well-sorted fine sand, and 2) an unsorted clay. Theoretically, they should be positively skewed, because of the unsorted fine grained clay contribution: the samples with the greatest clay contribution having the highest skewness values. If two samples with similar fine sand median diameters have dissimilar amounts of clay, then their skewness values should also differ (S-81 and S-112). A plot of the median diameter of the fine sand population versus the skewness (Table 4) should enable separation of those samples deposited under identical energy conditions but in which the relative concentration of the clay material was not

TABLE 4

SKEWNESS AND MEDIAN DIAMETER OF THE FINE SAND COMPONENT OF SOME TYPE NO. 2 SAMPLES

Sample No.	Skewness*	Median Diameter	Location
S-14	-2.84	0.064 mm.	
S-15	+1.01	.125	
S-43	+0.29	.037	
S-45	-0.14	.155	
S-52	-7.93	.040	E
S-62	+0.31	.085	A
S-65	+1.95	.155	S
S-67	-0.22	.115	T
S-71	-0.52	.120	
S-79	+0.45	.105	B
S-92	+0.22	.085	A
S-97	+0.38	.072	Y
S-98	+0.26	.110	
S-125	-2.89	.150	
S-126	-2.60	.165	
S-132	+1.24	.062	
S-133	-0.29	.070	
S-26	-4.75	< 0.040 mm.	
S-29	-2.83	.040	
S-31	-1.44	.200	W
S-39	+0.91	.055	E
S-60	+0.19	.070	S
S-69	+2.14	.056	T
S-70	+2.44	.115	
S-76	+1.43	.075	B
S-80	+1.34	.105	A
S-81	+0.87	.085	Y
S-134	+0.74	.085	

TABLE 4 (Contd)

Sample No.	Skewness*	Median Diameter	Location
S-107	-1.36	0.210 mm.	
S-111	+1.00	.077	
S-112	+1.33	.080	
S-114	+0.67	.080	BAR FLATS
S-115	+0.38	.080	
S-146	+0.48	.120	and
S-147	+1.11	.115	
S-153	+0.63	.110	FOX BASIN
S-159	-0.60	.200	
S-172	+0.00	.075	
S-178	+0.03	.160	
S-179	-0.61	.155	
S-180	+0.03	.155	
S-182	+0.81	.170	

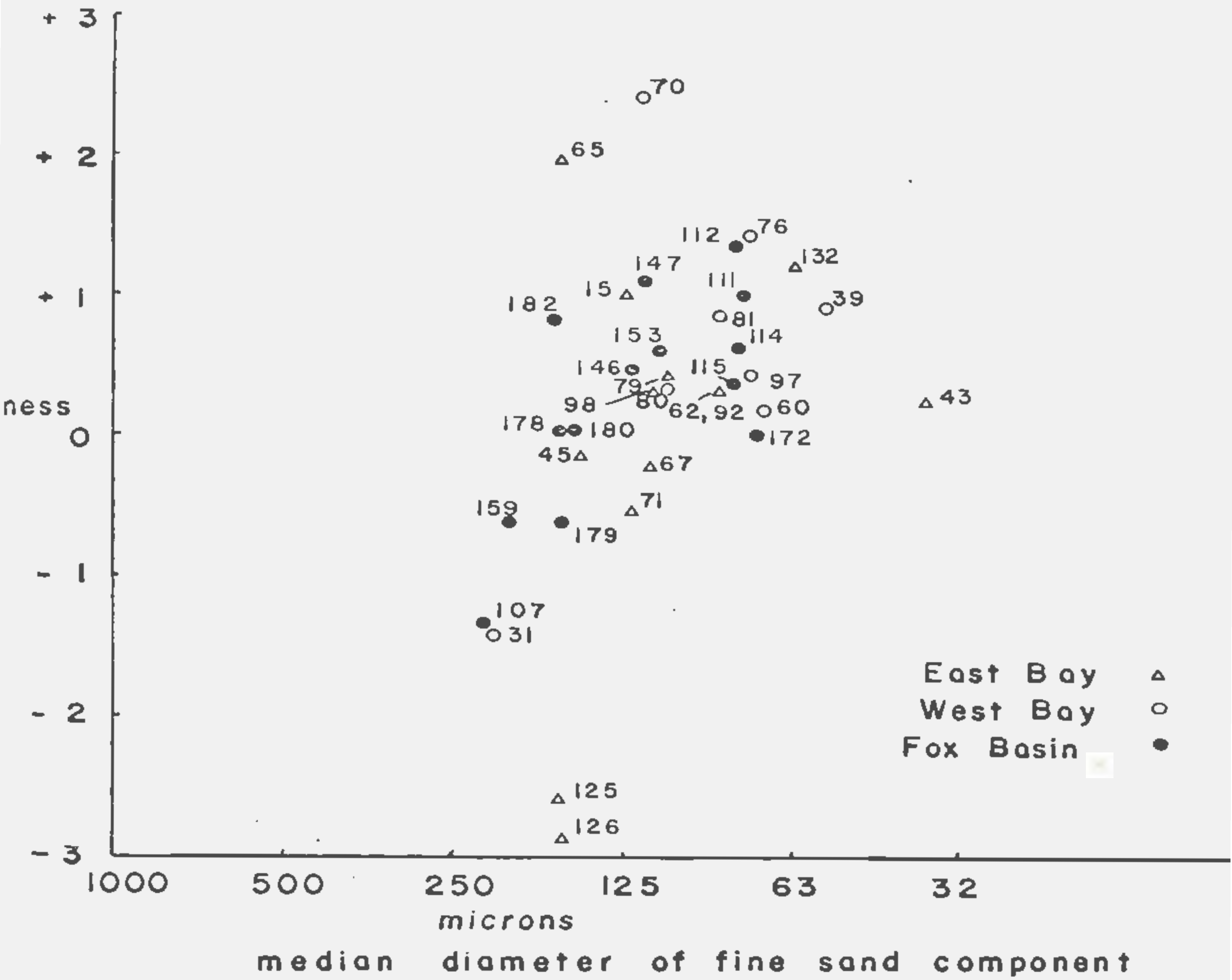
*Skewness values taken from Appendix B.

the same. In Figure 23 a plot of these parameters from samples in East Bay, West Bay, and the Fox Basin show no distinction among the different bays. The probable explanation for this failure is the irregularity in the distribution of the coarse tails of the cumulative curves. In the calculations of the skewness, these tails are emphasized, and any component due to factors unrelated to the dominant depositional regime will, in fact, not be sympathetic to any changes in this regime, and will hence mask its expression in terms of the skewness. These tails, as has been pointed out, are thought to be due mostly to the ice rafting of beach sands. This ice-rafted component, then, is proposed as being responsible for the erratic skewness values. In Figure 24 similar shaped curves from samples taken in Barataria Bay in Louisiana by Krumbein and Aberdeen (1937) are shown. Their resemblance to the Port au Port curves in the finer grades is gratifying as well as is the dissimilarity in the coarser grades. Presumably, the coarser grades here are much more regular because of the lack of ice-rafted material.

A need for the examination of the fine tails alone of these cumulative curves, then, is necessary. If it is assumed that the slope of any one segment of the cumulative curve varies according to the relative amounts of the fine sand and clay populations present, then the change in slope

FIGURE 23

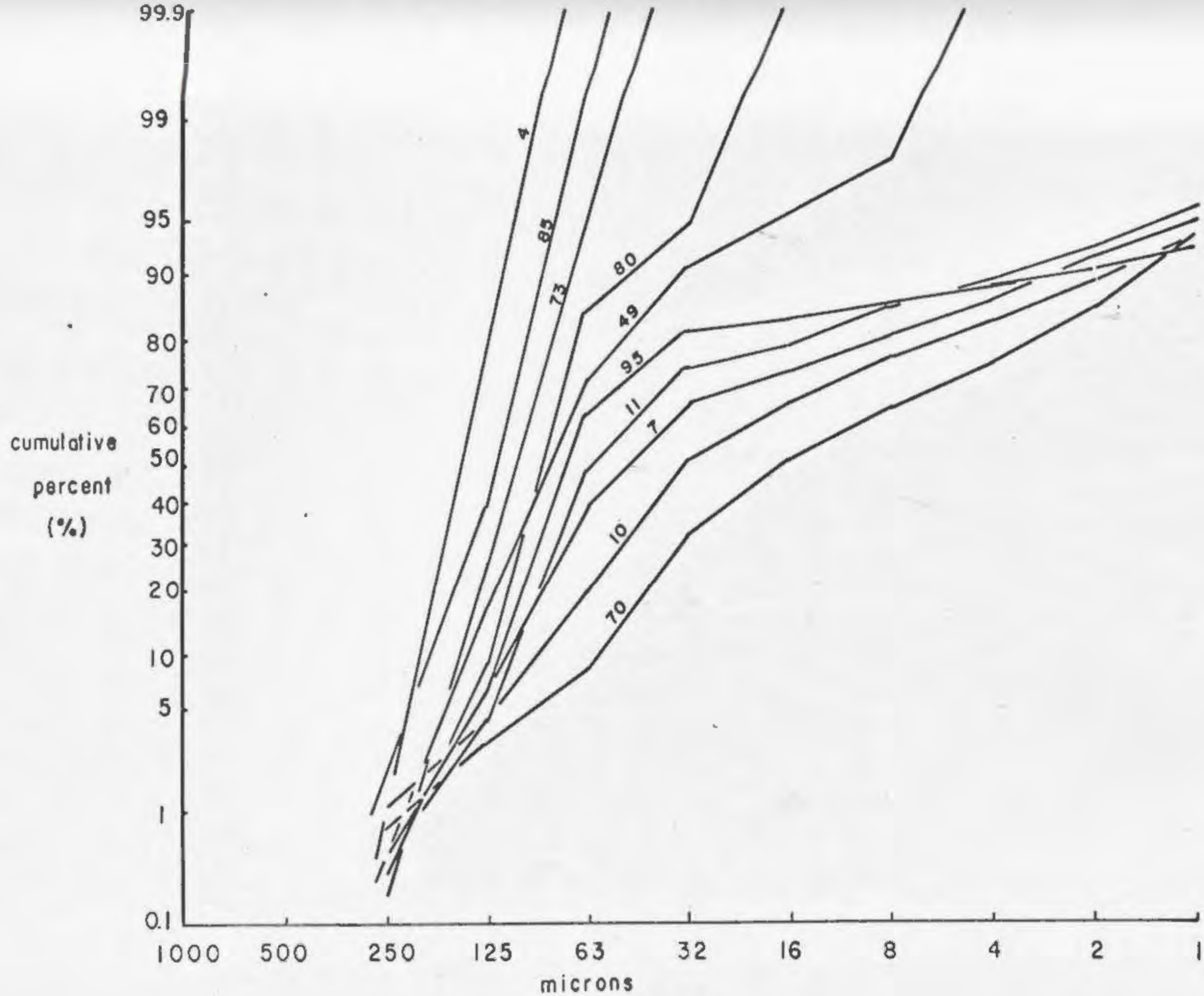
Plot of the skewness versus the median diameter of the fine sand population of some type No. 2 samples.



+ 3
+ 2
+ 1
ness
0
- 1
- 2
- 3
1000
500
250
125
63
32
microns
median diameter of fine sand component
East Bay
West Bay
Fox Basin
70
65
112
76
132
147
111
15
182
39
81
153
114
146
115
97
79
98
80
62, 92
60
43
178
180
172
45
67
71
159
179
107
31
125
126

FIGURE 24

A representative sampling of the range of sediment size distributions from Barataria Bay, Louisiana.



BARATARIA BAY cumulative curves
from Krumbein and Aberdeen (1937)

of the segment at a given point expresses the change in the relative amounts of the two populations.

It is essential in this case to examine a segment of the cumulative curves which is affected to the greatest extent by the relative changes in the fine sand-clay components. The segment of the cumulative curve between 45 and 63 microns (4.-4.5 ø) is part of the clay population in the coarse samples (S-15) and gradually as the samples become finer grained the same segment becomes part of the fine sand population (S-43). The slope of this segment, then, is sensitive to small changes in the relative contributions of either population. If the slope or angle subtended by this segment is recorded at say 50 microns (Figure 25) and plotted against the corresponding fine sand population median diameter (data recorded in Table 5), similar fine sand population samples with dissimilar amounts of the clay population will plot apart. With a variation in relative concentrations of the fine material, the slope at this given point will vary accordingly. A graph (Figure 26) shows the resultant plot of these two parameters. A reasonable separation between those samples collected in the Fox Basin with those collected in the East and West Basins exists. For a given median diameter, sediments in the Fox Island area have a larger Tan θ value than those sediments from other areas. That is, the

FIGURE 25

Method of Tangent θ measurement of the 45-63 micron size fraction.

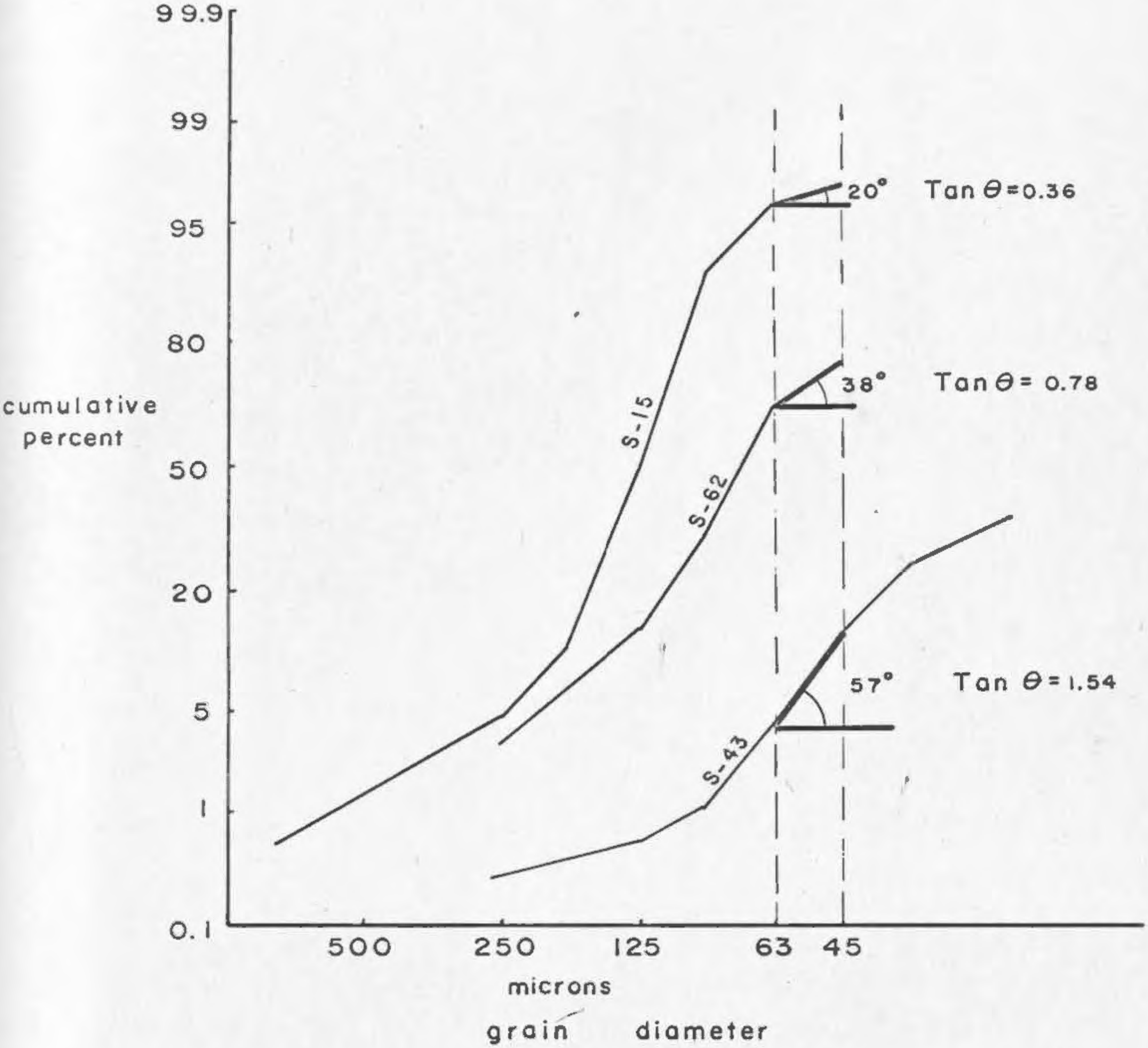

99.9
99
95
80
50
20
5
1
0.1
cumulative percent
S-15
S-62
S-43
20°
Tan θ=0.36
38°
Tan θ= 0.78
57°
Tan θ= 1.54
500
250
125
63
45
microns
grain diameter

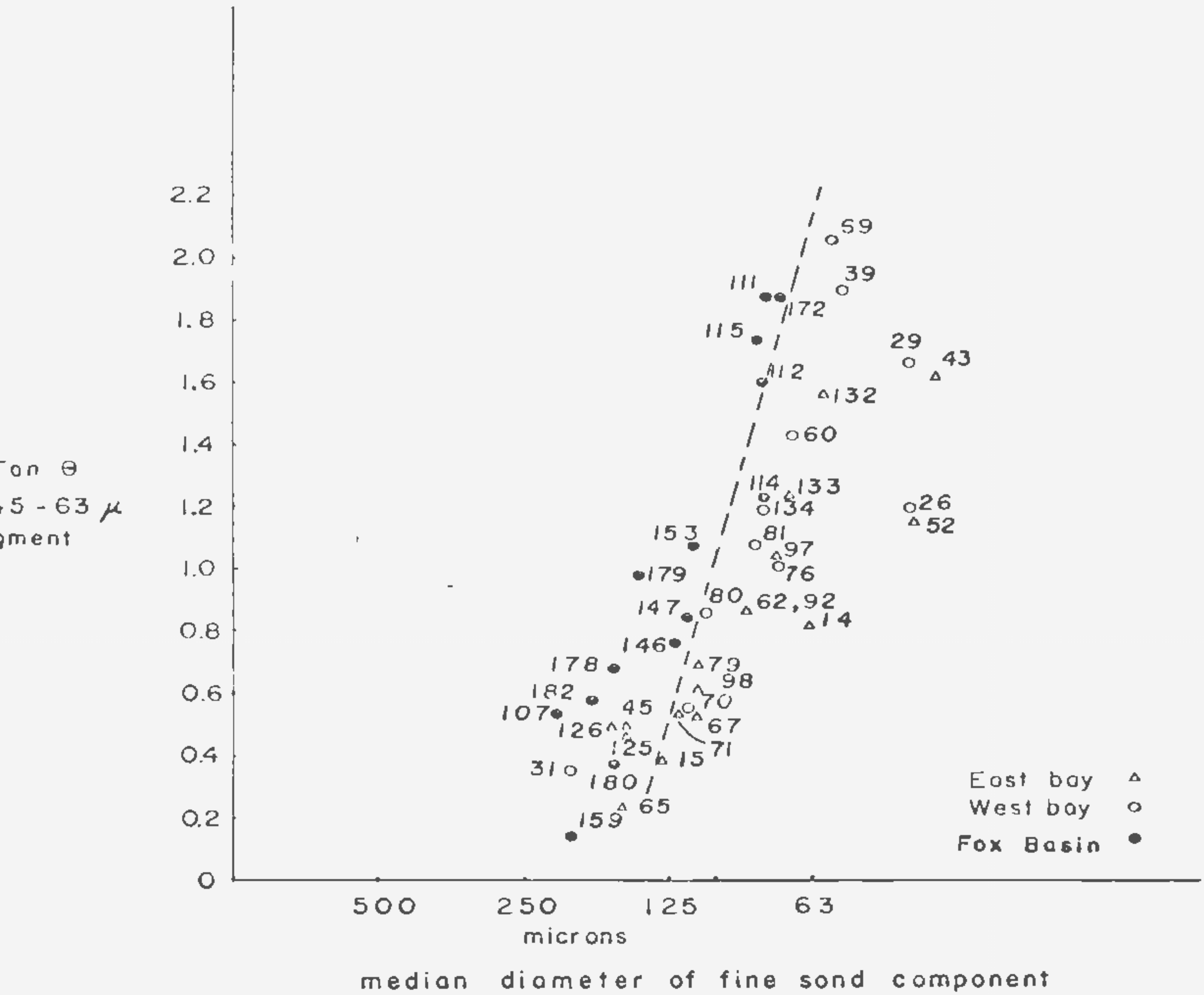
TABLE 5

TANGENT θ VALUES FOR THE 45-62 MICRON SEGMENT AND MEDIAN DIAMETER OF THE FINE SAND COMPONENT OF SOME TYPE NO. 2 SAMPLES

Sample No.	Angle θ (Deg.)	Tangent θ	Median Dia.	Location
S-14	39.5	0.82	0.064 mm.	
S-15	20	0.36	.125	
S-43	58	1.60	.037	
S-45	26	0.49	.155	
S-52	49	1.15	.040	E
S-62	40	0.84	.085	A
S-65	13	0.23	.155	S
S-67	27	0.51	.115	T
S-71	28.5	0.54	.120	
S-79	34	0.67	.105	B
S-92	40	0.84	.085	A
S-97	46	1.03	.072	Y
S-98	31.5	0.61	.110	
S-125	25	0.47	.150	
S-126	25	0.47	.165	
S-132	57	1.54	.062	
S-133	51	1.23	.070	
S-26	50	1.19	$<$ 0.040 mm.	
S-29	59	1.66	.040	
S-31	20	0.36	.200	W
S-39	62	1.88	.055	E
S-60	55	1.43	.070	S
S-69	64	2.05	.056	T
S-70	29	0.55	.115	
S-76	46	1.03	.075	B
S-80	40	0.84	.105	A
S-81	47	1.07	.085	Y
S-134	50	1.19	.085	
S-107	28	0.53	0.210 mm	
S-111	62	1.88	.077	
S-112	58	1.60	.080	
S-114	51	1.23	.080	
S-115	60	1.73	.080	BAR FLATS
S-146	37	0.75	.120	
S-147	40	0.84	.115	and
S-153	47	1.07	.110	
S-159	8	0.14	.200	FOX BASIN
S-172	62	1.88	.075	
S-178	34	0.67	.160	
S-179	44	0.97	.155	
S-180	20	0.36	.155	
S-182	30	0.57	.170	

FIGURE 26

Plot of Tan θ of the 45-63 micron segment versus the median diameter of the fine and population of some type No. 2 samples.


Tan θ
5 - 63 μ
gment
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
500
250
125
63
microns
median diameter of fine sand component
East bay
West bay
Fox Basin

subtended angle of the 45 to 63 micron segment is greater than in other areas. The larger the angle of the segment, the less the relative concentration of the clay material. Therefore, for samples with very similar or identical fine sand components the one with the greatest slope (Tan Θ) has the smallest relative concentration of fines.

These results verify the initial observations from comparison of the visually located knick-point lines. The reasons for the lower relative concentration of fine material in the Fox Island area, as already mentioned, is thought to be the lower relative availability of the clay population with respect to the fine sand population in the source areas within each basin system.

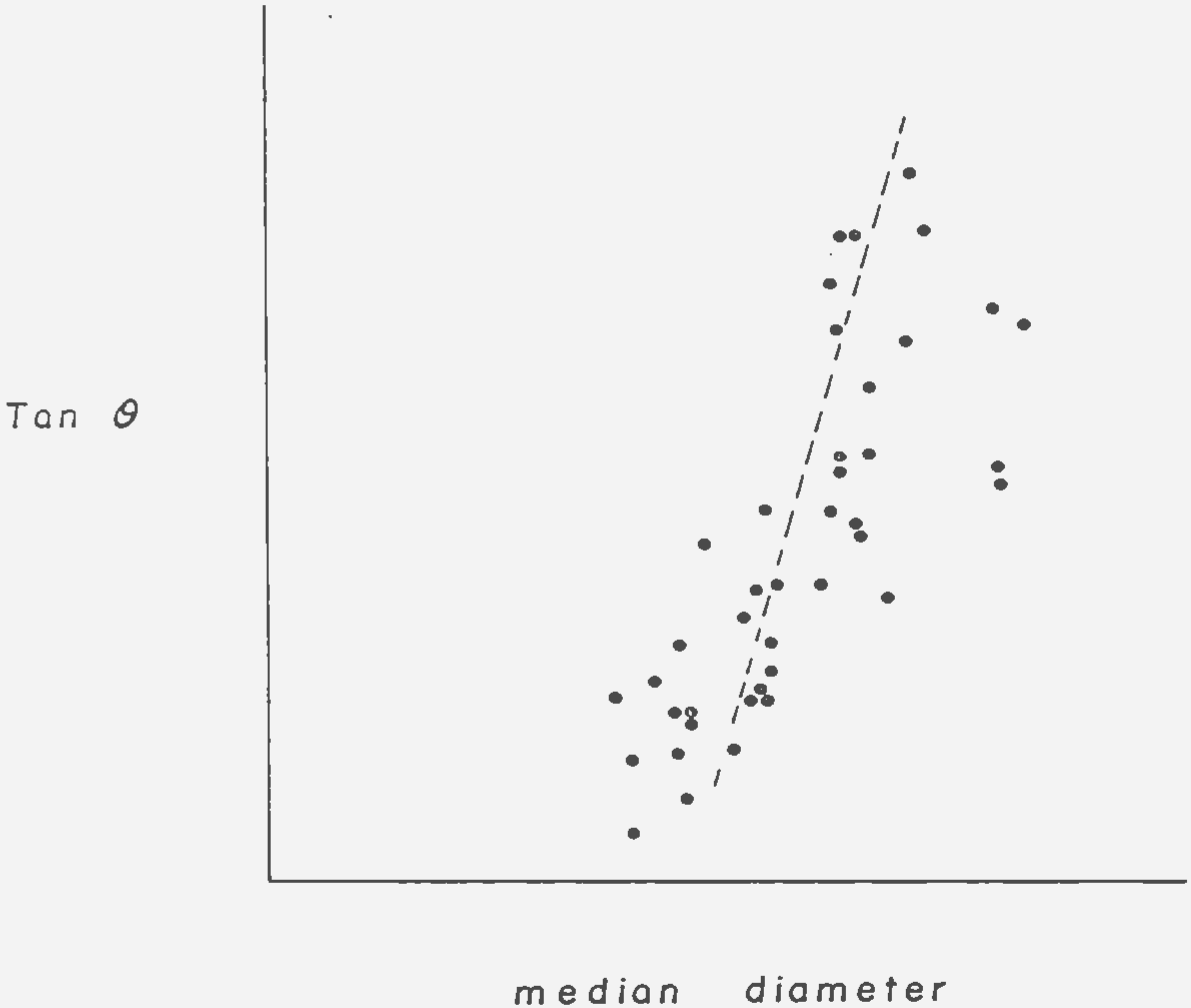
If is of interest to point out here that if these sediments had been consolidated and the samples collected as such from bedrock outcrops, with no knowledge of their separate depositional basins, the presently performed test does not enable the researcher to define or outline the two groupings which, in fact, do exist (Figure 27).

Now that the knick-point line concept has been established, an attempt to investigate the actual mechanism responsible for the bimodal nature of these fine sediments will be made. Let us consider the three most probable possibilities below.

1) Friedman (1967), Visher (1965, 1969), and Moss

FIGURE 27

Plot of the Tan θ segment versus the median diameter as in Figure 26, but without the distinction between the various basins.


Tan θ
median diameter

(1962, 1963) in their studies of river sands believe this bimodality may be due to the two different modes of transport: traction (saltation) and suspension. The suspension load in a stream could be trapped in the interstices of the sand and gravel in the bed-load by clogging of the so-called "traction carpet" (Moss, 1963). The suspension load would thus be present in the bottom sediment possessing its original size distribution. The upper limit (maximum grain diameter) of the suspension load is governed by the velocity of flow in the stream channel (given certain bottom roughness conditions). In this manner, depending upon the prevailing velocity at the time of deposition, different upper limits for the suspension load would exist.

In contrast to this environment is the tidal current environment where velocities are cyclic and fluctuate between a peak velocity and zero. Because of the fact that the velocities at any given point in the bay will decrease to zero every cycle, the situation governing the nature of the deposition of the suspended load is different than with the somewhat steady state flow in rivers and streams.

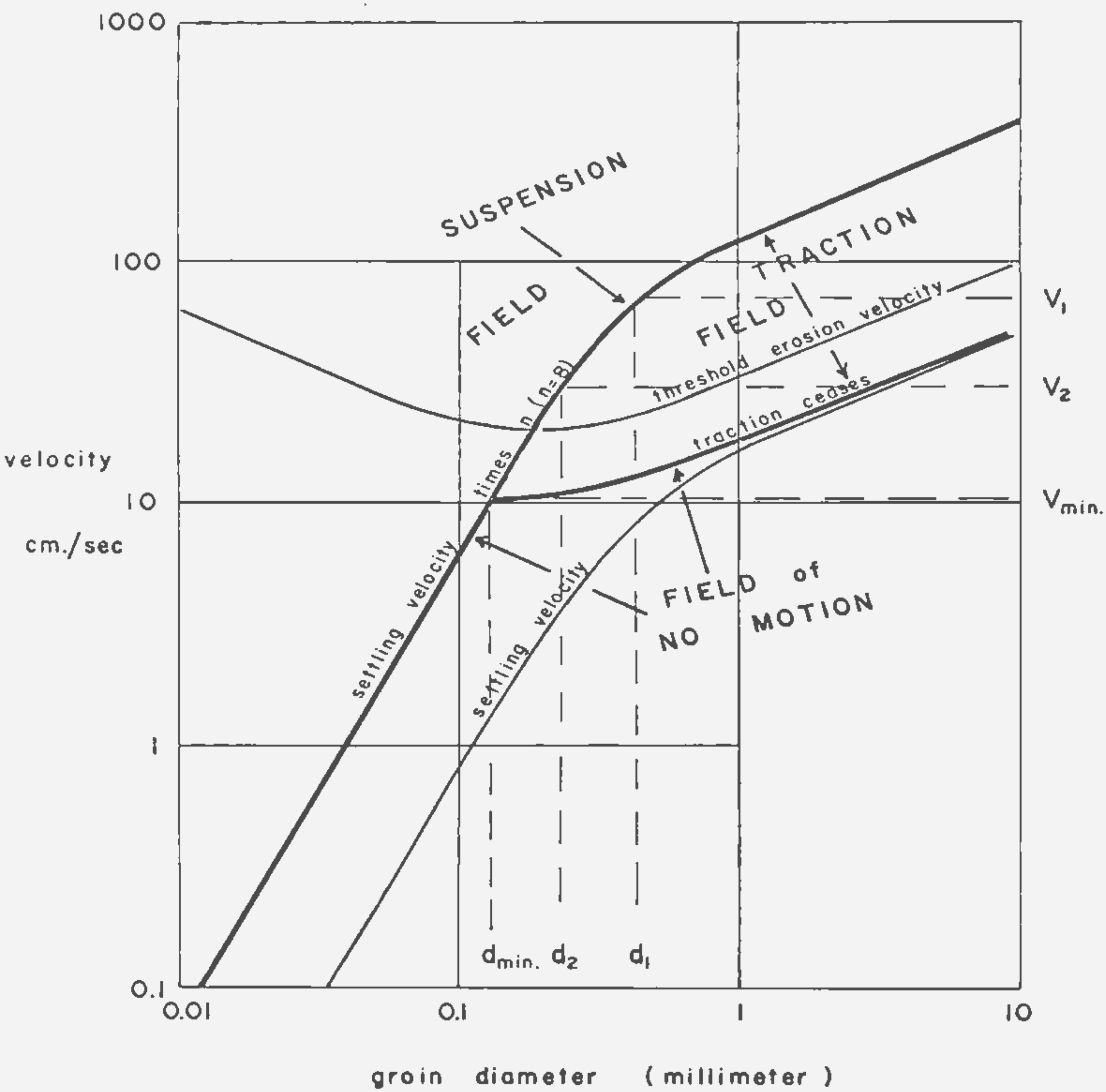
At this point, it is necessary to examine the principles of Hjulstrom (1939) and the proposals of Menard (1950), Nevin (1946), and Inman (1949) with regard to the suspension load. A summary of the above studies follows.

The erosion velocity of particles varies depending upon the particle diameter and is a minimum for particles with diameters around 0.180 mm. In contrast to this, the settling velocity of particles decreases with particle size: 1) proportional to the square root of the diameter for particles greater than 1 mm. in diameter, and 2) proportional to the square of the particle diameter for particles with diameters less than 1 mm. The temperature, as it affects viscosity, is also significant when dealing with settling velocities. Nevertheless, once already in motion the velocity at which particles will cease to move is neither the erosion velocity nor the settling velocity. The minimum transport velocity for sand size material is slightly below that needed to initiate motion, but, in the finer grades, the velocity contrast between erosion and deposition is great. Work by Menard (1950) and Nevin (1946) has shown that there exists a so-called minimum traction velocity. They have found that movement along the bottom ceases at around velocities of 10 cm./sec. and 20 cm./sec. respectively. Crude flume experiments by the author have confirmed this minimum velocity to be in the 10-20 cm./sec. range. Below this velocity the suspension load is the only material being transported. The current transporting any grains in suspension must be considerably greater than the settling velocity, to enable enough vertical turbulence to develop so that suspension is maintained. Let us choose then a factor n by which the transporting velocity must exceed the settling velocity in order to maintain suspension of any given particle. This factor n will vary with the bottom roughness which, in turn, varies with grain size, but for simplicity's sake, here, we will use only one n for all sizes. The intersection of the minimum traction velocity and the settling velocity multiplied by n would seem a necessity for a given bottom roughness condition. Figure 28 is an attempt to summarize the ideas presented above. A brief description of the behaviour of particles at given velocities as defined by this set of curves is attempted below.

At velocity V_1, the particle size representing the division between bed load and suspension load is coarser than it would be with a velocity V_2. The significance of this is that the maximum particle diameter in suspension at V_1 is coarser than that of the largest particle in suspension at V_2. It is of importance to note that at a location where velocity V_2 prevails particles with diameters equivalent to those of the maximum particle size in suspension at V_1 will now move in the bed load. As the transporting velocity decreases, the maximum size carried in suspension decreases. At V_{min} traction transport ceases and transport by suspension only occurs. This is an important feature in the study area where transportation is due to tidal currents which do fall to very low velocities on a regular basis. Therefore, even if at the peak tide,

FIGURE 28

Theoretical diagram of the modes of transport for given grain diameters when moving at various velocities, modified from the work of Hjulstrom, Nevin, Menard and Inman.



1000
100
10
1
0.1
0.01
0.1
1
10
velocity
cm./sec
groin diameter (millimeter)
SUSPENSION
FIELD
TRACTION
FIELD
threshold erosion velocity
traction ceases
times n (n=8)
settling velocity
settling velocity
FIELD of
NO MOTION
V_1
V_2
$V_{min.}$
$d_{min.}$
d_2
d_1

sediments are being transported as at V_1 (for example), with the subsequent decrease in velocity accompanying a tidal reversal, all the coarser material (d_1 to d_{min}) travelling in suspension at peak tide will travel in the bed load. It is only when V_{min} is reached that suspended matter will be deposited directly. It is proposed, then, that in the deposition of sediments transported by tidal currents, the division between the suspended sediments and those deposited from the traction carpet will be an almost constant particle size (d_{min}).

The factor n, mentioned earlier, being essentially dependent upon the bottom roughness, should vary little within one depositional basin where most of the sizes encountered are below 0.250 mm. in diameter. Therefore, for a single basin (East Basin, etc.), if the knick-point in the cumulative curves is to represent the traction-suspension boundary in the sediment, one would not expect it to have such a range in sizes (0.100 mm. to 0.030 mm.).

It has been shown that it is at least possible in the river and stream environment to have different maximum sizes in suspension (in bottom samples) depending upon the prevailing velocity. Nevertheless, even though one is not restricted to one given size for the suspension-traction break as with tidal currents, it is questionable even there (rivers and streams) that the two populations represent the two different modes of transport.

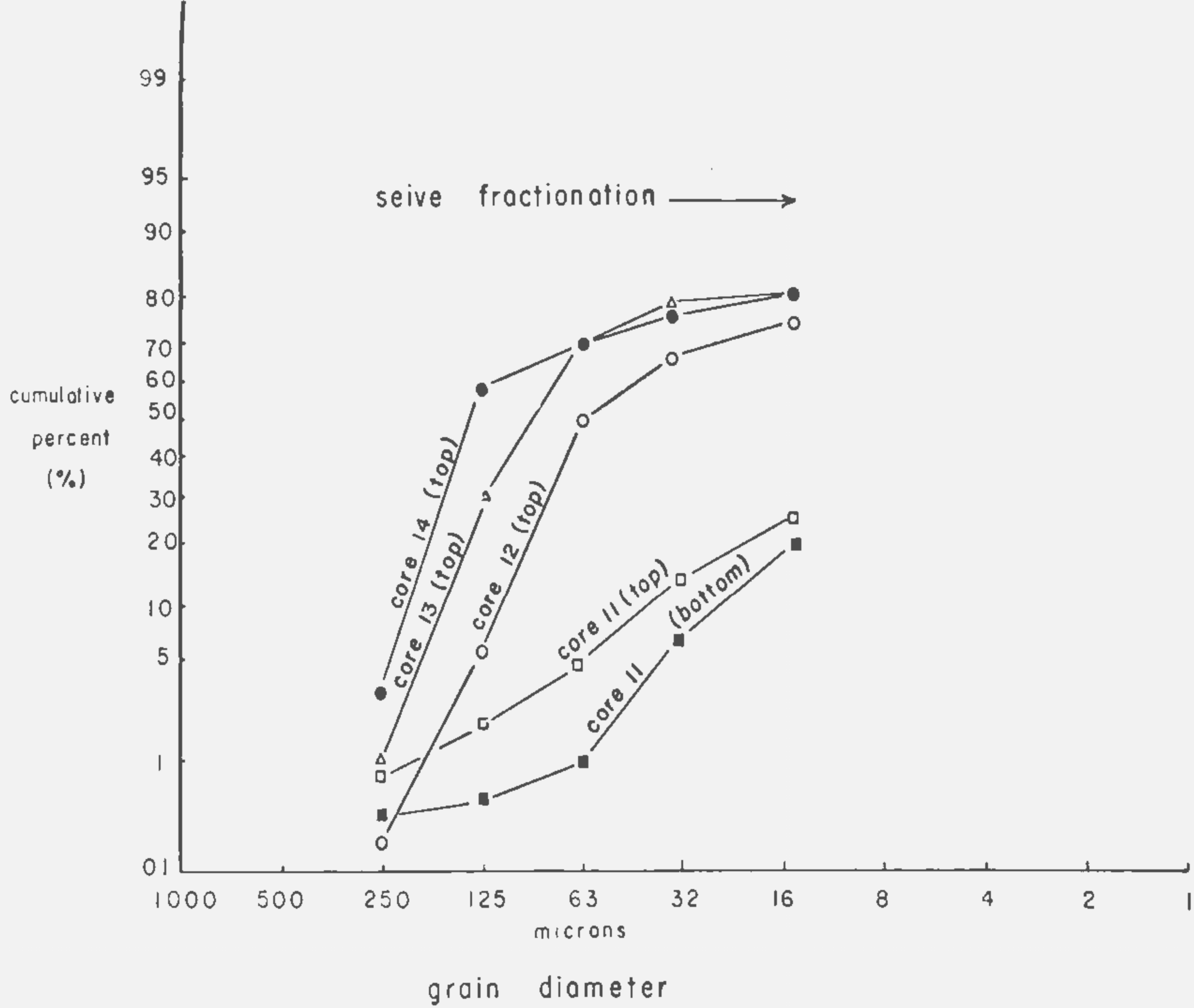
Modifications to the above discussion can arise when one considers the peak tidal velocities and their relationship to the threshold erosion velocity. The threshold erosion velocity will effectively limit the size available for transport, but, if the source for these deposits is indeed the shoreline, then wave action with the accompanying high velocities can be assumed to mobilize, in the first instance, most of the particles in the sand to clay size range.

2) Another cause to which this bimodality may possibly be related has been mentioned by Krumbein (1936) where he attributes the change in his method of size analysis, sieve to pipette, as the cause of a slight but distinct break in the slope of the cumulative curves at around 0.063 mm. In the study area a number of samples, S-39, S-69, S-69, S-132, and S-115 show prominent breaks at 0.045 mm. which is, in fact, the size where sieving was stopped and the hydrometer analysis begun. Nevertheless, many other samples have knick-points at other sizes with no change in the analytical methods having been made.

Belderson (1964)in his size analysis of some samples collected in the Irish Sea has sieved to the 18 micron (0.018 mm.) size. Figure 29, after Belderson, shows well defined breaks in the cumulative curves which for obvious reasons are not due to the change in method of analysis. He has attributed this departure from log-normality as being

FIGURE 29

Cumulative curves of sediments from cores taken in the Irish sea by Belderson. (1964)



after Belderson (1964)

due to the disaggregation during analysis of coagulated clay particles. As well, he has proposed that the size at which the break is observed ($\cong 60 \mu$) is the upper limit of the size of coagulated particles. Nevertheless, the densities of coagulated particles are much less than solid grains so that the energy needed to transport a coagulated particle of 60 microns is much less than a solid particle of 60 microns or even one of considerably greater diameter. Therefore, if Belderson's conclusion is correct a significant hydrodynamic break must occur at 60 microns as well. Simply invoking coagulated particles in the minus 60 micron sizes to construct a log-normal size distribution, supposedly representative of one consistent energy regime, is incorrect.

3) Pettijohn (1957), Tanner (1959), Spencer (1963), and Rogers et al. (1963a, b) have all discussed the phenomenon of sizes commonly deficient in the geological record. Pettijohn (1957) has defined three fundamental methods of producing sediment particles: (a) physical disintegration processes forming gravel material, boulders and pebbles; (b) granular disintegration forming sand size particles, many of which are mono-mineralic; and (c) chips from physical disintegration and clay particles from chemical disintegration.

Rogers et al. (1963a, b) have proposed that the size distribution of each of these fundamental populations is different as a result of their different modes of production. Granular disintegration formed by repeated crushing and multi-cycle abrasion theoretically produces a log-normal distribution. This being the main mode of production of sand grain sizes explains why many sand deposits in equilibrium with the prevailing energy level are log-normal. Large blocks are produced by single-stage crushing in which disintegration is defined by Rosin's Law of Crushing (Pettijohn, 1957). On the other hand, small chips are formed by the breakage of small fragments from the block size fragments by collision. The size distribution of (a) these chips and (b) the chemically decomposed material is theoretically "arithmetic-normal" (Rogers et al., 1963a, b). With reference to the study area, the well-sorted sands (fine sand population) encountered may represent material formed from multi-cycle granular disintegration while the poorly-sorted clays may represent the chips (glacial rock flour) and the chemically-formed material. The distinct deficiency of material between the smallest median diameter of the fine sand population ($\simeq 40$ microns) and the almost constant median diameter of the clay population ($\simeq 8$ microns) could then be explained as being due to the inherent scarcity of material of these sizes in the geologic record (and in Port au Port Bay) and not simply to two populations each representative of a different mode of transport. The deficient sizes mentioned above are identical to those particle sizes located between the "sand" and "clay" populations of Spencer (1963).

It is therefore proposed that the division between the suspended load and the traction load sediments is not at the knick-point areas of the cumulative curves, and that, instead, they represent a mixture of two populations, each of which is a result of a different physical mechanism acting in the natural environment. The conclusion reached here is succinctly stated by Rogers and Schubert (1963a):

> Transportational processes either move whole populations or truncate populations by moving their finer portions, but transportation does not control the nature of the characteristic size distribution of the populations.

The depositional environment will nevertheless define the upper and lower grain size limits in the sediment, even if it is not directly concerned with the specific shape of the cumulative curve. As observed at the beginning of this discussion of Type No. 2 cumulative curves, it is the relative concentration of these two populations (produced by two different physical mechanisms) which is essentially responsible for the characteristic shape of the cumulative curve.

An attempt at determining where the actual suspension-traction boundary occurs will be made later when discussing the distribution and interpretation of the sediments in Port au Port Bay.

Cumulative Curve Type No. 3

The samples comprising this type of cumulative curve have characteristically a very large range in sizes: from < 0.045 mm. to > 10 mm. Table 6 is a list of all the marine gravels analysed and shown in Figures 30, 31, and 32.

With even cursory examination of the cumulative curves, the striking bimodal nature of the samples is apparent. There seems to be a real scarcity of material between the sizes of 1 mm. and 10 mm. Below the 1 mm. size a well-sorted sand component is very often present. Likewise, above 10 mm. in diameter a well-sorted pebble component exists. There is no simple answer to the reason for this bimodality, but a number of ideas will be presented below.

It must be pointed out that, because of the large diameters of the particles collected in any one given sample (therefore, low in number), it is quite possible that a representative size distribution of the sediments occupying this point on the bottom was, in fact, not obtained. There is no way of distinguishing a sample in which the size distribution is correct from one in which it is not, although, generally, the coarser a sample is, the less likely is the sediment sample to be representative. In any case, it must be assumed that they are representative with the knowledge that, in fact, they may not be.

To simplify the analysis at this point it will be assumed that the pebble fraction of the sediment is made up

TABLE 6

CUMULATIVE CURVE TYPE NO. 3 SAMPLES

Sample No.	Depth (ft)	Type[1]	Nature[2]	Location
S-10	10	C	R	
S-17	36	CS	R	
S-40	10	CS	R	
S-41	28	D		
S-46	33	D		E
S-49	14	CS	R	A
S-50	12	D		S
S-54	60	D		T
S-72	185	D		
S-74	12	CS	R	B
S-75	19	CS	R	A
S-95	78	D		Y
S-99	88	D		
S-100	40	D		
S-164	41	D		
S-165	30	D		
S-166	50	D		
S-167	38	CS	R	
S-4	12	D		
S-5	12	CS	R	
S-8	36	D		
S-18	16	CS	R	
S-22	14	CS	A	
S-23	20	D		W
S-32	20	C	R	E
S-34	34	D		S
S-35	18	D		T
S-36	35	D		
S-38	20	CS	R	B
S-55	34	D		A
S-56	20	CS	R	Y
S-59	50	D		
S-68	42	D		
S-77	38	D		
S-82	36	D		
S-83	30	CS	R	
S-101	22	CS	R	
S-169	54	CS	R	

TABLE 6 (Contd)

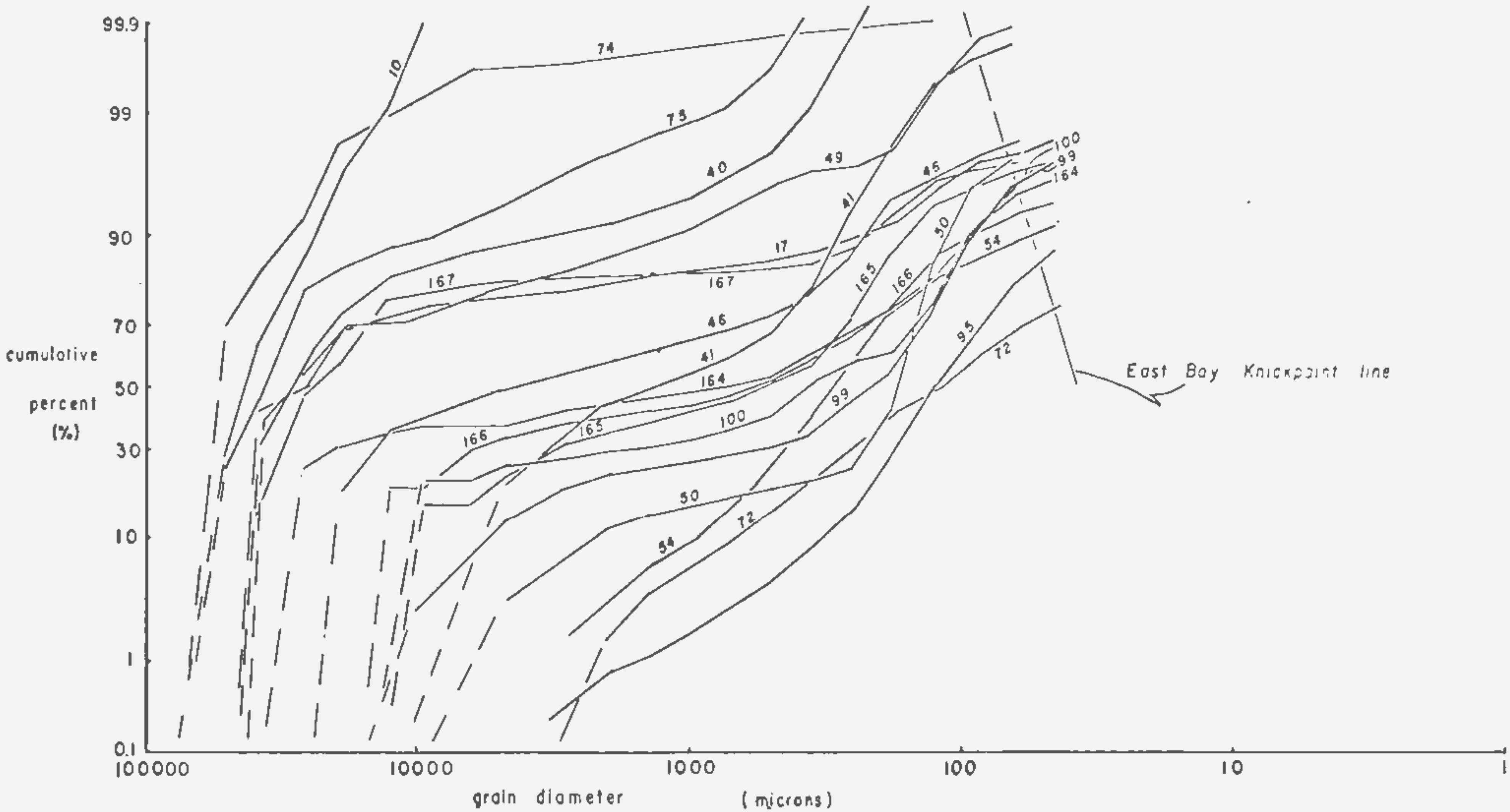
Sample No.	Depth (ft)	Type[1]	Nature[2]	Location
S-102	54	C	R	
S-103	56	CS	R	
S-109	76	C	R	BAR
S-150	40	C	R	FLATS
S-161	58	C	R	
S-162	60	C	R	
S-163	60	C	R	
S-104	100	CS	R	EAST
S-106	95	CS	R	BASIN
S-149	86	CS	R	SILL
S-177	50	CS	R	FOX
S-181	42	D		BASIN
S-144	134	CS	R	F.B. SILL
S-138	137	C-R	R	
S-140	76	C-R	R	
S-141	148	C-R	R	
S-142	132	C-R	R	SERPENTINE
S-158	70	CS	A ?	BASIN
S-174	90	C-R	R	
S-175	88	C-R	R	
S-176	72	C-R	R	

[1]C Compact
CS Compact and Interstitial Sand
D Dispersed
C-R Compact-Rock (Bedrock ?)

[2]R Residual
A Active

FIGURE 30

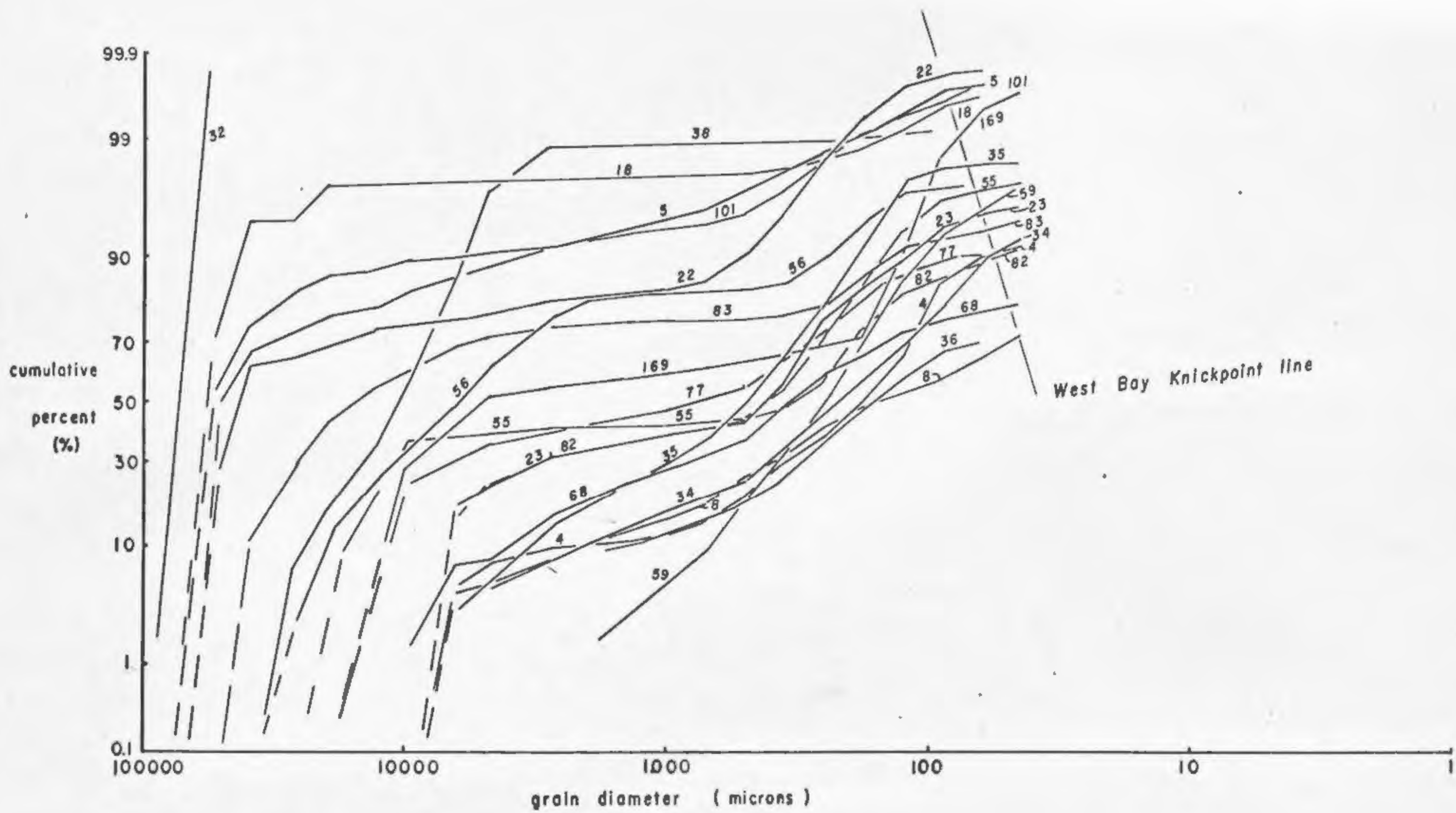
Grain size distribution (cumulative curves) of the cumulative curve type No. 3 samples in East Basin. All the samples shown in Figures 30-32 are marine with the usual prefix S of these numbers being omitted.



EAST BAY cumulative curve type No. 3

FIGURE 31

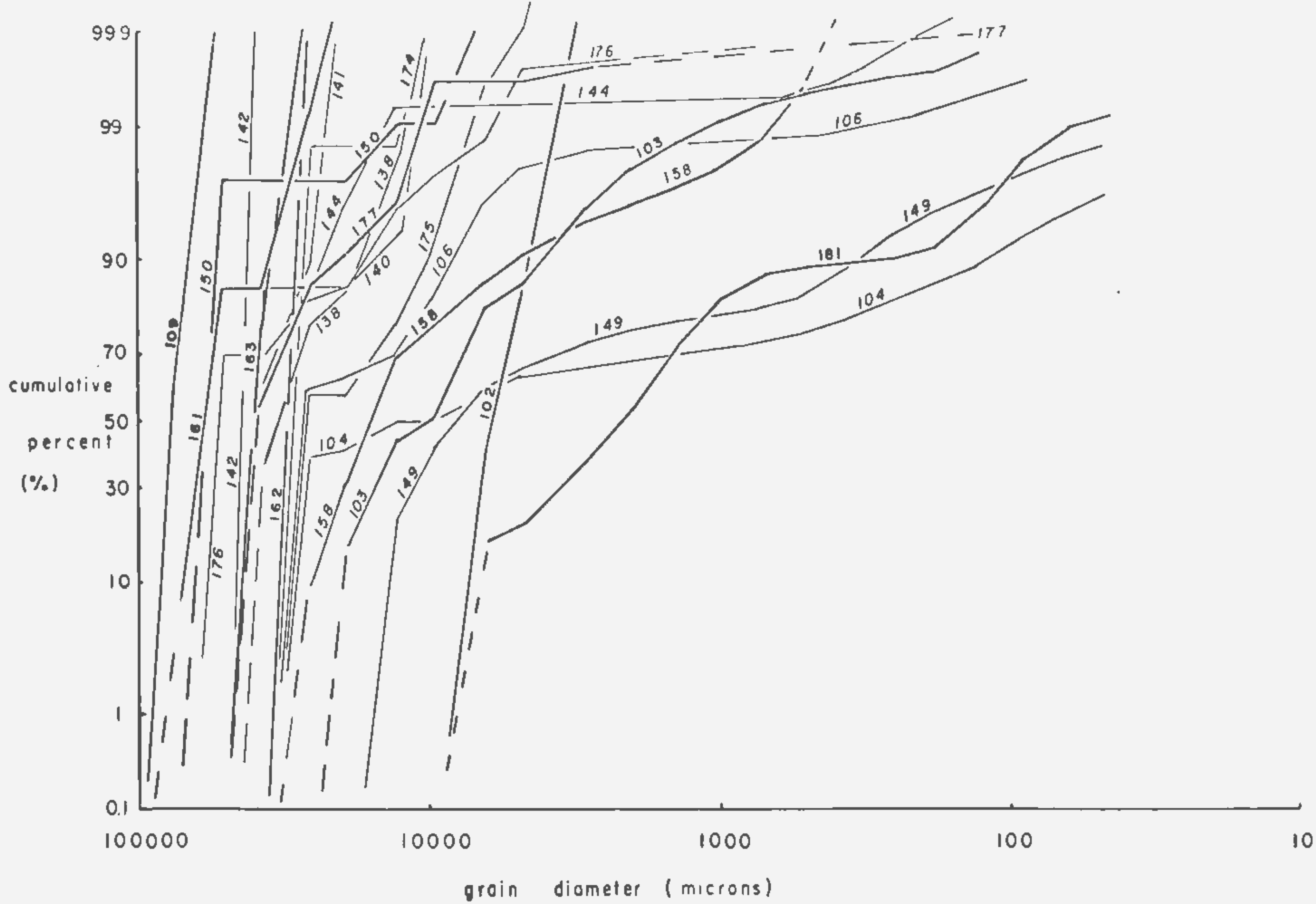
Grain size distribution (cumulative curves) of the cumulative curve type No. 3 samples in West Basin.



WEST BAY cumulative curve type No.3

FIGURE 32

Grain size distribution (cumulative curves) of the cumulative curve type No. 3 samples in Fox-Serpentine Basins.



FOX and SERPENTINE BASIN and adjacent SILL areas

cumulative curve type No. 3

of grains with diameters $>$ 10 mm., with the sand size fraction being composed of grains less than 1 mm. in size.

Generally, two main types of gravels have been documented in the geological record: the closely-packed gravel in which adjacent pebbles are in contact and the well-dispersed gravel in which adjacent pebbles are not in all cases touching (Moss, 1963 and Pettijohn, 1957). Assuming a bimodal distribution consisting of pebbles with diameters only $>$ 10 mm. and sand grains with diameters only $<$ 1 mm., then the sandy material will occupy the void spaces between the pebble grains. Depending on the type of packing, the sediment, if of the closely-packed variety, may have between 48% (cubic packing) and 26% (rhombohedral packing) void spaces. If, in fact, the void spaces become greater than 48% of the total space taken up by the sediment, then the gravel is defined as a dispersed one.

In the non-dispersed or compact gravel, the enclosed sandy material is likely unrelated to any prevailing energy conditions and exists in the given sediment only because it became trapped in the interstices. In contrast to this, in the dispersed gravels the pebbles would seem to be present mainly as a by-product of the transportation of the sand size material by saltation. Moss (1963) has discussed how coarser material travelling by surface creep (rolling) may move with sand which travels in saltation.

The problem of correlating these two types of gravel to depositional environment is complicated by the fact that the sea level in post-glacial times was temporarily lower than the present level (Chapter IV). Since the time of maximum emergence (anywhere between 6000 and 10000 yrs. B.P.) slow submergence of the land areas has taken place from this lowest stand of the sea (approximately minus 35 feet). This lower sea level may have provided much higher energies at locations where now much less wave and tidal current energy exist.

It is necessary to distinguish between gravels forming under the present-day environment and those which were formed at a time of higher energy associated with a lower sea level. The main forces generating the high energies needed for formation of gravel deposits are storm waves and tidal currents.

A number of criteria may be mentioned here which may enable one to distinguish the present-day gravels from the fossil ones.

1) The orbital velocities at the break point for storm waves in Port au Port Bay as calculated from the formula

$V_{max} = \dfrac{\pi H}{T \sinh \dfrac{2\pi H}{\lambda}}$ (Shepard, 1963) based on recorded H,* wave height, T,* period and λ*, wavelength, during one

---

*H = 2 meters
T = 4 seconds
λ = 25-30 meters

storm in September 1967, are around 170 cm./sec. The corresponding break point is calculated (Shepard, 1963) to be at a depth of about 11 feet. Theoretically, then, velocities of 170 cm./sec. may exist at a depth of 11 feet during reasonably severe storms in Port au Port Bay. This velocity will initiate movement of pebbles with diameters between 3 and 4 cm.

2) The maximum tidal currents mentioned for Port au Port Bay are 2 knots or about 100 cm./sec. (Figures 9 and 10). Velocities of this magnitude will initiate motion of particles with diameters around 1 cm. but will move particles of 3 or 4 cm. in diameter once they have already been put into motion.

3) (a) The majority of the pebbles brought up from the bottom have organic coatings of various sorts on them indicating relative immobility, at least in the recent past. Generally, they have (1) one-sided growths of the coralline alga "Lithothamnion", (2) small colonies of bryozoans, or (3) a cover of lichen-like material. The late H. D. Lilly (personal communication) has found that substantial coatings of Lithothamnion may grow during periods as short as a few months. In gravels composed dominantly of limestone (immediately off shore at Long Point) much pitting and corrosion of the pebbles has occurred.

3) (b) Likewise, many of the sandy components of these gravels were found to have coatings of calcareous cement which would seem to preclude transportation at the present time. The time needed for this post-depositional process to occur is unknown. With respect to this coating on the sand grains, it may, in fact, be due to post-depositional processes operating on the grains while they were members of the outwash sequence and have little relation to their subsequent transportation and deposition in the marine environment.

As mentioned above, the correlation of the sandy material to a given depositional environment poses a problem when dealing with gravel sediments. One approach to this problem might be to compare the knick-points of these various samples with those established for Type No. 2 cumulative curve. Coincidence of the knick-points should enable the picking out of those samples in which the sand fraction is indeed representative. Correction of the cumulative curves, omitting the gravel portion, is necessary if the knick-points from these samples are to be compared on an equal basis with those of cumulative curve Type No. 2. Nevertheless, seeing that in most cases the gravel samples have an excess of clay, a recalculation, omitting the gravel fraction, would show even a greater disparity in the knick-points (an even greater excess of clay).

There are two main reasons why the knick-points of the sand size fraction of these gravels are thought not to coincide with the established one. (1) If the gravels are of the compact type mentioned above, then, the filling of the interstitial areas with sand and clay takes place by random deposition which is unrelated to the actual prevailing energies. (2) If the gravels are dispersed with the sand size particles originally being representative (knick-point lines coincident with those of Type No. 2), the sediment itself having formed at some time in the past, then post-depositional processes can have altered the original size distribution. If, since deposition, a decrease in energy occurred one might expect deposition of finer material to take place now. Some of this material will, no doubt, fall into the interstices of the sandy gravel. This post-depositional addition of finer material will effectively decrease the sand percentage contribution to the sediment and cause the knick-point to move to the coarser size ranges.

In Figures 30 and 31 (Samples S-41, S-49, S-50, S-99, S-100, S-164, S-169) the knick-points are in positions very similar to those expected. Only in these samples can the sand sizes be taken to be indicative of the present-day depositional regime. All these samples are of the dispersed kind excepting S-49 (which must be considered unique).

Considering the mode of transport of the pebbles in this type of gravel (dispersed), evidence of their activity should be visible in those samples considered representative (active).

At this point it should be mentioned that no pebbles with diameters >1 cm. exhibited truly fresh surfaces indicative of movement at the present time. No evidence of energies or velocities >100 cm./sec. exists, with many instances where much lower velocities seem to predominate. With reference to this fact, many of the above mentioned (active) dispersed gravels (S-41, S-49, S-164, and S-169) contained residual pebbles with diameters less than 1 cm. It is unclear how residual pebbles can be present in a dispersed type gravel (with active sands), but it may possibly be due to an unrepresentative sample or introduction of the pebbles by drift ice. One can also picture active sands being transported over areas of rock and scattered residual pebbles. At this point, it may be pertinent to mention that many of the finer dispersed gravels may, in fact, be mixtures of two or more depositional regimes (Samples S-34, S-35, S-36, S-54, S-59, S-68, S-72, and S-95). In this respect, their poorer sorting is presumably a result of this bi or tri-environment history. The whole sample thus formed may be residual or one section of the sediment (presumably the finest) may still be active.

Looking at the reverse problem, a number of dispersed gravel samples (S-22, S-23, S-35, S-46, S-54, and S-158) have fresh pebble populations ($<$1 cm. diameter) accompanied at the same time by fine grained components which seem unrepresentative (excess clay). This is accountable in the compact gravels (S-22 and S-158) but nevertheless presents a problem with the dispersed gravels. This apparent impossibility might find its explanation in the fact that these gravels are not dispersed as defined above. No material of diameters between 1 mm. and 10 mm. must be present if the samples are to be dispersed when $>$48% void space occurs. However, if material between 1 and 10 mm. in diameter is present, it is possible for a sample to contain $>$48% of particles smaller than 1 mm. in diameter (void filler) and yet to have a compact gravel. In such cases, the enclosed sands need not show knick-point conformities, even though the pebble surfaces are fresh.

To summarize the above discussion, it is observed that essentially three types of gravel deposits exist:

a) compact gravels;

b) compact gravels with interstitial sands; and

c) dispersed gravels.

The compact gravels themselves may be either 1) residual, formed in the past during a time of higher energy, or 2) active at the present time. Criterion 3(a) mentioned above is the basis on which a gravel is judged residual or active.

The compact gravels with interstitial sands are mostly residual, although some may be active with the sands being trapped very recently. In any case, the sands are not expected to indicate energies involved. In this case as well, criterion 3(a) is used to distinguish residual from active deposits.

In Table 6 above, these compact deposits are labelled by type and designated as residual or active. The dispersed gravels are also noted in Table 6 with no mention of their nature as it is more difficult with dispersed gravels to identify the residual from active types because of the sometimes conflicting picture presented by the sand size fractions. The alternatives are presented in Table 7 below.

The residual nature of the sand in Subtype 2 as we have proposed is only apparent because the subtype itself is likened to a compact gravel.

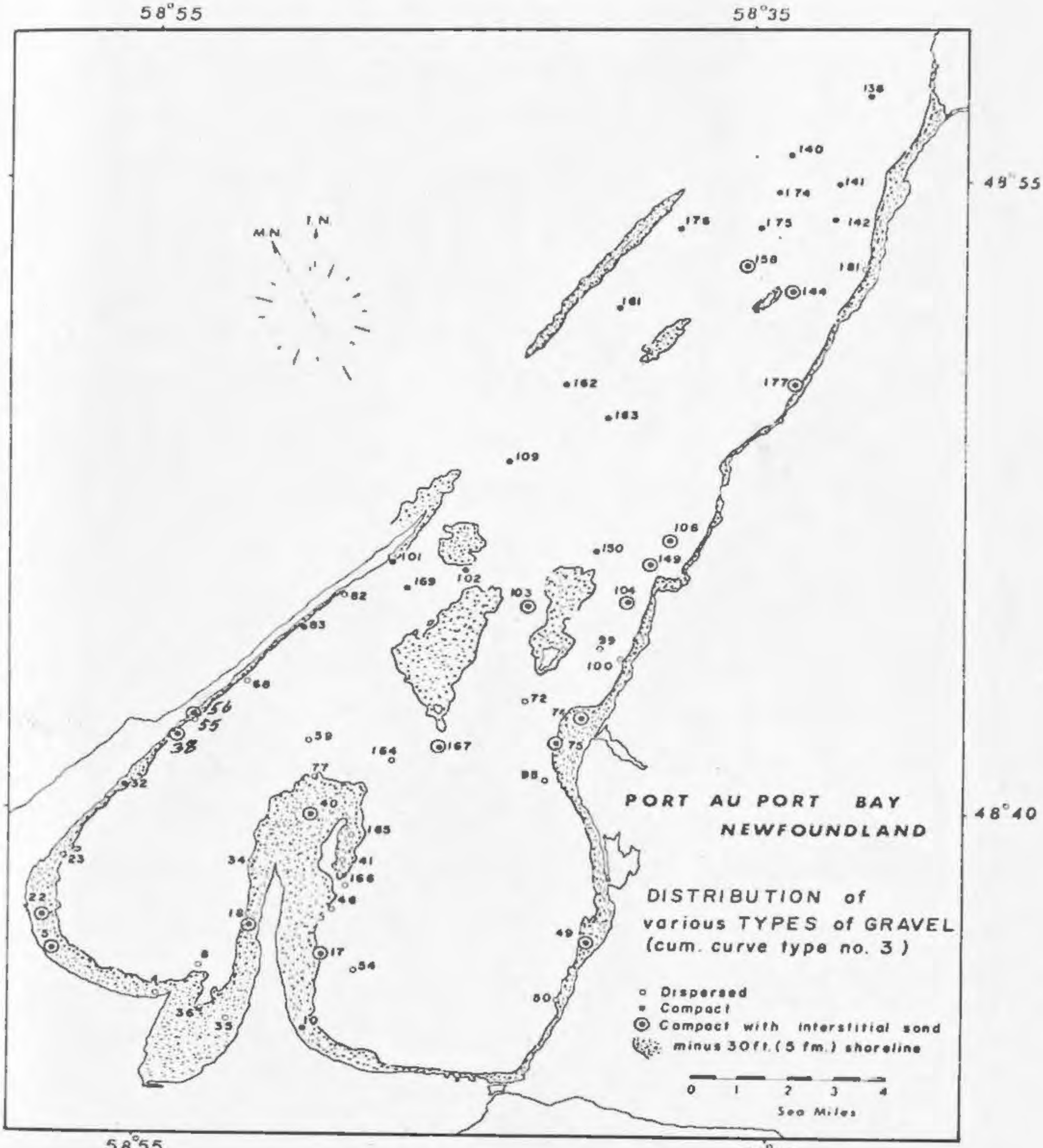
The distribution of all the active gravels must be explained by one or other of the criteria 1 and 2 above. Samples S-35, S-46, S-54, S-99, S-100, and S-158 lie in the path of strong ebb and flood currents which may adequately explain their active nature. The remaining samples (S-22, S-23, and S-50) are in water shallow enough to have permitted their formation by wave action during any recent storms.

Figure 33 shows the distribution of the various types of gravel and the shape of Port au Port Bay at a sea level of about -30 feet. It is evident that this land-sea configuration must have had a large effect in determining the distribution of many of the now residual gravels. Most of them are within the zone affected by the lower stand of sea level or are in tidal channels where the velocities must have been considerably higher during this minimum stand of the sea. In particular, the Bar Flats, the West Basin sill and the East Basin sill due to their narrowing and shoaling (with the drop in datum) must have had much higher peak tidal velocities than they do at present.

Insignificant amounts of sand and/or clay material have been deposited in much of the area affected by the lower sea level (areas of exposed residual gravels). This implies that either (1) no supply of detrital material to these areas exists at present, or that (2) the current velocities over these areas has always been high, thus preventing deposition (more likely (1)). It is not really understood why nothing was trapped in the residual compact gravels since their formation. Samples S-8, S-72, and S-95 seem to have an abnormal amount of coarse material even when lower sea levels and tidal currents are considered.

FIGURE 33

The distribution of the various types of gravel (cumulative curve type No. 3) within Port au Port Bay.


58°55
58°35
48°55
48°55
48°40
48°40
58°55
58°35
M.N.
T.N.
PORT AU PORT BAY
NEWFOUNDLAND
DISTRIBUTION of
various TYPES of GRAVEL
(cum. curve type no. 3)
Dispersed
Compact
Compact with interstitial sand
minus 30 ft. (5 fm.) shoreline
0 1 2 3 4
Sea Miles

They, perhaps, are examples of sediments which have ice-rafted pebbles as significant components.

The gravels in the Serpentine Basin are somewhat of a dilemma as they are too deep to have been a result of storm wave action or tidal currents associated with the post-glacial sea level minimum. In fact, the Serpentine Basin and adjacent areas have dominantly a bedrock bottom which is thought possibly to be a result of glacial scouring. The lack of sedimentation, other than by ice rafting, in post-glacial times, can be attributed mainly to lack of supply (associated with weaker currents). It is interesting to note that the pebbles which are found possess a wide range in roundness. This is governed by the source of the ice-rafted material which must be from beaches, till, and coastal scree alike.

Along much of the shoreline of Port au Port Bay the late Wisconsin till, the so-called "St. George's River Drift" crops out (MacClintock and Twenhofel, 1940). At Tea Cove, on the east and west side of Shoal Point, at The Gravels and at various other localities, this unit is visible. As mentioned above, it seems to be absent in the Serpentine Basin area and on Long Point where it either was not deposited (Serpentine Basin) or else it has been eroded by wave action during the isostatic rise of the land immediately following deglaciation (Long Point).

Evidence of till existing in certain areas of the floor of Port au Port Bay is found even from a cursory lithological examination of the gravels.

Sample S-55 very near the base of Long Point is composed mainly of pebbles of acid igneous rocks similar to those found in the Long Range mountains or Indian Head hills to the east. S-54 is composed of a similar suite of rocks. Contrary to this, some gravels seem to reflect directly the bedrock lithology on which they lie. S-56 and S-38 located very close to Long Point are in fact 100% limestone of the Long Point Group. S-68 near Long Point, S-77 and S-61 north of Shoal Point are dominated by weak friable shales very similar to the Humber Arm rocks found on Shoal Point itself, and presumably reflect their existence directly beneath these points. It would seem that the majority of the residual gravels were formed by reworking of till during times of higher hydrodynamic energies associated with the minimum stand of the sea in post-glacial times or are ice-rafted material scattered over glacially-scoured bedrock surfaces. Gravels which are found close to a shoreline composed of raised outwash deposits may be the result of reworking of these outwash sediments instead of till.

Facies Distribution and Interpretation

It is common habit to describe the sediment distribution by way of well-known terms, such as mud, sand and gravel, with various adjectives added to provide an apparently more definite description of any particular sediment. Folk (1954) has given a classification along these lines, where the terms have little meaning or significance with respect to environment.

It is reasonable in the present case to plot the distribution of the sediments in Port au Port Bay according to the units already described in the text (i.e., cumulative curve types Nos. 1, 2 and 3). Figure 34 shows the distribution in Port au Port Bay of these three dominant types of sediment.

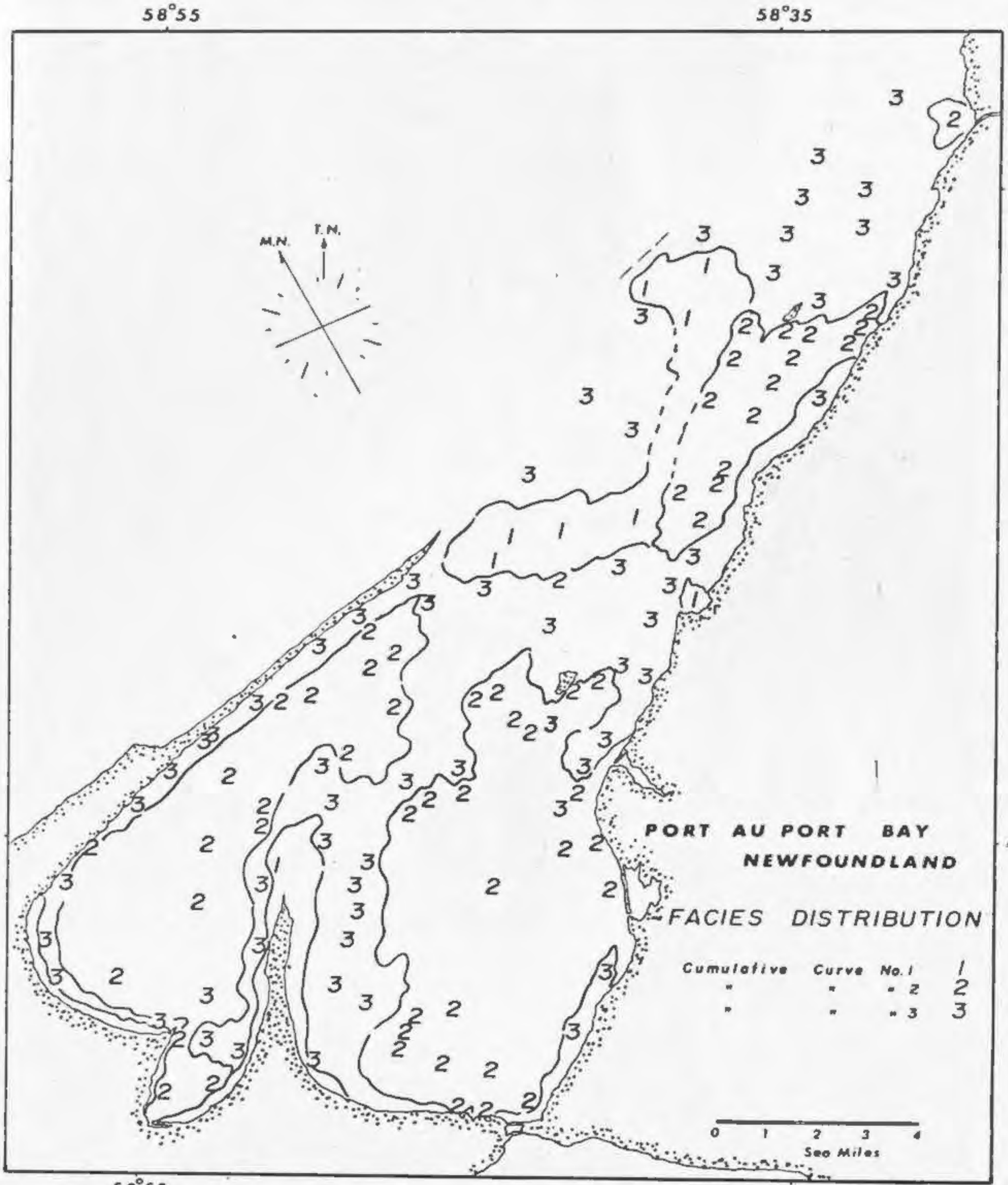
Distribution of Cumulative Curve Type No. 1

There are four areas in which cumulative curve type No. 1 is present: (a) east of the Long Ledge, (b) east of the tip of Long Point, (c) north of Shoal Point, and (d) in Broad Cove. There seems to be no nearby sediment source for areas (a) and (b) and till outcropping on Shoal Point is the closest source for area (c). In Broad Cove, however, nearby outwash deposits provide an ample sediment supply.

Sediments of this type have an insignificant fine tail (Figure 17) and participate in traction transport, as evidenced by the presence of ripple marks, during the time

FIGURE 34

The distribution of the cumulative curve types No. 1, 2 and 3 sediments within Port au Port Bay.



58°55
58°35
48°55
48°40
M.N.
T.N.
PORT AU PORT BAY
NEWFOUNDLAND
FACIES DISTRIBUTION
Cumulative Curve No. 1 1
" " " 2 2
" " " 3 3
0 1 2 3 4
Sea Miles

of peak tidal currents (areas (a) and (b)) or average wave action (areas (c) and (d)). They are unimodal and possess high sorting values with particle diameters one standard deviation distant from the mean diameter being within 0.3 to 0.5 Ø units. These deposits are active at the present time and are thought to represent faithfully the energies in force at the site of deposition.

The origin and source for two of these Type No. 1 deposits (areas (a) and (b)) is not obvious, and warrants some detailed discussion. Sandy beds of the Long Point and Clam Bank Formations and scattered pockets of clastic Carboniferous rocks which outcrop along the western shoreline of the Port au Port Peninsula could provide the sand size clastic material of which the offshore bodies are composed (areas (a) and (b)). Longshore transport along the west side and around the tip of Long Point is indicated by the appearance of shale pebbles at Beach Point from the upper part of the Long Point Formation, which are not present in the bedrock section on the east side of Long Point. This fact would seem to be a direct result of the stronger and/or more persistent flood tidal current stream entering Port au Port Bay. Deposition at these locations would presumably have been due to a decrease in the flood tide velocity. Shoreline erosion and retreat associated with the recent transgressive trend of sea level change would continually provide clastic debris to the marine environment.

A very stable heavy mineral assemblage composed almost wholly of very well-rounded opaques, zircons and garnets is present in these sediments of areas (a) and (b). If these sand bodies are indeed composed of detrital grains from the bedrock outcrops along the western shore of the Port au Port Peninsula, then one would expect either a similar mineralogical composition to exist in these source rocks, or one would have to assume that during the longshore transport from the source area to the depositional area the unstable minerals had been destroyed and the resistant ones worn considerably in order to give them their high roundness.

The heavy mineral suites in the Long Point, Clam Bank and Carboniferous rocks are not sufficiently well-known to prove or disprove the first alternative given above, nevertheless, from cursory examination it is not believed that such a mature suite is present. Likewise, the longshore transport does not seem of sufficient distance to give the roundness observed in most of the heavy and light minerals making up the offshore sand bodies. The above statement is based on the assumption that little reworking of these deposits occurs once deposition from the transporting tidal current has taken place. Of interest is the fact that the sands immediately north of Shoal Point (vicinity S-28) contain an almost identical heavy mineral suite with equally well-rounded grains, as do the two bodies further north. This would seem to substantiate somewhat the pessimism shown above as to the validity of the bedrock source for these deposits (those of (a) and (b)).

With reference to the post-glacial lower sea level phase, which is believed to have occurred in the study area, local reworking of till deposits in areas (a), (b), and (c) does not seem an unlikely possibility. Cursory lithological examination of tills outcropping at the base of "The Gravels" at Port au Port shows them to contain significant quantities of the heavy minerals found in these Type 1 deposits, as well as many other unstable varieties. If it is assumed that other tills in the bay have a similar suite, then continuous reworking of these tills might produce the heavy mineral selection now found in the deposits of cumulative curve Type No. 1. If one pictures a till deposit reworked at the lowest or at least a lower sea level than now by wave action with the sand size material being moved offshore, a clean pebble mat will be left covering the till deposit and will effectively prevent further reworking of the till. The sands from this reworked till zone will, nevertheless, be shifted around according to the energy changes accompanying the eustatic rise in sea level and will be constantly reworked. Because of the slow rate of introduction of new material to these isolated areas, the sands will not become buried after having undergone only little reworking but will be constantly available to transport and shifting in line with any changes in the depositional environment.

It is of interest to note that most of the quartz grains in sample S-28 taken from north of Shoal Point are very well rounded and somewhat frosted, but not polished as one would expect if rounded by water wear. It would seem that a stage of wind transport (dune formation) may have existed in the history of this sediment. Burial of this dune sand upon submergence by the transgressing sea has apparently not happened, although morphological modifications must certainly have taken place.

Sample S-105, from Broad Cove, on the other hand, has an immature mineral suite similar to that of the outwash material along the shore from which it was derived. Presumably, the coincidence of the grain size distribution of this sample with the others of Type No. 1 reflects no more than a coincidence in transporting energies.

Distribution of Cumulative Curve Type No. 2

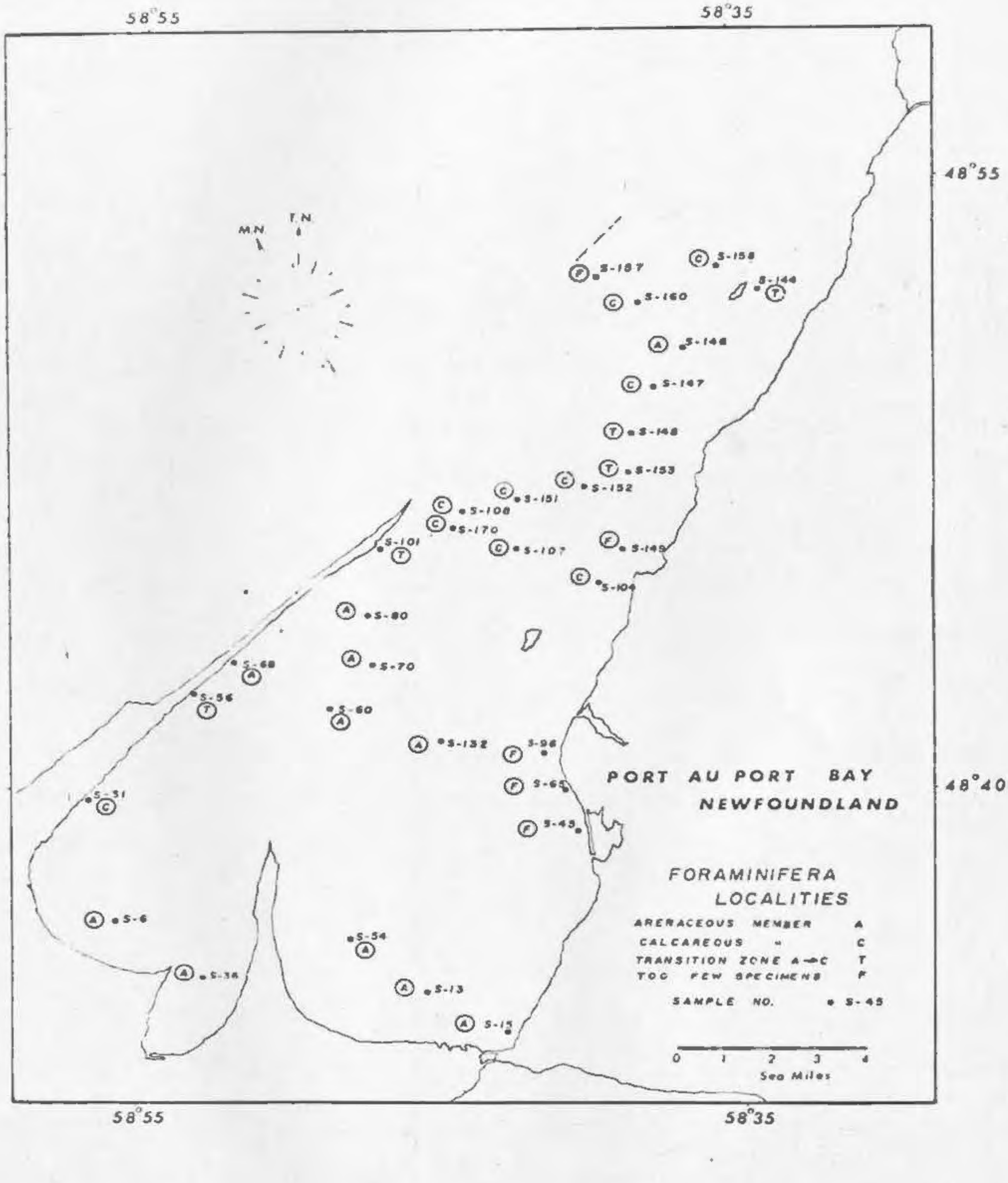
The sediments composing this type range from deposits almost as coarse as those of Type No. 1 to the finest ones found in the study area. They are found in areas very nearshore, off Fox Island River, to those areas furthest offshore in the middle of the basins (Figure 34). The distribution of this sediment type (i.e., from the basin areas to close inshore) permits the comparison of these samples with one another in the vertical sense (with depth). This type of cumulative curve is thought to have sections which represent both the traction and suspension modes of transport. The coarser members of this type may be wholly transported by traction in contrast to the finer members which may be completely representative of suspension transport. It is thought that sediments present below the deepest sill in the respective basins might have a consistent upper grain size representing the maximum size transported in suspension. Above the sill depth the sediments are likely not transported wholly as one mode, but, in fact, will most probably be a mixture.

Let us now examine the reasons why the basin areas may, in fact, be areas where the suspension mode of transport is dominant. The physical oceanographic conditions in Port au Port Bay in the summer time have been described previously in Chapter II. Because of the apparent isolation of the basin water from the surface layer, in summer, it is proposed that the bottom currents during this time are insignificant or completely absent. This would imply transport of sediment by suspension only, at least while the surface and bottom water masses did not mix. The renewal in the winter time of the oxygen content in the bottom waters of the basin implies exchange with the surface waters and the flowing to the basin bottoms of slightly denser water. If the velocity of the inflowing waters (during this time of exchange) were of sufficient magnitude to transport grains along the bottom (traction transport) one would expect to find some evidence of this; i.e., layering in the core samples from the basin areas. Examination of a number of cores show no layering whatsoever, other than some zones with a sprinkling of sand grains from ice rafting. The absence of layering seems not to be attributable to mixing of the sediment by bottom living fauna as the author did not see any evidence of organic activity (see Chapter II). The presence of H_2S gas in the basin sediments below the uppermost 2 or 3 cm. indicates reducing conditions, which must be due to the oxidation of organic material (presumably bacteria and organic debris from planktonic and shoreline sources). The possibility of the mixing of the bottom deposits during the decaying process and/or the mixing by bottom crawling organisms is nevertheless far from conclusive proof that the original layering has been subsequently mixed. If layering was initially present (indicating possible alternating suspension and traction deposition), one would not expect its complete obliteration to be achieved in an area where the rate of mud deposition is relatively high ($\simeq$ 20 feet in 13500 yrs.; $\simeq$ 0.5 mm./yr.) compared to the ocean basins, where deposition is extremely slow and where some layering is still present even in zones where intense reworking by bottom organisms occurs. The author, diving in some areas of very little current activity, has noticed that near the bottom, a transparent film of sediment in suspension just above the hard bottom often exists. Perhaps this framework of organic material(?) or mat-like appearance may effectively prevent traction transport from occurring or at least prevent the expected layering from being formed. Until year-round measurements of the physical oceanographic properties and accurate observations of the biological activity on the bottom can be made, one can do no more than enthusiastically speculate, on the basis of the above presented arguments, that, in fact, only one mode of sediment transport (suspension) exists below the deepest sill depth.

The distribution of foraminifera in Port au Port Bay seems to enforce somewhat the above (albeit) tentative conclusion. Appendix C shows the fauna observed in each of the tested samples and Figure 35 shows the distribution of these samples within Port au Port Bay. From cursory examination of the fauna present it is apparent that two somewhat different suites exist: an arenaceous one composed

FIGURE 35

Locations of various foraminiferal suites inside Port au Port Bay.



58°55
58°35
48°55
48°40
M.N.
T.N.
S-157
S-158
S-144
S-160
S-146
S-147
S-148
S-153
S-152
S-151
S-108
S-170
S-101
S-107
S-149
S-104
S-80
S-70
S-68
S-56
S-60
S-132
S-98
S-31
S-65
S-45
S-6
S-54
S-36
S-13
S-15
PORT AU PORT BAY
NEWFOUNDLAND
FORAMINIFERA
LOCALITIES
ARERACEOUS MEMBER A
CALCAREOUS " C
TRANSITION ZONE A→C T
TOO FEW SPECIMENS F
SAMPLE NO. • S-45
0 1 2 3 4
Sea Miles

primarily of Eggerella advena and a calcareous one composed mainly of Elphidium clavatum. Other samples seem to be composed equally of calcareous and arenaceous forms and are designated as transitional types in the discussion below. Yet another group of samples contained too few species for a proper determination of the suite to which they may have belonged and samples S-155 plus S-114 from the Fox Island Basin and S-43 and S-69 from the center of the East and West Basins respectively were entirely barren.

Table 8 and Figure 36 show the data and plot of the foraminiferal suites versus depth for the West Bay, East Bay and joint Fox Basin-Bar Flats area.

In East and West Bays, no calcareous suite was found (due probably to lack of sampling in the 0-20 foot range) and the arenaceous suite was found in deeper water than the transitional suite. Likewise, in the Fox Basin-Bar Flats area, the transitional suite was found in deeper water than the calcareous suite. It is apparent that the calcareous suite is representative of a higher energy environment than are the other two members. Nevertheless, even the arenaceous member is present only to depths of about 10 feet below the deepest sill. Presumably, at a given depth below the deepest sill conditions are unfavorable for the existence of benthonic foraminifera. This absence may be related (as is the macrofauna) to the low percent oxygen

TABLE 8

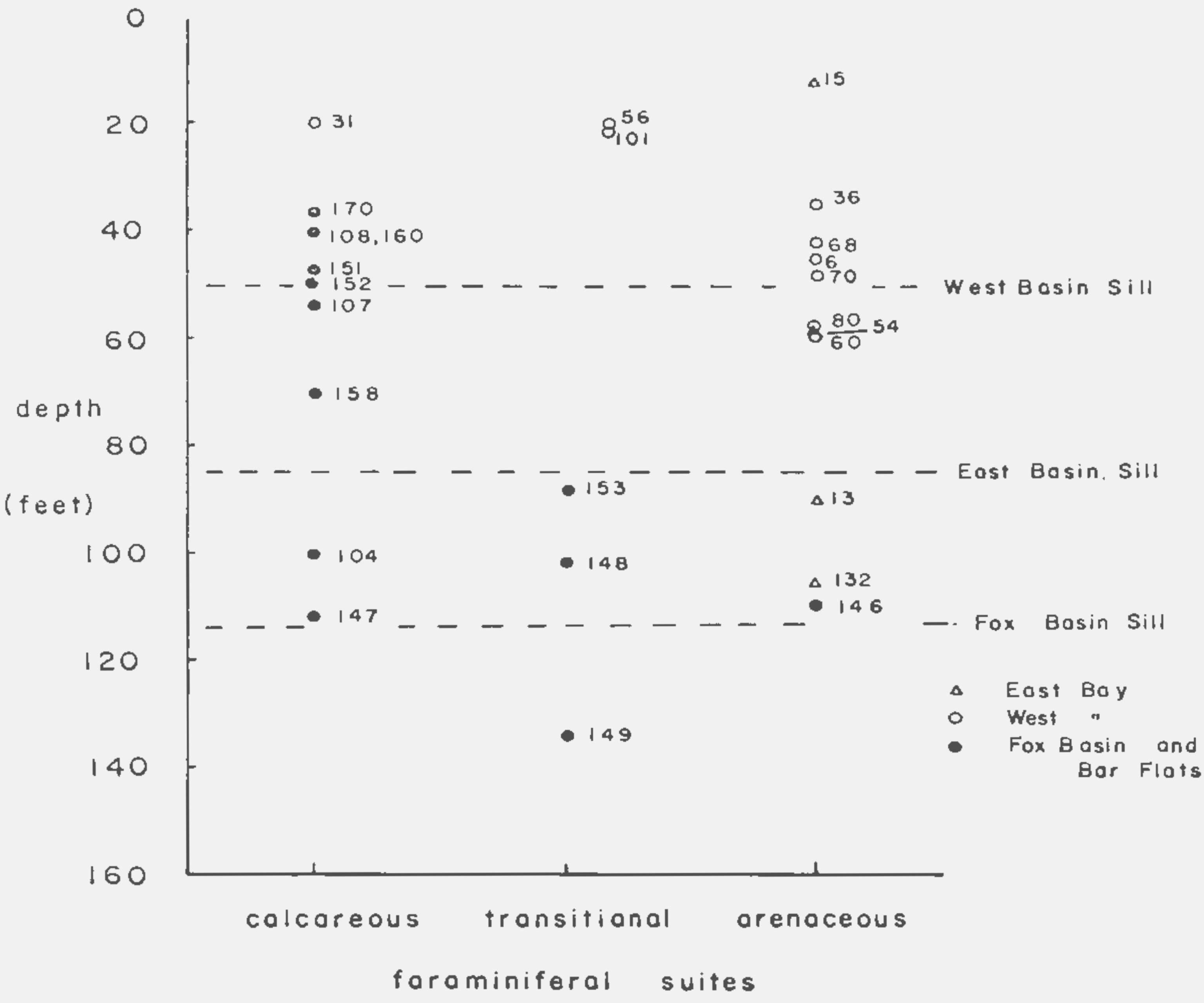
FORAMINIFERAL SUITES

Sample No.	Depth (ft)	Foraminiferal* Suite	Location
S-13	90	A	
S-15	12	A	
S-45	15	F	EAST
S-54	60	A	
S-65	12	F	BAY
S-96	24	F	
S-132	106	A	
S-6	45	A	
S-31	20	C	
S-36	35	A	WEST
S-56	20	T	
S-60	60	A	BAY
S-68	42	A	
S-70	48	A	
S-80	59	A	
S-101	22	T	
S-104	100	C	
S-107	54	C	
S-108	40	C	BAR FLATS,
S-144	134	T	
S-146	110	A	FOX BASIN,
S-147	112	C	
S-148	102	T	SERPENTINE
S-149	86	F	BASIN
S-151	47	C	
S-152	50	C	
S-153	88	T	
S-157	32	F	
S-158	70	C	
S-160	40	C	
S-170	36	C	

*Arenaceous Suite A
Transitional Suite T
Calcareous Suite C
Too Few Species F

FIGURE 36

Plot of the various foraminiferal suites versus depth for the East Bay, West Bay and the Fox Basin-Bar Flats area.



0
20
40
60
80
100
120
140
160
depth
(feet)
31
56
101
15
170
36
108,160
68
151
6
152
70
West Basin Sill
107
80
54
60
158
East Basin. Sill
153
13
104
148
132
146
147
Fox Basin Sill
East Bay
West "
Fox Basin and Bar Flats
calcareous
transitional
arenaceous
foraminiferal suites

saturation values which are thought to exist in the basin bottoms in the late fall.

If we continue with the premise that deposition of sediment in the basin areas is from suspension, then, when the parameter which best represents the prevailing energies (for each sample) is plotted versus the depth of that sediment, the distinction between samples composed wholly of matter deposited from suspension from those composed of a mixture should be apparent.

In the discussion of the Type No. 2 curves, composed of the fine sand and clay populations, the size distribution of the clay population was found to be almost constant, although their relative abundance varied considerably. On the contrary, the size of the fine sand population was found to vary, presumably as a result of different transportational energies. The maximum size of this fine sand population presumably is a measure of the competency of the transporting fluid. In the present case the maximum size of a given fine sand population is difficult to pick out because of the ice-rafted component causing much larger coarse tails than would normally be present. An alternative approach would be to pick instead the median or mean diameters of these fine sand populations. In this respect, it is easier to locate the median diameter than to recalculate the mean diameter omitting the clay population.

It is pertinent, here, to investigate the role of coagulation in the depositional process of these Type No. 2 sediments. In this respect, coagulated floccules may have diameters many times those of the constituent clay population grain diameters so that they behave in the transporting fluid as if they were members of the fine sand population, and, as long as these floccules do not incorporate particles from the fine sand population, the present interpretation of what is environmentally sensitive remains correct. If, on the other hand, the floccules did include particles from the fine sand population, then the median diameter of this fine sand component no longer is significant and one is left with no possible link between sediment and energy.

A summary of the settling of coagulated particles has been given by Gripenberg (1934). She has found that coagulation increases with the concentration of the electrolyte and that the maximum sized aggregate formed from very fine particles are around 10-20 microns as determined by Stokes' settling velocities. If these diameters are adjusted, in consideration of the lesser density of the aggregates, diameters of around 30 microns may be assumed. Likewise, Tuorila (Gripenberg, 1934) has found that the maximum size of coagulated aggregates, even where particles of diameters up to 100 microns are available, is between 20 and 40 microns. Thus, the flocculation of particles in the manner observed by these two workers would not seem to alter or change any of the ideas proposed above for the Type No. 2 sediments.

Now that justification for using the median diameter of the fine sand population to relate the depositional energy at that point has been obtained, it would seem instructive as well to plot those segments of Type No. 1 and Type No. 3 samples which are environmentally sensitive. In this respect, the mean or median diameter of the Type No. 1 sediments and the median diameter of the sand fractions (active at the present time) from the Type No. 3 sediments are those thought suitable for plotting. In Table 9 the depths and median diameters of the environmentally sensitive samples have been listed. The results of plotting these median diameters versus the corresponding depth is shown in Figures 37-39.

It is evident upon cursory examination of the plots that below a given depth in each bay a median size of about 0.080 mm. is not exceeded. On the contrary, above this given depth both large and small median sizes are encountered. The most probable explanation for the constant upper median-size limit of the fine sand population below this given depth is to assume that deposition from suspension only is taking place. Then, from this, the maximum

TABLE 9

MEDIAN DIAMETER OF SIGNIFICANT SEGMENT AND DEPTH OF SAMPLES CONSIDERED ENVIRONMENTALLY SENSITIVE

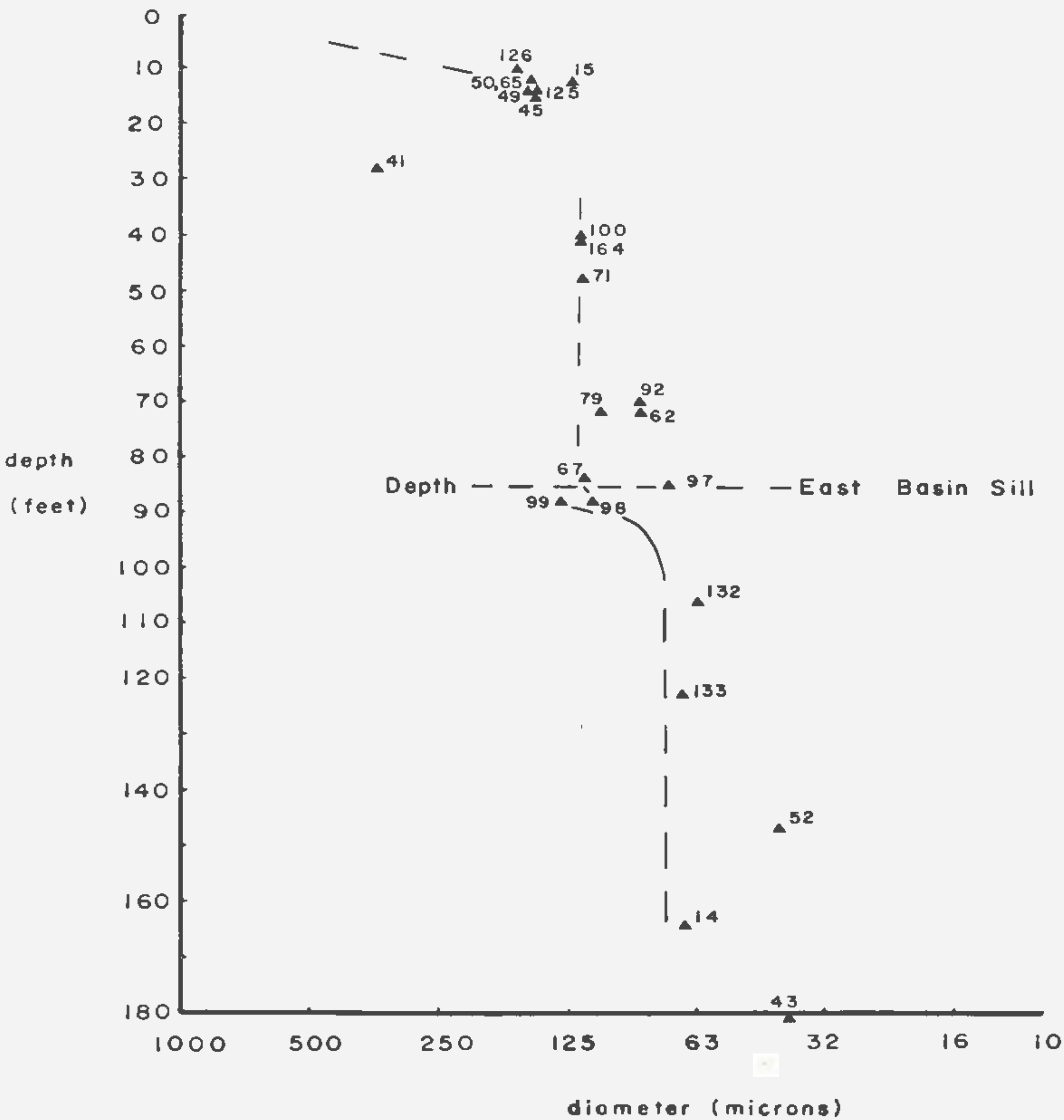
Sample No.	Depth	Median Diameter	Cum.Type	Locality
S-14	165	0.064 mm.	2	
S-15	12	.125		
S-43	182	.037		
S-45	15	.155		
S-52	147	<0.040		
S-62	72	.085		
S-65	12	.155		E
S-67	84	.115		A
S-71	48	.120		S
S-79	72	.105		T
S-92	70	.085		
S-97	85	.072		B
S-98	88	.110		A
S-125	14	.150		Y
S-126	10	.165		
S-132	106	.062		
S-133	123	.070		
S-41	28	.350	3	
S-49	14	.155		
S-50	12	.155		
S-99	88	.130		
S-100	40	.120		
S-164	41	.120		
S-28	12	0.320 mm.	1	
S-26	50	<0.040	2	
S-29	60	.040		
S-31	20	.200		W
S-39	72	.055		E
S-60	60	.070		S
S-69	72	.056		T
S-70	48	.115		
S-76	54	.075		B
S-80	59	.105		A
S-81	72	.085		Y
S-134	76	.085		
S-169	54	.140	3	

TABLE 9 (Contd)

Sample No.	Depth	Median Diameter	Cum. Type	Locality
S-105	25	0.310 mm.	1	
S-152	50	.450		
S-156	64	.350		
S-160	40	.320		BAR FLATS
S-107	54	.210	2	
S-111	140	.077		
S-112	114	.080		
S-114	130	.080		and
S-115	145	.080		
S-146	110	.120		
S-147	112	.115		
S-153	88	.110		FOX BASIN
S-159	70	.200		
S-172	145	.075		
S-178	36	.160		
S-179	42	.155		
S-180	40	.155		
S-182	50	.170		

FIGURE 37

Plot of the median diameter of the segment of the sample considered environmentally sensitive (fine sand population for type No. 2 samples, whole sample for type No. 1 curve, and sand fraction for type No. 3 curves) versus depth in East Basin.

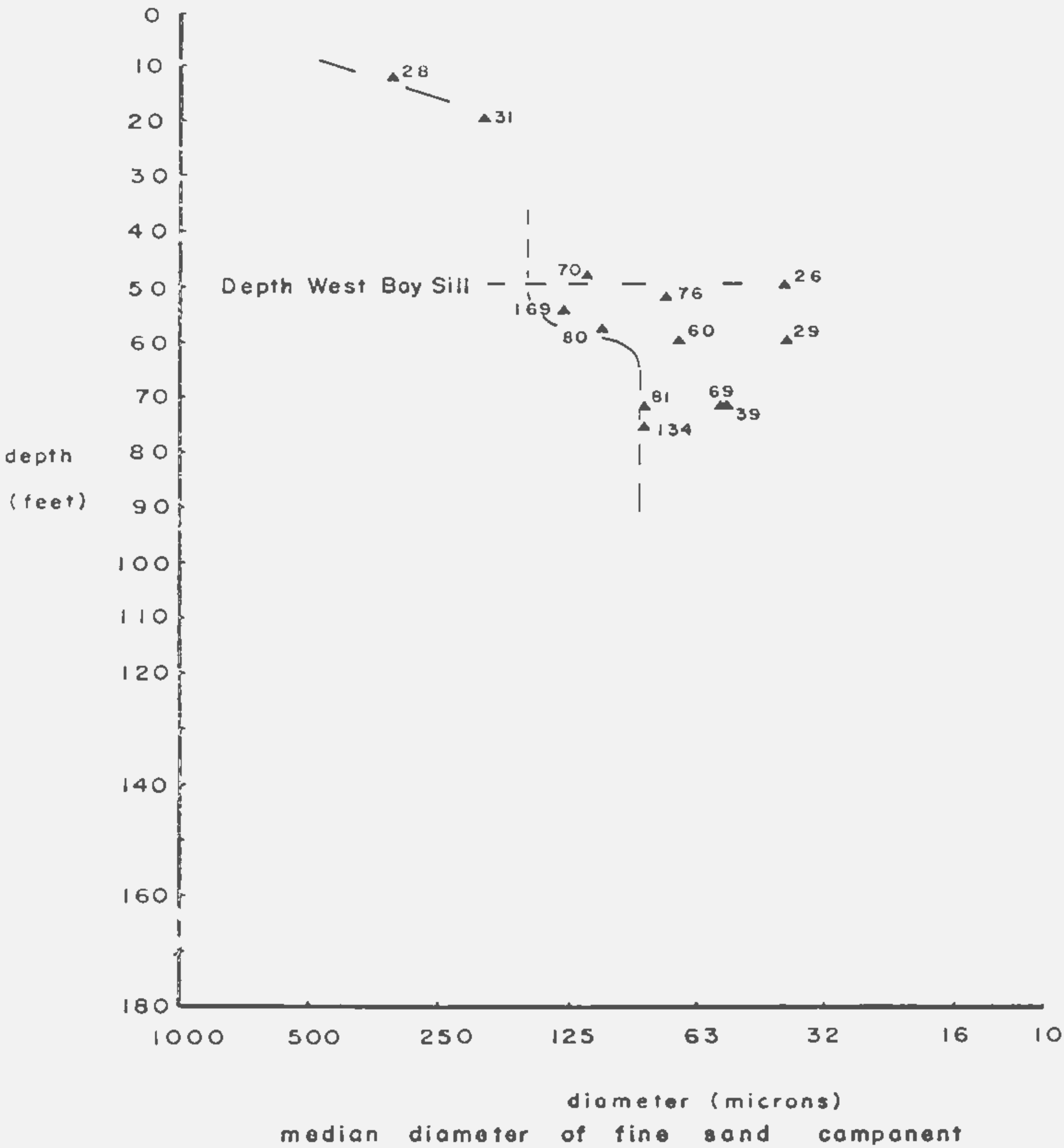


median diameter of fine sand component

EAST BAY

FIGURE 38

Plot of the median diameter of the segment of the sample considered environmentally sensitive versus depth in West Bay.

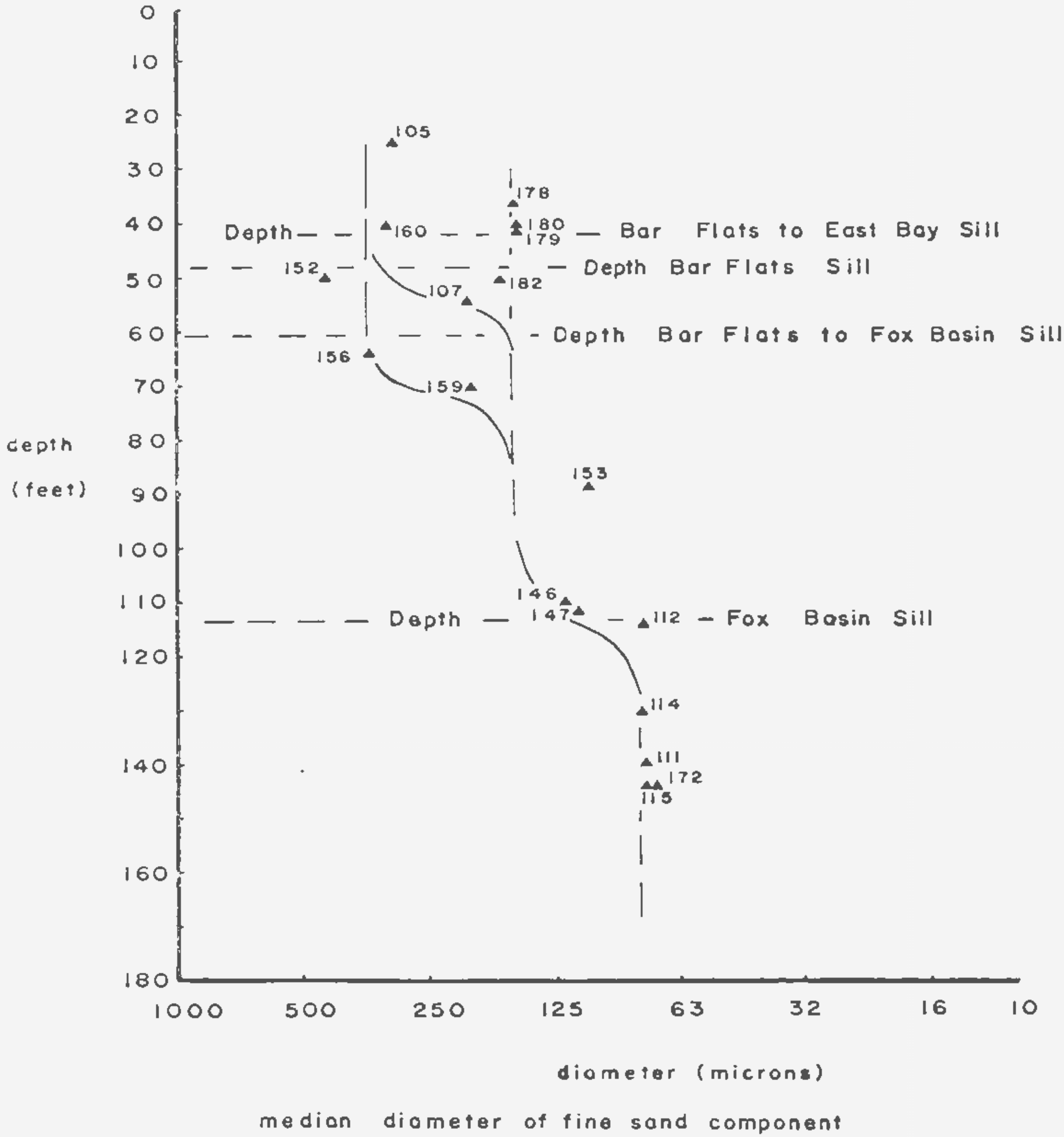


depth
(feet)
0
10
20
30
40
50
60
70
80
90
100
110
120
140
160
180
Depth West Bay Sill
28
31
70
26
76
169
80
60
29
81
69
39
134
1000
500
250
125
63
32
16
10
diameter (microns)
median diameter of fine sand component

WEST BAY

FIGURE 39

Plot of the median diameter of the segment of the sample considered environmentally sensitive versus depth in Fox Basin-Bar Flats area.



BAR FLATS and FOX BASIN

size transported in suspension may be estimated. Although the coarser fractions of these samples are somewhat skewed by mixing with ice-rafted sands (Figures 19-21) most of the samples have less than 5% of their grain diameters greater than 0.125 mm. The size range 0.125 mm. to 0.150 mm. is apparently the critical size dividing those particles transported by traction from those transported by suspension.

The critical depth in Fox Basin and East Bay coincides with the deepest sill while the critical depth in West Bay is about 10 to 15 feet below the deepest sill. At this point, a reexamination of the ebb and flood tidal current patterns (Figures 9 and 10) is necessary. Theoretically, an ebb or flood tidal current can set at any depth and will do so according to the shoreline configuration and bottom morphology.

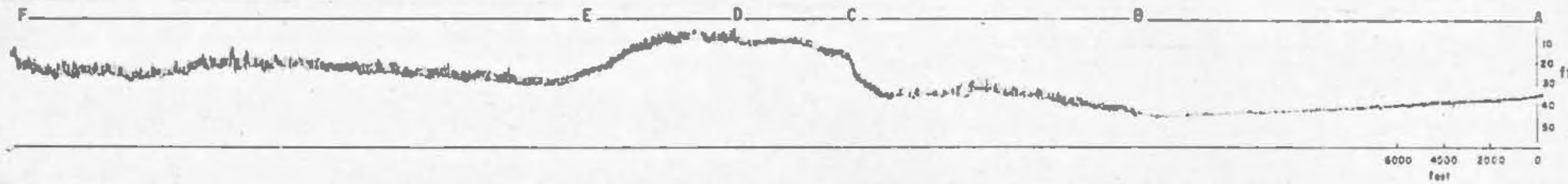
Two dominant flood tide streams seem to exist in the Port au Port Bay system: a) along the west side of Shoal Point and b) between Long Point and The Ledges in the Bar Flats area. The depth to which traction transport is feasible during flood tides is governed by the depth of the Bar Flats. (The current setting on the west side of Shoal Point is at a shallower depth, $\simeq$ 40 feet.)

Three dominant ebb tidal streams exist in Port au Port Bay. They are: a) along the east side of Shoal Point, b) along the northern stretch just east of Long Point, and c) in the Bar Flats area where all the outgoing currents converge. The ebb stream along the east side of Shoal Point seems to reach a depth of about 60 feet as evidenced by sample S-54. It is the ebb stream originating beside Long Point which is apparently responsible for the significant current velocities below the West Basin sill. The ebb current streams running out of the Bar Flats area are initially controlled by the sills in the respective basins. In this respect, the current in the Fox Basin area is present to depths equal to the Fox Basin sill. The coincidence of the critical depth with the depth of the deepest sill for the East Basin area is presumably due to its configuration which prevents ebb tidal streams to set at depths greater than the deepest sill.

Evidence as to the substantial effect of these ebb and flood currents can be seen in one echo sounding profile (Figure 40) taken from the head of West Bay around Shoal Point to the head of East Bay. At B in West Bay a distinct change in bottom sediment type exists. The change from segment AB (suspension) to segment CB (traction, sand), although at similar depths, is presumed to be due to the flood tidal current which sets on the west side of Shoal Point. Likewise, the distinct contrast in sediment types at D is thought to be due to the ebb current flowing along the east side of Shoal Point.

FIGURE 40

Detailed trace of an echo sounding profile from East to West Bay (see Figure 12 for the exact positioning of the profile) in which contrasting bottom lithologies are evident.



F
E
D
C
B
A
10
20
30
40
50
ft
6000
4000
2000
0
feet

Figure 41 shows a plot of the percentage of particles with diameters below 45 microns in Port au Port Bay. The heads and deepest parts of the basins unquestionably are the areas of highest fine sediment accumulation. The figure shows that a distinct increase in $\% < 45$ microns occurs as one progresses towards the head of the bays. This presumably is associated with the progressive decrease in tidal velocities towards the head of the bays, but may possibly be associated, as well, with increased availability of clay along the adjacent shorelines.

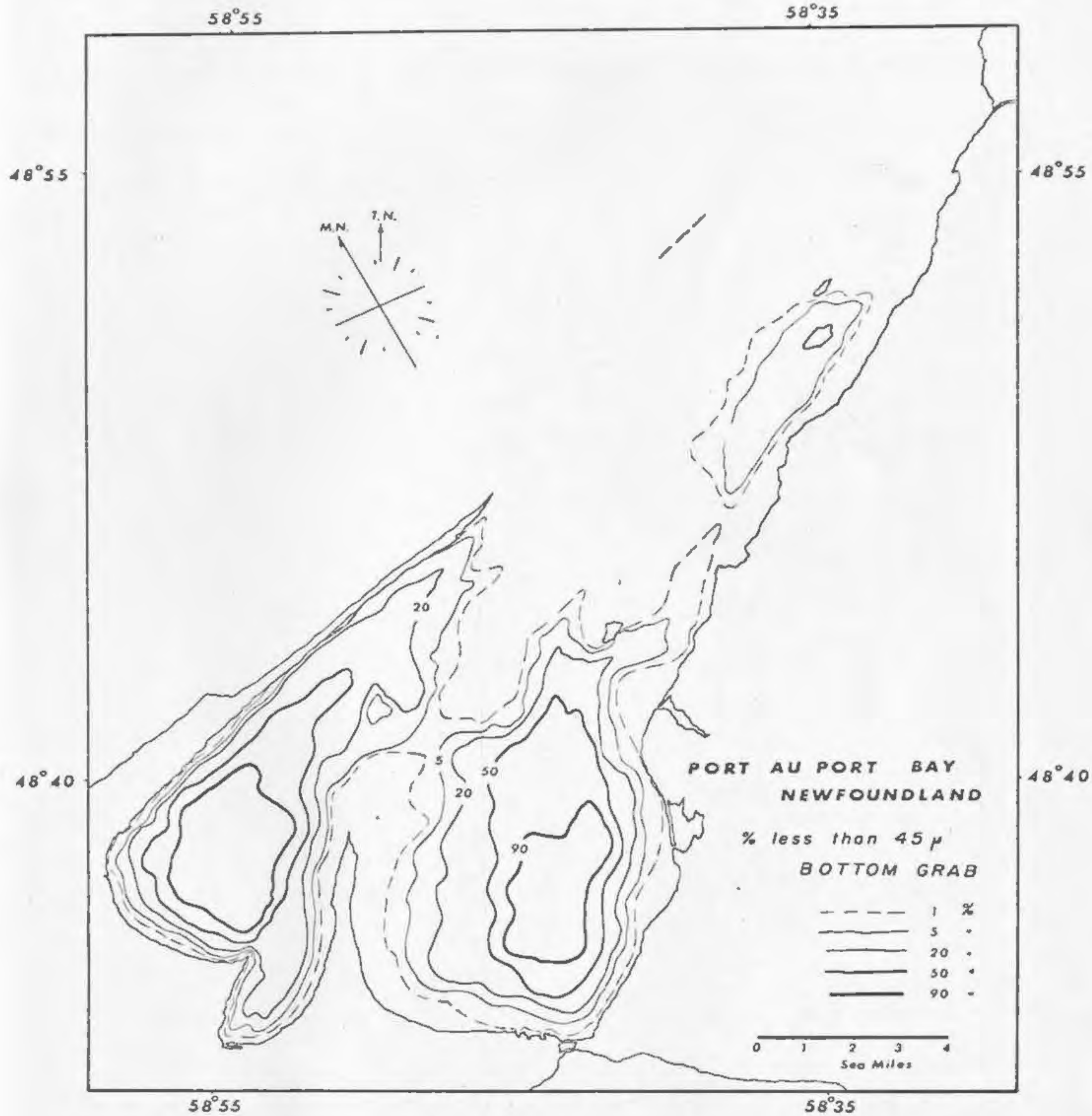
Presumably, the upper depth limit of deposits consisting wholly of particles brought in suspension is that depth to which storm waves possess orbital velocities equal to the erosion velocities of this fine material. This is around 30 feet deep for storm waves of the characteristics mentioned previously in the discussion of cumulative curve Type No. 3. The lack of tidal currents, because of the control exercised by the bottom morphology, and storm wave activity, seem to be the major factors responsible for the distribution of the blanket of fine-grained sediment deposited from suspension.

The mineral suite of the fine sand fraction of the Type No. 2 sediments is generally quite immature with an abundance of amphiboles, pyroxenes and olivine in the heavy fractions, and feldspars in the light fractions. This mineral assemblage is almost identical to that found in the

FIGURE 41

FIGURE 41

Abundance in the bottom sediments of particles with diameters less than 45 microns; distribution within Port au Port Bay.


58°55
58°35
48°55
48°55
48°40
48°40
M.N.
T.N.
20
5
50
20
90
PORT AU PORT BAY
NEWFOUNDLAND
% less than 45 μ
BOTTOM GRAB
1 %
5
20
50
90
0 1 2 3 4
Sea Miles
58°55
58°35

raised terrace and beach samples and reflects the small amount of wear involved in moving and depositing the Type No. 2 material in contrast to those sediments of Type No. 1. Obviously, once deposition of Type No. 2 sediments has taken place, they are not remobilized but become buried. This is certainly the case with the sediment particles deposited from suspension, but it seems that even where the sediment is partially transported by traction (S-125, S-126, S-107, S-159, and S-31) enough fine material is present to seal the deposited sediment, necessitating rather high current velocities for any remobilization to occur. The initial arbitrary division between cumulative curves Type No. 1 and Type No. 2 seems to be significant in that it divides deposits that have been remobilized many times (Type No. 1) from those which were deposited only once and quickly buried (Type No. 2).

Distribution of Cumulative Curve Type No. 3

The distribution and genetic interpretation of the sediments of Type No. 3 have already been discussed fully. Nevertheless, their location may be characterized by the following statement:

The distribution of the gravel facies at depths below present-day storm wave-base is not determined by conditions permitting transport and deposition of the gravels, but by conditions preventing the deposition of sand and mud (mainly an absence of local supply). In general, the gravels are either a relict or residual feature from times of a lower sea level, when till could have been reworked by wave action and/or tidal currents.

CHAPTER VI

CONCLUDING REMARKS

The detailed analysis of the sizes and distribution of the marine sediments in Port au Port Bay has been presented above. An attempt now to describe these deposits and their origin in more general terms will be made.

In Wisconsin time, the area of Port au Port Bay was covered by glacier ice and modified considerably by glacial erosion and subsequent deposition of till. Hence, the complete section of marine sediments now present on the bottom of the bay has been laid down after the melting of the ice in the bay area, i.e., after "local deglaciation".

The clastic material deposited since then can have been derived from the bay floor itself, from the various shore-lines of the bay, and from areas farther inland. In the first case, it would have been stirred up by waves and tidal currents, in the second case mobilized by coastal breakers, and in the third case, supplied chiefly by running water. In all three cases, consolidated bedrock as well as unconsolidated deposits would have been exposed to erosive attack; the latter, however, yielding readily, undoubtedly have provided the bulk of the material laid down on the bay floor in post-glacial time, whereas the bedrock has been of limited significance because of its much higher resistance. In the beginning, the Wisconsin drift--perhaps together with some kames and eskers--would have been the only unconsolidated deposit of significance present, but soon glacio-fluvial and glacio-marine deltas, solifluction sheets, landslides and slips, and other such minor deposits that were developing could also provide debris for marine sedimentation. In the more recent past, the widespread delta deposits along the coast, now raised to expose even parts of their bottomset beds, certainly have been the most important source for the modern sediments of the bay.

Submarine erosive removal of particles from glacial drift on the bay floor would have been possible only where the energy of the eroding agents (tidal currents and waves of oscillation) exceeded the threshold erosion velocities required. Conditions suitable for such erosion would have existed only in areas with relatively high current velocities such as shoals and tidal channels; in areas with low current velocities, however, no erosion would have been possible and deposition would have reigned from the start. Submarine removal of some clay, silt, and sand from glacial drift in areas permitting erosion would soon have developed a surficial layer of residual stones too heavy to be moved, a layer offering efficient protection to the underlying till against further erosion of its finer-grained particles.

Therefore, submarine erosion can probably be ruled out as a significant source of clastic matter for the post-glacial sediments in the bay. Of course, this statement is not meant to exclude the remobilization of sediment particles deposited during tide reversals or between storms in areas normally exposed to strong water movement.

As is well known, erosion at the sea coast is achieved primarily by breakers, which can dislodge particles of small and large diameters at the shore-line proper as well as offshore as far out as the line where they originate. Secondarily, mass wasting, rain wash, and wind, and the formation of ice in the winter time, assist the waves in eroding the coast-line. Evidently, the progress of coastal erosion depends upon the differential resistance of the materials attacked; loose sands and gravels such as are common in the topset and foreset beds of the raised deltas around Port au Port Bay offer much less resistance than their bottomset silts and clays, or than till; and the latter deposits, in turn, offer much less resistance than solid bedrock. As unconsolidated deposits of the kinds just mentioned still constitute large segments of the present coast-line of the bay, supply of clastic debris from the coast to the bay sediments must have been ample throughout post-glacial time.

Inland areas can supply clastic material for sedimentation in the bay only by means of streams flowing into the bay (the transporting role of the wind being negligible in Newfoundland). Most of these streams traverse areas of till and of other unconsolidated deposits and can erode these with ease whenever their speed exceeds the threshold erosion velocities.

Under "normal" conditions streams transport little solid load; at best, some sand grains may creep or saltate along in the stream beds, but when in flood after heavy rains or at the time of the spring thaw, streams can erode and move great quantities of debris. Similarly, coastal erosion does not occur, or has little significance, while the sea is calm or but moderately agitated. During storms, however, the eroding effect of the breakers is great. The backwash and rip currents will carry the particles mobilized away from the shore-line, and where velocities are equal tidal currents will take over the task of transporting and sorting the solid load, until it comes to rest offshore. It is clear that marine sedimentation like that in Port au Port Bay must not be considered as a continuous process but as an interrupted one coupled in the main with short spells of efficient coastal erosion during storms, or with similarly short spells when streams are in flood.

Although discontinuous erosion along the shore-line by waves is the main source for the marine sediments of Port au Port Bay, once this mobilized material is transported by wave action processes into areas of tidal current flow little difference to that depositional regime existing during calmer periods will occur. This is based on the fact that the tidal current velocities will vary little, from their average velocities, during a storm except for local tidal amplification within the wave base. The sediments representative of storm wave activity will be deposited only in areas where the prevailing storm energies exceed the average wave or tidal current energies. Because of this, storm sediments are found mostly on the beaches and in the shallow offshore areas where tidal currents do not flow. Offshore and in nearshore areas where tidal currents are effective little change in the <u>size</u> distribution of the deposited sediments will exist, although the <u>rate</u> of sedimentation will be considerably higher in all areas during and immediately following storm periods.

Considering Newfoundland's present weather trends through the year, more spells of active sedimentation would occur in the stormy autumn months than the calmer summer period, whereas winter, though stormy, tends to "tame" the streams by ice and snow and the waves by development of a bay ice cover. In the spring, however, ice-rafting of particles frozen-in at the shore is possible all over the bay, a factor of sedimentation fundamentally different from the action of waves and currents.

As explained in Chapter IV of this thesis, sea level in the Port au Port area has not been stable in post-glacial times but has both risen eustatically as the result of world-wide deglaciation and dropped as the result of regional isostatic rebound, in a complex interplay. Hence, the local conditions of erosion and sedimentation in the study area have undergone substantial changes during the time interval involved. Some parts of the bay floor now receiving sediment must have been subjected to erosion while sea level was lower, whereas the present coastal zone now subject to erosion received sediments while sea level was higher than at present. The complexity of these geological events is a source of uncertainty in the interpretation of some of the bay sediments studied.

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APPENDIX A

PHYSICAL OCEANOGRAPHIC DATA

EAST BASIN

Date	Sample No.	Depth ft.	Salinity o/oo	Temp. °C	Density	Diss. Oxygen ml./l.
June 18	S-1	50	31.725	7.4	24.80	7.06
June 20	S-11	70	32.023	6.0	25.23	7.14
	S-13	90	32.016	5.2	25.32	6.87
	S-14	165	32.215	3.3	25.67	6.01
June 27	S-46	33	31.758	8.5	24.67	7.04
	S-51	153	32.097	6.0	25.30	6.21
June 29	S-62	72	31.880	7.5	24.90	7.10
July 1	S-78	110	31.970	6.7	25.11	6.89
July 6	S-94	133	32.068	4.3	25.46	5.85
	S-95	78	31.870	8.8	24.72	6.86
	S-96	24	31.604	11.1	24.12	6.57
	S-97	85	31.829	9.6	24.57	6.57
July 21	S-121	30	31.719	12.9	23.87	6.17
	S-122	88	31.711	12.8	23.88	6.27
	S-123	90	31.706	10.8	24.26	6.21
	S-124	96	31.780	9.1	24.60	5.82
	S-127	122	32.052	4.5	25.42	4.89
	S-128	140	32.027	4.8	25.35	4.95
	S-129	130	31.999	5.4	25.27	5.39
July 23	S-135	106	31.877	6.6	25.02	5.58

APPENDIX A (Contd)

WEST BASIN

Date	Sample No.	Depth ft.	Salinity o/oo	Temp. °C	Density	Diss. Oxygen ml./l.
June 18	S-2	12	31.668	10.8	24.22	6.44
	S-3	12	31.536	12.6	23.80	6.53
June 19	S-4	12	31.656	10.2	24.32	6.67
	S-5	12	31.724	10.2	24.38	6.78
	S-7	45	31.846	7.5	24.88	7.20
June 25	S-19	48	31.621	9.6	24.40	6.71
	S-21	48	31.693	9.8	24.40	6.83
	S-24	50	31.698	9.7	24.43	6.71
	S-29	60	31.707	9.6	24.46	6.72
June 26	S-39	72	31.678	9.5	24.46	6.59
June 29	S-55	34	31.724	9.7	24.45	6.77
	S-57	52	31.613	9.4	24.40	6.79
July 1	S-77	38	31.698	10.7	24.27	6.61
	S-80	59	31.762	9.5	24.50	6.95
July 21	S-116	38	31.671	13.6	23.70	5.89
	S-117	56	31.563	13.2	23.70	5.86
	S-118	30	31.608	13.5	23.65	5.82
	S-119	20	31.620	14.0	23.59	5.91
	S-120	12	31.638	14.2	23.53	6.17
	S-130	57	31.665	12.5	23.90	6.19
	S-131	68	31.649	12.0	24.00	5.98

APPENDIX A (Contd)

FOX, SERPENTINE BASINS AND BAR FLATS

Date	Sample No.	Depth ft.	Salinity o/oo	Temp. °C	Density	Diss. Oxygen ml./l.
July 9	S-102	54	31.805	10.2	24.42	6.52
	S-103	56	31.753	10.5	24.36	6.52
	S-109	76	31.886	10.4	24.47	6.65
July 23	S-136	105	31.643	10.6	24.25	5.90
	S-137	100	31.434	12.9	23.67	6.24
July 24	S-138	137	32.027	6.5	25.17	5.96
	S-139	144	32.049	6.0	25.26	5.49
	S-140	76	31.578	11.8	23.98	6.23
	S-141	148	32.055	5.1	25.36	5.48
	S-142	132	31.993	6.1	25.19	5.53
	S-143	120	31.802	9.5	24.55	5.79
	S-144	134	32.105	5.0	25.41	5.02
	S-146	110	31.603	10.8	24.18	6.05
	S-147	112	31.720	9.8	24.42	6.15
	S-148	102	31.580	11.4	24.06	5.74
	S-150	40	31.353	14.4	23.28	6.12
	S-151	47	31.416	13.4	23.53	6.21
	S-156	64	31.479	12.7	23.73	6.38
	S-161	58	31.341	13.8	23.40	6.24
	S-162	68	31.323	14.2	23.29	6.22

APPENDIX B

APPENDIX B(1)

COMPUTER PROGRAM FOR SIZE PARAMETERS

```
C       SIZE PARAMETERS FOR SEDIMENT SAMPLES FROM PORT AU PORT BAY
C      MOMENT MEASURES BASED ON FORMULAE AS GIVEN BY FRIEDMAN (1961)
       DIMENSION X(30),Y(30)
         REAL ISAMP
     N=1
  8   IF(N-135)10,10,11
 11     IF(N-150)12,12,13
 10    M=14
       READ 20,ISAMP,JDEP,(X(I),I=1,M)
 20    FORMAT(R5,1X,A3,1X,14F5.2)
       READ 25, (Y(J),J=1,M)
 25      FORMAT(10X,14F5.2)
      GO TO 100
 12     M=28
       READ 30,ISAMP,JDEP,(X(I),I=1,14)
 30    FORMAT(R5,1X,A3,1X,14F5.2)
      READ35,(X(I),I=15,M)
 35      FORMAT(10X,14F5.2)
        READ40,(Y(J),J=1,M)
 40      FORMAT(10X,14F5.2)
       GO TO 100
 13       M=20
     READ45,(ISAMP,JDEP,(X(I),I=1,10))
```

```
45      FORMAT(F5,1X,A3,1X,10F5.2)
        READ50,(X(I),I=1,M)
50       FORMAT(10X,10F5.2)
        READ55,(Y(J),J=1,M)
55       FORMAT(10X,10F5.2)
100       N=M+1
          SY=0.
         SXY=0.
         SXM=0.
         SSK=0.
        SKU=0.
          DO 120 I=1,M
        SY=SY+Y(I)
120      SXY=SXY+X(I)*Y(I)
         XMEAN=SXY/SY
        DO 140 I=1,M
       SKU=SKU+Y(I)*(X(I)-XMEAN)**4
        SSK=SSK+Y(I)*(X(I)-XMEAN)**3
140      SXM=SXM+Y(I)*(X(I)-XMEAN)**2
         STDVS=(SXM/(SY-1.))**0.5
       SKNSS=(SSK/(SY-1.))/STDVS**3
         AKRTS=(SKU/(SY-1.))/STDVS**4
         PRINT 300,ISAMP,JDEP,XMEAN,STDVS,SKNSS,AKRTS
        PUNCH300,ISAMP,JDEP,XMEAN,STDVS,SKNSS,AKRTS
300       FORMAT(15X,P5,5X,A3,4F11.3)
          GO TO 6
            END
         FINIS
```

SIZE PARAMETER DATA

MARINE SEDIMENTS

EAST BAY

SAMPLE NO	DEPTH(FT)	MEAN Ø	STAND DEV Ø	SKEWNESS	KURTOSIS
S-1	50	3.055	1.306	-0.743	7.870
S-10	10	-4.000	0	2.000	2.000
S-12	72	4.156	1.842	.374	1.986
S-13	90	3.966	2.410	.930	2.198
S-14	165	5.692	.821	-2.835	12.572
S-15	12	3.028	.754	1.008	9.643
S-17	36	-3.506	3.020	1.593	4.307
S-41	28	-0.451	1.994	-0.358	2.409
S-43	182	6.694	2.004	.285	2.205
S-45	15	2.578	1.010	-0.139	6.836
S-46	33	-1.361	2.840	.510	2.106
S-49	14	-3.927	2.210	1.499	4.234
S-50	12	1.978	1.760	-1.199	4.165
S-52	147	5.892	.635	-7.930	77.965
S-54	60	2.085	2.268	1.828	7.466
S-61	38	-4.000	0	2.000	2.000
S-62	72	4.013	1.265	.305	2.687
S-64	86	4.708	2.125	.432	2.122
S-65	12	2.758	.717	1.954	11.411
S-67	84	3.313	1.706	-0.218	3.071
S-71	48	3.472	.654	-2.374	17.370
S-72	185	3.161	2.080	-0.039	2.066
S-74	12	-5.705	.612	4.568	45.308
S-75	19	-4.868	1.385	2.288	8.843
S-79	72	3.502	1.037	.446	7.104
S-92	70	4.032	1.267	.219	2.953

S-93	88	4.915	2.592	.847	2.658
S-95	78	2.730	1.051	-1.173	5.317
S-96	24	1.967	.820	2.605	14.697
S-97	85	4.311	1.160	.378	2.301
S-98	88	3.245	.917	.260	8.717
S-99	88	1.392	2.393	-0.615	2.320
S-100	40	.324	3.020	-0.156	1.664
S-125	14	2.816	.555	2.886	19.492
S-126	10	2.568	.781	-2.600	20.824
S-132	166	5.171	1.922	1.242	3.966
S-133	123	4.561	1.214	-0.295	3.887
S-164	41	-0.492	3.596	-0.036	1.548
S-165	30	.679	2.252	-0.137	2.534
S-166	50	.129	3.050	.059	1.851
S-167	38	-3.302	3.000	1.694	4.556

WEST BAY

S-2	12	3.209	1.420	1.022	3.038
S-3	12	2.975	1.580	1.007	2.967
S-4	12	2.260	2.079	-0.646	3.879
S-5	12	-0.419	2.164	.331	2.586
S-6	45	8.028	2.777	-0.316	3.506
S-8	36	2.641	3.024	-0.101	2.041
S-9	8	1.721	1.179	.412	2.522
S-18	16	-5.623	1.380	5.728	36.782
S-22	14	-4.061	2.673	1.319	3.254
S-23	20	.450	2.461	.080	2.248
S-26	50	5.796	.768	-4.748	30.211
S-28	12	1.638	.563	.382	7.101
S-29	60	5.666	.835	-2.827	12.744
S-31	20	1.913	1.448	-1.439	5.680
S-34	34	1.901	2.245	-0.235	2.713
S-35	18	.694	1.720	.008	3.678
S-36	35	2.779	2.521	-0.353	2.543

S-37	16	3.115	.915	.783	10.777
S-38	20	-3.331	1.182	4.144	33.134
S-39	72	5.787	2.327	.909	2.399
S-40	10	-4.338	1.703	2.072	6.584
S-55	34	-0.640	3.493	-0.196	1.443
S-56	20	-2.051	2.431	1.474	4.725
S-59	50	1.929	1.280	.541	4.014
S-60	60	4.400	1.144	.189	2.522
S-68	42	1.684	2.786	.100	2.132
S-69	72	4.926	1.936	2.138	7.664
S-70	48	3.175	.546	2.442	16.001
S-76	54	5.317	3.146	1.430	3.616
S-77	38	-0.244	3.516	.061	1.953
S-80	59	3.455	.826	1.336	7.686
S-81	72	4.022	1.016	.870	3.727
S-82	36	.901	2.804	.087	1.967
S-83	30	-2.336	3.511	1.137	2.883
S-86	50	3.081	1.698	-0.578	4.183
S-89	70	4.657	1.620	1.605	6.294
S-101	22	-4.676	2.229	2.138	7.261
S-134	76	4.185	1.104	.749	2.216
S-169	54	-1.139	3.257	.189	1.419

FOX AND SERPENTINE BASINS

S-104	100	-2.085	3.357	.836	2.319
S-105	25	1.675	.488	.689	13.668
S-106	95	-4.280	1.194	3.200	20.004
S-111	140	3.975	.907	1.061	4.374
S-112	114	3.810	.795	1.326	6.325
S-114	130	3.828	.999	.668	4.651
S-115	145	3.871	1.089	.383	3.887
S-138	137	-4.000	0	2.000	2.000
S-140	76	-4.000	0	2.000	2.000
S-141	148	-4.000	0	2.000	2.000

S-142	132	-4.000	0	2.000	2.000
S-144	134	-5.120	.699	6.807	73.938
S-145	153	3.447	1.324	.874	2.678
S-146	110	2.800	.858	.476	6.919
S-147	112	3.124	.702	1.107	10.036
S-149	86	-2.059	2.250	1.434	4.245
S-153	88	3.190	.756	.626	6.857
S-154	134	3.964	.843	1.289	4.663
S-155	154	3.650	1.481	.670	3.307
S-158	70	-3.673	1.186	1.986	7.840
S-159	70	2.232	.608	-0.603	11.865
S-172	145	4.136	1.113	-0.004	5.196
S-174	90	-4.000	0	2.000	2.000
S-175	88	-4.000	0	2.000	2.000
S-176	72	-4.000	0	2.000	2.000
S-177	50	-5.132	.593	3.420	30.612
S-178	36	2.629	.477	.033	13.815
S-179	42	2.629	.580	-0.610	8.702
S-180	40	2.652	.511	.027	15.393
S-181	42	-0.945	1.746	1.356	5.055
S-182	50	2.549	.554	.811	9.401

BAR FLATS

S-102	54	-4.000	0	2.000	2.000
S-103	56	-3.288	.998	1.291	6.621
S-107	54	2.153	.741	-1.356	9.906
S-108	40	1.318	.526	-0.319	3.035
S-109	76	-4.000	0	2.000	2.000
S-150	40	-4.000	0	2.000	2.000
S-151	47	1.220	1.155	-2.371	8.875
S-152	50	.979	.771	-0.987	5.150
S-156	64	1.563	.414	.982	6.934
S-157	32	.902	.677	-0.223	2.394
S-160	40	1.610	.423	-0.224	3.410

S-161	58	-4.000	0	2.000	2.000
S-162	60	-4.000	0	2.000	2.000
S-163	60	-4.000	0	2.000	2.000
S-170	36	1.595	.499	.468	8.915

BEACH SEDIMENTS

SAMPLE NO	MEAN	STAND DEV	SKEWNESS	KURTOSIS
B-1	-1.759	.989	1.124	3.726
B-2	-1.818	1.154	-0.405	2.076
B-3	-0.031	1.494	-1.287	2.986
B-4	-0.922	2.005	.126	2.349
B-7	1.563	.765	.656	16.538
B-9	-0.028	1.976	-0.543	2.161
B-12	.538	2.027	-0.819	2.601
B-14	.554	1.404	-0.892	4.325
B-16	-0.151	1.364	.168	3.987
B-17	1.436	.911	.139	11.572
B-20	.339	1.690	-0.771	3.028
B-27	1.349	1.121	-1.975	9.839
B-30.	1.293	.746	-0.957	6.965
B-31.	1.685	.582	.641	13.511
B-41	1.577	.761	-2.927	15.947
B-49	-0.207	1.929	-1.323	3.111
B-50	.635	.633	-0.015	3.209
B-55	.925	.835	-0.123	3.994
B-58.	.544	.399	-1.865	13.513
B-60	.605	.946	-0.176	5.489
B-61	1.165	1.031	-1.229	4.516
B-64	.992	1.361	-1.875	6.017
B-65	1.338	.418	1.434	13.411
B-68	1.197	.690	-0.225	14.919
B-69	.376	.754	-1.192	4.804
B-71	.939	.789	1.629	13.279

R-73	-1.398	.841	-0.894	3.457
R-76	-0.125	.793	.453	3.046
R-80	.520	1.030	-1.112	3.303
R-81	.534	2.179	-1.129	2.518
R-88	.495	.648	-0.538	4.505
R-162	1.321	1.360	-1.512	4.190
R-164	1.905	.536	2.575	21.633
R-166	.890	1.440	.067	3.655
R-168	1.847	.647	.284	10.458
R-169	1.567	1.948	-1.111	3.782
R-172	1.523	.621	.848	11.077
R-176	1.615	.794	-1.180	5.184
R-177	1.498	.553	-0.653	5.041
R-178	1.127	.938	-0.381	3.375
R-179	.637	1.143	-1.073	4.170
R-186	1.505	.660	-0.811	12.437
R-188	1.223	.742	-1.936	14.634
R-191	.307	1.794	-0.663	3.093
R-203	.833	1.754	-1.200	3.539
R-206	1.164	.503	-0.201	3.950

RAISED OUTWASH SEDIMENTS

RR	2.448	4.754	.623	2.407
P-11	1.851	.798	1.830	14.481
P-23	2.920	1.315	.920	3.553
P-26	1.762	1.715	-0.341	4.011
P-42	-0.142	2.049	.617	4.351
P-29	3.085	1.205	-0.409	6.641
P-44	2.295	.475	1.218	7.715
P-45	1.865	.869	.252	11.086
P-46	1.473	.829	.762	11.163
P-47	2.540	.870	-1.648	8.210
P-53	1.317	1.456	-1.149	4.724
P-59	-0.333	.552	.261	3.186

P-66	1.623	.849	-2.225	9.348
P-74	-0.235	2.624	.348	2.546
P-75	2.886	.963	1.230	5.763
P-83	2.497	.721	-0.041	7.747
P-84	2.855	.821	1.622	9.291
P-86	2.286	.750	.070	5.161
P-152	.846	4.497	.984	3.125
P-154	1.801	.854	.867	5.234
P-156	-0.113	2.329	.522	3.121
P-158	2.500	1.240	-1.298	5.999
P-161	1.861	4.524	.221	2.467
P-171	1.002	1.487	-1.103	3.359
P-174	1.861	1.674	-0.906	4.028
P-184	3.496	1.259	-0.098	4.727
P-185	3.042	2.243	-0.767	3.578
P-187	.879	1.752	.323	4.417
P-190	1.654	1.049	2.817	12.351
P-192	2.154	.466	.745	13.236
P-193	2.085	1.361	.757	5.548
P-196	2.978	1.281	.912	3.529
P-199	2.723	1.394	.944	3.644
P-200	2.023	1.386	-0.602	4.892

APPENDIX P(2)

SIZE DISTRIBUTION DATA

MARINE SEDIMENTS

EAST BAY

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SAMP  DEPTH (FT)            MID POINT IN PHI UNITS
                      PERCENT VALUES

S-1     50 -2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25
             2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00
             0.81 0.96 0.61 0.35 0.36 0.36 0.41 0.78 2.8212.14
            31.4024.4012.58 4.75 7.34 0.00 0.00 0.00 0.00 0.00

S-10    10 -4.00
            100.0

S-12    72   0.25 1.50 2.35 3.00 3.50 3.90 4.25 5.00 6.00 7.00
             1.50 4.9014.4020.8012.20 4.60 6.70 8.10 5.0021.60

S-13    90   0.5  1.5  2.33 3.0  3.5  3.83 4.25 8.00 0.00 0.00 0.00 0.00 0.00 0.00
             1.86 7.1030.3324.40 6.73 2.64 2.1124.80 0.00 0.00 0.00 0.00 0.00 0.00

S-14   165 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
             0.07 0.04 0.01 0.04 0.04 0.06 0.10 0.11 0.31 2.00 5.68 5.2186.30

S-15    12   0.50 1.50 2.25 2.75 3.25 3.75 4.25 6.00
             1.40 3.30 6.7036.5041.50 6.60 1.10 2.90

S-17    36 -5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
             1.75 2.25 2.75 3.25 3.75 4.25 6.00
            41.6010.0216.80 4.62 2.26 1.19 1.05 2.33 1.66 1.10 0.88 1.03 1.16 1.55
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          2.22 2.30 3.59 1.72 0.54 0.27 2.13

S-41   28 -5.00-2.75-1.60-0.75-0.25 0.25 0.75 1.25 1.75 2.25
          2.75 3.25 3.75 4.25 6.00
          5.2014.2024.20 5.60 4.20 5.90 7.7011.8014.10 4.90
          1.60 0.26 0.12 0.04 0.07

S-43  182 -0.75 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25
          4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.28 8.7510.00
          0.05 0.04 0.12 0.09 0.11 0.10 0.09 0.45 3.01 8.74
         12.40 8.20 8.2010.0010.00 5.53 6.57 5.63 3.9016.80

S-45   15 -0.50 0.50 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          3.00 3.20 3.70 7.4016.9042.8016.10 3.50 1.00 2.50

S-46   33 -4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25
          0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
         19.0615.62 4.82 4.82 4.08 5.78 3.85 3.53 2.67 3.07
          3.66 5.74 8.57 8.30 1.90 1.41 0.75 0.29 2.16

S-49   14 -5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
          1.75 2.25 2.75 3.25 3.75 4.25 6.00
         39.2018.4011.52 0.00 3.13 5.41 2.31 3.60 2.91 2.33 2.07 2.53 1.98 0.99
          0.46 0.91 1.67 0.39 0.06 0.02

S-50   12 -2.75-1.60-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          3.70 8.00 2.30 2.00 1.90 1.70 1.70 3.1018.1043.00 9.90 2.00 0.80 2.00

S-52  147 -1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          0.20 0.00 0.05 0.10 0.10 0.05 0.10 0.10 0.10 0.10 0.10 0.65 2.3296.00

S-54   60 -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75
          3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.2510.00
          2.06 1.60 3.05 3.05 6.35 9.4715.9818.2014.13 8.20
          3.65 3.25 1.82 1.56 1.29 0.46 0.23 0.46 0.74 4.40
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S-61    38 -4.00
           100.0

S-62    72 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
            0.09 0.04 0.17 0.49 0.80 2.07 3.81 6.9421.2030.6010.2023.65 0.00 0.00

S-64    86 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75
            4.25 4.75 5.25 5.75 6.25 8.00
            0.26 0.16 0.37 0.86 1.36 3.06 4.00 6.6214.5018.80
           10.86 4.90 3.80 3.80 2.1723.80

S-65    12  0.50 1.50 2.25 2.75 3.25 3.75 4.25 6.00
            0.30 6.2021.1051.0014.80 3.10 1.00 2.40

S-67    84 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
            1.16 1.29 2.02 2.40 3.04 3.94 3.96 4.0313.0527.4012.80 6.7118.10 0.00

S-71    48 -0.25 0.25 0.75 1.25 2.25 2.75 3.25 3.75 4.25 6.00
            0.12 0.11 0.14 0.40 1.14 2.8541.0045.50 6.38 0.89 1.52

S-72   185 -1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            0.25 1.55 2.33 2.13 3.45 5.22 7.26 9.70 8.90 7.3410.92 9.56 5.6925.70

S-74    12 -6.00-5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
            1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           70.1013.50 8.60 5.80 0.83 0.42 0.34 0.03 0.03 0.00 0.01 0.01 0.02 0.02
            0.03 0.03 0.02 0.02 0.01 0.01

S-75    19 -6.00-5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
            1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           24.1020.8034.30 4.32 3.76 1.26 3.12 1.78 2.79 1.10 0.78 0.44 0.45 0.57
            0.45 0.18 0.05 0.03 0.01 0.01 0.01

S-79    72 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
            0.53 0.19 0.11 0.24 0.25 0.41 0.68 1.0717.2046.5017.50 5.3110.00 0.00
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S-92    70 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.16 0.10 0.22 0.74 0.96 1.68 1.72 6.0224.7029.7210.0024.00 0.00 0.00

S-93    86 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75
           4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.7510.00 0.00
           0.05 0.19 0.39 0.69 1.27 2.91 6.0610.8013.2215.00
           9.32 3.69 3.78 3.97 4.98 3.97 3.57 1.3914.72 0.00

S-95    78 -1.90-1.25-0.75-0.25 0.25 0.75 1.50 2.25 2.75 3.25 3.75 4.25 6.00
           0.46 0.47 0.47 0.83 1.40 2.3512.0014.9024.4018.9016.00 7.57 0.00

S-96    24 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           0.30 0.40 1.00 1.90 7.7058.3019.80 5.10 1.60 1.00 0.70 2.20

S-97    85 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
           0.07 0.07 0.20 0.23 0.54 0.72 2.5817.8035.2013.7828.65 0.00 0.00 0.00

S-98    88 -0.50 0.50 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           1.30 0.50 0.70 1.10 3.1025.7044.5014.40 3.30 5.20

S-99    88 -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
           1.75 2.25 2.75 3.25 3.75 4.25 6.00
           3.50 4.26 5.31 7.12 3.33 2.19 1.49 1.71 2.54 3.69
          10.58 8.2719.4215.54 6.22 1.83 2.88

S-100   40 -4.00-2.75-1.60-0.75-0.25 0.25 0.75 1.25 1.75 2.25
           2.75 3.25 3.75 4.25 6.00
          18.2014.00 5.00 1.40 1.80 2.90 4.70 8.20 6.40 2.90
          10.8013.40 5.10 1.80 3.50

S-104 100 -5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
           2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.00
          40.70 0.00 8.61 0.00 8.24 5.97 2.84 1.74 1.62 1.70 1.75 2.16 3.28 4.06
           3.10 2.94 3.48 2.68 1.29 0.78 0.66 0.49 1.98

S-125   14  0.50 1.50 2.25 2.75 3.25 3.75 4.25 6.00
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         0.30 0.9014.0067.0012.80 2.60 0.80 1.60

S-126  10 -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
         1.56 0.00 0.25 0.06 0.12 0.25 0.89 3.6727.1053.0010.30 1.56 0.45 0.66

S-132 106 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75
         4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.2510.00
         0.13 0.00 0.02 0.11 0.14 0.22 0.28 1.05 4.7924.00
        23.30 9.5  5.03 4.37 8.08 1.97 5.46 1.75 1.31 8.30

S-133 123 -1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
         0.13 0.24 0.03 0.07 0.08 0.03 0.03 0.06 0.16 1.8513.2029.1018.1037.30

S-164  41 -5.00-4.50-3.95-3.45-1.90-1.25-0.75-0.25 0.25 0.75
         1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
        24.10 6.20 4.42 1.89 5.33 1.94 1.59 1.94 2.00 3.15
         7.70 7.38 6.24 7.90 8.42 4.02 1.42 4.61

S-165  30 -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
         1.75 2.25 2.75 3.25 3.75 4.25 6.00
         6.25 0.00 6.16 9.17 3.41 3.02 3.27 3.28 5.88 6.57
        14.0915.70 6.80 1.56 1.26 0.63 3.00

S-166  50 -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
         1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
        19.80 0.00 9.92 3.10 4.67 1.97 1.87 2.10 3.30 5.00
         6.73 7.70 8.9810.85 3.82 2.80 1.16 6.15

S-167  38 -5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
         1.75 2.25 2.75 3.25 3.75 4.25 6.00
        14.0033.0010.3818.80 1.58 2.08 0.99 0.71 0.36 0.35 0.24 0.31 0.54 0.87
         3.22 4.69 3.18 0.92 0.65 0.30 2.69
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WEST BAY

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S-2     12  0.25 1.50 2.25 2.75 3.25 3.75 4.25 6.00
            0.7011.2015.4037.2012.30 4.00 1.8017.40

S-3     12 -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            0.15 0.05 0.17 0.15 0.38 1.16 3.6618.9831.7015.53 4.42 3.93 1.3416.42
S-4     12 -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
            2.25 2.75 3.25 3.75 4.25 6.00
            4.60 2.28 1.84 0.41 0.58 1.03 2.32 5.20 8.73 8.50
           11.8817.2019.40 5.15 1.82 9.36

S-5     12 -3.75-3.25-2.75-2.25-1.75-1.25-0.75-0.25 0.25 0.75
            1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            6.20 8.20 7.10 7.00 7.00 7.30 6.70 5.30 9.20 8.60
            7.40 6.10 5.50 3.80 2.10 0.80 0.30 1.40

S-6     45 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25
            5.75 6.25 6.75 7.25 7.75 8.25 8.7512.00
            0.19 0.19 0.05 0.38 0.83 0.70 1.12 1.06 0.90 0.85 2.88 6.03 5.53 2.05
            1.91 5.8112.4014.2011.73 6.72 4.2020.10

S-8     36 -2.75-1.60-0.50 0.50 1.50 2.40 3.00 3.50 3.90 4.25 5.00 6.00 7.00
            8.30 6.20 4.40 9.7015.20 9.70 4.60 4.90 3.10 5.20 7.30 3.3018.10

S-9      8 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            0.30 4.1810.3816.0017.6714.5410.1810.28 7.56 5.71 3.03 0.21

S-18    16 -6.00-5.50-4.50-3.45-2.95-2.45-1.90-1.25-0.75-0.25
            0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           72.2022.00 2.72 0.30 0.05 0.07 0.00 0.02 0.02 0.02
            0.05 0.10 0.31 0.39 0.24 0.64 0.37 0.11 0.06 0.16

S-22    14 -6.00-5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
            1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           28.8033.10 3.31 4.26 4.04 1.30 1.56 1.50 3.02 0.50 0.98 1.22 2.21 4.01
```

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        5.28 3.15 1.09 0.36 0.10 0.02 0.00 0.18

S-23   20 -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
        2.25 2.75 3.25 3.75 4.25 6.00
       18.68 5.00 7.73 2.68 2.45 2.37 2.28 2.4613.2020.10
        7.08 5.82 3.93 1.32 0.51 4.49

S-26   50 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
        0.10 0.11 0.08 0.09 0.14 0.21 0.27 0.33 0.36 0.24 1.27 5.2291.60

S-28   12 -0.50 0.50 1.50 2.40 3.00 3.50 3.90 4.25 6.00
        0.30 8.5067.1022.70 1.20 0.05 0.03 0.02 0.10

S-29   60 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
        0.08 0.04 0.06 0.15 0.15 0.27 0.30 0.33 0.43 3.3510.6284.00

S-31   20 -2.45-1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25
        2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00
        2.98 3.50 1.92 1.36 1.12 1.27 1.56 4.7816.6629.60
       25.50 7.10 1.25 0.39 1.04 0.00 0.00 0.00 0.00 0.00

S-34   34 -2.75-1.67-0.50 0.50 1.50 2.33 3.00 3.50 3.83 4.25 6.00 0.00 0.00 0.00
        5.04 7.05 4.95 7.4 22.11 7.8311.2810.82 2.93 3.43 8.04 0.00 0.00 0.00

S-35   18 -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
        2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
        3.67 1.90 8.10 5.01 4.98 5.60 8.5012.2216.7414.68
       10.35 5.39 0.68 0.15 0.08 2.10 0.00 0.00 0.00 0.00

S-36   35 -2.95-2.45-1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75
        2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
        3.30 2.11 2.45 1.52 1.28 1.48 2.38 4.02 6.9010.93
       11.4811.27 7.05 3.44 3.3527.10 0.00 0.00 0.00 0.00

S-37   16 -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
        0.45 0.00 0.12 0.06 0.05 0.15 0.36 1.86 8.1035.7041.50 5.12 0.87 5.83
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S-38    20 -5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25
           0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           6.62 9.4016.8021.8029.5012.38 2.11 0.11 0.01 0.00
           0.00 0.00 0.01 0.05 0.10 0.12 0.06 0.05 0.05 0.74

S-39    72 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25
           4.75 5.25 5.75 6.25 6.75 7.25 7.7510.00 0.00 0.00
           0.05 0.03 0.03 0.08 0.17 0.33 0.55 2.0616.6124.60
          11.16 6.64 4.43 4.43 3.87 2.78 2.7819.40 0.00 0.00

S-40    10 -5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
           1.75 2.25 2.75 3.25 3.75 4.25 6.00
          33.1527.5013.76 8.26 2.12 2.77 0.98 2.01 1.14 1.52 1.47 1.55 1.35 1.56
           0.70 0.09 0.03 0.03 0.02 0.01

S-55    34 -4.9 -2.75-1.85-1.25-0.75-0.25 0.25 0.75 1.25 1.75
           2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
          36.5  2.75 1.74 0.34 0.31 0.35 0.72 2.43 9.9016.80
          12.40 9.20 2.70 0.64 0.46 2.72 0.00 0.00 0.00 0.00

S-56    20 -5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25
           0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           2.75 9.6013.43 8.5314.8013.6514.40 4.26 1.62 0.28
           0.13 0.17 1.08 4.91 4.50 2.40 0.45 0.28 0.26 2.50

S-59    50 -1. 9-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           0.43 1.12 1.58 2.67 5.10 8.8014.4219.2817.4617.00 5.23 2.62 1.50 3.04

S-60    60 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
           0.08 0.09 0.21 0.34 0.73 1.08 2.18 9.5335.5020.6029.71 0.00 0.00 0.00

S-68    42 -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
           1.75 2.25 2.75 3.25 3.75 4.25 6.00
           1.66 6.04 0.75 7.24 3.82 4.18 3.58 4.42 5.6711.43
          10.77 6.10 7.10 3.45 2.30 2.1319.26
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S-69    72  0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75
            5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.7512.00
            0.05 0.10 0.13 0.19 0.21 0.48 4.8028.5031.20 7.70
            5.14 4.12 2.40 1.72 2.40 2.57 2.57 2.06 3.77

S-70    48 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
            0.04 0.02 0.04 0.13 0.34 1.3232.5053.10 8.76 1.41 1.95 0.00 0.00 0.00

S-76    54 -0.25 0.50 1.25 1.75 2.25 2.75 3.25 3.75 4.25 5.50 12.0 0.00 0.00 0.00
            0.40 0.49 0.60 1.20 1.66 4.3412.5127.5517.2517.4316.72 0.00 0.00 0.00

S-77    38 -5.00-2.75-1.60-0.50 0.50 1.50 2.40 3.00 3.50 3.80 4.25 6.00
           23.8011.20 6.50 4.90 8.0018.4011.80 3.10 1.20 0.60 0.6010.00

S-80    59 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
            0.10 0.06 0.07 0.20 0.38 0.81 1.6615.6048.0 21.7  4.88 6.37 0.00 0.00

S-81    72 -0.75-0.75 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
            0.06 0.07 0.03 0.08 0.15 0.28 0.39 3.5825.6039.8012.2017.77 0.00 0.00

S-82    36 -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
            2.25 2.75 3.25 3.75 4.25 6.00
           14.90 8.53 6.91 3.12 2.40 2.19 2.23 3.13 3.40 9.54
           16.53 9.30 3.15 3.03 2.09 9.54

S-83    30 -5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
            1.75 2.25 2.75 3.25 3.75 4.25 6.00
           11.1318.6014.2011.13 5.32 7.83 2.86 2.75 0.74 0.36 0.22 0.22 0.36 0.72
            2.92 6.60 4.58 1.16 1.19 1.22 6.00

S-86    50 -2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25
            2.75 3.25 3.75 4.25 6.00
            0.68 1.68 0.77 1.22 1.00 1.43 2.28 3.98 6.71 8.92
           13.2019.4017.45 9.4011.95
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S-89    70  0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75
            5.25 5.75 6.25 6.75 7.25 7.7510.00 0.00 0.00 0.00
            0.04 0.08 0.20 0.46 0.71 1.47 7.6031.5025.50 9.08
            4.47 3.67 2.88 1.91 3.18 2.72 4.47 0.00 0.00 0.00

S-101   22 -6.00-5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
            1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           48.4017.07 6.63 4.60 2.01 3.86 3.34 1.92 3.13 1.00 0.77 0.52 0.60 1.10
            1.52 1.74 0.79 0.36 0.17 0.19 0.15 0.40

S-134   76 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            0.00 0.02 0.04 0.07 0.12 0.26 4.2526.9528.8015.2824.25

S-169   54 -4.9 -2.75-1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75
            2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
           29.6022.00 3.27 1.67 1.53 1.27 2.16 2.24 2.33 2.25
            3.2118.60 8.30 1.04 0.19 0.37 0.00 0.00 0.00 0.00
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S-105  25 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
          0.20 0.15 0.76 4.7324.4551.0016.11 2.32 0.15 0.04 0.04 0.15 0.00 0.00

S-106  95 -5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25
           0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          60.40 3.11 6.7013.4411.90 2.16 0.68 0.04 0.04 0.04
           0.04 0.08 0.10 0.16 0.16 0.20 0.23 0.15 0.07 0.09

S-111 140  0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
           0.10 0.08 0.27 0.39 0.40 2.4022.8042.4017.5513.40 0.00 0.00 0.00 0.00

S-112 114  0.5  1.5  2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00 0.00
           0.3  0.3  0.3  3.1 30.5 42.2 14.6  8.5  0.00 0.00 0.00 0.00 0.00 0.00

S-114 130 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
           0.15 0.19 0.31 0.62 1.31 1.63 4.0927.7540.0011.0312.90 0.00 0.00 0.00

S-115 145 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.10 0.08 0.12 0.29 0.81 2.20 3.65 6.0118.4337.1515.3014.70 0.00 0.00

S-138 137 -4.00
          100.0

S-140  76 -4.00
          100.0

S-141 148 -4.00
          100.0

S-142 132 -4.00
          100.0

S-144 134 -5.50-5.00-4.50-3.95-2.45-1.90-1.25-0.75-0.25 0.25
           0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
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          52.8030.2012.70 3.60 0.03 0.03 0.01 0.01 0.01 0.03
           0.05 0.14 0.20 0.08 0.02 0.01 0.01 0.01 0.03

S-145 153 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
           0.06 0.05 0.18 0.69 3.3120.1030.10 5.9112.3011.0016.30 0.00 0.00 0.00

S-146 110 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
           0.27 0.02 0.12 0.10 0.39 3.2711.2017.3026.6027.60 8.84 1.80 2.12 0.00

S-147 112 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.09 0.10 0.09 0.10 0.46 2.31 8.4026.6045.0011.20 2.12 2.55 0.00 0.00

S-149  86 -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
           1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          22.0019.5518.95 6.26 7.50 2.69 1.81 1.36 1.67 2.46
           4.55 4.25 2.17 1.40 1.09 0.72 0.39 1.17

S-153  88 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
           0.05 0.12 0.21 0.99 4.23 7.3321.0038.3021.00 4.05 2.44 0.00 0.00 0.00

S-154 134  0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00
           0.03 0.13 0.32 0.50 2.5820.3044.7019.6011.60 0.00 0.00 0.00 0.00 0.00

S-155 154 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 7.00 0.00
           0.06 0.05 0.19 0.51 1.90 5.50 7.2814.40 9.5820.3017.3010.9012.00 0.00

S-158  70 -5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25
           0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           9.6821.6038.50 7.60 9.05 3.97 3.74 1.42 1.15 0.80
           1.08 0.98 0.50 0.10 0.03 0.03 0.01 0.00 0.00 0.01

S-159  70 -1.6 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
           0.27 0.11 0.14 0.45 1.33 7.5016.2041.7029.50 2.10 0.18 0.07 0.30 0.00

S-172 145 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
           0.47 0.00 0.09 0.04 0.24 0.41 0.49 0.66 2.1517.6037.3019.6020.60 0.00
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S-174  90 -4.00
          100.0

S-175  88 -4.00
          100.0

S-176  72 -4.00
          100.0

S-177  50 -5.50-5.00-4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
           1.75 2.25 2.75 3.25 3.75 4.25 6.00
          56.1029.50 5.31 4.82 3.89 0.00 0.00 0.11 0.03 0.02 0.00 0.00 0.00 0.01
           0.01 0.01 0.02 0.02 0.01

S-178  36 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.11 0.10 0.08 0.19 0.63 4.6227.6052.7012.50 1.09 0.25 0.26 0.00 0.00

S-179  42 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
           0.32 0.41 0.95 1.92 5.8622.5048.7016.60 2.13 0.40 0.24 0.00 0.00 0.00

S-180  40 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.2  0.1  0.2  0.2  0.5  4.1 26.1 52.7 13.6  1.6  0.2  0.4  0.00 0.00

S-181  42 -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
           2.25 2.75 3.25 3.75 4.25 6.00
          17.40 4.1218.1014.5218.7110.31 4.59 1.18 0.50 0.47
           1.61 3.98 2.66 0.85 0.25 0.84

S-182  50 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
           0.06 0.03 0.24 1.5211.3032.4037.2016.20 0.30 0.37 0.45 0.00 0.00 0.00
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BAR FLATS

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S-102  54 -4.00
          100.0

S-103  56 -4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25
           0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          16.2326.00 6.6230.80 4.06 9.73 2.14 0.94 0.51 0.31
           0.13 0.11 0.07 0.04 0.12 0.03 0.01 0.00 0.00

S-107  54 -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
           0.45 0.26 0.59 0.50 0.72 1.96 8.1222.0032.0029.00 3.60 0.37 0.11 0.20

S-108  40 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 0.00 0.00 0.00 0.00 0.00 0.00 0.00
           0.9  5.7 18.6 35.8 32.5  6.0  0.6  0.00 0.00 0.00 0.00 0.00 0.00 0.00

S-109  76 -4.00
          100.0

S-150  40 -4.00
          100.0

S-151  47 -2.75-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25
           2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00
           5.52 1.29 0.41 0.17 0.20 0.49 7.8841.5030.20 9.75
           2.23 0.23 0.10 0.06 0.03 0.00 0.00 0.00 0.00 0.00

S-152  50 -1.6 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 4.00 0.00 0.00 0.00 0.00
           2.7  2. 0 3.8 10.8 26.0 32.5 17.8  3.8  0.7  0.1  0.00 0.00 0.00 0.00

S-156  64  0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
           0.13 3.2845.5038.5010.34 1.86 0.14 0.04 0.04 0.02 0.00  .00 0.00 0.00

S-157  32 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 0.00 0.00 0.00 0.00 0.00 0.00
           2.1  6.4 22.5 20.1 28.2 16.1  2.4  0.1  0.00 0.00 0.00 0.00 0.00 0.00
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S-160  40  0.25 0.75 1.25 1.75 2.25 2.75 3.25 0.00 0.00 0.00 0.00 0.00 0.00 0.00
           0.58 6.9027.8050.8012.90 1.15 0.06 0.00 0.00 0.00 0.00 0.00 0.00 0.00

S-161  58 -4.00
          100.0

S-162  60 -4.00
          100.0

S-163  60 -4.00
          100.0

S-170  36 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.06 0.25 1.01 7.9830.2044.6013.56 1.95 0.18 0.10 0.05 0.08 0.00 0.00
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B-1     -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25
        12.4126.5033.00 7.59 7.49 4.87 4.41 2.76 0.81 0.15 0.05 0.01 0.01

B-2     -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25
        11.08 0.0019.00 1.7821.3516.0019.9010.20 0.79 0.02 0.00 0.00 0.00

B-3     -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25
        19.20 0.00 0.57 0.15 0.67 2.7018.2643.8012.82 1.39 0.07 0.02 0.01

B-4     -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
         1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
        13.60 4.53 2.30 8.4012.24 8.18 7.56 7.20 6.45 9.10
         7.62 8.34 2.84 0.90 0.22 0.08 0.03 0.47

B-7     -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
         0.79 0.56 0.66 0.73 0.90 7.0027.7049.70 9.18 1.22 0.39 0.23 0.14 0.93

B-9     -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
         1.75 2.25 2.75 3.25 3.75 4.25 6.00
        12.90 4.48 3.25 7.15 3.60 3.22 3.03 5.2110.2722.60
        19.60 3.24 0.68 0.18 0.08 0.05 0.39

B-12    -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
         1.75 2.25 2.75 3.25 3.75 4.25 6.00
        11.20 1.74 3.69 4.05 2.11 2.93 3.08 4.75 8.3914.93
        19.2015.60 7.28 0.20 0.46 0.06 0.41

B-14    -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
         2.25 2.75 3.25 3.75 4.25 6.00
         4.35 3.23 5.83 1.88 3.23 3.72 6.6023.0028.9015.30
         2.70 0.50 0.14 0.05 0.03 0.47

B-16    -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
         2.25 2.75 3.25 3.75 4.25 6.00
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            3.82 2.9310.68 9.5011.5212.2614.2216.24 9.40 7.20
            1.44 0.18 0.07 0.04 0.03 0.49

B-17       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            1.42 1.08 1.76 1.54 2.96 8.7325.5046.80 7.75 0.93 0.27 0.15 0.09 1.10

B-20       -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
            1.75 2.25 2.75 3.25 3.75 4.25 6.00
            2.66 5.68 7.24 4.92 1.62 1.93 2.45 6.6021.6324.60
           13.34 4.76 1.62 0.35 0.01 0.03 0.42

B-27       -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
            2.25 2.75 3.25 3.75 4.25 6.00
            3.63 0.00 0.45 0.62 0.94 1.43 3.26 8.9527.0034.50
           15.92 2.60 0.29 0.16 0.10 0.32

B-30.      -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            0.60 0.93 1.24 2.70 6.6913.4028.8036.40 7.83 1.01 0.16 0.03 0.01 0.10

B-31.      -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
            0.11 0.35 0.35 1.54 5.6122.8046.0019.08 3.42 0.25 0.05 0.00 0.31 0.00

B-41       -2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25
            1.54 0.57 0.19 0.19 0.42 0.78 5.8022.4048.8016.20 2.39 0.44 0.07 0.01

B-49       -4.50-3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25
            0.75 1.25 1.75 2.25 2.75 3.25
            6.26 8.03 1.50 3.25 1.48 0.87 0.36 0.70 2.9515.70
           35.9020.50 2.42 0.09 0.02 0.00

B-50       -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 0.00 0.00 0.00
            0.60 2.7310.9127.9029.1021.10 6.68 0.63 0.11 0.05 0.04 0.00 0.00 0.00

B-55       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 0.00
            0.50 1.42 2.73 7.1015.6524.3026.5014.60 4.52 1.69 0.56 0.25 0.15 0.00
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B-58.      -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 0.00 0.00 0.00
            0.83 0.00 0.22 2.5537.7052.55 6.27 0.12 0.00 0.00 0.01 0.00 0.00 0.00

B-60       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75
            3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00 0.00
            2.50 4.41 6.37 8.7415.1024.5528.85 6.55 1.65 0.67
            0.19 0.06 0.03 0.23 0.00 0.00 0.00 0.00 0.00 0.00

B-61       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 0.00 0.00 0.00
            3.87 1.74 2.76 3.59 6.5211.9027.1026.3012.39 3.48 0.32 0.00 0.00 0.00

B-64       -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
            2.25 2.75 3.25 3.75 4.25 6.00
            6.50 2.21 0.55 0.92 0.80 1.08 3.3311.4334.3529.50
            6.90 1.92 0.42 0.11 0.05 0.04

B-65       -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
            0.12 1.2311.9461.6020.10 3.66 1.11 0.21 0.06 0.01 0.05 0.00 0.00 0.00

B-68       -1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            1.19 0.58 0.53 1.34 4.0416.8053.1517.73 2.74 0.88 0.26 0.15 0.07 0.30

B-69       -2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 0.00 0.00 0.00
            0.83 2.25 2.00 6.5811.4725.6533.0017.20 0.81 0.04 0.00 0.00 0.00 0.00

B-71       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
            0.15 0.47 1.92 5.6316.1822.1046.50 2.93 1.05 1.00 0.71 0.56 0.22 0.55

B-73       -3.45-2.95-2.45-1.9 -1.25-0.75-0.25 0.25 0.75 0.00 0.00 0.00 0.00 0.00
            6.2  5.1  1.9118.6934.7524.50 7.70 1.27 0.05 0.00 0.00 0.00 0.00 0.00

B-76       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 0.00 0.00 0.00
            1.78 8.3026.0024.7317.5013.20 5.30 2.60 0.49 0.12 0.01 0.00 0.00 0.00

B-80       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 0.00 0.00
            8.00 4.40 5.75 4.26 9.8027.3032.90 7.18 0.56 0.08 0.02 0.01 0.00 0.00
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B-81        -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
             1.75 2.25 2.75 3.25 3.75 4.25 6.00
            19.80 0.00 3.40 0.00 0.28 0.77 0.25 0.30 1.6217.30
            39.6014.93 1.46 0.11 0.05 0.04 0.09

B-88        -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 0.00 0.00 0.00 0.00
             4.97 2.14 5.9733.2339.35 8.88 4.36 0.86 0.10 0.01 0.00 0.00 0.00 0.00

B-162       -2.45-1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25
             2.59 5.60 4.28 1.93 1.38 1.98 3.3811.0234.4026.20 6.95 0.29 0.05 0.04

B-164       -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00
             0.04 0.27 1.8510.8053.3025.90 6.27 0.87 0.12 0.00 0.57 0.00 0.00 0.00

B-166       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
             6.8  4.17 7.56 8.9510.90 8.8011.0020.1015.91 3.93 0.55 0.20 0.12 1.22

B-168       -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
             0.22 0.93 2.48 4.5212.1238.2034.00 6.64 0.42 0.14 0.06 0.40 0.00 0.00

B-169       -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
             2.25 2.75 3.25 3.75 4.25 6.00
             7.80 1.41 4.44 1.79 2.63 1.59 1.02 0.69 1.11 8.90
            38.9026.00 1.10 0.52 0.34 2.20

B-172       -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
             0.16 0.36 4.1714.2022.5043.1013.28 1.54 0.21 0.10 0.06 0.31 0.00 0.00

B-176       -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
             0.14 2.82 4.50 2.78 3.9714.4041.4024.20 5.31 0.29 0.05 0.04 0.06 0.00

B-177       -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
             0.30 0.18 0.34 2.5913.9326.0043.4011.10 1.84 0.16 0.03 0.01 0.00 0.00

B-178       -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
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          0.37 0.86 3.55 8.8315.5410.7111.7634.3012.71 1.00 0.07 0.03 0.01 0.14

B-179    -2.75-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25
          3.50 3.04 1.30 4.4310.4017.4015.2019.2021.80 3.24 0.32 0.07 0.05 0.04

B-186    -1.60-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          1.10 0.60 1.00 2.20 7.6029.5045.4010.60 1.40 0.20 0.10 0.10 0.20

B-188    -2.75-1.60-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          1.20 0.70 0.60 1.20 4.2016.4044.3026.30 4.20 0.60 0.10 0.10 0.10 0.10

B-191    -3.25-2.75-2.25-1.75-1.25-0.75-0.25 0.25 0.75 1.25
          1.75 2.25 2.75 3.25 3.75 4.25 6.00
          9.60 4.40 4.30 1.50 2.00 3.40 3.50 7.9015.1026.60
         15.20 3.50 1.40 0.50 0.30 0.10 0.70

B-203    -2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75
          2.25 2.75 3.25 3.75 4.25 6.00
         11.72 3.30 0.76 1.52 1.98 2.02 2.06 3.2621.6037.20
         11.75 2.10 0.28 0.09 0.03 0.46

B-206    -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25
          0.55 1.00 4.2732.0037.0022.00 2.85 0.21 0.03 0.01 0.01
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RAISED OUTWASH SEDIMENTS

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RB       -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75
          3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.7512.00
          6.12 2.70 5.31 3.24 7.00 4.02 4.42 3.89 4.27 4.93 3.68 4.50 3.40 3.40
          1.98 3.63 4.31 2.08 1.66 1.99 2.15 2.66 2.66 1.83 1.83 1.6610.60

P-11     -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00
          0.26 0.65 0.96 1.21 2.3212.0055.2020.00 3.14 1.13 0.86 0.59 1.54 0.00

P-23     -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
          0.10 0.11 0.17 1.96 6.2017.0017.1817.5314.1810.60 5.30 9.63 0.00 0.00

P-26     -2.45-1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25
          2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00
          4.52 1.92 1.50 2.21 2.75 3.69 7.0912.6116.6915.13
         14.90 8.06 3.38 1.74 3.75 0.00 0.00 0.00 0.00 0.00

P-29     -1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          0.72 0.50 0.63 0.46 0.62 0.97 1.82 4.67 9.4324.7628.3015.21 5.72 6.20

P-42     -3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
          1.75 2.25 2.75 3.25 3.75 4.25 6.00
         11.59 0.00 4.66 9.67 5.43 6.02 8.3714.3018.5212.52
          2.43 0.64 0.76 0.56 0.46 0.30 3.88

P-44      0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
          0.10 0.18 1.6818.1857.1017.80 2.31 0.54 1.86 0.00 0.00 0.00 0.00 0.00

P-45     -1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          0.32 0.75 1.41 1.09 1.47 2.9010.7339.6032.50 6.31 1.01 0.41 0.38 1.24

P-46     -1.8 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          0.43 0.87 0.85 1.06 3.2011.9134.5030.4011.92 2.66 0.76 0.31 0.33 0.80

P-47     -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
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          0.89 0.99 0.77 1.31 1.58 2.94 7.4518.9039.0022.20 3.43 0.42 0.28

P-53      -2.45-1.9 -1.25-0.75-0.25 0.28 0.75 1.25 1.75 2.25
           2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00
           3.78 4.48 1.12 1.22 0.65 1.84 6.58 5.3033.6014.64
           4.73 0.96 0.29 0.25 0.59 0.00 0.00 0.00 0.00 0.00

P-59      -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 0.00 0.00 0.00 0.00 0.00
           0.74 7.7233.2031.1021.50 4.87 0.78 0.18 0.02 0.00 0.00 0.00 0.00 0.00

P-66      -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 0.00
           2.37 0.55 1.22 1.19 1.64 5.1014.3042.9026.20 4.20 0.19 0.05 0.04 0.00

P-74      -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75
           1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
          11.89 6.07 6.76 2.58 7.08 4.95 5.40 6.50 7.42 9.16
           6.51 7.20 5.11 3.96 2.49 1.60 0.71 4.51

P-75       0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00 0.00 0.00
           0.03 0.99 2.35 9.7321.1027.9019.9010.36 3.24 4.41 0.00 0.00 0.00 0.00

P-83      -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.20 0.38 0.70 1.44 4.2912.3324.8038.0015.21 1.91 0.31 0.70 0.00 0.00

P-84      -0.25-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.16 0.11 0.17 0.40 0.93 5.6118.8342.1022.80 4.38 0.97 3.60 0.00 0.00

P-86      -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
           0.13 0.17 0.79 2.95 9.8820.4022.3629.7611.60 1.33 0.24 0.42 0.00 0.00

P-152     -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75
           3.25 3.75 4.50 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.7512.00
          16.00 3.47 7.70 4.32 8.10 3.74 3.80 4.02 4.41 5.68 4.40 4.62 2.32 1.69
           1.54 1.82 2.65 2.76 1.77 1.66 1.54 1.54 1.98 1.10 1.32 5.98

P-154     -1.25-0.75-0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00 0.00 0.00
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0.06 0.21 1.06 8.2330.0028.2014.10 7.60 5.72 2.28 1.38 0.34 0.90 0.00

P-156 -3.95-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25
1.75 2.25 2.75 3.25 3.75 6.00
4.0312.00 6.5813.15 4.57 3.87 3.46 4.9812.4013.92
9.70 3.42 1.64 0.85 0.82 4.60

P-158 -1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
1.54 1.38 1.47 1.70 1.84 2.10 3.21 8.2514.2029.6523.10 8.24 2.32 1.12

P-161 -3.95-3.45-2.95-2.45-1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75
3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.7512.00
25.70 2.64 0.00 0.82 1.88 0.70 0.78 0.88 1.08 1.99 2.08 3.78 3.95 5.85
7.30 9.00 8.20 4.34 2.80 2.18 1.55 1.70 1.86 1.40 1.24 0.78 5.43

P-171 -2.45-1.50-0.50 0.50 1.25 1.75 2.25 2.75 3.50
8.30 6.10 5.6010.8016.3034.2013.40 2.35 2.90

P-174 -2.45-1.9 -1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25
2.75 3.29 3.75 4.25 6.00 0.00 0.00 0.00 0.00 0.00
1.90 5.42 3.78 3.54 2.34 1.49 1.88 1.71 5.2630.60
35.80 2.43 0.83 0.49 2.56 0.00 0.00 0.00 0.00 0.00

P-184 -0.50 0.50 1.50 2.25 2.75 3.25 3.75 4.25 6.00
2.00 1.60 3.20 3.8015.7029.0023.50 9.3011.90

P-185 -2.75-1.60-0.50 0.50 1.50 2.25 2.75 3.25 3.75 4.25 6.00
4.20 2.60 3.10 3.60 2.90 3.0021.8023.21 0.70 5.8019.40

P-187 -2.75-1.60-0.50 0.50 1.50 2.25 2.75 3.25 3.75 4.25 6.00
5.2010.00 9.4020.1039.60 7.10 2.70 1.00 0.60 0.40 3.80

P-190 -0.50 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
0.30 2.4013.2035.3033.10 8.80 1.70 0.60 0.40 0.30 4.00

P-192 -0.50 0.50 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00

0.05 0.70 5.3025.5051.0016.40 0.40 0.20 0.10 0.20

P-193 -1.60-0.50 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
2.20 1.60 2.50 6.2015.5024.0021.1013.60 4.20 2.20 1.60 5.50

P-196 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
0.27 1.32 6.3214.7615.7020.3015.14 9.96 6.96 9.32

P-199 -0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
0.15 0.31 1.32 3.71 9.6317.6017.2618.0611.40 6.82 4.04 9.70

P-200 -1.90-1.25-0.75-0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 6.00
2.55 2.06 2.94 2.58 3.33 3.57 5.5011.5125.5029.15 6.92 1.27 0.61 2.42

APPENDIX C

FORAMINIFERAL SPECIES LISTING
Identifications by Dr.G.A.Bartlett, Queen's Uni

S-6 Almost entirely shells. _Eggerella advena_, few _Ammotium cassis_, _Trochammina lobata_, on _Quinqueloculina agglutinata_.

S-13 Dominant _E. advena_, Also _Elphidium bartletti_, _E. orbiculare_, _E. subarctica_, _Rheophax curtus_, _Cribrostomoides crassimargo_, _Sacammina atlantica_, _Adercotryma glomeratum_, _Dentalina ittai_, _Q. seminulum_, _Elphidium clavatum_, _Glomospina gordialis_, _Spiroplectammina biformis_, _Fissurina marginata_, _Buccella frigida_, _Lagina gracillina_, _L. semilineata_, _Triloculina_ sp. cf. _T. trihedra_, _Scutuloris tegminis_, _Glandulina laevigata_, _Nonionellina labrodorica_, one _Q. agglutinata_, _T. lobata_, and _Orbulina universa_.

S-15 Abundant _T. lobata_, also _E. advena_, _E. subarctica_, _P. novangliae_, _E. clavatum_, _M. fusca_, _L. gracillina_, _A. pulchella_.

S-31 Many ostracods. _E. clavatum_, _E. incertum_, _E. margaritacium_, _E. subarctica_, _M. fusca_, _M. zaandamoe_, _A. arctica_, _S. tegminis_, _G. laevigata_, _E. advena_, _F. marginata_.

S-36 Same fauna as S-6, with plenty of wood and coal.

S-45 One specimen of _E. advena_ and one specimen of _E. incertum_.

S-54 Abundant _E. advena_, plus _T. lobata_, _S. atlantica_, _R. curtus_, _T. nana_, _T. squamata_, no Calcareous benthonics, one _Orbulina universa_.

S-56 Dominant _E. clavatum_, plus _E. advena_, _M. fusca_, _Q. seminulum_, _Q. arctica_, _Rosalina columbiensis_, _Tretomphaloas_ sp. _E. subarctica_, _C. lobatulus_, _E. margaritacium_, _Oolina costata_.

S-60 Same as S-6 or S-36, with _S. atlantica_ and _R. curtus_ and _C. crassimargo_.

S-65 Few forms and ostracods, fibres. _E. advena_, _A. glomerata_, _T. nana_, _B. frigida_, _E. clavatum_, _E. incertum_, _E. subarctica_, _L. semilineata_, _R. curtus_, _M. zaandamoe_.

APPENDIX C (Contd)

S-68 Abundant E. advena, plus M. fusca, E. subarctica, E. clavatum, E. incertum, T. lobata, E. orbiculare, Q. costata, T. squamata, Q. seminulum, C. lobatulus, S. atlantica, P. novangliae.

S-70 Large majority E. advena, common T. lobata, rare C. lobatulus, and coal, etc.

S-80 Almost wholly arenaceous. Abundant E. advena, plus T. lobata, S. atlantica, R. curtus, A. cassis, rare E. orbiculare, and R. columbiensis.

S-96 Few species. Mainly E. advena, plus T. lobata, E. incertum, E. subarcticum.

S-101 E. advena, E. clavatum, E. subarctica, E. incertum, E. margaritacium, C. lobatulus, R. columbiensis, P. novangliae, O. melo, Q. seminulum, B. frigida, much debris.

S-104 Abundant E. clavatum, also I. islandica, C. lobatulus, E. subarcticum, I. tenetis, E. orbiculare, B. frigida, T. angulosa, one specimen of E. advena.

S-107 Abundant C. lobatulus, also E. subarcticum, E. clavatum, R. columbiensis, Q. seminulum, G. laevigata, L. apiopleura, one specimen of E. advena.

S-108 Lots of debris. Abundant C. lobatulus, plus E. clavatum, Q. seminulum (common), P. novangliae, E. subarcticum, apparently no arenaceous forms.

S-132 Abundant E. advena and R. curtus, plus E. orbiculare, E. bartletti, R. turbunatus, T. lobata, A. glomerata, T. squamata, F. marginata, L. gracillina, L. semilineata, B. frigida (common), N. labradorica, S. atlantica, C. crassimargo, E. incertum, P. novangliae, I. teretis, S. biformis, A. cassis, L. apiopleura.

S-144 Abundant E. clavatum and E. advena and C. lobatulus, plus E. subarcticum, B. frigida, I. islandica, S. atlantica, Q. seminulum, A. teretis, C. crassimargo, T. squamata, T. lobata, T. angulosa, R. curtus, L. apiopleura, O. melo.

S-146 Dominant E. advena, (common) T. lobata, C. lobatulus, also B. frigida, O. melo, L. apiopleura, E. subarcticum, P. novangliae, S. atlantica, A. pulchella, many ostracods.

APPENDIX C (Contd)

S-148 Dominant C. lobatulus, with E. subarcticum, and E. advena, E. clavatum. Also Q. seminulum, L. apiopleura, G. laevigata, O. melo, L. gracillina, R. columbiensis, variety of ostracods.

S-151 Small fauna, dominant E. clavatum and C. lobatulus, also E. subarcticum, Q. seminulum.

S-152 Like S-151. Plus P. novangliae, R. columbiensis, B. frigida.

S-153 E. subarcticum, E. advena, C. lobatulus, T. lobata, B. frigida, L. apiopleura, E. clavatum, rare S. atlantica, Q. seminulum, E. incertum, E. margaritacium, B. elegantissima, R. curtus, O. melo, R. columbiensis.

S-157 About 6 species of C. lobatulus, 1 of B. frigida, debris.

S-158 Abundant Q. seminulum, with C. lobatulus, E. subarcticum and E. clavatum. Also P. novangliae, Glabratella sp. R. columbiensis.

S-160 Few E. clavatum, C. lobatulus, E. incertum, debris.

S-170 Similar to S-158, without Glabratella & Rosalina but with I. teretis, I. islandica.

S-147 Abundant E. subarcticum, with C. lobatulus & E. clavatum, also L. apiopleura, R. columbiensis, B. frigida, E. incertum, T. angulosa, O. costata, Q. seminulum, G. laevigata, O. melo, A. gallowavi, Triloculina, sp., E. advena (common), L. gracillina, L. williamsoni.