

RECENT SEDIMENTS OF THE
GIBRALTAR POINT AREA LINCOLNSHIRE

by

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ABSTRACT.

In this thesis the Recent sediments deposited in the vicinity of Gibraltar Point on the Lincolnshire coast are described and the factors influencing their texture, composition and structure are discussed.

The first part of the thesis deals with the aim and nature of the investigation, and the geographical setting of the area studied. The physiography of the area and its general evolution over the past two centuries are then described in detail. It is shown that the area can be sub-divided into a number of physiographically distinct environments and sub-environments of deposition. The Sediments which characterise these are described with emphasis on the significance of their grain size frequency distributions. The sedimentary structures are described and their origins discussed, and the compositions of the sand fractions (greater than 0.62 m.m.) are presented along with the results of a brief study of the mineralogy of the deposits.

The latter part of the thesis is concerned with a general discussion of the dynamics of the sedimentation and an interpretation of the stratigraphy of the deposits studied.

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CHAPTER 1.

Introductions.

General.

An investigation has been made of the Recent sediments of the Lincolnshire coast between Skegness and the outfall of the River Steeping.

The work forms part of a programme of research on the sedimentology of the Wash and adjoining coasts of Norfolk and Lincolnshire being undertaken at Imperial College. This study is the second of a proposed series. The first was made by Evans (1960) who studied the intertidal sediments near the Witham outfall. It has since been found that this area studied by Evans is broadly typical of much of the intertidal zone bordering the Wash.

During an early reconnaissance it was noted that different types of sediment were forming in response to different processes on the north east corner of the Wash embayment in the vicinity of Gibraltar Point, where the wide intertidal flats which characterise the sheltered coasts pass into the narrow more exposed beaches of the Lincolnshire coast. Records show that in this area, the Gibraltar Point area, there has been a considerable build out of sediment over the past two centuries, and the process appears to be still continuing. This thesis describes the characteristics of these sediments and attempts to explain their mode of formation. In the latter part of the thesis a suggested stratigraphy of the deposits has

been made.

Aim of the Study.

The purpose of the work has been to make a study of the sediments accumulating in certain modern environments of deposition, and the various processes which affect their distribution and characteristics. The study has been made in such a way that the results may be used as an aid to the identification of ancient sediments which may have accumulated in similar environments of deposition.

Nature of the Study.

In the early stages of the investigation, the physiography of the area was studied, and it was found that the area could be divided into a number of physiographic units. These units were also found to be distinct environments and sub-environments of deposition which are characterised by particular types of sediments and organisms. Hence these physiographic units will be described as environments and sub-environments of deposition.

A map of the area was produced from air photographs taken in 1955 and the distribution of the various physiographic units and sub-environments were plotted on this.

The composition, texture and structures of the sediments and flora and fauna of the various environments and sub-environments were studied and compared. The distribution of

the surface dwelling and burrowing organisms was studied and appears to be related to a number of factors including grain size. The effects of these organisms on the sediments and processes of sedimentation were also examined.

Stratification and other sedimentary structures were studied in shallow cores and by making wax impregnations of vertical sections of the sandy deposits obtained by driving large metal boxes into the sediments. It was found that the bedding characteristics of the deposits of the various sub-environments differ markedly from one another.

From the information gained it has been found possible to present conclusions concerning the processes of sedimentation and the source of materials. Although the study was essentially limited to the top 2 - 3' of sediment, the information gained from shallow cores and sections combined with historical data and records of earlier borings provided a basis upon which a reasonable picture of the stratigraphy of the recent sediments could be developed. However this picture is in part hypothetical and more information about the three dimensional aspects of the sediments is required before many of the conclusions can be confirmed.

Geographical Setting.

The area studied forms the north east corner of the Wash embayment on the east coast of England, at the point where the trend of the coastline swings abruptly from approximately

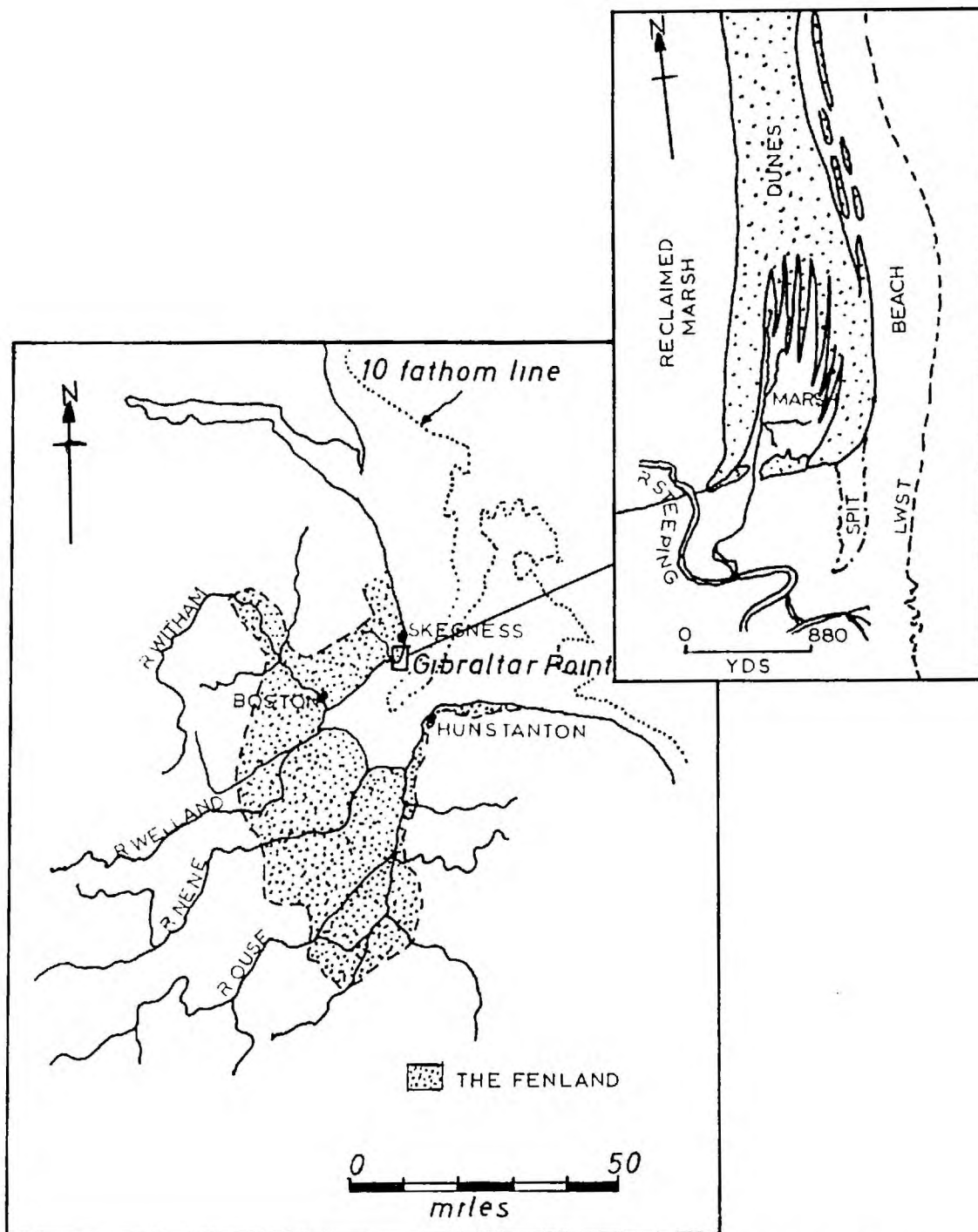


FIG.1. THE WASH EMBAYMENT AND LOCATION OF THE AREA STUDIED.

north-south to north-east, south-west (see Fig. 1). It extends from Skegness in the north to the River Steeping (Wainfleet Haven) in the south, a distance of about four miles. It is bounded by extreme low spring tide line to the east and the western boundary taken is the road running along the river edge of the westerly dune ridge. This artificial boundary is also a significant natural one, as it separates the wide marshlands of Lincolnshire from the beaches and dunes which characterise most of the coast as far north as the Humber estuary. The average distance between these two boundaries is approximately $\frac{3}{4}$ mile, being about $\frac{1}{2}$ mile in the north and increasing to about 1 mile in the south.

It will be seen therefore that Gibraltar Point is an extremely interesting area since it is there that the relatively sheltered environment of deposition - the intertidal flat of the Wash - pass into a much more exposed environment - the beach and dune coast of Lincolnshire to the north.

History of Research.

The Gibraltar Point area has received considerable attention from botanists, zoologists and geographers in recent years. In particular King and Barnes (1951) and King (1953, 59) have made detailed physiographic studies and topographic surveys of the spit and associated features, but previous to the study made by the present author no work on the geological aspects of the area have been undertaken.

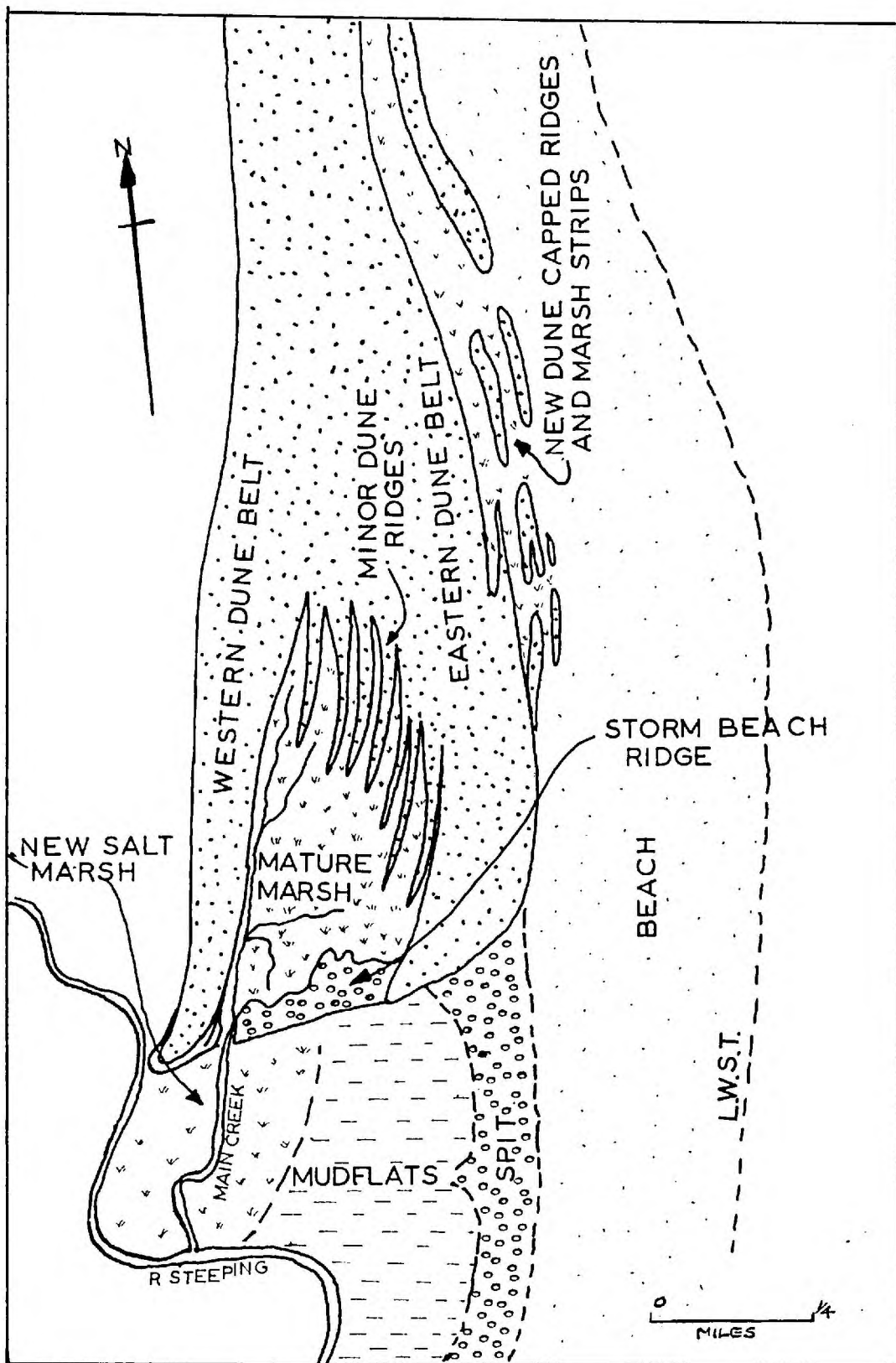


FIG. 2. DISTRIBUTION OF THE ENVIRONMENTS AND SUB-ENVIRONMENTS OF THE GIBRALTAR POINT AREA.

CHAPTER 2.

Physiography.

At the commencement of the study the writer made a physiographic survey of the area and confirmed the observations of King and Barnes (1951. 57) and King (1959). In the following chapter the physiography and physiographic evolution of the Gibraltar Point area over the past two centuries are reviewed. Although this has already been described by King and Barnes, it is redescribed with minor alterations and additions, as it forms an essential background for the study of the sediments.

In the area, several distinct physiographic units can be distinguished. As stated earlier, these will be referred to as sub-environments of deposition and are as follows:-

1. Beach.
2. New dune capped ridges and marsh strips.
3. Mud flats and new saltmarsh.
4. Storm beach ridge.
5. Older dune capped ridges. (*minor dune ridges*)
6. Mature marsh.

The general distribution of the sub-environments is shown in Fig. 2, Map. 1 (in folder at back of thesis) and can be seen on the air photograph.

In the west a dune belt runs the whole length of the area. In the extreme north another major dune belt diverges southwards from it and encloses a complex of smaller lower dune ridges which also fan out to the south and pass into and

interfringe with a mature marsh. The major dune ridges and the mature marsh are abruptly terminated at their southern ends by a strikingly anomalous sandy feature, the storm beach ridge, which is orientated east-west and hence cuts across the predominant north-south trend of the main features. South of this, extending to the Steeping is an area of mudflat on which a salt marsh is developing in the west.

Fronting the complex of the mudflats, marshes and dunes and to the east of them is a wide sandy beach. In the centre of the area however, the sigmoidal trend of the eastern dune belt results in a concavity which is occupied by a relatively new complex of dune capped ridges and marsh strips.

The Beach.

The beach, which is sigmoidal in its trend, has an overall width from low to high spring tide levels of approximately $\frac{1}{4}$ mile. It is composed mainly of sand and gravelly sand but mud tends to accumulate occasionally on the lower areas. It may be divided physiographically into a relatively featureless lower part - the forebeach; and an upper part - the backbeach, which shows a seasonal development of elongate ridges and depressions which are orientated sub-parallel to the coastline.

According to King (1951) the overall gradient of the beach is approximately $1/85$. In its detail however, this general gradient is actually found only on the lowest part of the beach for in the upper part it is only an average value



PLATE.1. Forebeach to seaward of outer backbeach
ridge. NB Rippled surface and Arenicola
marine casts.



PLATE 2 Mudcliffs on lower forebeach .



PLATE 3 Lanice covered hummocks

because of the seasonal development of ridges and depressions (~~see Fig. 2~~).

Forebeach.

The forebeach is a uniformly shelving area approximately $\frac{1}{2}$ mile wide immediately above low spring tide level. The air photographs (1955) were taken at approximately mid-tide, so they do not show the full extent of the forebeach. It is a relatively featureless area throughout the year except for a ripple marked surface, and randomly scattered casts of Arenicola marina (see plate 1). At periods of low tide however, rill marks and shallow creeks formed by ebb waters draining from the depressions on the backbeach, extend across the forebeach to low tide level. Sheets of mud are occasionally deposited on the area during periods when wave and current action are at a minimum. These are later reworked as wave and current action increase producing small mud cliffs sometimes as much as 4 - 5" in height (see plate 2).

In the south, at low spring tide level, there is an occasional patchy distribution of low hummocks (see plate 3). These are colonised by Lanice Conchilega, whose cemented tubes are found in large numbers projecting above the surfaces of the hummocks. Filamentous algae also occur: many of the filaments being attached to the Lanice tubes. The author suggests that these organisms act as sediment traps, and their activities result in the formation of hummocks whenever they occur in large numbers. It was noted that the isolated Lanice tubes, which lie away from the hummocks, project further above

the forebeach surface. This suggests that reworking by wave and current action resulted in a lowering of the forebeach surface excepting isolated patches where the organisms tended to concentrate. Other organisms occasionally found in the area are: *Nereis* sp., *Pectinaria* sp. and small hermit crabs.

The surface of the forebeach is characterised by an absence of pebbles, although scattered shells, particularly those of molluscs are occasionally found.

Backbeach.

The topography of the backbeach changes seasonally. Throughout the winter., there is no marked break in slope between the forebeach and backbeach. During the early summer however, a series of long ridges, separated by elongate depressions, form on the backbeach and attain their maximum development by the late summer. These features are commonly destroyed by the storms of late autumn and early winter. The air photographs were taken during April and show the ridges at an early stage of their development.

King observed that the ridges are arranged en echelon so that only two ridges and runnels are present in any one traverse normal to the shoreline. This is not strictly true as can be seen from the air photograph. However, the en echelon arrangement appears to be characteristic. None of the ridges extends the full length of the beach; their continuity being broken by small ebb channels (see air photo.)

During the summer when the ridges and runnels reach their

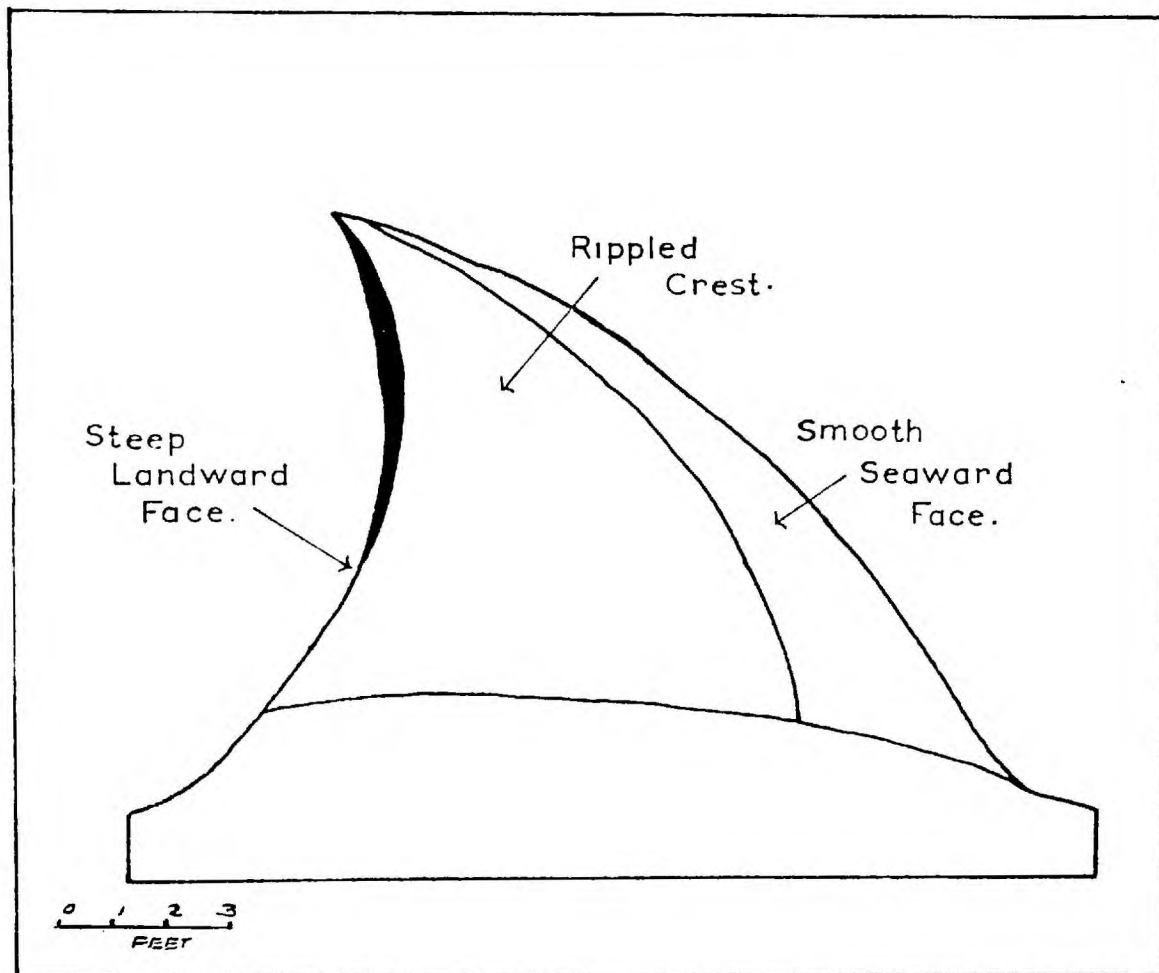


FIG 3. Diagram showing form of a backbeach ridge.



PLATE 4 BACKBEACH RIDGE SHOWING RIPPLED CREST
AND RUNNELS TO LANDWARD AND SEAWARD.



PLATE 5 STEEP LANDWARD FACE OF BACKBEACH
RIDGE. NB. TERRACES.

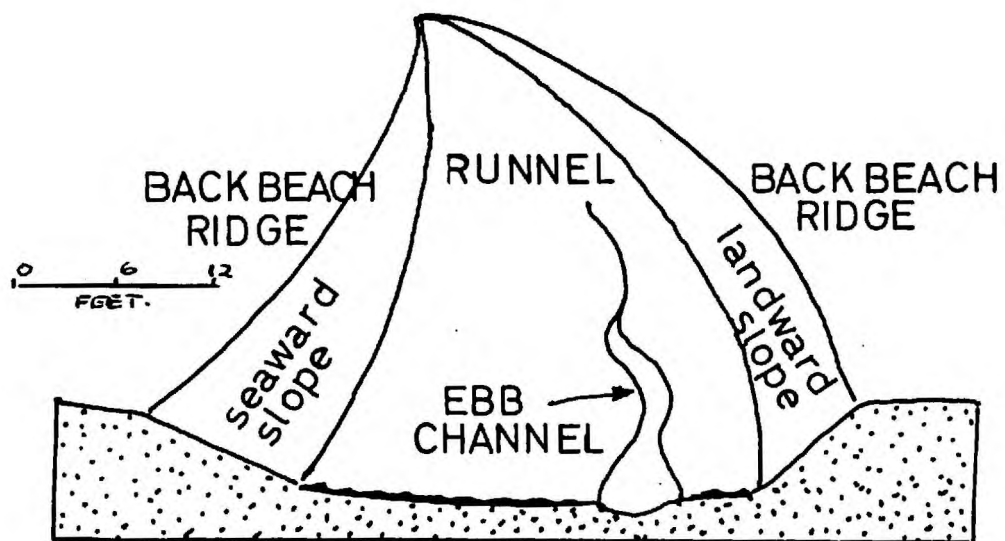


FIG.4. Diagram of backbeach runnel



PLATE 6. LOWER PART OF RUNNEL NB. EBB CHANNEL



PLATE 7. MEGA-RIPPLE MARKS ON LOWER PART
OF RUNNEL. NB. ORIENTATION NORMAL TO
LONG AXIS OF RUNNEL.

maximum development, the ridges are markedly asymmetric in cross section. Each ridge has a smooth seaward or swash slope, not exceeding 20° ^{and} a wide flattened crest, the surface of which is ripple marked, and a very steep landward face with inclinations up to 60° (see Fig. 3 and plates 1, 4 & 5). The landward face may show erosion scars or may be terraced while beach cusps often develop on the seaward facing slopes. The origin of these features will be discussed in a subsequent chapter. Each runnel is also asymmetric in cross section with a flat floor (see Fig. 4 plate 6). They all slope southwards along their lengths and it is at the lowest points that tidal creeks, which flow in the bottoms of the runnels, swing sharply seaward cutting a channel through the beach ridge to seaward. The floors are ripple marked and symmetrical mega ripples aligned at right angles to the long axis of the runnel are sometimes found in the lower southern parts (see plate 7).

The upper part of the backbeach continues southwards past the point, where eastern dune belt ends, as a low ridge of gravelly sand. This is about 600 yards long, 30 yards wide with a crest height of about +11.5' O.D. and shows two recurves. This ridge is the so called "spit" of King (1951). In reality it is a beach ridge and is probably continuous with a similar feature which lies under the main eastern dune belt (see air photo). Like the beach ridges the spit tends to attain a maximum development during summer but during winter it is considerably lowered and flattened by more destructive



PLATE 8. DEBRIS DEPOSITED ALONG THE
STRAND LINE.

waves.

Vegetation, largely Aeropyrum junceum (sea couch grass) and Salsola kali (saltwort) (see Chester 1950 rep. P.57) has sparsely colonised the southern end of the spit on two occasions. Firstly in the summer 1950; disappearing again by the end of August, 1951. There is no evidence of their reappearance to date: indicating the relative instability of the spit.

South of the spit and to landward of the ridges and runnels the backbeach forms a broad sandy and gravelly plain extending to the River Steeping (see air photo.). During Summer asymmetric mega ripple marks are formed on this surface.

The backbeach is characteristically devoid of organisms except for sand hoppers on the highest part in front of the dunes. On one occasion however, the author found a few Arenicola sp. casts in the lowest part of one of the runnels but these disappeared and have not been noticed since.

Pebbles and shells, particularly those of molluscs and gastropods are often found scattered in large numbers over the surface of the area, while considerable accumulations of bryozoan (skeletons) and echinoderm tests are often found along the strand line (see plate 8).

New Dune Capped Beach Ridges and Marsh Strips.

Midway along the coast section and occupying the concavity formed by sigmoidal trend of the eastern dune belt (see air photo.) the beach does not pass inland into the high



PLATE. 9 NEW DUNE RIDGES AND MARSH STRIPS.



PLATE .10 NEW DUNE RIDGES AND MARSH STRIPS
-VIEW FROM EASTERN DUNE BELT.



PLATE II. WASHOVER FANS ONTO MARSH
STRIP.

eastern dune belt as it does to the north and south but into a complex of dune capped ridges and marsh strips (see plates 9 and 10).

The low sandy ridges are aligned sub-parallel to the coastline and vary in the length from approximately 500 to 1500 yards. Each one is about 20 yards wide and their crest heights vary from 13 to 18' O.D. Occasionally, when stormy weather coincides with high spring tides, washover fans develop which extend onto the surface of the marsh strips behind the outer ridges (see plate 11).

The ridges are not continuous but are interrupted by ebb channels. These are characteristically deflected to the south where they cut through the ridges, in the same manner as the ebb channels cutting through the ridges on the backbeach (see air photo.). To the north and south the ridges abutt against the eastern dune belt. The low dunes which cap these ridges are colonised by marram grass during the early stages of development. As the dunes become stabilised this is replaced by Agropyron junceum and Hippophae rhamnoides.

The areas between the ridges are occupied by strips of salt marsh. Their surfaces vary in elevation from +10 to +11' O.D. and they may be as much as 50 yards in width. They are colonised by Sueda maritima, Salicornia sp. Glaux maritima and Glyceria maritima. Narrow channels up to 6 - 8' wide and 2' deep drain along the outer marsh strips. In places these have degenerated into a series of isolated saltpans, which are devoid of vegetation. The inner marsh strips show no creeks

(11)



PLATE .12. ARENICOLA MARINA CASTS IN BOTTOM OF CREEK
IN MARSH STRIP



PLATE.13. ARENICOLA MARINA CASTS EXTRUDED INTO
WATER.



PLATE 14. REMAINS OF 1779 SPIT ON SOUTHERN END
OF WESTERN DUNE BELT.

but merely saltpans.

Large Arenicola casts are often found on the floors of creeks (see plates 12 & 13) and casts of Heteromastus sp. are occasionally seen. The floors of saltpans and sides of creeks were sometimes covered by large numbers of Hydrobias.

The marsh strips are only inundated by high spring tides, and during these periods the sandy ridges stand out as islands. The most northerly of the marsh areas, which is the largest, has been artificially sealed and is now permanently covered with brackish water.

Dunes.

The two major dune belts that diverge southward from Skegness, enclose a complex of minor dune ridges, which die out southward as they pass into the mature marsh. (see map and aerial photo.) Near Skegness the dunes form a single complex, the details of which are largely obscured by building and the construction of a golf course. Each ridge of the complex has an undulating crest line and is composed of a series of hummocky dunes which are classified as 'foredunes' according to King (1959) and Smith(1954). Each dune ridge is symmetrical in cross section.

The western dune belt is composed of two well defined ridges in its central part which attain a maximum height of 20' O.D. and a width of about 30 yards. They become lower southwards and pass into a series of low dunes covering a gravelly ridge which curves to the west. (see plate 14). This

gravelly ridge which is exposed in the banks of the River Steeping, was interpreted as an old spit by King (1951). The writer agrees with this interpretation. These dune ridges have been stabilised by a thick cover of vegetation, in which the grass Aeropyron junceum, predominates with occasional shrubs, particularly Sambucus nigra (elder) Rubus caesius (dewberry) and Hippophae rhamnoides (sea buckthorn); the latter being more prominent in the slacks running between the ridges.

The eastern dune belt is sigmoidal in trend and consists of three well developed ridges in the south but when traced northwards they are less easily defined from one another. The inner ridge is the most conspicuous attaining a height of 25' O.D. in the south. When they are followed to the south the ridges swing sharply towards the southwest and at the same time they become lower and narrower and eventually die out as they merge into the dunes of the storm beach ridge. Here they are truncated along the line of the storm beach ridge. Where the dune ridges terminate, traces of features which appear to be the former continuation of these ridges can be seen extending in the south westerly direction across the mudflats south of the storm beach ridge (see air photo.).

The eastern dune belt varies in width along its length. In the south, where it is directly fronted by the beach, it attains its maximum width of approximately 250 yards. Further north, where it is fronted by the lower dune capped ridges and marsh strips, it is narrower.

Stabilisation of the dunes by vegetation is shown in a traverse across the southern part of the eastern dune belt.



PLATE .15. CLIFFS CUT IN DUNES.



PLATE .16. SMALL CLIFFS CUT IN NEW
DUNE RIDGE.

The newest foredunes to seaward are colonised by Salsola kali which appears to be the primary coloniser of accumulations of wind blown sand in the area. This is only found on dunes, the crest of which are less than 15' O.D. As the height increases above 14' O.D. Aeropyron junceum and Ammophila arenaria occur and these two plants with patches of Elymus arenaria in higher places form the characteristic vegetation of the frontal ridge. Behind this ridge the surface tends to become increasingly protected from wind action by the spread of Hippophae rhamnoides, Rubus caesius and occasionally clumps of Sambucus nigra.

The dune ridges are separated by dune slacks which may be as low as 12' O.D. and which are continuous through the length of the belt. Hippophae rhamnoides is characteristically prominent on these lower areas.

Occasionally when storms coincide with periods of high spring tides, the seaward face of the northern and southern ends of the eastern dune belt is notched by small cliffs where it abuts directly onto the beach (see plates 15 & 16). These cliffs may be as much as 10' in height in places but are rapidly obliterated by slumping and addition of fresh wind blown sand.

In the northern part of the area, near Skegness, this erosion which influences the exposed parts of the eastern dune ridge and outer ridge of the dune capped ridge and marsh strip complex has been very severe. A system of groynes has been constructed and the dunes have been artificially planted



PLATE 17(a). MINOR DUNE RIDGES AND INTERVENING
STRIP OF MATURE MARSH.



PLATE 17(b). SAME VIEW DURING HIGH
SPRING TIDE INNUDATION.

with marram grass in order to protect the coast at this point from further erosion.

A series of minor dune ridges occurs between the eastern and western dune belts. Seven ridges can be distinguished (see aerial photo. and map). Each shows a similar sigmoidal trend to that of the eastern dune belt. They become more conspicuous southwards where they fan out, in part by virtue of the tongues of marsh which extend northwards in the depressions between them. Like the eastern dune belt they curve southwestwards at their southern extremities, but they do not extend as far south as the latter. These ridges are relatively minor features being lower than the ridges of the western and eastern dune belts (see plates 17 a, b). However, they become successively higher towards the eastern dune belt, increasing in height from approximately 12' O.D. to 18' O.D. These ridges are colonised by Acrolydon junceum a grass which resembles the A. pungens so prominent in the mature marsh to the south.

Two strikingly sigmoidal salt pans are seen cutting across the trend of the minor ridges (see map and aerial photos.). These bear a striking resemblance to the ebb channels which drain the strips of saltmarsh of the new dune capped ridges and marsh strip complex, which in turn, as pointed out earlier are similar to the ebb channels of the backbeach.

Mature Marsh.

The mature marsh forms the low area between the



PLATE 18. MATURE MARSH.



PLATE 19. CREEK, IMMATURE MARSH - NOTE
ZONATION OF FLORA.

southernmost ends of the eastern and western dune belts. To the north it interfingers with the minor dune ridges while to the south it is abruptly terminated by the storm ridge (see aerial photo. and plate 18). The surface is essentially flat; varying from +11.2' O.D. to +11.5' O.D. The most significant feature is the system of creeks which occurs in the west of the marsh. These lead into 'main Creek' which flows southwards through the storm beach ridge to the Steeping. (see map and aerial photos.). The two northern tributaries extend back into the marshes between the lower minor dune ridges. The east-west tributary running alongside the path across the marsh appears to be artificial. The southernmost tributary, called 'South Salting Creek,' runs northwards from the storm beach ridge. King(1951,1957) suggested that this was formerly a southward flowing creek which suffered a reversal of drainage. This suggestion is in part supported by the fact that the creek becomes narrower northwards. The reversal probably resulted from the development of the storm beach ridge across the marsh.

The creeks have an average depth of about 6' and may be more than 12' in width. They are bordered by natural levees which rarely rise more than a foot above the general level of the marsh but because of the extreme flatness of the latter the levees form striking features. They are further emphasised by the distribution of vegetation (see aerial photo. and plate 19). The marsh is colonised by Halimione portulacoides and Aeropyron pungens but other plants are locally dominant e.g. Artemesia maritima, Simmonium sp. Glauk maritima



PLATE.20. SALT PANS IN MATURE MARSH.

and Glyceria maritima. The creeks are always fringed along their inner banks by Halimione portulacoides while the levees are covered by Agropyron pungens.

The general surface of the marsh is below spring tide level but the storm beach ridge forms a natural barrier to advancing tidal waters which consequently normally only have access to the marsh via the main creek. During these periods of high tides the sea floods over the levees and inundates the greater part of the marsh. During neap tides the sea only covers the creek floors. Here and there on the marsh surface there are small depressions - saltpans which are generally devoid of vegetation. These are of two types; primary and secondary pans (Chapman 1937) (see plate 20). The primary pans are circular or slightly elongate features and appear to have been formed by tidal scouring during the earlier stages of marsh development. The secondary pans are often sinuous and presumably were formed by the sealing off of old creeks near their heads.

Mudflats and New Salt Marsh.

The mudflats and new salt marsh occupy the area enclosed between the storm beach ridge to the north and the spit to the east and extend southward to the River Steeping (see aerial photo.). The mudflats form the lower south east part of the area and extend from 7' O.D. at a point just to the west of the southern end of the spit, up to approximately +8' O.D. whereas the new salt marsh forms the north west part and extends from approximately +8' O.D. up to +11'. This small area of mudflats and new salt marshes forms the



PLATE. 21. SALT PANS ON MUOFLAT.



PLATE. 22 SALT PANS ON MUOFLATS JOINED
TO FORM A SMALL CREEK.

north easterly part of the wide area of mudflats and salt marshes which extends for many miles to the southwest but the two are separated by the meandering Steeping.

Mudflats.

The surface of the mudflats slopes gently toward the southwest. Throughout much of the year it is an essentially uniform surface apart from minor features such as ripple marks and tracks and other markings of Scrobicularia sp. Hydrobia sp Corophium and birds etc. It is characteristically devoid of vegetation except for scattered patches of the filamentous alga Enteromorpha.

During winter and after storms the surface may be broken up into a series of shallow elongate depressions (see plates 21 and 22). They are usually about 6" deep and about 3' to 5' respectively in width and length. These are primary pans referred to earlier. These pans sometimes coalesce to form minor drainage channels but they are ephemeral features and soon become infilled during normal calm conditions.

A few small creeks, which are found at all seasons of the year, meander across the lower mudflats and drain into the River Steeping.

In the east, washover fans of gravelly sand and sand spread out from the spit onto the mudflats surface, and in the north similar outwash fans spread out southwards from the storm beach ridge. (see plate 27). These features are formed during periods of stormy weather.

The essential difference between the mudflats and new salt marsh is that the latter possesses a dense plant cover.



PLATE. 24. MAIN CREEK IN NEW SALT
MARSH.

The boundary between the two, although relatively sharp, is gradational as the plant cover thins out, and its position may vary seasonally (~~see plate 23~~). As in other salt marsh areas described by Chapman (1937, 1960), Chesters (1950), King and Barnes (1951) and others, there are well marked plant zones closely related to the height of the marsh.

The outer and lower part of the marsh is colonised by Spartina sp. and Salicornia sp. but in the extreme northwest, that is the inner of high part, it possesses a denser cover in which Sueda maritima and Halimione sp. dominate.

Salt pan depressions are not often found in this area and apart from Main Creek (see plate 24) the area has no well developed drainage pattern.

Storm Beach Ridge.

The storm beach ridge is made up of sand and gravelly sand capped by small hummocky dunes. It trends approximately east-west extending from the end of the eastern dune belt to the southern end of the western dune belt and separates the mature marsh from the new salt marsh and mudflats (see aerial photo.). Its crest is some 4' high ranging from 11' to

15' O.D. and has an average width of 50 yards. In the west it is cut by Main Creek and about half way along its length it has been breached apparently by storm waves which formed a small channel through it called South Salting Creek. The ridge is asymmetric in cross section, the seaward south facing slope is relatively steep, 20-30° and the back slope



PLATE. 25.
BEACH FACE OF STORM
BEACH RIDGE.



PLATE. 26.
BEACH CUSPS ON
STORM BEACH RIDGE.



PLATE. 27. OUTWASH FANS FROM STORM
BEACH RIDGE ONTO MUDFLATS.



PLATE. 28. WASHOVER FANS FROM STORM BEACH
RIDGE ONTO MATURE MARSH.

more gently rarely exceeding 10° . The bare seaward face is devoid of vegetation and forms a beach which grades seaward into the mudflats and new salt marsh. Sometimes well developed beach cusps form on this face (see plates 25, 26 and 27) and outwash fans spread out southwards onto the surface of the mudflats. This beach continues eastward and westward across the southern ends of the eastern and western dune belts. The crest is capped in the main by small hummocky dunes. The back slope consists of a complex of sand and gravelly sand fans which have been washed over by storms, together with wind blown sand (see plate 28). The bare surfaces of recent washover fans can be seen on the air photograph.

It is important to notice here, that the line of the storm beach ridge is continued on the west side of the Steeping by a marsh cliff. This latter is strictly not in the area studied but it will be shown later that it is the continuation of a feature upon which the storm beach ridge rests.

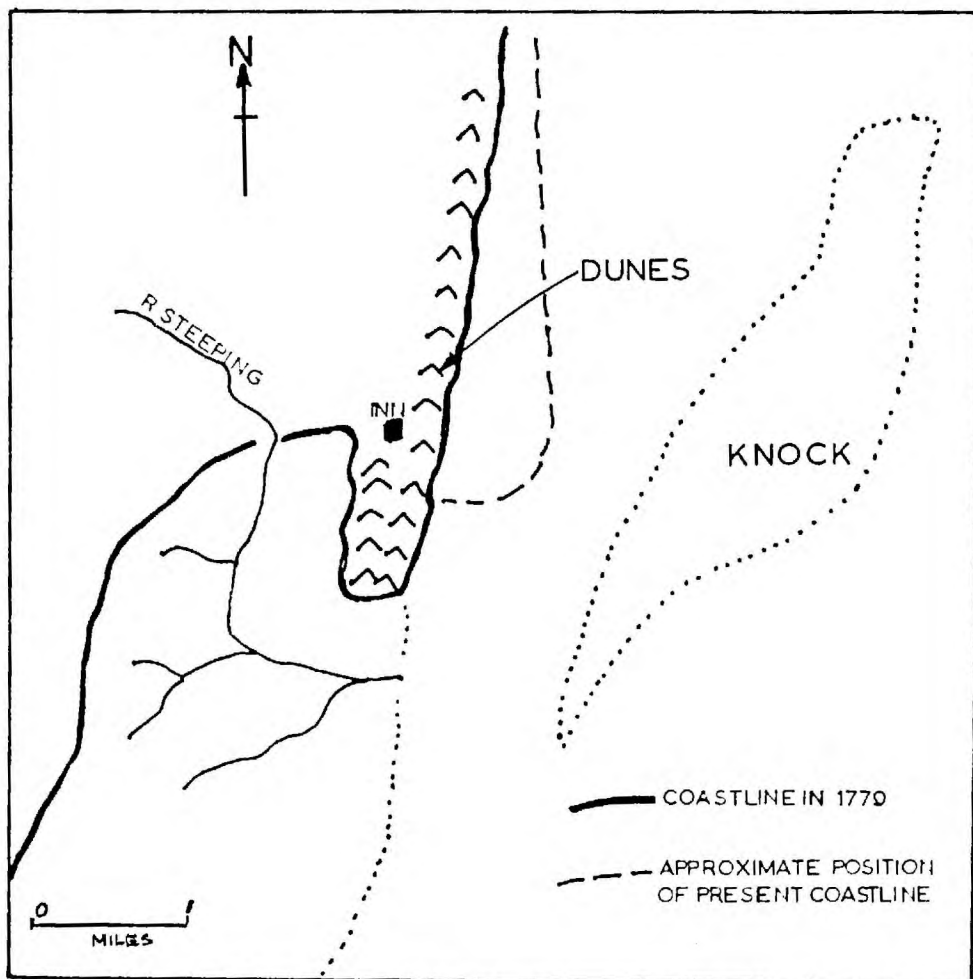


FIG 5 GIBRALTAR POINT AREA AS
MAPPED BY ARMSTRONG 1779.

CHAPTER 3.

Coastal Evolution of Gibraltar Point During the Last Two Centuries.

In the following pages the maps of the area made over the last two centuries will be described with emphasis on the changes which occurred between the respective surveys. This was done by King and Barnes (1957) who also interpreted those changes. However in the light of the present investigation some of their interpretations will be contested.

The earliest reliable map of Lincolnshire appears to be that made by Armstrong (1779). The map showed a single belt of dunes extending approximately north-south in a relatively straight line from Skegness to Gibraltar Point (see Fig. 5). The dunes separated the Lincolnshire marshlands from a sandy beach to seaward. The coastline at that time was about a mile west of the present one and the dunes shown on Armstrong's map now form the western dune belt. A long spit capped by wind blown sand projected south from the site of the old inn at Gibraltar, at the southern end of the dune belt. Approximately 1 mile offshore a large sandbank, the Knock, extended for four miles, aligned approximately northeast-southwest sub-parallel to the coastline. King and Barnes (1957) believed that the large areal extent of the Knock provided the shelter which allowed the formation of the spit, the development of which caused the outfall of the Steeping to be diverted southwards.

The first edition O.S. 1" map (1824) (see Fig. 6) shows three significant changes; there was a partial breakdown of the

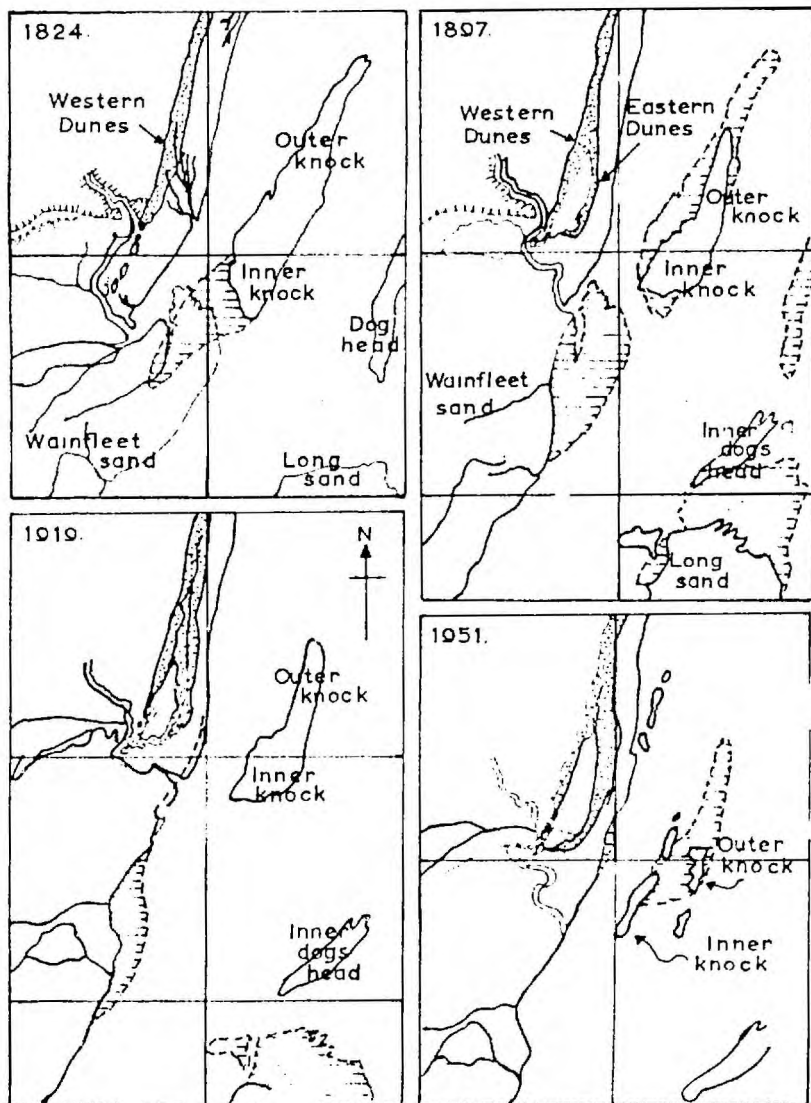
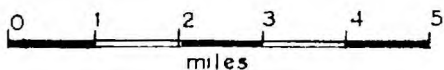


FIG 6. COASTAL AND INSHORE CHANGES AROUND GIBRALTAR POINT.



area lowered to below low water ordinary tides since previous survey.



southern end of the Knock, the spit was split up into four separate segments, and Wainfleet sand to the south was enlarged. King and Barnes suggested that the breakdown of the Knock occurred under stormy conditions. This left the coast relatively exposed and led to the breakdown of the spit. The eroded material so produced, was transported southwards and caused the extension of Wainfleet sand. The present writer draws the attention, at this point, to the drainage channels on the beach shown on this map. These are similar to those occurring on the present beach and they suggest that the beach in 1824 also possessed a ridge and runnel form. The writer also suggests that the sigmoidal salt pans, now seen cutting across the mature marsh and minor dune ridge complex, are relics of these runnels and ebb channels (see Fig. 6 and aerial photos. 1955).

No further map was produced until 1897, 73 years later, and a comparison of the 1824 and 1897 O.S. maps shows that most profound changes occurred during these years (see Fig. 6). There had been a considerable build up of material on the wide beach, particularly at the Point, where the coastline had also built out seawards. A prominent dune belt had become established and this now forms the eastern dune belt. It had much the same sigmoidal configuration as it shows to-day, being joined onto the western dune belt in the north but swinging away seawards from it in the south. Although the ground between the two dune belts which now forms the present mature marsh, was represented on the 1897 O.S. map as a marsh

area. It is reasonable to suppose that the minor dune ridges which interfinger with the mature marsh must also have been in existence at that time. Furthermore the present writer has pointed out in an earlier paragraph that the beach, which was the site of accretion between 1824 and 1897, appears to have possessed a ridge and runnel form. It has already been shown that the physiographic evidence suggests that these dune ridges evolved from a beach ridge and runnel complex. It can also be seen from the maps that during the latter part of the 19th century, Wainfleet sand and the Knock became considerably reduced in area. According to King and Barnes, these changes, which they believe were the result of storms, were largely responsible for controlling the form of the coastline as we see it to-day, because they exposed the southern and northern parts of the area to wave attack. The modifications, which occurred in these two areas, and the reasons for the changes, will, for clarity, be discussed separately. In the southern part of the area there appears to have been a northward recession of the coast. The southern end of the western dune belt and the remnants of the 1779 spit were eroded, only the basal portion of the 1779 spit remained as a markedly hooked feature on the southern end of the western dune belt. King and Barnes suggested that the stormy conditions at this time were also responsible for the construction of the storm beach ridge, which resulted in a reversal of some of the marsh drainage. Evidence collected during the present study shows that this feature does, in fact, rest upon a small mud

cliff which it seems logical to suppose was formed as the result of the cutting back of the marsh which developed between the eastern and western dune belts. As pointed out in the discussion earlier, this feature follows the line of the storm beach ridge and continues westward across the River Steeping. King and Barnes also suggested that the material to build the storm beach ridge was derived in part from a second and newer spit which developed at the southern end of the eastern dune belt after 1824. They state that pebble patches found in the new salt marsh are suitably disposed to represent parts of the foundation of such a spit. However, there is no cartographic evidence to support this theory and any field evidence has since been destroyed or covered up by later deposits. It is reasonable to suggest however, that such a feature may have existed and provided the shelter that allowed the accumulation of the marsh deposits presumably destroyed during the formation of the storm beach ridge, but its exact location and form remains uncertain.

King and Barnes stated that, as a result of the removal of the remnants of the 1779 spit, the outfall of the Steeping was no longer diverted southwestwards and in 1897 entered the sea close to its present day outfall. More will be said about the migrations of the outfall of the River Steeping later in the discussion.

According to King and Barnes the destruction of the northern end of the Knock shown by comparison of the 1824

and 1897 maps, exposed the northern part of the area to erosion. However, while both southern and northern parts of the area suffered erosion the coast between them was still protected by the remaining portion of the Knock and continued to build out seawards. This they believe resulted in the concavo-convex form of the coastline expressed by the

sigmoidal trend of the eastern dune belt. This interpretation implies that erosion was responsible for the embayment of the eastern dune belt where it swings inland and northwards to join the western dune belt, just south of Skegness.

Superficially this embayment appears to truncate the minor dune ridges. However, when traced in the field and on the air photographs (1955) the minor dune ridges show a similar trend to that of the eastern dune belt and there is no clear indication of truncation. Consequently the present writer suggests, as an alternative to King and Barnes suggestion, that the sigmoidal trend of the coastline has been a natural trend of accretion since sometime before 1897. That this is so, is expressed by the sigmoidal form of the minor dune ridges, which ante-date the eastern dune belt. It is further supported by the fact that the accretions of more recent years and particularly the present beach also possess a marked sigmoidal trend, although it may be argued that this would still be the case if erosion was responsible for the initial sigmoidal trend in development.

The 1919 O.S. map shows that after 1897 and during the early part of the 20th century accretion continued, despite

the fact that there was further slight reduction in the size of the Knock and Wainfleet sand. At the Point the beach, built out seawards and the eastern dune belt generally increased in width. The marsh between the western and eastern dune belts appears to have been reduced in area during this time, probably as the result of the addition of wind blown sand carried inland from the rapidly growing beach and eastern dune belt to seaward and by development of the storm beach ridge. The outfall of the Steeping in 1919 was situated further north than in 1897 and, according to King and Barnes, entered the sea as a point equivalent to the southern end of the present spit.

The latest map to be produced by the survey was that in 1951. When compared with the 1919 map it shows that considerable changes again occurred in the years between these surveys. The Knock has been broken down into a number of smaller offshore banks; the two larger ones being called the Inner and Outer Knocks, according to their respective positions relative to the coastline; the former being $\frac{3}{4}$ mile, the latter $1\frac{1}{2}$ miles offshore. Wainfleet sand, however, showed little modification.

The storm beach ridge and southern end of the eastern dune belt appear to have suffered erosion after 1919 which according to King and Barnes was again associated with the breakdown of the Knock. However, the coastline north of the Point, although more exposed during these years, continued to build out and by 1951 was as much as $\frac{1}{4}$ mile to seaward of its

position in 1919. Also new dune ridges and marsh strips had developed in the northern embayment. The marsh area between the eastern and western dune belts also appears to have become more extensive.

Finally the writer draws attention to the fact that since 1951 up until the present, the Gibraltar Point area has been more exposed than ever in the previous two hundred years. The offshore banks, now even further diminished in area, afford little protection, and although the area has been effected by several severe storms in recent years (e.g. that of 1953), accretion has still been dominant (see aerial photo. and 1951 O.S. map). Therefore the present writer suggests in opposition to King and Barnes' conclusions, that the breakdown of the offshore banks has not been the controlling factor in the development, and in particular the sigmoidal form of the coastline, are largely the result of the natural trend of accretion. That the area has built out more at the Point than further north is due to the fact that the Point marks the terminal point of longshore drift. The break in trend of coastline at the Point is responsible for considerable wave refraction and as a result of the reduction in wave energy much of the load transported by longshore drift is deposited there. This will be discussed in greater detail in a later chapter.

The River Steeping outfall, running across the N-S trend of the coastline just south of the Point may also have been a

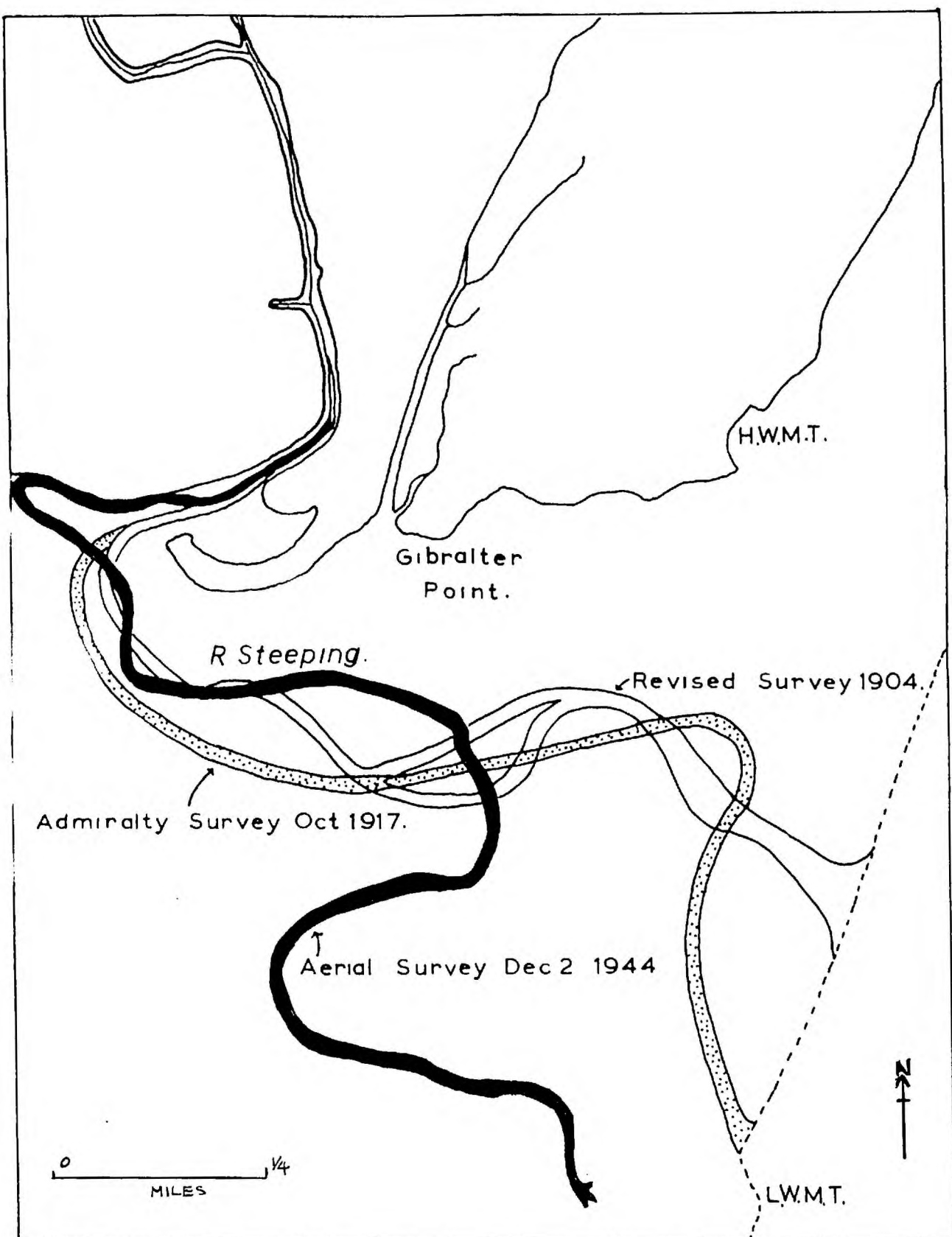


FIG. 7. Migration of the River Steeping outfall
from 1904-1944.

considerable influence. It can be shown (see Fig. 7) that the Steeping outfall has changed position quite markedly throughout the last two centuries. Its constant migration may have been responsible for many of the changes in the southern part of the area attributed by King and Barnes to the breakdown of the southern end of the Knock which exposed this part of the area to storm waves.

The present writer, however does not discard the suggestion that storm waves have played a part in controlling the trend of development of the area, and for example, supports King and Barnes' belief that such waves were responsible for the formation of the storm beach ridge and marsh cliff upon which it rests.

CHAPTER 4.

THE SEDIMENTS.

Grannlometric Analysis.

General.

The grain size frequency distributions of over 100 surface samples, covering all environments and sub-environments, have been determined, but in order to avoid repetition only about sixty have been plotted. The sampling stations are shown on a map (see map 1) and the results presented in tables (see tables 1-4) at the back of the thesis.

Sampling.

The surface samples were collected by pushing small waxed cartons into the surface sediment. These provided small cores of the top 2 inches. Essentially, the sampling was done on a series of traverses across the area, but in addition, samples of features of specific interest were also collected. Care was taken to use only the top $\frac{1}{2}$ inch for analysis.

Pretreatment and Methods of Analysis.

The Samples were treated with 30⁰ H₂O₂ to break down the binding effect of the organic matter. This treatment was repeated until all the organic matter was oxidised. This was not necessary with the sands, but in order to attain uniformity, all samples were so treated.

The samples were then washed, dried, weighed and dispersed using a dilute solution of Calgon (30 gms./litre) as a dispersing agent. Wherever material greater than 2 mm was present this was sieved off and weighed. The remainder was transferred to a 1000 ml cylinder and pipette analysis was made

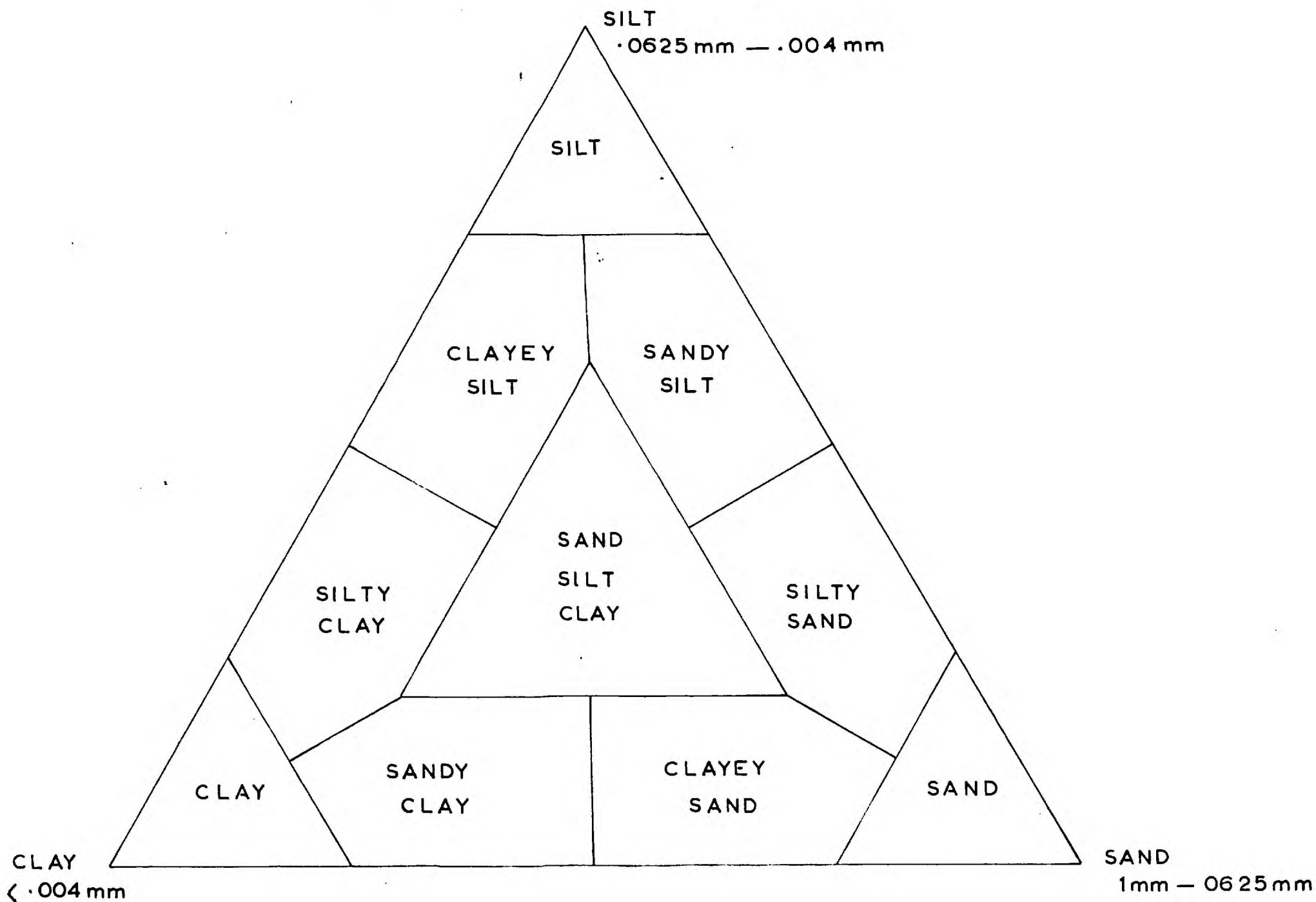


FIG. 8. REVISED NOMENCLATURE BASED ON SAND / SILT / CLAY
RATIOS. (After Shepard 1954).

to determine the proportions of material in the grades 0.062-0.031; 0.031-0.016; 0.016-0.008 and 0.008-0.004 mm. Material less than 0.0625 mm in size was then decanted off. It was usually found that ten decantations were required for the clayey sediments.

The remaining sand fraction was dried, and weighed and then split on a rotary sample splitter into fractions each approximately 4 gms. in weight.

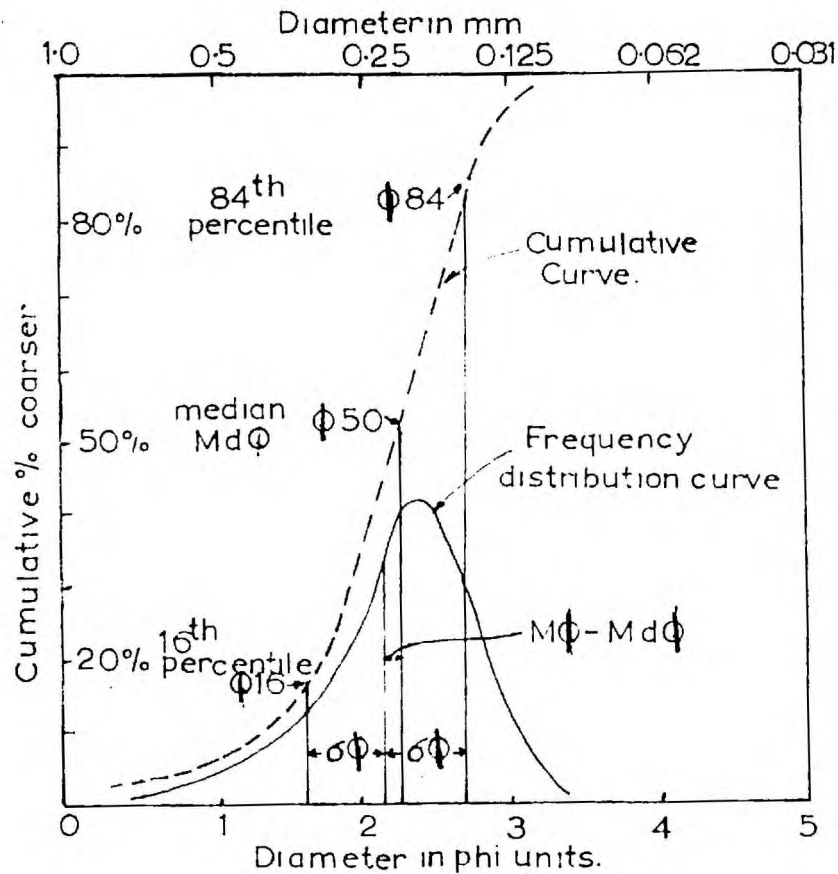
One of these splits was then analysed for material between the grades 0.5: 0.5-0.35; 0.35-0.25; 0.25-0.177; 0.177-0.125; 0.125-0.088; 0.088-0.0625 mm., using a settling tube method (see Emery 1958). The volume of material accumulated being plotted against time. The results of the pipette, settling tube and sieve methods of analysis were combined and the percentages of the various grades calculated and presented in tables (see tables 1-4).

Presentation of Results.

The results are plotted in several ways. They are plotted on triangular diagrams with sand, silt and clay as the end members, using the terminology of Shepard (1959) (see Fig. 8). However, due to a wide range of grain sizes and considerable quantities of gravel in certain samples it is more convenient to plot deposits with gravel, sand and silt + clay as end members. In addition the sediments have also been described using the terminology suggested by Kruit (see Nota 1958). This system of nomenclature is again based on a

triangular plot of the ratios between the main components of sediment. The critical limits are 5% and 30%, the naming does not include the components representing less than 5% of the total sediment. If a component forms more than 30% of the whole, the name is generally a noun; if it makes up 5-30% of the sediment it is indicated by an adjective. However if two components make up more than 30% of the sediment the finer grained component is indicated by a noun, the other by an adjective with the adverb 'very'. For example "silt, very sandy" and not "sand, very silty." "Pelite" is the collective name for totally terrigenous material smaller than 0.05 mm. Apparently the quantitative limits of 5% and 30%, which include a broadly spaced central interval, were chosen for several reasons. First the discrepancies between estimates and analyses of the ratios of the main components are greatest in the central part of the gradation series. Secondly, a mixture of two sediment components in ratios of 40% and 60% will not differ essentially from a mixture of the same two components in ratios of 60% and 40% respectively; however, a mixture of the same two components in ratios of 80% and 20% will clearly differ in structure from a mixture of the same two components in ratios of 60% and 40% respectively.

Cumulative curves have been constructed for each sample. These have been drawn in two ways. In the one, the diameters are plotted in linear mm. units on arithmetic probability paper using the method devised by Doeglas (1941, '46, '50). In the



First three moments {

- Median diameter $Md\phi = 50^{th}$ percentile
- Mean diameter $= \frac{1}{2}(\phi_{84} + \phi_{16})$
- Standard deviation measure (sorting)
 $= \sigma\phi = \frac{1}{2}(\phi_{84} - \phi_{16})$
- Skewness measure or asymmetry
 $= \alpha\phi = \frac{M\phi - Md\phi}{\sigma\phi}$

FIG.9. GRAPHIC ILLUSTRATION OF INMAN'S PARAMETERS.
 (INMAN 1955)

other, they are plotted in phi units on arithmetic probability paper. The median diameter, standard deviation and skewness measures have been calculated wherever possible. (These are presented in tables at the back of the thesis). They were calculated using the method of Inman (1949, '52, '53). Inman recommended the use of five parameters, computed from the five percentile diameters ϕ 5, ϕ 16, ϕ 50, ϕ 84 and ϕ 95. These parameters are the mean (or median), standard deviation, kurtosis and two measures of skewness (see Fig.9). The second of the two latter measures is sensitive to the skew properties in the "tails" of a sediment distribution. These represent five significant points on the cumulative curve and according to Inman not only increase the value of the data listed for a sediment but in many cases eliminates the need to include the complete mechanical analysis of the sediment. Inman's method, however, has a severe limitation in that it is often not possible to determine the 16th, 84th and sometimes even the 50th percentiles of many coarse and fine grained sediments, so that the median, standard deviation and skewness measures cannot be calculated. This is illustrated by a comparison of grain size frequency distribution curves of sediments studied in the present investigation, which cover a wide range of grain sizes (see Fig.10).

Van Andel (1954) pointed out that Inman's parameters are only applicable to unimodal sediment distributions and were of no significance when dealing with bimodal and polymodal

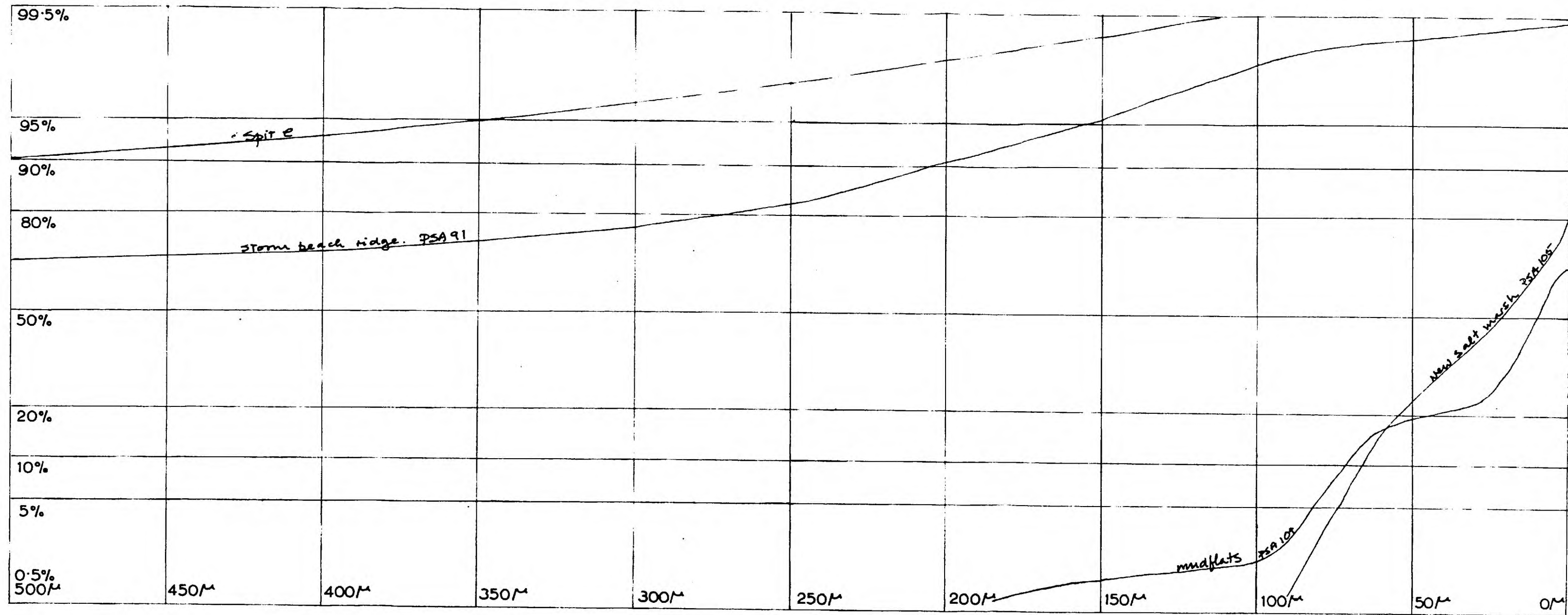


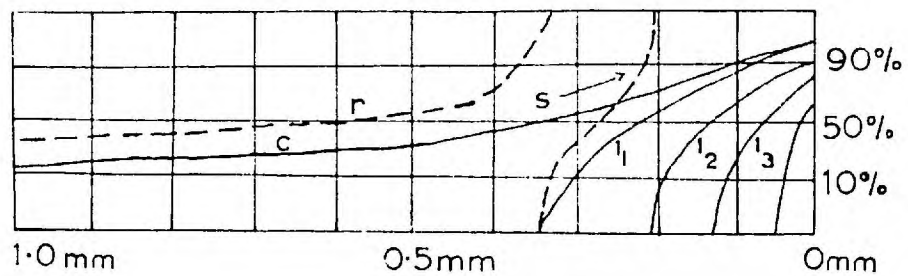
FIG10. Diagram to show limitations of parameters proposed by Inman 1952.

distributions. The sediments of the forebeach and dunes, in the area studied, are essentially unimodal but those of the backbeach, spit and storm beach ridge are strongly bimodal. The latter are largely sand and gravel distributions with only a very small overlap. This is shown by the shapes of the cumulative curves which are essentially flat between 0.25mm and 0.5mm. It is evident in the field that the backbeach, spit and storm beach ridge would exist and continue to develop even if gravel was not available. Further, although the sand fraction is in movement under all conditions of wave activity, the gravel fraction is only moved by strong wave action. It was decided therefore to analyse the deposits of the backbeach spit and storm beach ridge in two ways:-

1. The sand and gravel were analysed together.
2. The sand fractions were isolated and treated as a separate distribution.

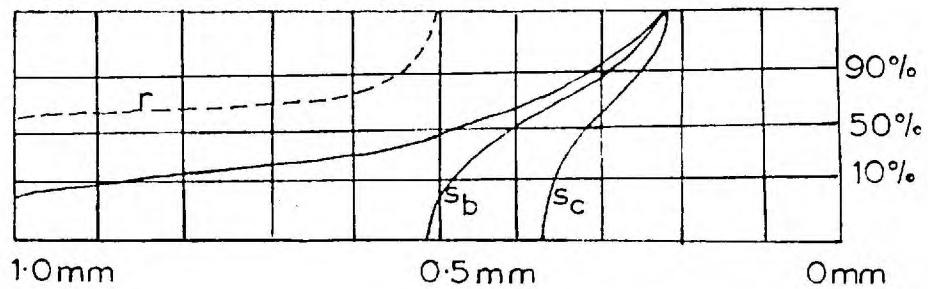
The latter method allows the sands of the forebeach, backbeach spit, storm beach ridge and dunes to be compared and also allows them to be compared with similar deposits from other parts of the world, which were studied by Mason and Polk (1958) Stewart (1958), ^{and Chamberlain} Shepard and Young (1961), Friedman (1961) and Inman (1955).

As mentioned earlier, the results are also plotted on arithmetic probability paper of the type used by Douglas (1941 etc). He worked on the basis that the transporting media separate the sediment load into well defined fractions



differentiation of transported material.

(after Doeglas 1946)



Differentiation of bottom material

(after Doeglas 1946)

FIG.11.

FIG.12.

Curve A-B is the result of mixing fractions t_1 - t_5

NB. The straightness of the curve.

(after Doeglas 1941)

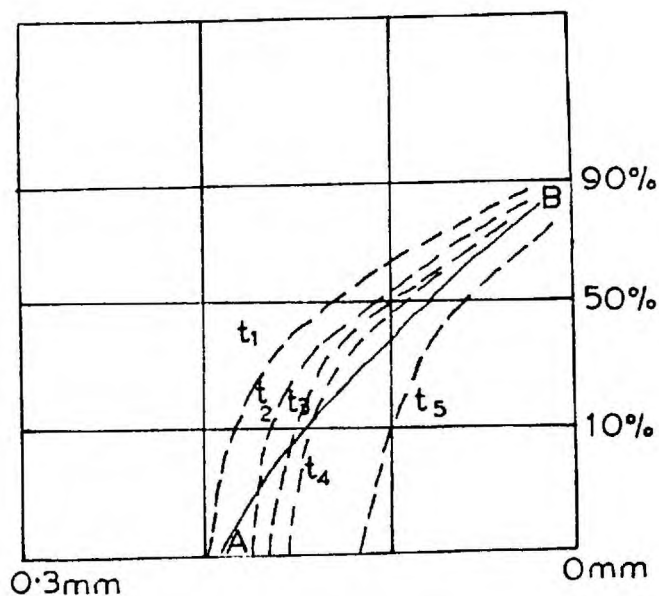


FIG.13.

Curve X is a composite curve made by mixing several 't' fractions hence the almost straight trend.

Curves Z and Y show the effects of adding coarse grains forming a tail.

and producing a curve concave upwards instead

of convex. (after Doeglas 1946)

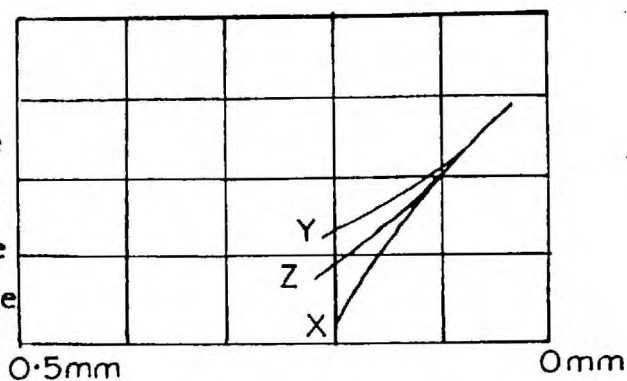
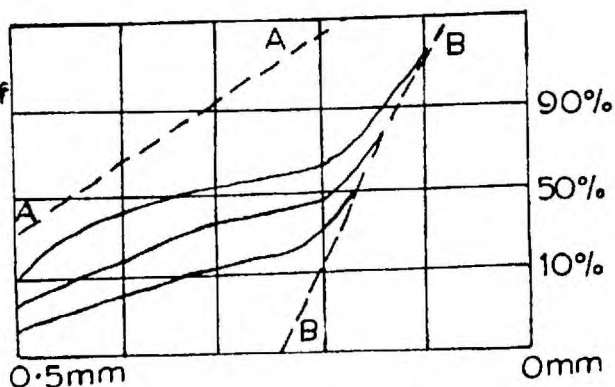


FIG.14

Synthetic mixtures of two components A and B each of which has a symmetrical size frequency distribution (after Doeglas 1946)



50A + 50B
25A + 25B
10A + 90B

which he termed "r" "s" and "t" distributions (see Fig. 11). He realised that natural processes rarely differentiate the sediment into these simple fractions, but that more often in nature these fractions were mixed, giving rise to composite size frequency distributions. However he showed that mixing of two or all of the r, s and t distributions resulted in a straightening of the size frequency curve (see Fig. 12). Also if coarser particles are added to the "mixed" or "unmixed" sediments, say of the argillaceous type they produce a concave curve rather than the convex and straight curves shown by the unmixed and mixed sediments respectively (see Fig. 13). Doeglas also demonstrated the effects of mixing of two sediments with symmetrical grain size frequency distributions (see Fig. 14), and showed that the size frequency distributions of both could be deduced from the curve. However, this was not possible for mixtures of three or more components.

His method shows that grain size frequency distributions can be interpreted in terms of the two processes "differentiation" and "mixing" and cumulative curves of sediments of r, s and t types or their mixtures can be related to the conditions of deposition and so can be valuable indicators of facies.

The results of the granulometric analyses made during the present investigation are presented in the various ways described in order that they may be compared with those of Dutch geologists such as Nota (1957), Koldewijn (1958), Van Anđel (1954) and Doeglas (1941, '46, '50, '51), who favour arithmetic probability paper, and also with those of such

American workers as Inman and Chamberlain (1955), Stewart (1958) and Shepard and Young (1961) who in recent years have tended to favour the use of triangular plots and various computed parameters.

Interpretation.

The sediments of the Gibraltar Point area, are termed sandy gravels, gravelly sands, sands, pelitic sands, sandy pelites and pelites according to the nomenclature of Kruit, but in the terminology of Shepard (1954) the sands, pelitic sands, sandy pelites and pelites of Kruit are called sands, silty sands, sandy silts, clayey silts and silty clays. It was found that the sediments of certain environments such as the dunes and marshes possess relatively limited ranges in grain size and are easily distinguished from one another, while others, such as those of the spit and storm beach ridge, although easily distinguished from the above cannot be separated from one another in terms of granulometry alone.

When compared with sediments of dunes, beaches and intertidal flats described by Doeglas (1940, '41 etc.), the deposits of the Gibraltar Point area are mainly "composite" or "mixed" sediments. They consist essentially of a sandy component (s type of Doeglas) with either a finer or coarser component (t type or r type of Doeglas), or both. Some of the deposits, particularly those of the marshes consist almost entirely of fine material (t type of Doeglas), and being well laminated, each lamina may represent a "simple" sediment. No

pure sands (s type of Doeglas) were found. This may be due to the fact that bulk samples were used for analysis, in which sands with "s" type distributions may have been present as individual laminae. However, Doeglas pointed out that sandy deposits invariably contain smaller amounts of finer or coarser material.

Although a more detailed description and interpretation of the granulometric analyses of the deposits of the respective environments and sub-environments will be made in the following chapters, it is necessary at this point to discuss the possibility of modifications to the cumulative curves as a result of the method of sampling and techniques of analysis.
(Continued on next page).

As stated earlier, care was taken to use only the top $\frac{1}{2}$ inch of each sample collected for analysis. However, this was extracted and analysed in bulk, consequently it may be argued that such treatment of finely laminated deposits, as many of the samples were, would be responsible for many of mixed and composite sediment types shown by the resulting cumulative curves. However, in the case of samples of inter-laminated sand and pelite or silt and clay, the laminae were too thin to separate and analyse individually and so had to be subjected to bulk analysis along with the other samples.

In the present study the sand grades (2 mm - 0.625 mm) were analysed by a settling tube method, as opposed to the more commonly used sieve method. The combination of the methods, sieve-settling tube-pipette, instead of the two methods sieve and pipette may have increased the possibility of abrupt breaks in the cumulative curves which sometimes occur when more than one method is used. However, a careful study of the curves shows that whenever a break occurs at the two points at which the samples were split i.e. 2 mm and 0.625 mm, the break probably has a genetic significance. It may be noted that many of the curves continue across these points without any marked deviation, the break, if there is one, occurring above or below these two points. The writer therefore suggests that splitting the sample into 3 major fractions, each of which is analysed by a different method, does not have any apparent effect upon the cumulative curve,

which may render its interpretation inaccurate.

Furthermore the writer feels that the use of a settling tube method rather than sieves for the sandy material is justifiable on the basis that it takes into consideration the effective densities of particles rather than their diameters.

Consequently as for example, in the present study, sand sized particles of coal and mica with relatively low effective densities are concentrated with the silt and clay, by using a settling tube method. This is in accordance with their natural hydrodynamic conditions of deposition. If however sieves are used the coal and mica would be fractionated away as sand, thus producing an extended coarse "tail" on the cumulative curves for the sands. Heavy minerals on the other hand, having greater effective densities would, although less than sand size, be concentrated with the silt and clay if sieves were used; thus producing an extended "tail" on the finer end of the cumulative curve. This again is contrary to the natural conditions of deposition and may, if sieves are used, result in the impression that the sand fraction is badly sorted when in fact the converse is true.

Composition.

Coarse Fraction Analysis.

The compositions of the sand fractions of fifty samples of the sediments of the various sub-environments were investigated using the method of Shepard and Moore (1954). A split of each sample was soaked in Calgon solution to disperse

the silt and clay and after standing overnight was washed through a 0.0625 mm sieve. The residue was dried and split into smaller fractions, after which each was spread in a small tray and examined under a binocular microscope, fitted with a mechanical stage. Estimates were made of significant constituents, each being calculated as a percentage of the total. Three counts of 300 grains were made for each sample.

Constituents making up less than 1% of the total are regarded as insignificant but when they serve as further indicators of sub-environmental conditions of deposition they are given due consideration in the text.

It was found that terrigenous sand, consisting largely of quartz grains with smaller amounts of feldspar and rock fragments made up the bulk of the sediments in all sub-environments except the new salt marsh and mature marsh. * The reasons for

this and other differences are discussed in the following

* Hollow, spherical bodies called "SPHERES" are found in the chapters. marsh deposits. They are greater than 0.0625 mm in diameter. Two types are found: white to transparent, porous bodies, and smooth, Mineralogy. Yellow brown to black spheres. They are non-calcareous and are probably seed cases.

In the present investigation a cursory examination of the light and heavy minerals was made. Previous to this, Baak (1936) studied the heavy minerals of the Recent sediments of the North Sea area including the Wash. Hardy (1920) and Evans (1960) made limited studies of the Recent intertidal sediments of the Wash. The results of the present examination correspond very closely with those of the earlier workers.

It was found that heavy minerals formed 10-15% by weight

of the terrigenous fractions of all the samples examined. Of these, amphiboles, pyroxenes, garnets, zircons, epidote and opaques were the most common constituents. The pyroxenes consisted in the main of augite and the amphiboles mainly of hornblende. Opaques and garnets were notably more common in the coarser grained sediment, while zircons were more common in the finer. This agrees with the results of Baak (1936) and Evans (1960). Other minerals found less frequently were:- anatase, andalusite, brookite, clinozoisite, corundum, kyanite, rutile, sillimanite, staurolite, tourmaline and zoisite.

The light fractions were found to consist of quartz, mica and feldspar. Quartz was found to be the dominant constituent in most sub-environments making up as much as 80-90% of the total light minerals in many cases, particularly in the coarser sediments. Mica however, was found to be abundant in the finer sediments of the marshes, particularly in the new salt marsh and mature marsh.

Staining showed that feldspar was present in small amounts in all samples, but never exceeded 18% of the total light fraction. Estimates showed that orthoclase feldspar was for more common ^{than} plagioclase and in one case made up as much as 13% of the total while the plagioclase rarely exceeded 5% and was sometimes absent.

The author feels that a more intensive study of the mineralogy may prove to be a further means of distinguishing

between sub-environments.

Sedimentary Structures.

A great deal of the writers time was spent studying the sedimentary structures of the deposits of the various sub-environments. Attempts have been made, whenever possible to relate their origin to sub-environmental conditions (see later chapters).

Methods of Study.

A study was made of all the surface features, such as ripple marks, trails etc. and these were photographed and sketched.

Following this the sub-surface features were studied; several methods were used in this investigation.

1. In the early stages of the research, trenches were dug at various localities to expose the stratification. The surfaces so exposed were left to dry and wind currents allowed to etch out the structures.
2. Approximately sixty shallow cores each about 2' in length were collected. These were split open in the laboratory and allowed to dry until the structures were best displayed. They were photographed and sketched. It was found that cores of sandy deposits, containing relatively little or no silt and clay showed little evidence of sedimentary structures when treated as described as above.

However a method devised by Reineck (1961) for the study deposits was used with considerable success. In this method

(see Fig. 15), metal boxes were driven vertically into the sediment, and the boxes and the undisturbed samples they contained were then dug out. In the laboratory the boxes were placed in an oven until the sample was dry and the sand then impregnated with molten paraffin wax. The wax soaks into the sample and penetrates more readily along certain structural planes than others. It hardens on cooling and when the unimpregnated sand is carefully washed away from the back of the sample, a surface is exposed which displays the sedimentary structures in relief. These impregnated samples were photographed. In the field attempts were made to collect the samples with various orientations in order to study and record the sedimentary structures in three dimensions.

Structures (General).

The deposits of the Gibraltar Point area are in general well stratified and ^{the} terminology proposed by Holme and Heir (1957) (see Fig. 16) was found adequate for their description. Locally the stratification has been disturbed by inorganic and or organic agents. Consequently the structures may be divided into two groups according to their mode of origin i.e. 'inorganic' and 'organic' forms. These may be listed as follows:-

Inorganic. - Structures produced by wave current and wind action.

- a. stratification and cross stratification.
- b. diastems and scour and fill structures.
- c. unconformities.
- d. ripple marks.

- e. nodules.
- f. mud pellets, flakes and balls.
- g. air entrapment structures.
- h. pencecontemporaneous deformation structures.
- i. miscellaneous structures e.g. pill marks, beach cusps, lincation marks etc.

Organic. - Structures produced by:-

- a. molluscs.
- b. annelids.
- c. arthropods.
- d. birds.
- e. mammals.
- f. plants.

These will be described in detail in the following chapters.

QUALITATIVE TERMINOLOGY FOR LAYERED SEDIMENTS.

	<i>Horizontally Stratified</i>	<i>Cross-stratified</i>
BASIC UNIT; SINGLE LAYER	STRATUM	CROSS-STRATUM
GROUP OF STRATA (OR CROSS STRATA) IN CONFORMABLE SERIES	SET (OF STRATA)	SET (OF CROSS STRATA)
LAYER COMPOSED OF TWO OR MORE SETS	CO-SET	CO-SET
LAYER COMPOUNDED FROM STRATA AND CROSS-STRATA	COMPOSITE SET	

QUANTITATIVE TERMINOLOGY FOR LAYERED SEDIMENTS.

<i>Stratification</i>	<i>Cross stratification</i>	<i>Thickness</i>
VERY THICK-BEDDED	VERY THICKLY CROSS-BEDDED	GREATER THAN 120 cm
THICK-BEDDED	THICKLY CROSS-BEDDED	120 - 60 cm
THIN BEDDED	THINLY CROSS BEDDED	60 - 5 cm
VERY THIN BEDDED	VERY THINLY CROSS-BEDDED	5-1 cm
LAMINATED	CROSS-LAMINATED	1 cm - 2 mm
THINLY LAMINATED	THINLY CROSS-LAMINATED	2 mm or less

The classification of cross stratification used is primarily based on the lower bounding surface of a set of cross strata. It includes three basic types: SIMPLE, PLANAR, and TROUGH.

FIG16 THE CLASSIFICATION AND TERMINOLOGY FOR STRATIFICATION AND CROSS-STRATIFICATION AS PROPOSED BY MCKEE and WEIR 1952.

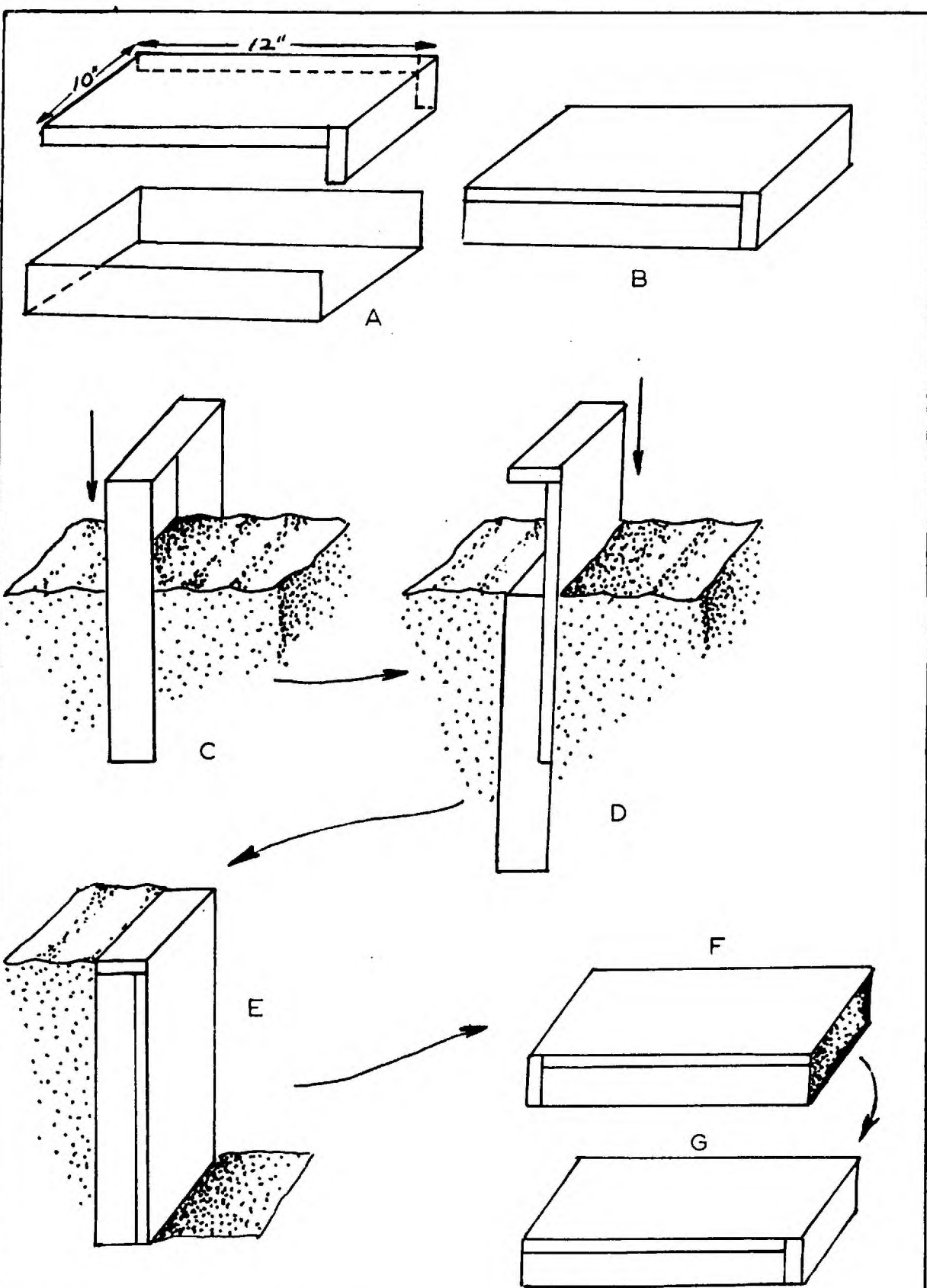
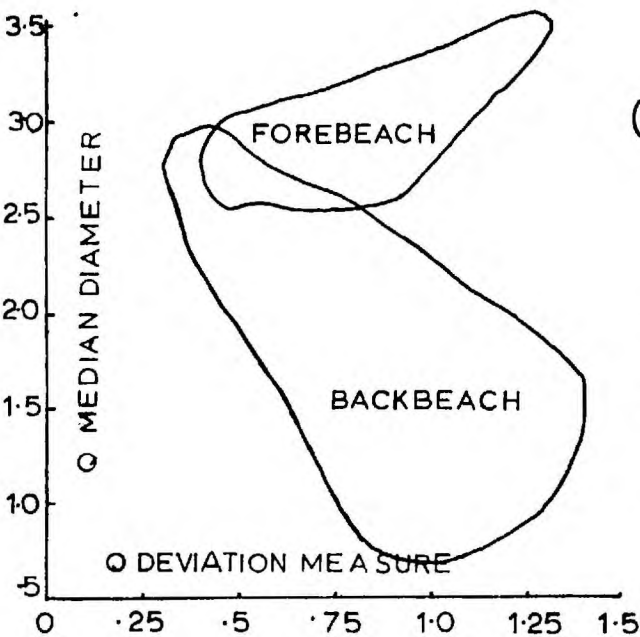
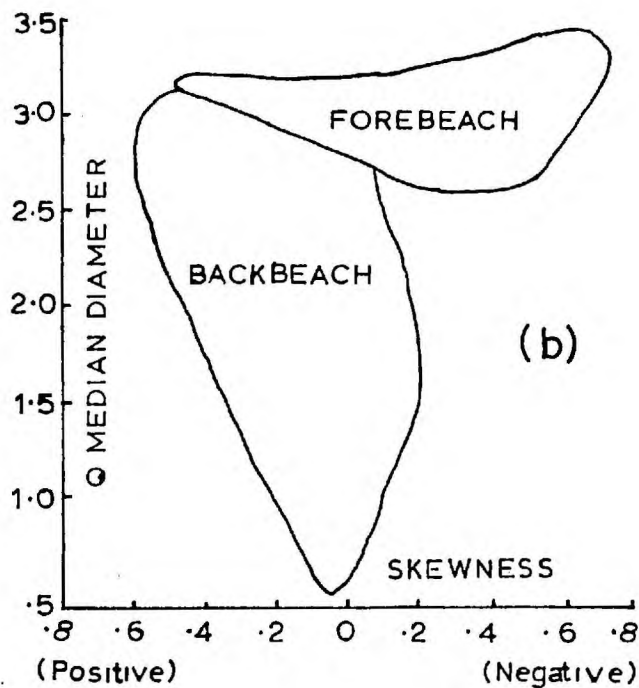


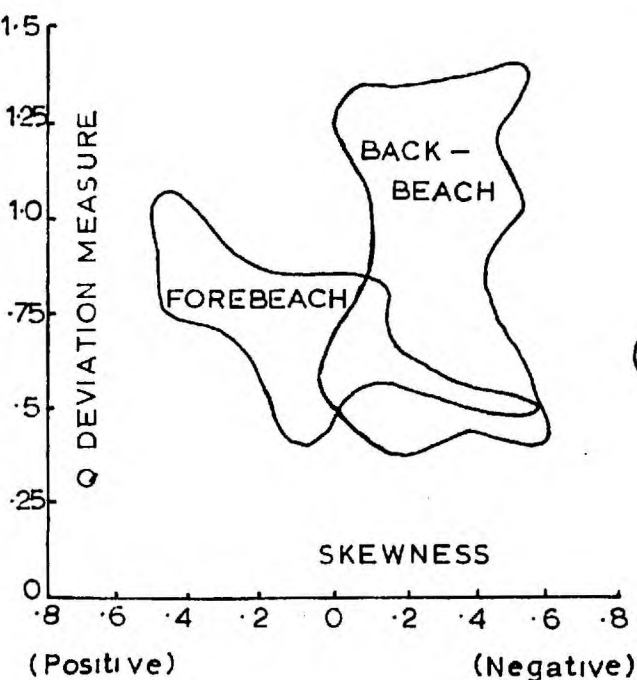
FIG 15 Diagram showing how metal boxes are used to collect undisturbed sand samples. (NB See also Reineck (1961).)



(a)



(b)



(c)

FIG.18.

Diagram showing ranges of Q median diameter, deviation measure, and skewness values for sand fraction of Forebeach and Backbeach deposits.

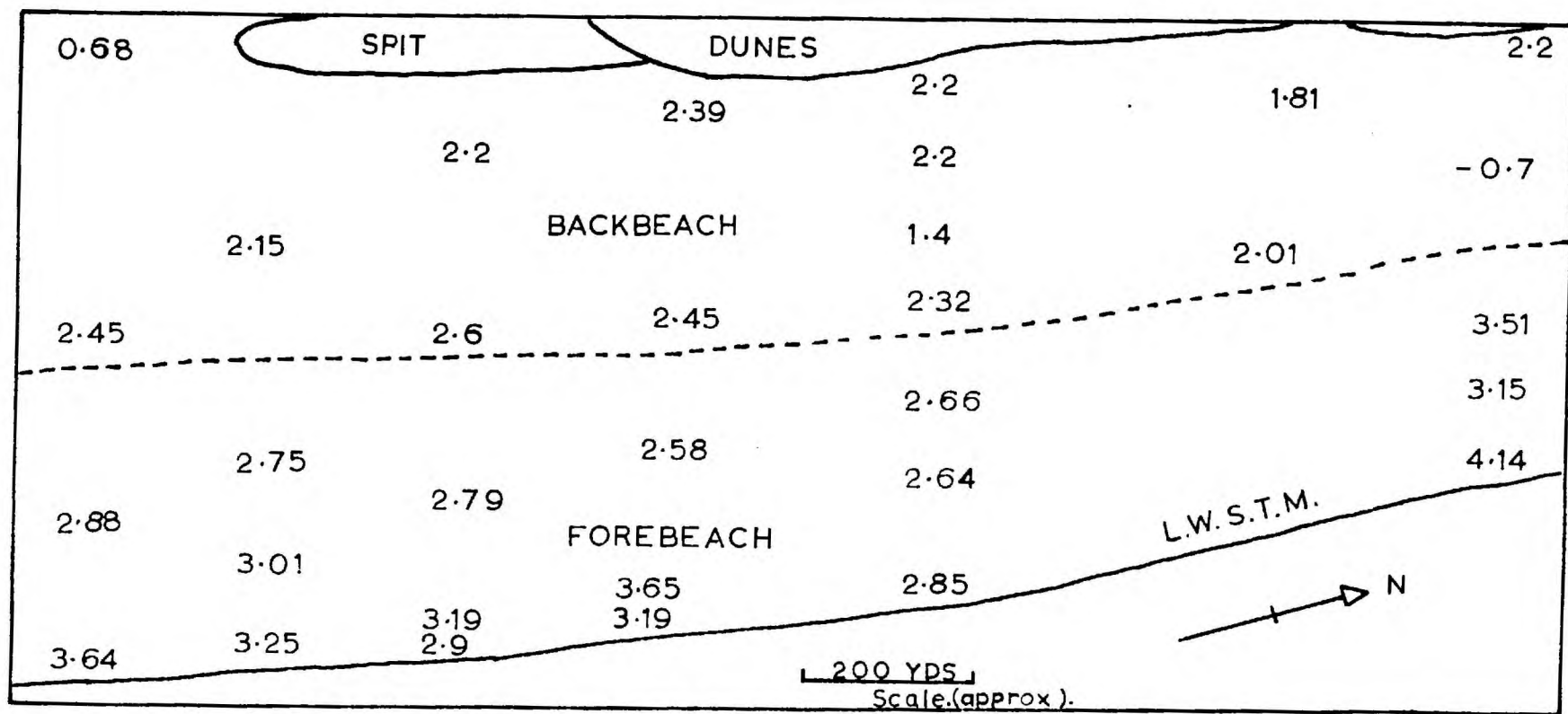


FIG.17. Diagram showing areal variation of Q median diameter of beach deposits.

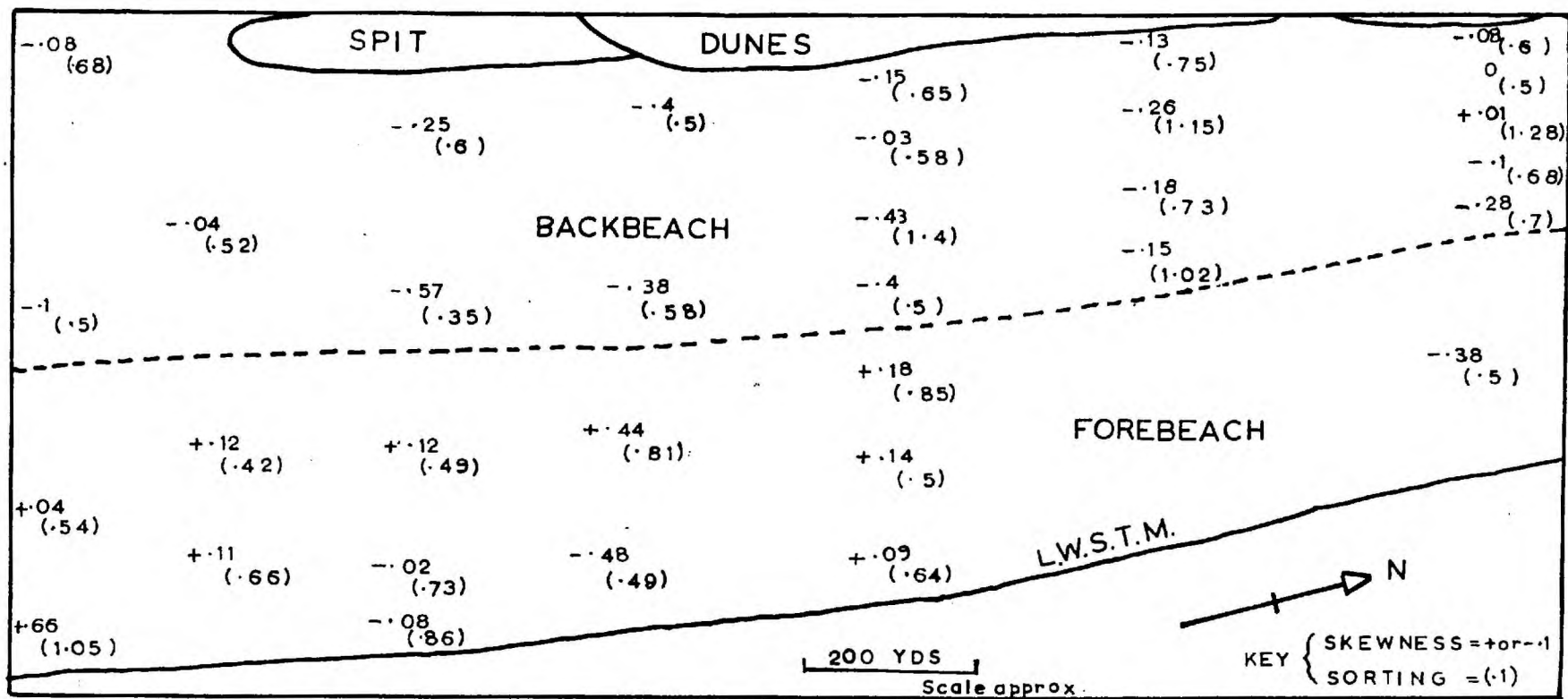


FIG 19. Diagram showing areal variation of Q deviation and skewness measures of the sand fractions of forebeach and backbeach deposits.

CHAPTER 5.

Beach Deposits.

The beach deposits are dominantly sands. On the back-beach the sand is locally gravelly and on the forebeach it tends to be muddy. There is a considerable areal variation in median diameter. It increases in value in a direction normal to the shoreline and shows a gradation from the forebeach to the backbeach (See Fig. 17).

The sand fractions of the forebeach are usually finer grained than those of the backbeach, but since these deposits are gradational there tends to be considerable amount of overlap in ϕ median diameter values. The ϕ deviation measure values show a similar irregular pattern, although the sands of the forebeach tend to be better sorted (see Fig. 18 (a)). ϕ Skewness values usually differ markedly from forebeach to backbeach. Whereas the forebeach sands tend to have a positive skewness, those of the backbeach tend to have a negative skewness (see Fig. 18 (b & c)) (Fig. 19.)

The beach deposits, as a whole, are well laminated, but whereas the forebeach deposits show abundant evidence of organic disturbance the backbeach sediments are virtually unaffected.

Forebeach Deposits.

Granulometric Analysis.

The deposits of the forebeach are sands with small amounts of silt and clay. According to the terminology of Shephard (1954) they are sands (see Fig. 20), but according

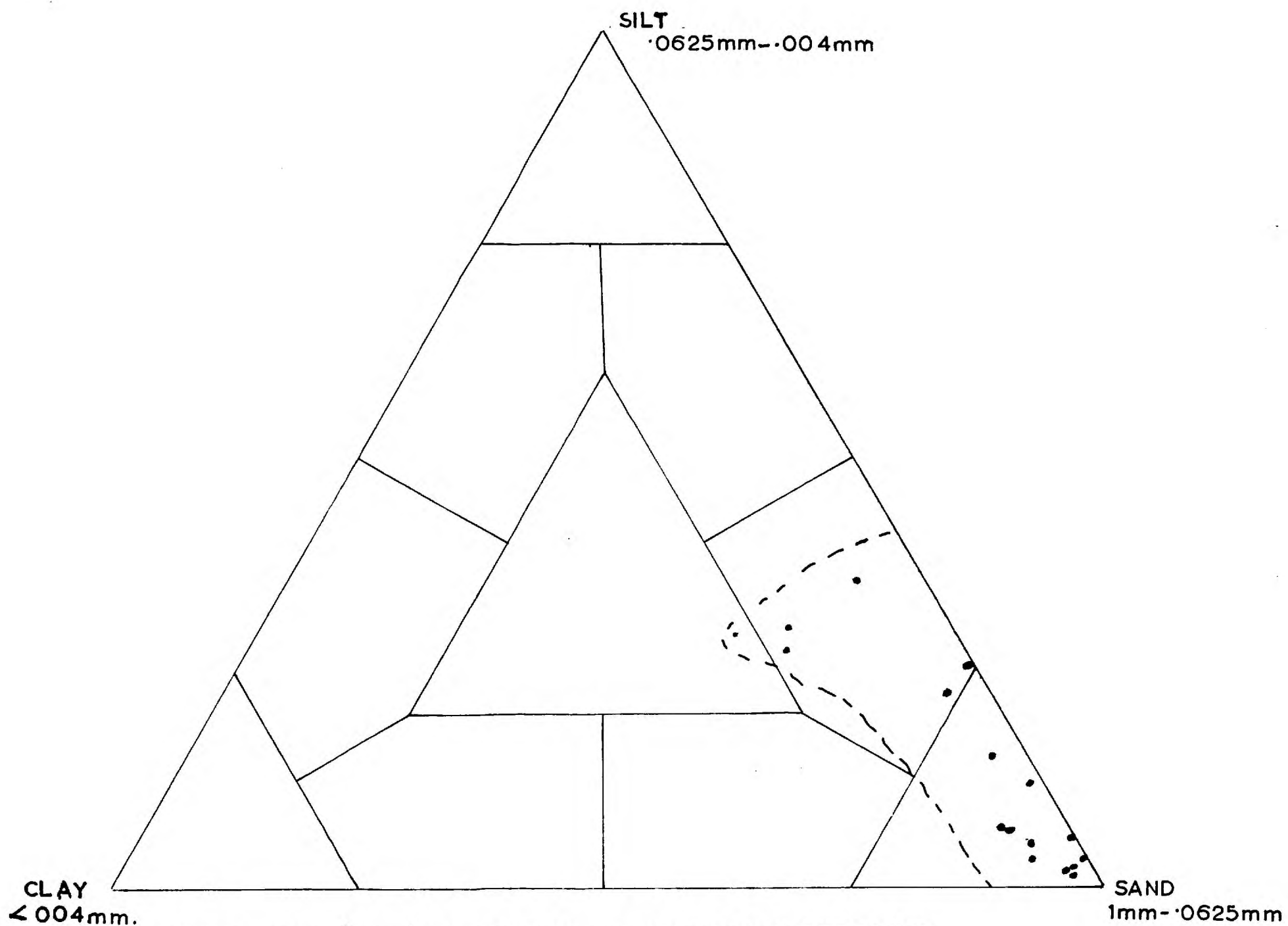
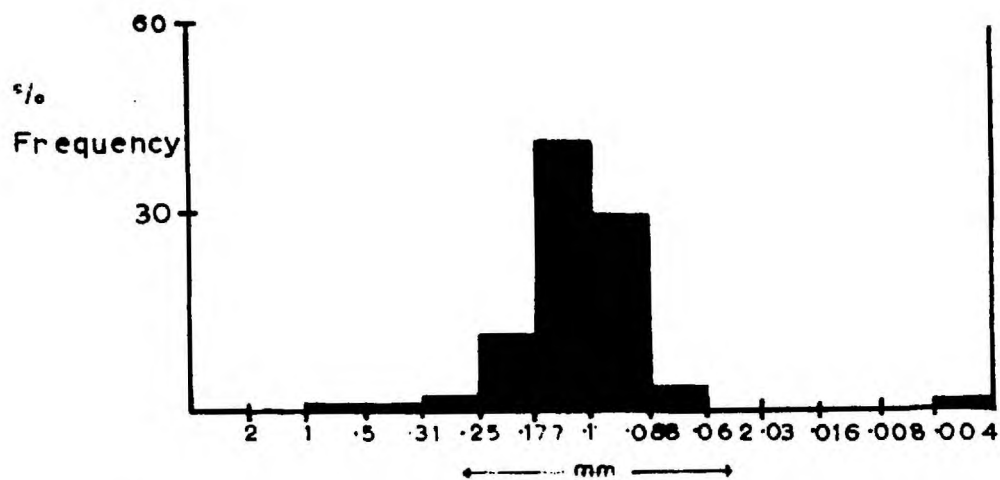
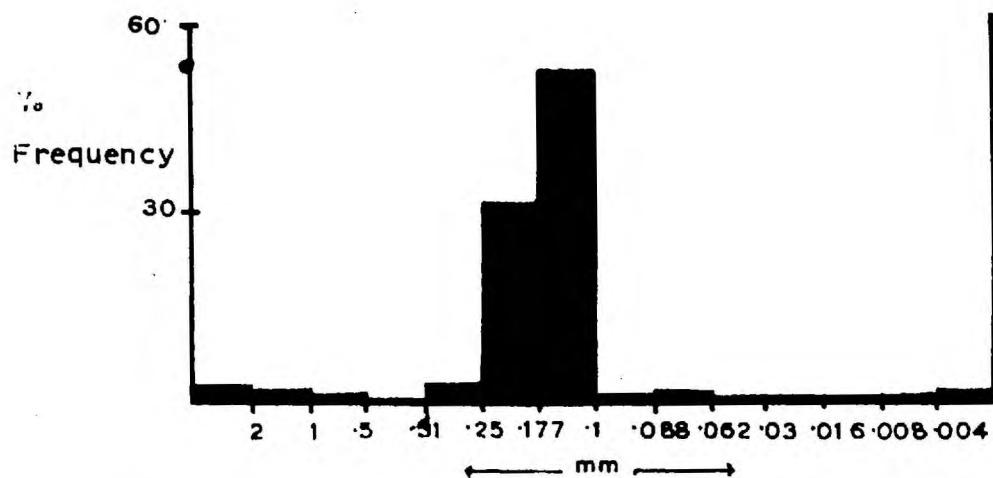


FIG 20 SAND/SILT/CLAY RATIOS OF FOREBEACH DEPOSITS.



(a) Histogram showing grain size distribution of sample PSA.45. from lower forebeach.



(b) Histogram showing grain size distribution of sample PSA 24 from upper forebeach.

FIG 24.

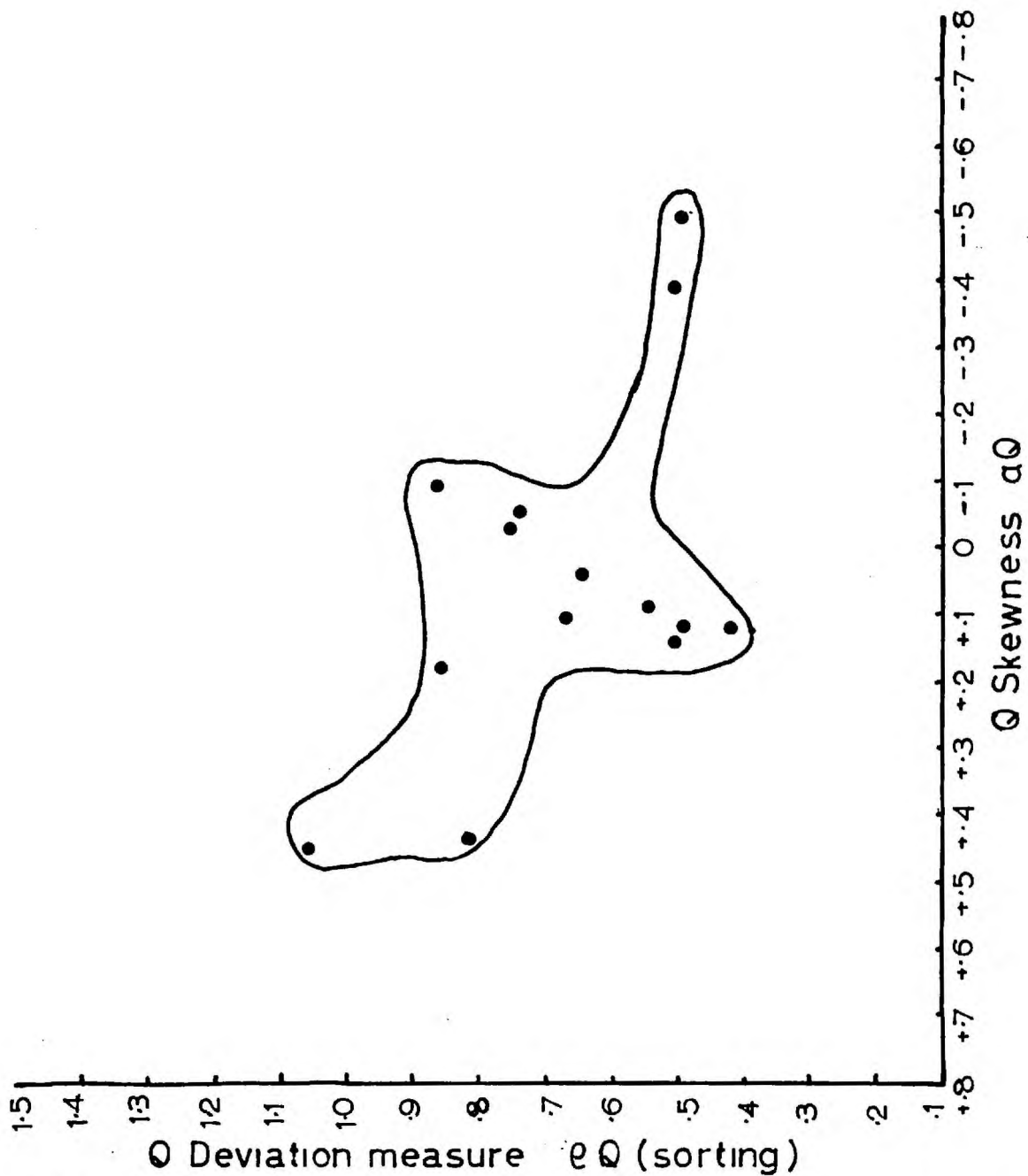


FIG 23. Sorting against skewness for Forebeach deposits.
- Sand fraction

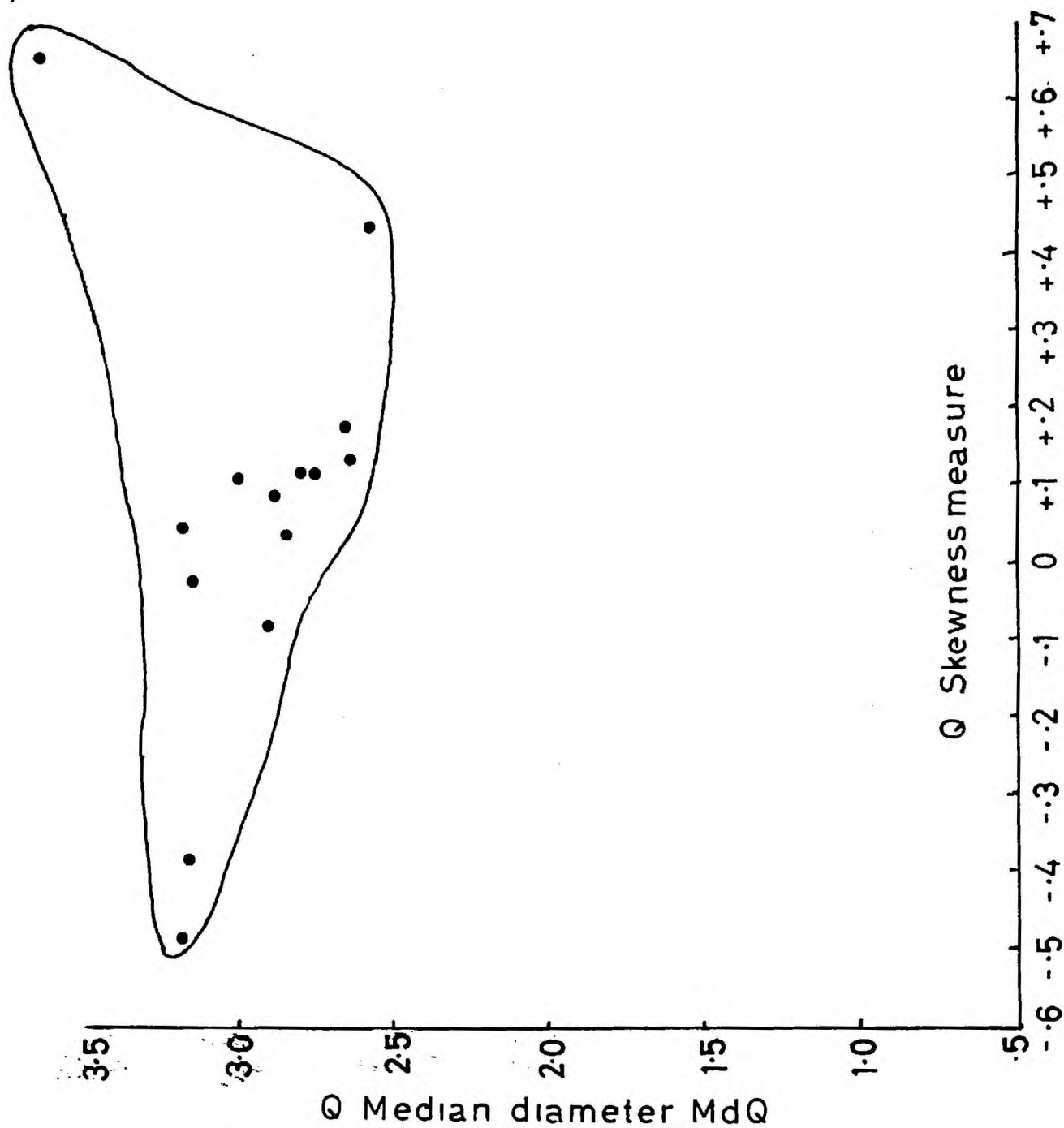


FIG22. Median diameter against skewness for
Forebeach deposits.- Sand fraction

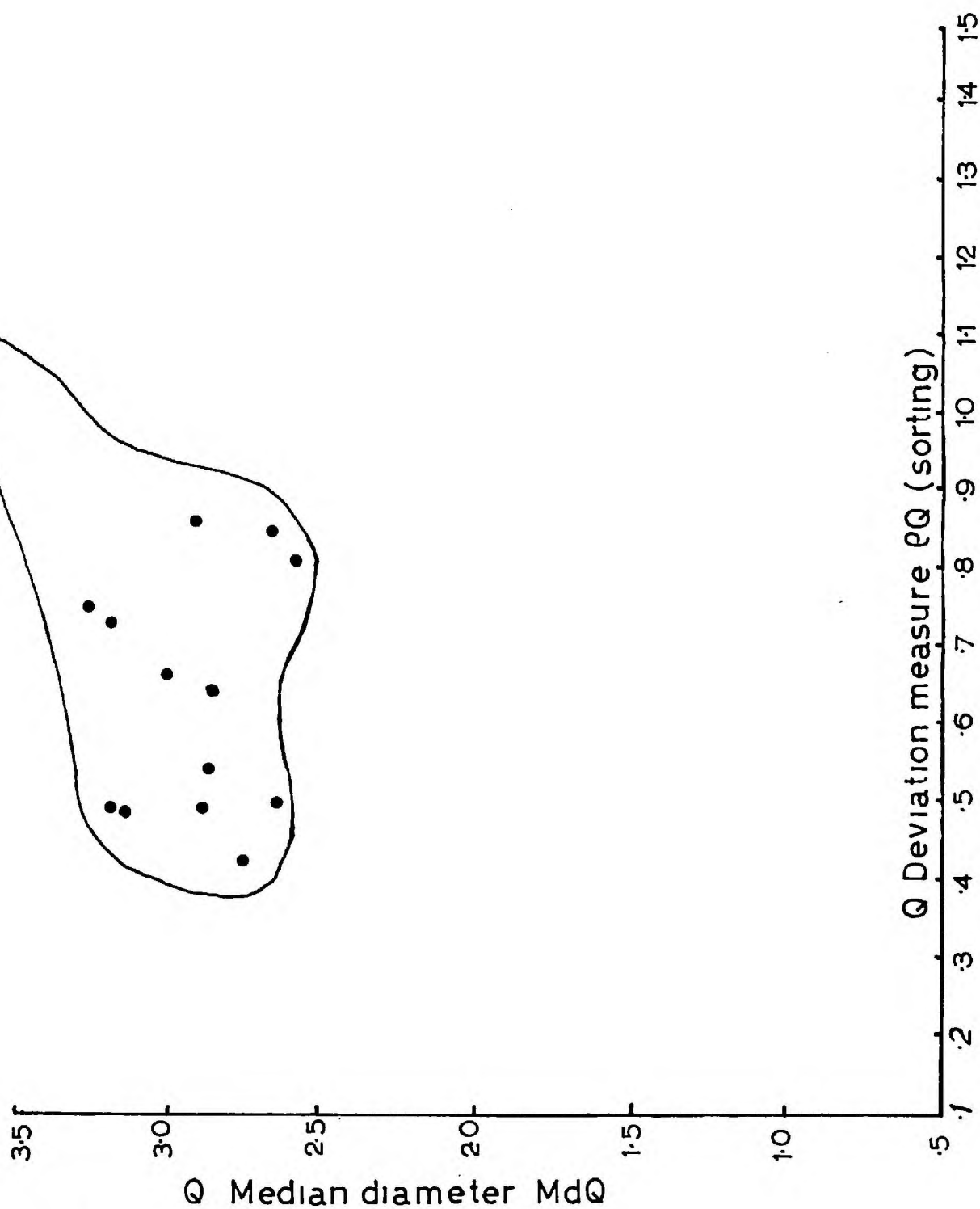


FIG 21. Median diameter against sorting for Forebeach deposits.- Sand fraction

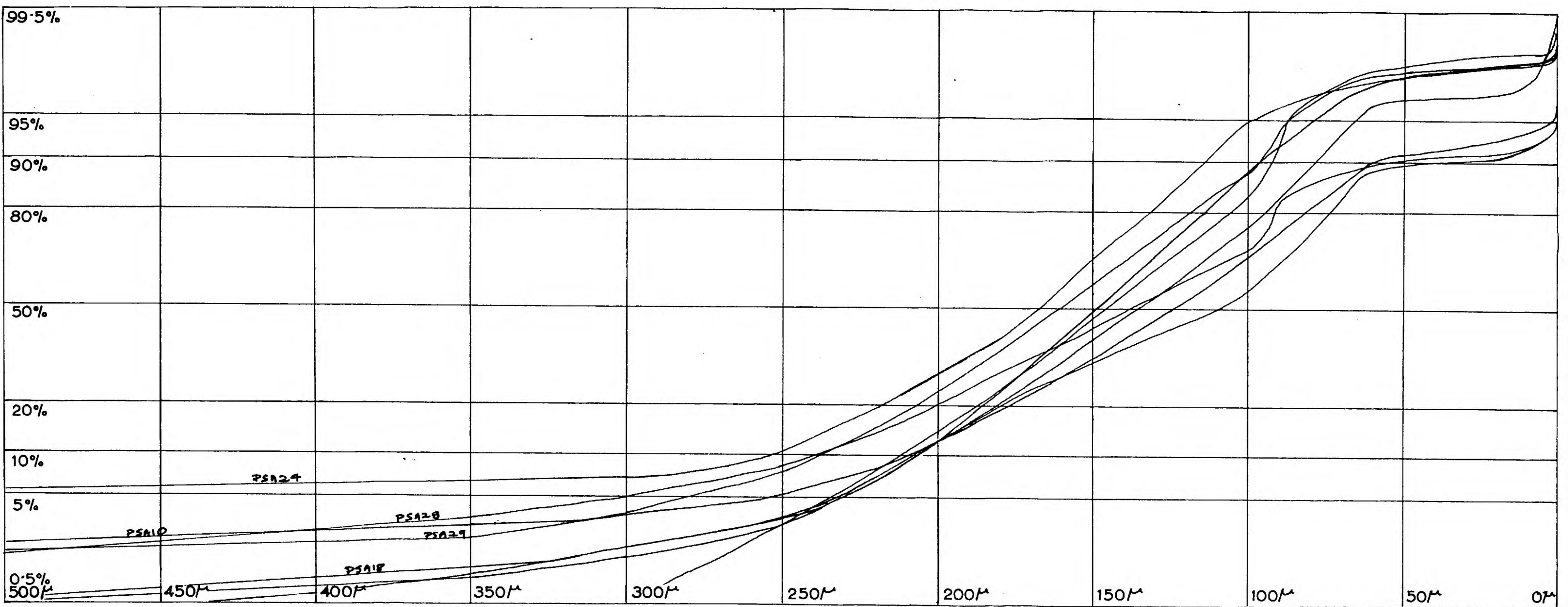


FIG 25. Grain size frequency distribution of fore beach deposits.

to Kruit (see Nota 1958), they are dominantly pelitic sands. Approximately 86% of each sample consists of very fine and fine sand (Wentworth 1922) that is, between the grade limits 0.0625 mm - 0.25 mm, of which the greater part is fine sand 0.125 mm - 0.25 mm.

The ϕ median diameter values range from 2.57 - 3.64, with an average value of 3.17. They are fairly well sorted sediments; the ϕ deviation measure values range from 0.42 - 1.05 with an average of 0.67 and the ϕ skewness measure values range from -0.48 to +0.66, with an average of +0.07 (see Figs. 21, 22, 23).

The deposits are unimodal (see Fig. 24). All the grain size frequency curves possess coarse 'tails.' They increase in steepness at about 0.125 mm (250μ) and rise consistently until they bend sharply to the right to form sub-horizontal saddles between 0.09 mm and 0.0625 mm. (i.e. 90μ and 60μ). They finally rise abruptly to 100% in the finest grades (see Fig. 25). Irregularities in the curves are due to small amounts of silt and clay or coarser sand intermixed with the main sandy component ('S' type of Doeglas). The maximum sizes of the coarser components vary from 0.3 to 0.5 mm. (i.e. 300μ to 500μ). This and the variation in the amounts of silt and clay indicate variations in current velocity.

Although the deposits of the forebeach are dominantly sandy they are termed "mixed" sediments in accordance with the

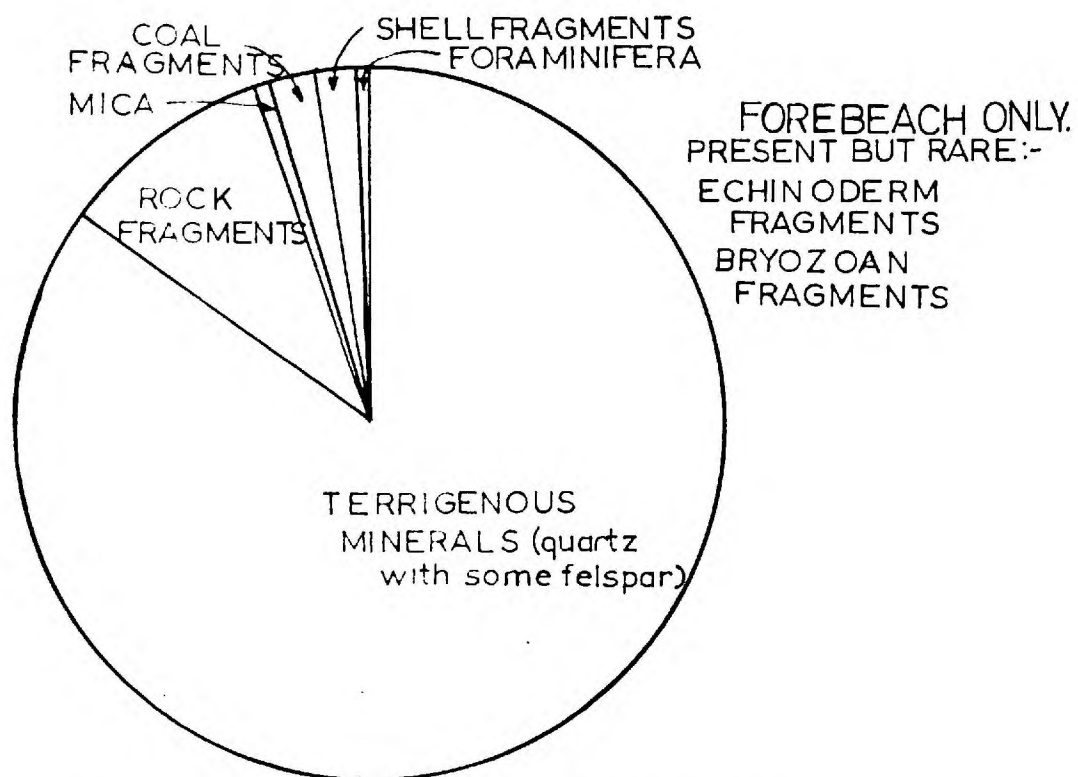


FIG 26. COMPOSITION OF THE COARSE FRACTION
(greater than 0.0625mm) OF BEACH DEPOSITS

nomenclature of Doeglas, because of the small amounts of silt and clay. The latter are deposited at high slack tide periods and particularly when wave and current action are at a minimum. They are mixed with the sand by gentle wave and current action which, when strong, often removes much of the finer material. Further mixing is produced by Arenicola marina which lives in large numbers in these deposits, although this organism is continually casting sediment onto the surface where it may be reworked by waves and currents during the following tidal inundation.

Composition.

The coarse fractions of the deposits of the forebeach i.e. material $> 1/16$ mm, consist largely of terrigenous material, mainly quartz with smaller amounts of feldspar, mica, heavy mineral grains, lithic and coal fragments. Foraminifera and broken shell fragments (mainly molluscan) are also found and occasionally echinoderm spines and ostracod tests (see Fig. 26).

Structures.

The structures of the forebeach may be split up into inorganic and organic types. The characteristic inorganic structures are, stratification, ripple marks, rill marks, mud balls and lineation marks, whereas the organic structures are the burrows and surface features produced by Arenicola marina, Lanice conchilega and Nereis sp.



PLATE. 29. ASYMMETRIC RIPPLE MARKS ON
FORE BEACH.

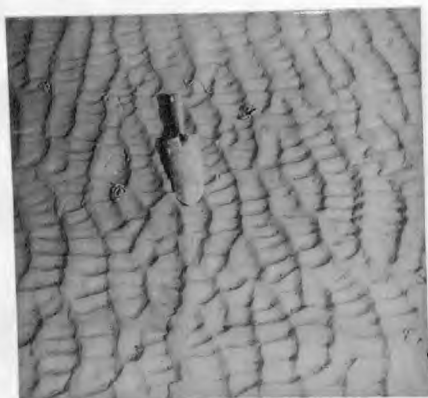


PLATE. 30. INTERFERENCE RIPPLE MARKS
ON FORE BEACH.

Inorganic Structures.

Stratification.

The sediments of the forebeach are well stratified, being generally laminated or very thinly bedded, but locally this stratification is interrupted or destroyed by ripple marks and burrows (see Plate A at back of thesis). The strata vary in thickness from 0.05" to 0.5" and tend to thin and die out laterally over distances varying from several inches to several feet. They possess a general dip seaward at angles never exceeding 5° and are generally parallel to the forebeach surface.

Occasionally muddy laminae are found, usually occurring at concavo-convex lenses infilling the troughs of ripple marks (see Plate A Section C).

Ripple Marks.

The surface of the forebeach is conspicuously ripple marked (see Plate 29). These are asymmetric in form with wave lengths of approximately 3-6 inches and heights of about 2 inches. They are generally orientated with their crests parallel to the shoreline and with their steeper lee or stoss slopes facing landwards. Usually the crests are sharp but may be flattened.

Similar ripple marks have been described by many writers, including Reineck (1961), Kuenen (1950) and Van Straaten (1952) who observed them on German and Dutch north sea beaches, and Evans (1941, 1949) who noted their presence on the beaches of fresh water lakes. It is generally accepted that these ripple

marks can be formed by variety of processes.

Some writers believe that the orientation and form of these ripple marks indicates that they are formed by the flood tide current and any modifications such as flattening of the crests, are due to the action of the ebb tide current. Others suggest that they are formed by wave action when the velocity of the swash exceeds that of the backwash. Under such conditions the water, landward of the breakpoint of the waves, is asymmetrically oscillated. The ripple marks suffer a vigorous landward push with each swash movement and so will develop with their steep slopes to landward. There will probably be little or no modification of their form by the gentler backwash.

The present writer agrees with Reineck (1961) that both tidal currents and wave action are responsible for the formation of these ripple marks. They are best developed when the directions of the swash, backwash and tidal currents are all essentially normal to the shoreline. They are initially formed during the flood tide inundation but are modified by the action of the swash, backwash and ebb tide currents of the outgoing tide.

The ripple marks exposed on the forebeach surface at low tide periods are asymmetric with steep slopes facing landwards because the swash velocity is greater than the combined velocities of backwash and ebb current. When the velocity of the swash, during the outgoing tide, is equal to or less



PLATE.31. INTERFERENCE RIPPLE MARKS ON
FOREBEACH - NOTE TROUGH INFILLED
WITH COAL FRAGMENTS - BORED PEAT BLOCKS.



PLATE.32. DOUBLE CRESTED RIPPLE
MARKS.

than the combined velocities of the backwash and ebb tide current the resulting ripple marks will be symmetric or asymmetric with steep slopes facing seawards respectively.

Occasionally crossed or interference ripple marks are found on the lower part of the forebeach (see Plate 30, 31). These are probably due to the combined effects of longshore currents and wave action at a late stage of outgoing tide. The longshore movement is related to the water movements in Boston Deep, a channel which lies immediately to seaward of the forebeach (see Fig. 96). Tidal waters enter and leave the Wash embayment along such channels. This movement is only effective on the lower part of the forebeach because as the tidal waters rise and fall over the higher parts of the forebeach they tend to move in a direction essentially perpendicular to the coastline. At a low stage of the ebb tide, ripple marks formed by wave action with crests orientated approximately parallel to the coastline are crossed by others formed by the longshore current and orientated normal to the coastline.

Double crested ripples are sometimes found (See Plate 31). It is reasonable to suppose that these are the result of weaker current action subsequent to initial ripple mark formation. Small terraces are occasionally cut on the sides of the troughs of ripple marks. These result from the oscillation, by wind action, of water retained in the troughs as the tide recedes.

It has been possible, with the aid of wax-impregnated sections, to show that the development of ripple marks on the forebeach surface often results in the interruption or partial destruction of the original stratification (see Plate A at back of thesis). McKee (1957), who noted that the surfaces of the forebeaches around the southern coast of the U.S.A. are practically always ripple marked, suggested that forebeach deposits are characteristically completely ripple bedded. The present study however, shows that this is not the case, but further work will be necessary before a satisfactory explanation can be found.

It was observed that cross laminae, produced during the formation of ripple marks, often extend to depths of 4-5 inches below the surface and similar cross laminae were to be found at various lower levels. At the base of each set of ripple formed cross laminae there is a rippled or irregular surface which was produced by erosion marking the depth to which the sediment was reworked during the formation of the ripple marks. This surface cuts the underlying stratification. In certain cases ripple formed cross strata may, themselves, may be reworked. The latter reworking may affect the sediment to a lesser extent than on the previous occasion and remnants of earlier formed cross strata may be retained as lenses or incomplete ripple marks. Such features have been termed "Linsen schichtung" by Reineck (personal communication). In some cases several erosion surfaces may be seen separating



PLATE.33. MUD BALLS BEING ROLLED BACK AND
FORTH IN SWASH ZONE.



PLATE.34. ARMoured MUD BALLS.

successive sets of cross laminae and normal gently inclined strata.

The average thickness of ripple formed cross laminae in the forebeach deposits, is approximately 0.1 inches and rarely exceeds 0.25 inches. Individual laminae vary in length from 1 - 9 inches depending on the size of the ripple marks.

Rill Marks, Mud Balls and Lineation Marks.

Other inorganic structures found on the forebeach are rillmarks, mud balls and lineation marks.

Rill marks are formed by ebb tide waters flowing from the runnels on the backbeach out across the forebeach to low tide level. They widen seawards, often being as much as 30 feet across at low tide mark. They undoubtedly disturb the stratification and are probably responsible for minor washout structures and cross bedding.

Unfortunately it was not possible to demonstrate this in sections.

Mud balls, varying in diameter from 0.5 - 4 inches, were often found on the forebeach. They are rounded by being rolled back and forth in the swash zone and are often left on the forebeach surface after the tide has retreated. Invariably they are armoured by pebbles, sand grains and shell fragments picked up during transport (See Plates 33 and 34).

Lineation marks of various types were also common. These develop as a result of the orientation of pebbles, shells or other debris in the direction of tidal flow.

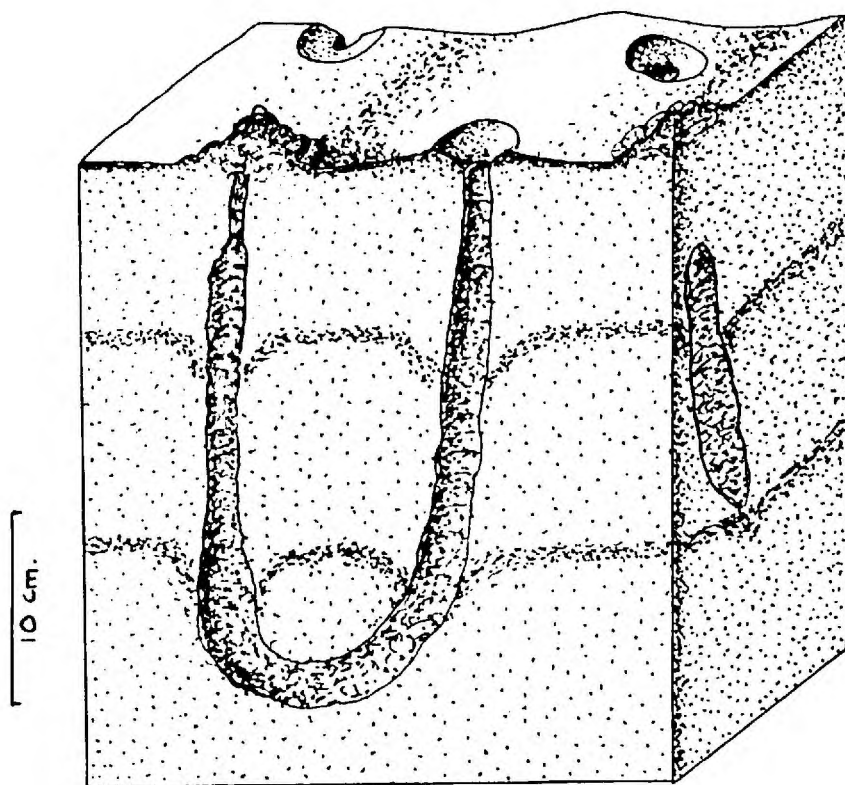


FIG28. Arenicola marina :- burrows , burrow openings and surface casts.



PLATE .36. LANICE TUBES ON LOWER
FOREBEACH.

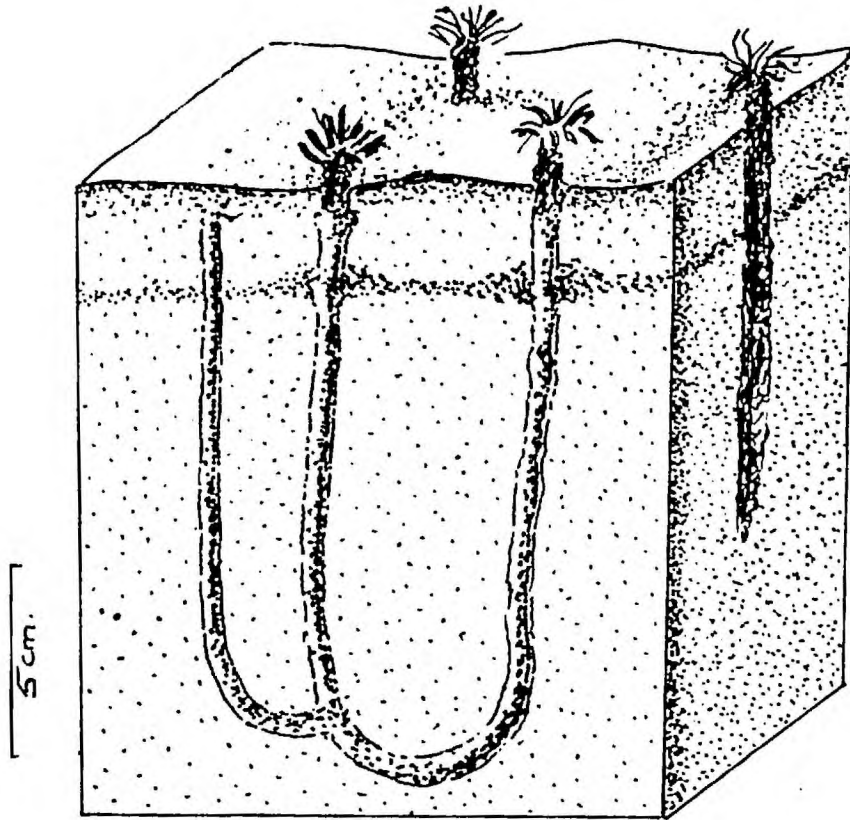


FIG 29. Lanice conchilega :- burrows and tubes

Organic Structures.

Arenicola marina.

The surface of the forebeach is often covered by large numbers of casts and feeding holes of Arenicola marina (See Plate 1-).

Impregnated sections show that the burrowing activities of Arenicola often interrupt or completely destroy the original crossed or gently inclined stratification (See Plate A Sections B, C, D etc.). The burrows often reach a depth of more than 1 foot and may be several inches in diameter. They have a characteristic U-shape (See Fig. 28) and each burrow has a disturbed periphery in which the strata are drawn downwards to form characteristic drag structures.

Lanice conchilega.

As pointed out in an earlier chapter Lanice tubes, consisting of cemented sand grains (See Plate 36 & Fig. 29), are found occupying small hummocks on the lower forebeach in the south of the area studied. The influence of these organisms upon the processes of sedimentation has already been discussed.

The tubes are approximately 0.25 inches in diameter and extend for 6 - 9 inches below the surface. Their resistance to erosion may be shown by the fact that they often protrude for several inches above the surface when the latter has been reworked and lowered by the scouring action of strong waves and currents. When they occur in large numbers they



PLATE 37. MUD BLOCKS BORED BY
PETRICOLA.



PLATE 38. LINEATION MARKS PRODUCED
BY ENTEROMOPHA STRANDS.

appear to act as sediment traps and as such may possibly be responsible for the formation of hummocks on the forebeach.

Nereis sp.

Nereis sp is not found in large numbers in the forebeach deposits and unlike Arenicola and Lanice is more commonly found in muddy sediments such as those of the mudflats and new salt marsh.

It is a relatively small organism when compared with the above and its burrows are narrower. The burrows ramify in all directions but only disturb the original stratification to any degree when the organism is present in large number (see later). Its burrows are only occasionally found in the forebeach deposits (See Plate A Section E).

Petricola sp.

This mud-boring bivalve is found on the forebeach near the low spring tide line in the north of the area studied. At this point silty mud tends to accumulate in lenses approximately 2 - 3 inches thick. They are usually covered by sand but are often exposed by strong wave action. Large numbers of Petricola produce almost vertical bore holes along the seaward eroded edges of the silty mud lenses. Blocks of this bored sediment are often broken off and carried southward by longshore drift to be distributed over the beach to the south (See Plate 37).

Backbeach Deposits.

In the following pages the texture, composition and structure of the backbeach deposits, including those of the

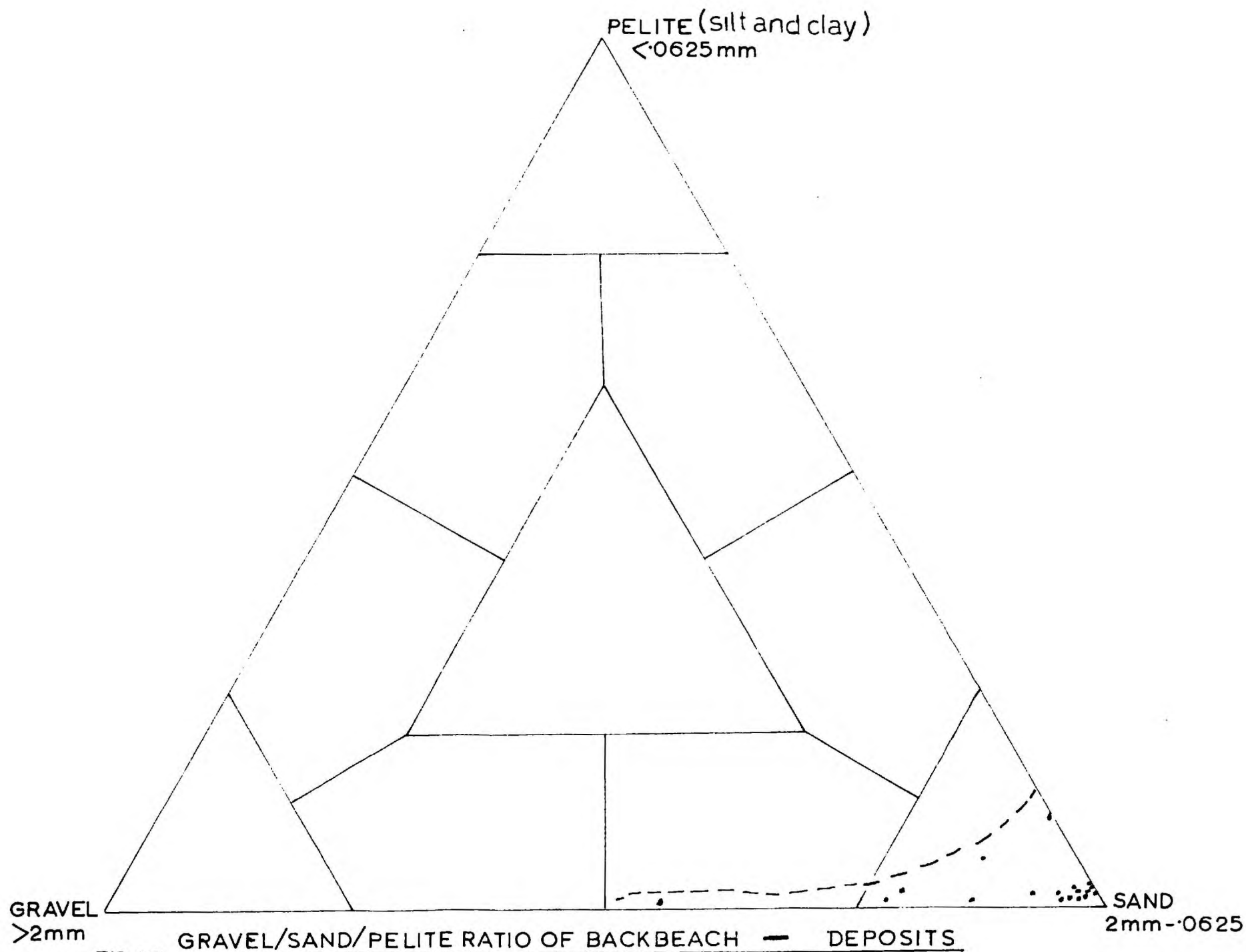
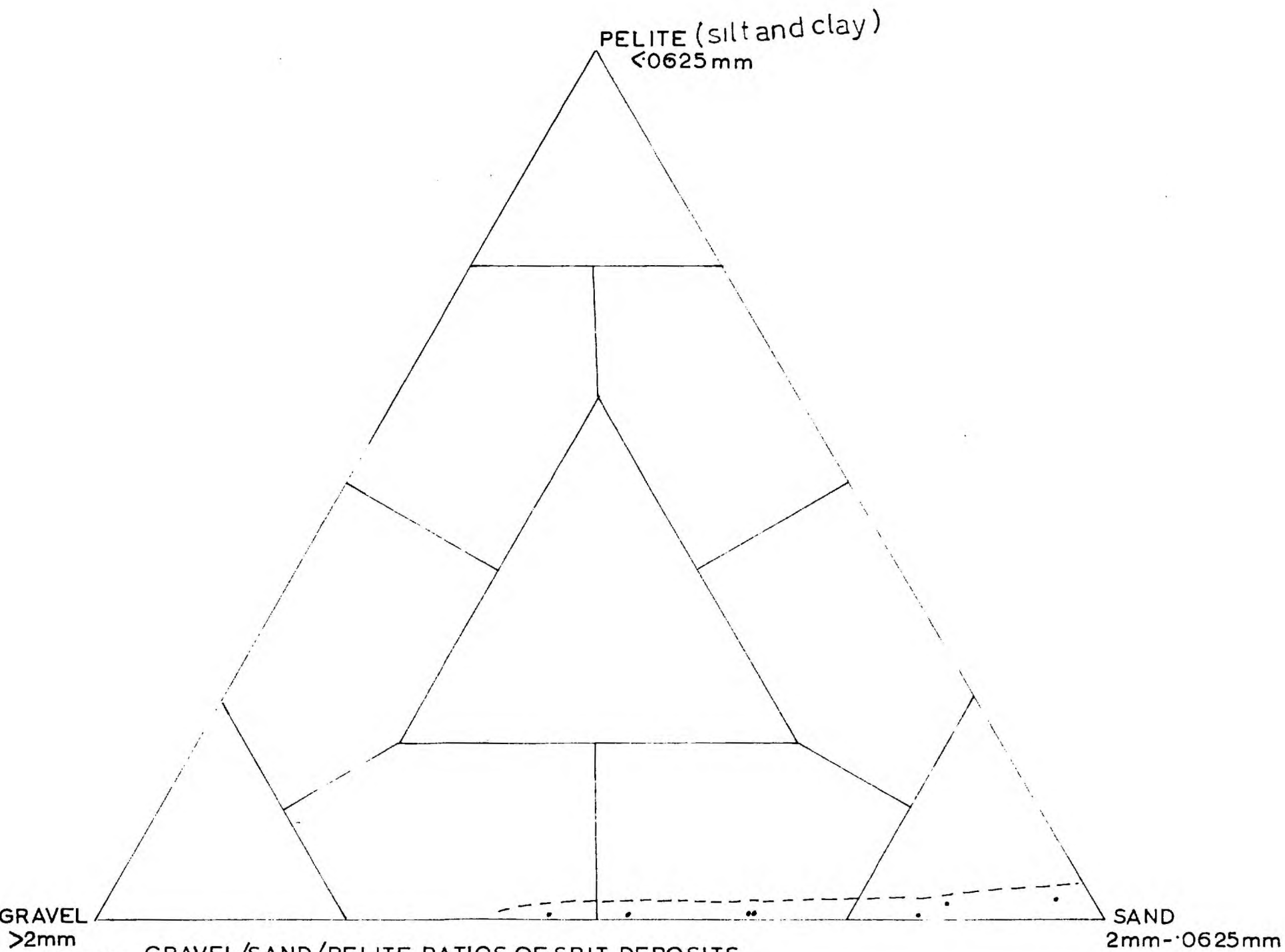


FIG 30.



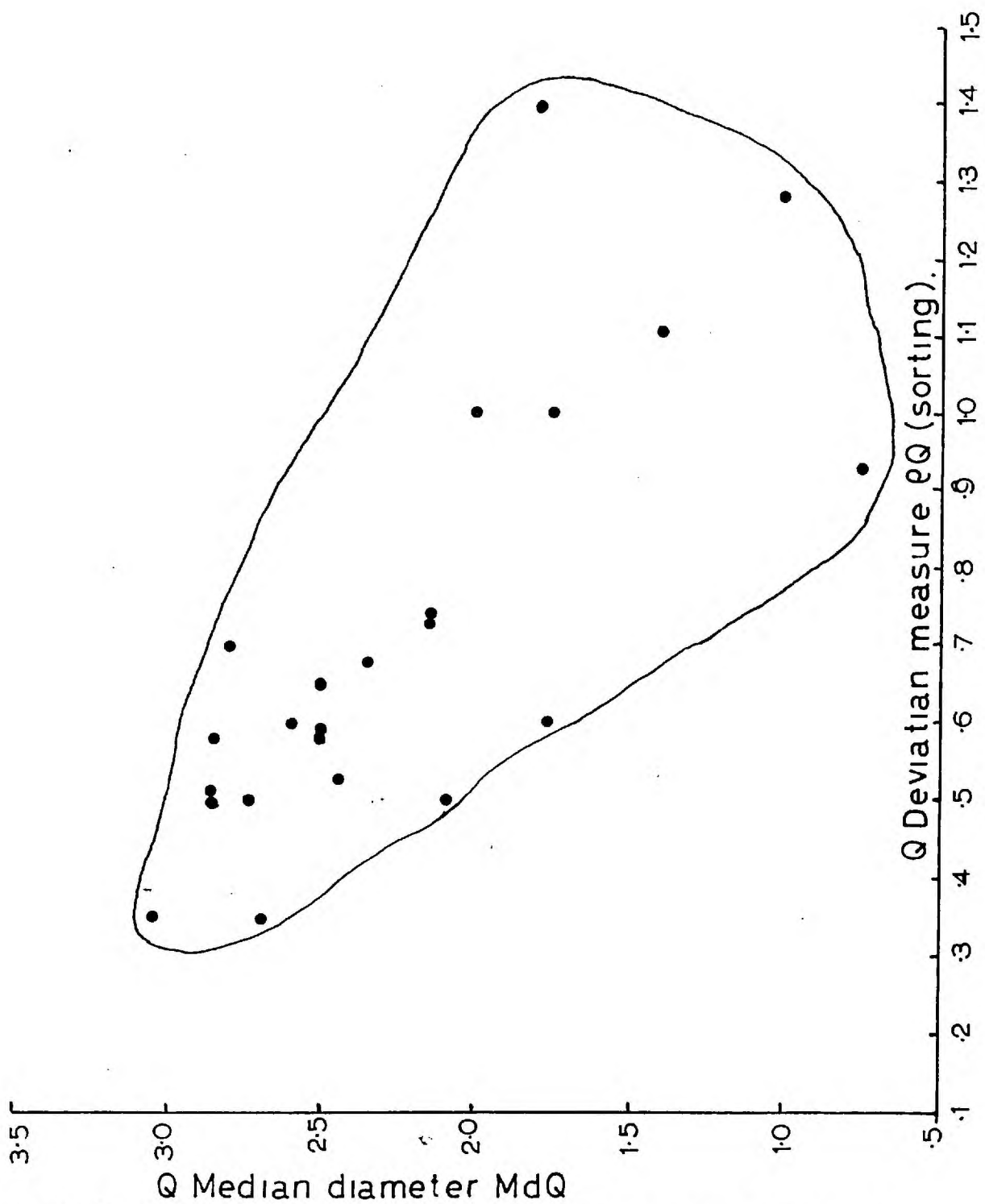
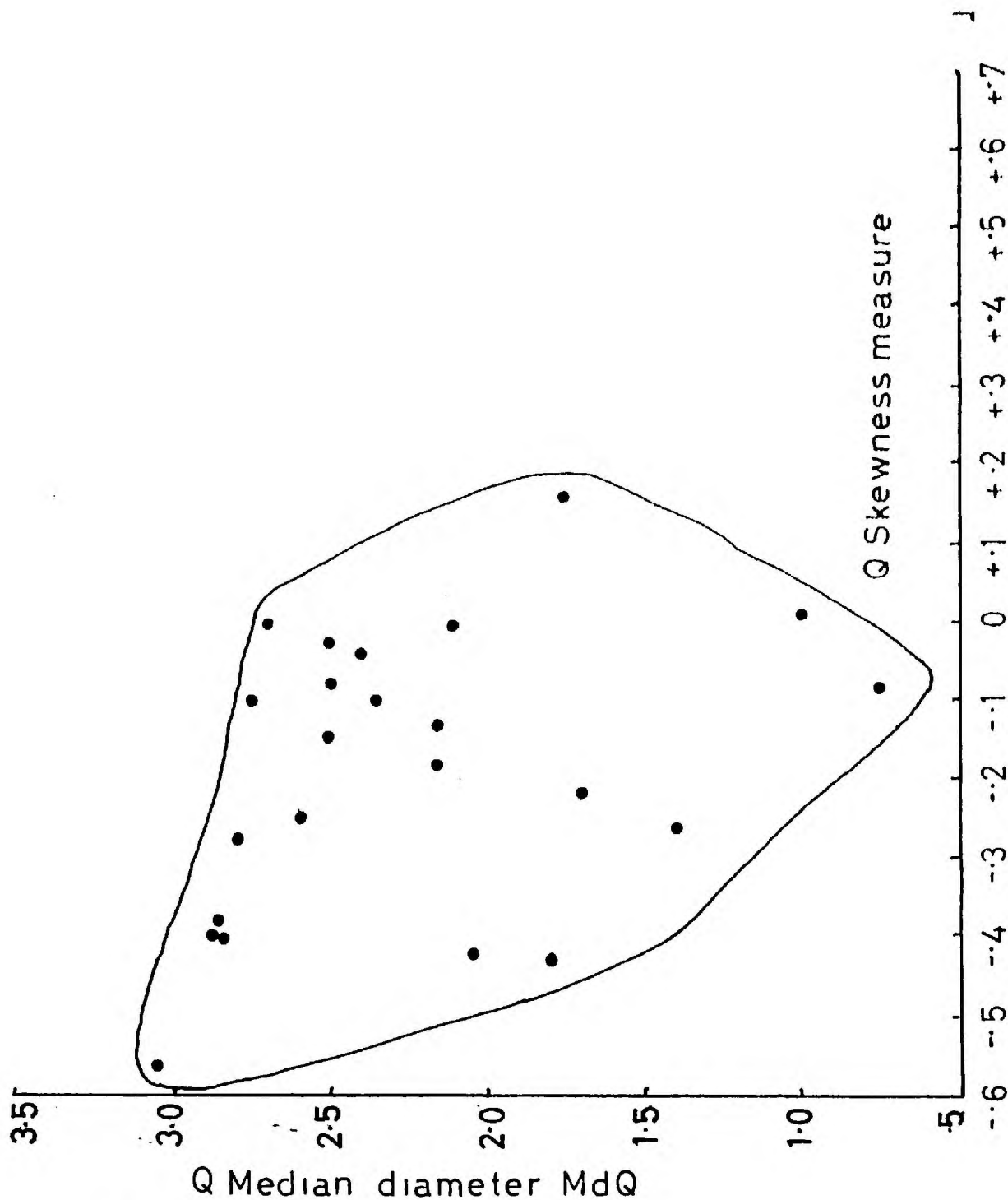


FIG 32 Median diameter against sorting for Backbeach deposits.



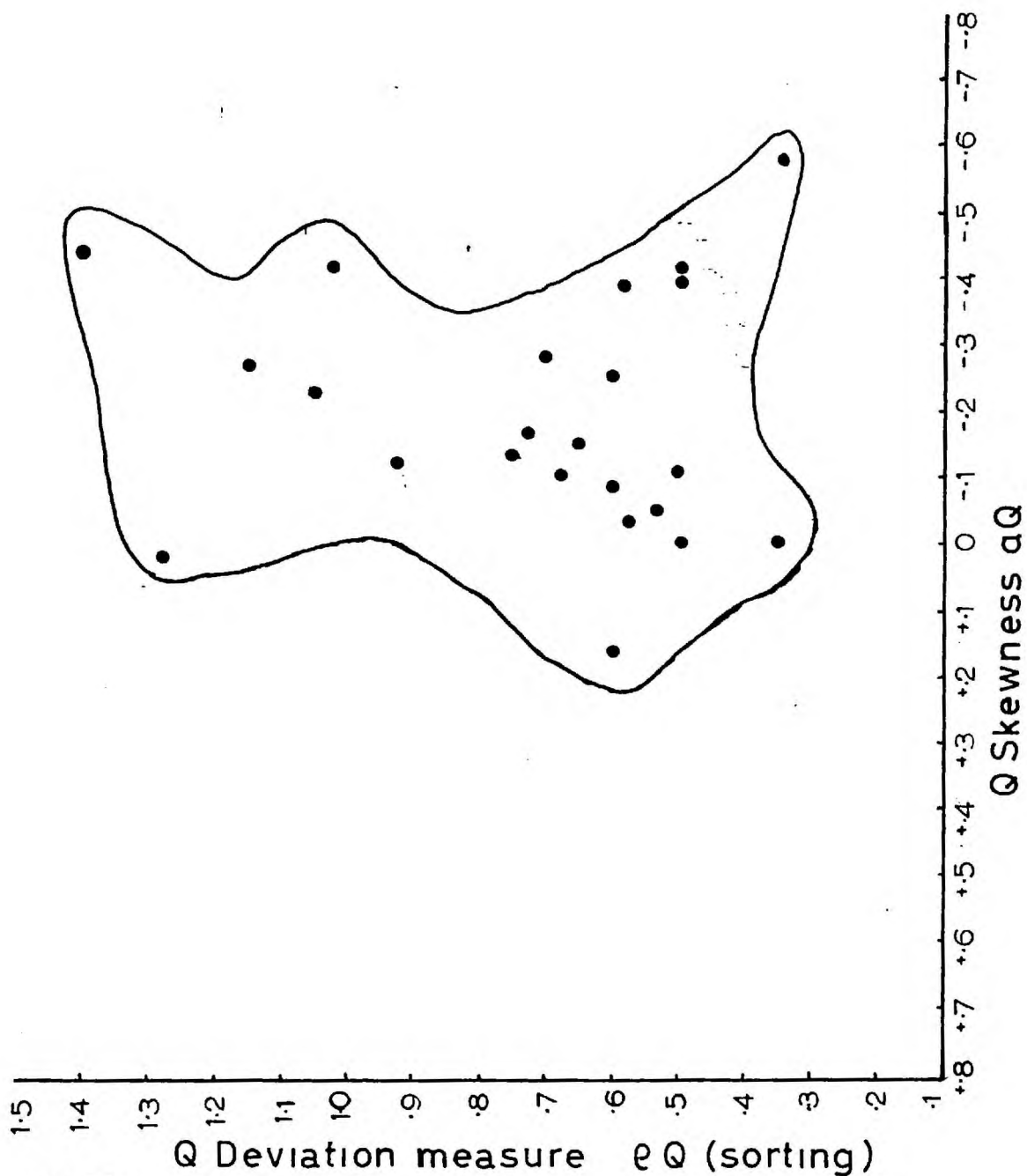


FIG 34 Sorting against Skewness for Backbeach deposits.

spit, will be described.

Granulometric Analysis.

Although they are gradational the deposits of this sub-environment are generally much coarser than those of the forebeach.

According to the nomenclatures of Shepard and Kruit the sediments of the backbeach are gravelly sands and sands, but on the spit sandy gravels are also found (See Figs. 30 and 31).

It is not always possible to calculate precisely the ϕ median, deviation and skewness measures of the backbeach and particularly the spit deposits, because the 50th and 16th percentiles cannot be fixed accurately. However, these measures have been calculated for the sand fractions. The ϕ median diameter values for the sand fractions of the backbeach deposits range from 0.75 - 3.05 with an average value of 2.24. These sands are usually coarser than those of the forebeach. The ϕ deviation and skewness measures range from 0.35 - 1.4 and from -0.5 - +0.16 with average values 0.72 and -0.19 respectively. They are not so well sorted as those of the forebeach and unlike the latter nearly always possess negative skewness values (See Figs. 32, 33 and 34).

The sand fractions of the spit deposits are often coarser. They possess ϕ median diameters which range from -1.5 to +2.6 with an average value of +1.42. They are poorly sorted with ϕ deviation and skewness measures

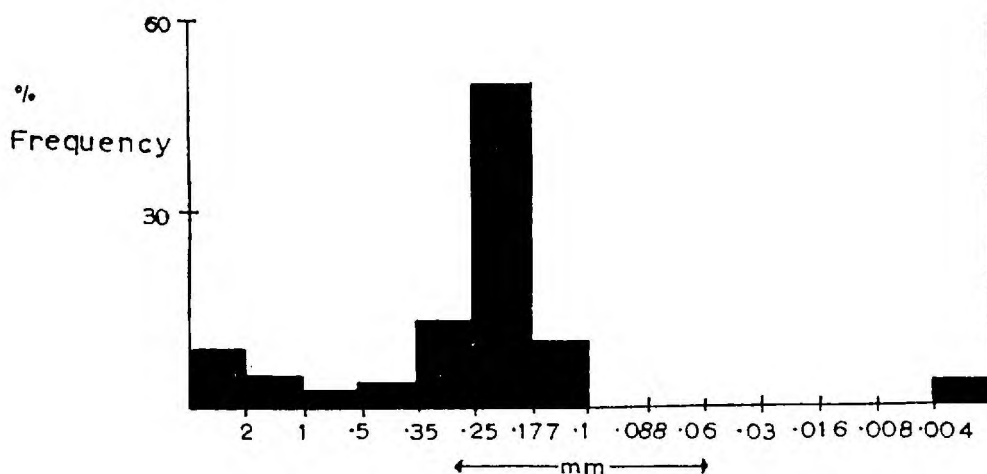


FIG38 Histogram showing grain size distribution of sample PSA 48 from beach runnel.

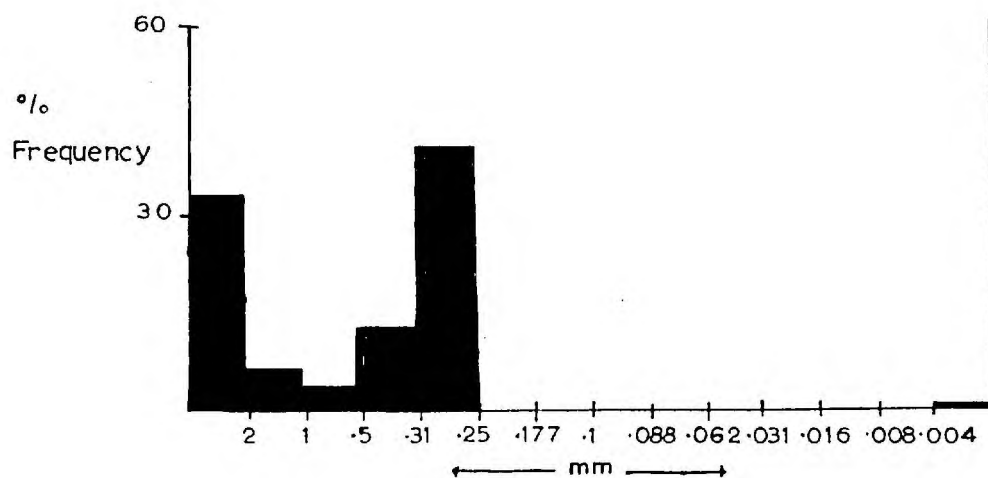


FIG35 Histogram showing grain size distribution of sample PSA sf from crest of spit.

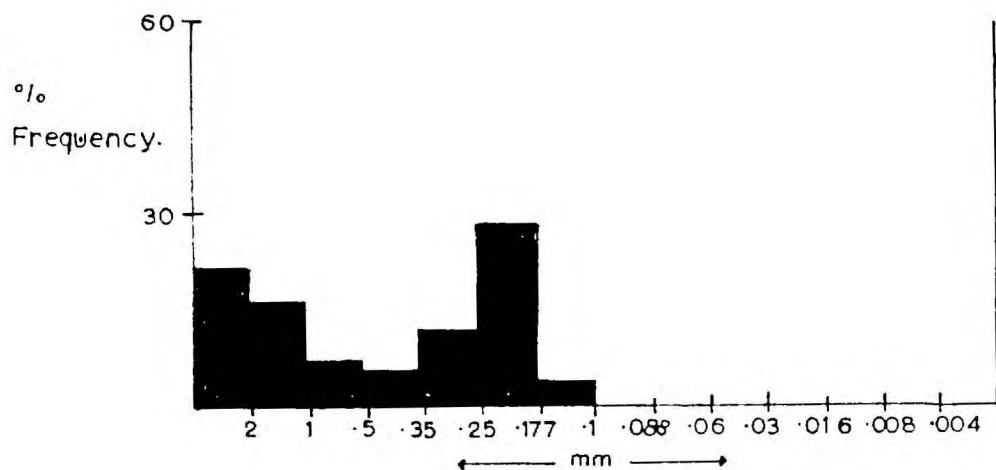


FIG.36.Histogram showing grain size distribution of sample PSA.32.
from beach ridge crest.

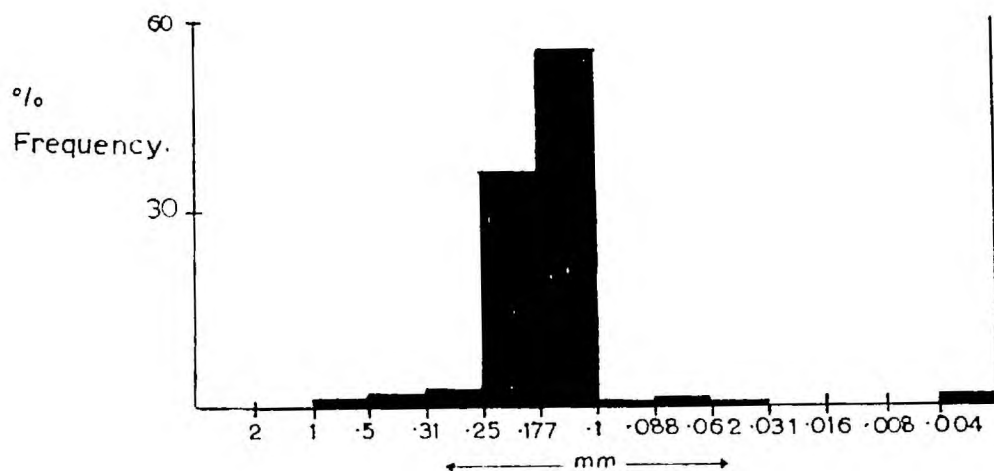


FIG37. Histogram showing grain size distribution of sample PSA.20.
from swash slope of beach ridge.

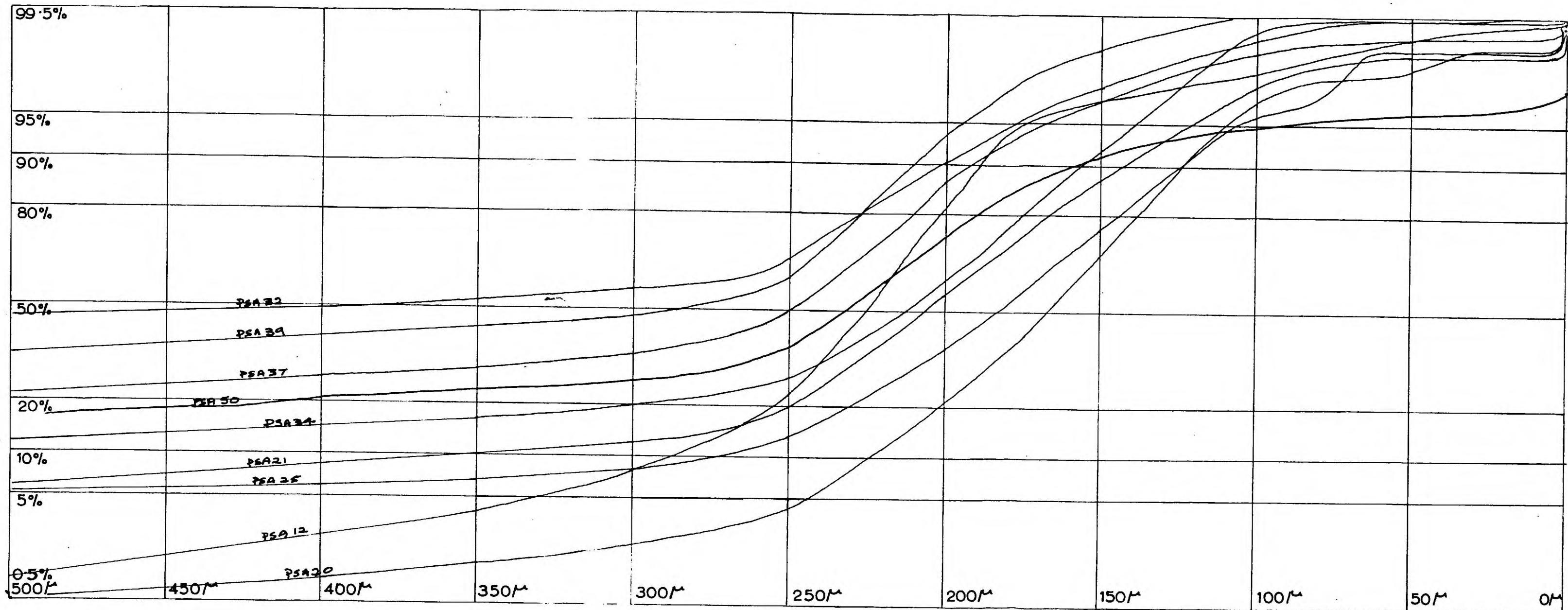


FIG 39a Grain size frequency distribution of back beach deposits.

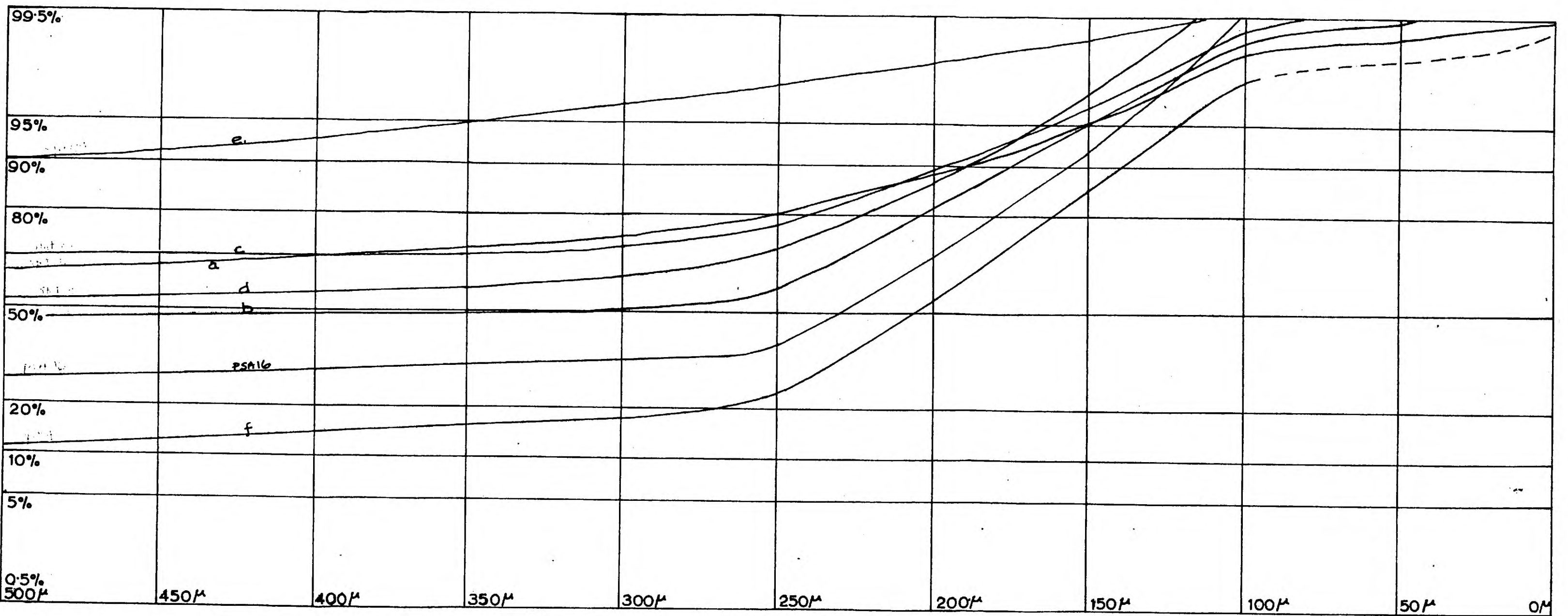


FIG 39b Grain size frequency distribution of spit deposits.

ranging from 0.5 - 1.35 and -0.68 - +0.2 respectively with average values of 1.1 and -0.33.

Field observations showed that the gravel tends to be concentrated on the crests of the beach ridges and spit. The deposits in these localities generally have bimodal grain size distributions and possess small amounts of median, coarse and very coarse sand (Wentworth) between the limits 0.25 mm and -0.5 mm; 0.5 mm - 1 mm and 1 mm - 2 mm respectively (See Figs. 35 and 36). The deposits of the seaward facing swash slopes of the ridges are not gravelly and are similar to the deposits of the forebeach. They are clean well sorted sands, with unimodal grain size distributions; as much as 80% is fine sand between the limits 0.25 mm - 0.125 mm (See Fig. 37). The deposits of the runnels are similar to those of the ridge crests but generally possess less gravel and more fine sand. (See Fig. 38).

The grain size frequency curves show that some of the deposits, particularly those on the crests of the spit and ridges, are similar to the "r" type of Doeglas (See Fig. 39a,b). Generally however, the deposits of the backbeach are mixtures of "r" and "s" types and therefore are referred to as mixed deposits in this thesis.

The relative coarseness of the backbeach deposits in contrast with those of the forebeach is due largely to wind and wave action. Although these factors are discussed in a later chapter dealing with the process of sedimentation, a brief note of them is made here.

As the flood tide rises, the breakpoint of the waves moves steadily landwards across the forebeach and backbeach and it is the disparity between swash and backwash actions of the breaking waves which is largely responsible for the sorting of the beach material. When the swash is stronger than the backwash, only the finer material of the total load deposited by the swash will be removed seaward by the backwash. If this condition exists during each tidal inundation, there will be a general transport of coarser material landwards and finer material seawards. Although this simple condition may not always be the rule its effect is shown by the gradual increase in median diameter from forebeach to backbeach.

The concentration of gravel on the crests of the ridges is attributed to two factors:

1. The winnowing effects of gentle waves breaking over the ridges which remove some of the sand and probably wash it into the runnels to landward of the ridges.
2. Wind action is often an effective agent in removing sand from the crests of the ridges when they dry out during low tide periods.

Wind and wave action have similar effects upon the spit, but the higher proportion of gravel on this feature is thought to be also due to the fact that the spit marks the terminal point of longshore transport of gravel sized material in the littoral zone along this part of the coast. The abrupt

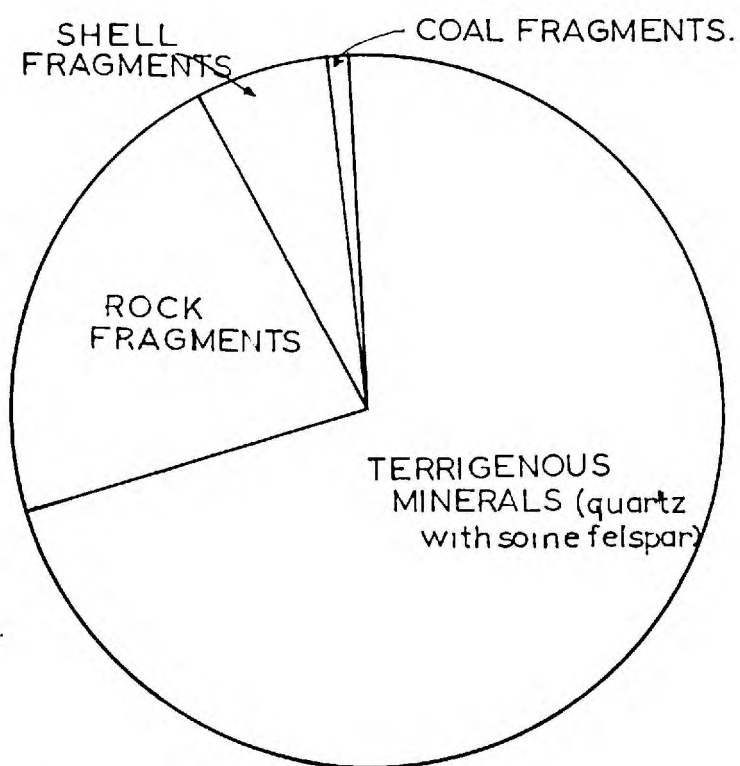


FIG 41 COMPOSITION OF THE COARSE FRACTION
(greater than 0.0625 mm) OF SPIT DEPOSITS.

change in trend of the coastline at Gibraltar Point is responsible for considerable wave refraction and with the consequent decrease in wave energy, much of the coarser material transported by longshore drift is deposited on the spit at the Point. Furthermore, the River Steeping outfall flowing seawards across the trend of the beach and spit may be responsible for preventing the transport of coarser material southwards: only the sand and finer material continues in that direction across the Steeping and into the Wash.

Composition.

The coarse fractions (2 - 1 $\frac{1}{2}$ 16 mm) of the backbeach consist largely of quartz with smaller amounts of felspar, rock, shell and coal fragments. Those of the spit possess slightly higher percentages of rock and shell fragments and lesser amounts of coal (See Figs. 26 and 41).

All the samples examined differed from those of the forebeach by the absence of mica, foraminifera, ostracod tests, echinoderm and bryozoan fragments. This may be due to the fact that these more fragile components are crushed when subjected to the vigorous swash and backwash action on the backbeach, or because of their low effective densities they may be removed by the winnowing effects of wind and wave action.

Structures.

Generally the backbeach is characterised by a greater diversity of types of surface and sub-surface structures

than the forebeach. There is a pronounced difference in the character of the stratification because of the development of ridges, runnels and mega ripple marks. Due to the increase in grain size of the backbeach deposits very fine laminae are not found. The stratification, unlike that of the forebeach is not destroyed by burrowing organisms.

Stratification.

Beach Ridges.

The external form of a backbeach ridge is broadly speaking an expression of its internal structure (See Plate B at back of the thesis). Each entire ridge is coarsely laminated and the laminae vary from $\frac{1}{4}$ - 1 inch in thickness.

On the seaward side of the ridge crest the laminae dip gently seaward at angles up to 5° or 10° . This angle decreases landwards in a direction normal to the crest of the ridge until at the crest itself the laminae are nearly horizontal. To landward of the crest they at first dip gently landward but the angle of dip increases gradually away from the crest until it reaches a maximum of 10° - 30° or more on the leeward side of the ridge. In sections parallel to the crest all the laminae appear to be nearly horizontal.

Close inspection of impregnated sections however, shows that individual laminae are rarely continuous from the seaward to landward sides of the ridges. More often in sections normal and parallel to the ridge crest, a single lamina may be traced for only a few feet before it is

terminated by a surface on which rest other similar laminae.

Ripple marked laminae are occasionally seen. These form on the broad crest of the ridge at an earlier stage of its development, but due to the continual reworking of the sediment on the crest, only truncated or incomplete ripple marks are usually found. Their restricted occurrence is due in part to the fact that only the surface of the ridge crest is ever ripple marked.

The ridges are best developed during summer and are built up on a surface flattened by strong waves during winter, that is, the "winter profile" of other writers. This surface dips gently seaward and the landward and seaward dipping laminae of the ridges meet it at varying angles, giving rise to a distinctive form of cross stratification which is termed "planar cross stratification" according to the nomenclature of McKee (1957). (See Fig. 16). Unfortunately it was not possible to show this surface in cores and impregnated sections but it was revealed rather indistinctly in sections dug in the field.

Most writers agree that the ridges are formed by gentle wave action. This is supported by the fact that they are only found on beaches exposed to a small fetch and attain their maximum development during summer when wave action is usually less severe. However Johnson (1919) who summarised the reports of earlier writers showed that their mode of origin was not clearly understood and even to-day

opinions on this subject differ markedly.

Evans (1940) who studied ridges on the shore of Lake Michigan suggested that they are formed at the breakpoint of the waves where the sand transported seaward by the backwash, accumulated with the material moving landward outside the breakpoint. But, Lake Michigan is tideless, and as pointed out recently by Guilcher (1958), King (1959), Williams and King (1949) and Williams (1960) this explanation is not strictly valid for tidal beaches such as the one studied in the present investigation, because in such cases the breakpoint is constantly moving with the tide.

King draws attention to certain tank experiments which show that the swashaction of gentle waves will form beach ridges. Apparently such waves move material towards the land in all depths both outside and inside the breakpoint. This material accumulates on the backbeach and as the tide rises the swash continues to push more material over the first accumulation until a ridge is formed.

The present writer agrees very largely with King's explanation and the internal structure of a ridge as shown in this thesis may well suggest that each lamina represents a small washover fan which is spread over those beneath it by some process similar to the action of the swash. However the writer feels that on particular occasions such as higher spring tide periods when the ridges are completely inundated, the breakpoint of the waves will pass over the

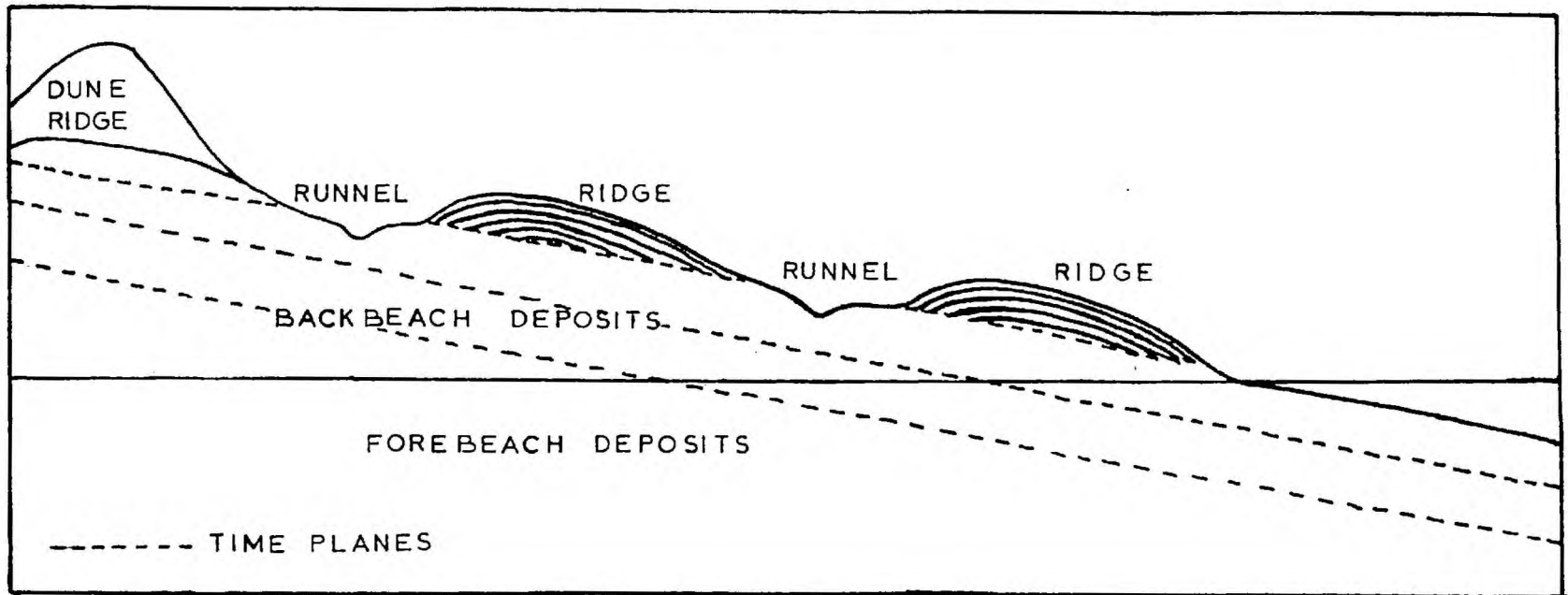


FIG. Diagram showing "Planar Cross Stratification" of beach ridge deposits.

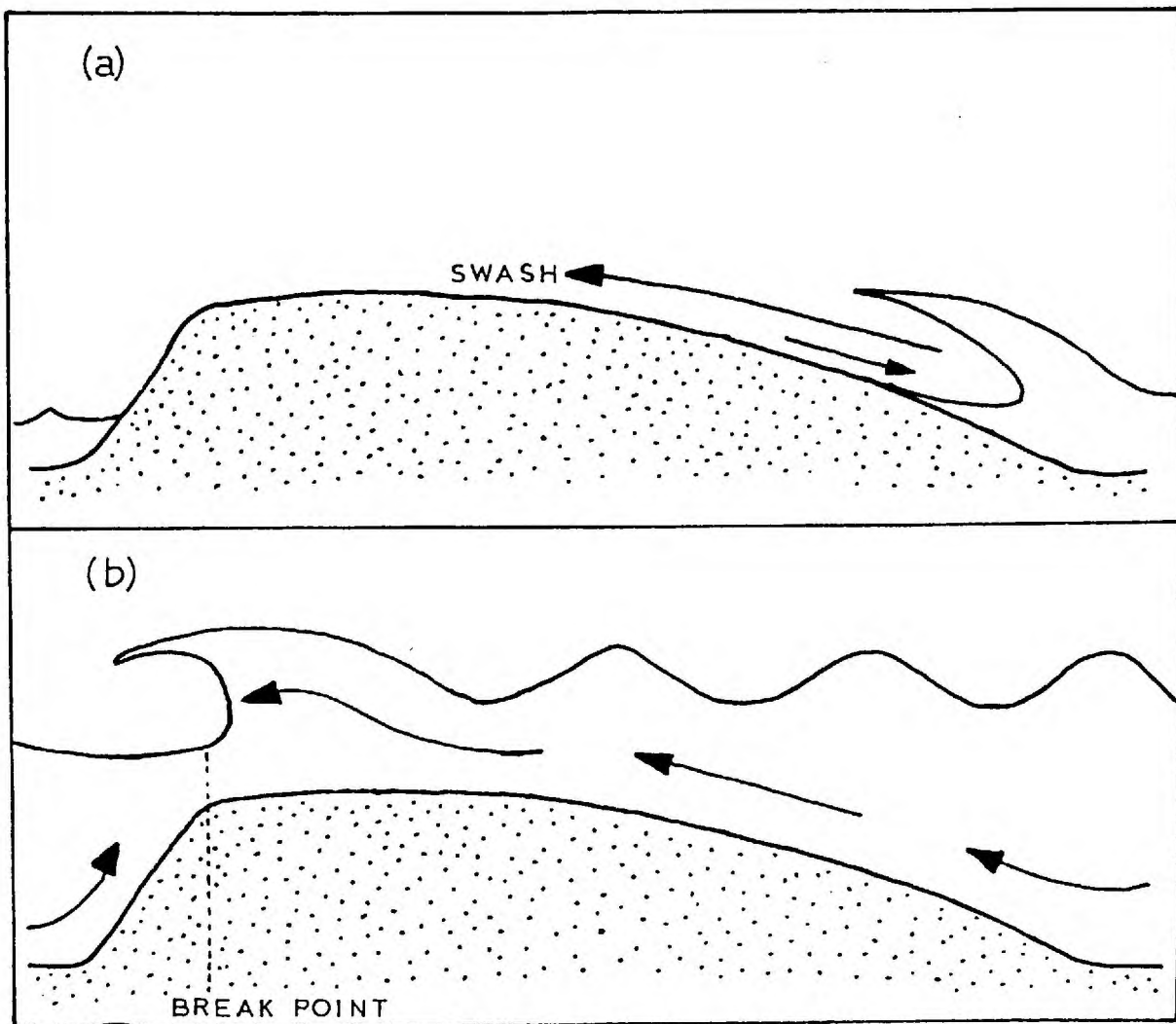


FIG 4.2. Diagram showing the possible influence of Swash and Breaking waves in the development of a Beach Ridge during the different stages of tidal inundation.

ridge crests and may well have some control on the form of the ridge, particularly in the development of steep landward facing slopes (See Fig. 42).

Beach Runnels.

The deposits of the runnels are also characteristically stratified. The individual laminae are similar in dimensions to those of the ridges but the overall internal structure appears to be more complex than that of the ridges.

The laminae dip gently to seaward but in some places there is a marked cross stratification (See Plate C at back of the thesis). This, it appears, results from the infilling of an ebb channel and is termed "trough stratification" in accordance with the nomenclature of McKee.

The deposits infilling the old ebb channel consist of laminae which dip seaward at angle of about 30° . These are separated by two erosion surfaces from an upper and a lower set of laminae also dipping gently seawards but at very low angles not exceeding 5° .

The lower surface of erosion is parallel to the dip of the steeply inclined laminae and cuts across the underlying gently dipping ones. It probably represents the floor of an old ebb channel cut by low ebb tide waters which drained southwards in the bottom of the runnel. The ebb channels increase in depth and width southward down the gradients of the long axes of the runnels and in the lower parts, often show well developed meanders. Erosion takes place on the outer concave sides of the bends and is accompanied by

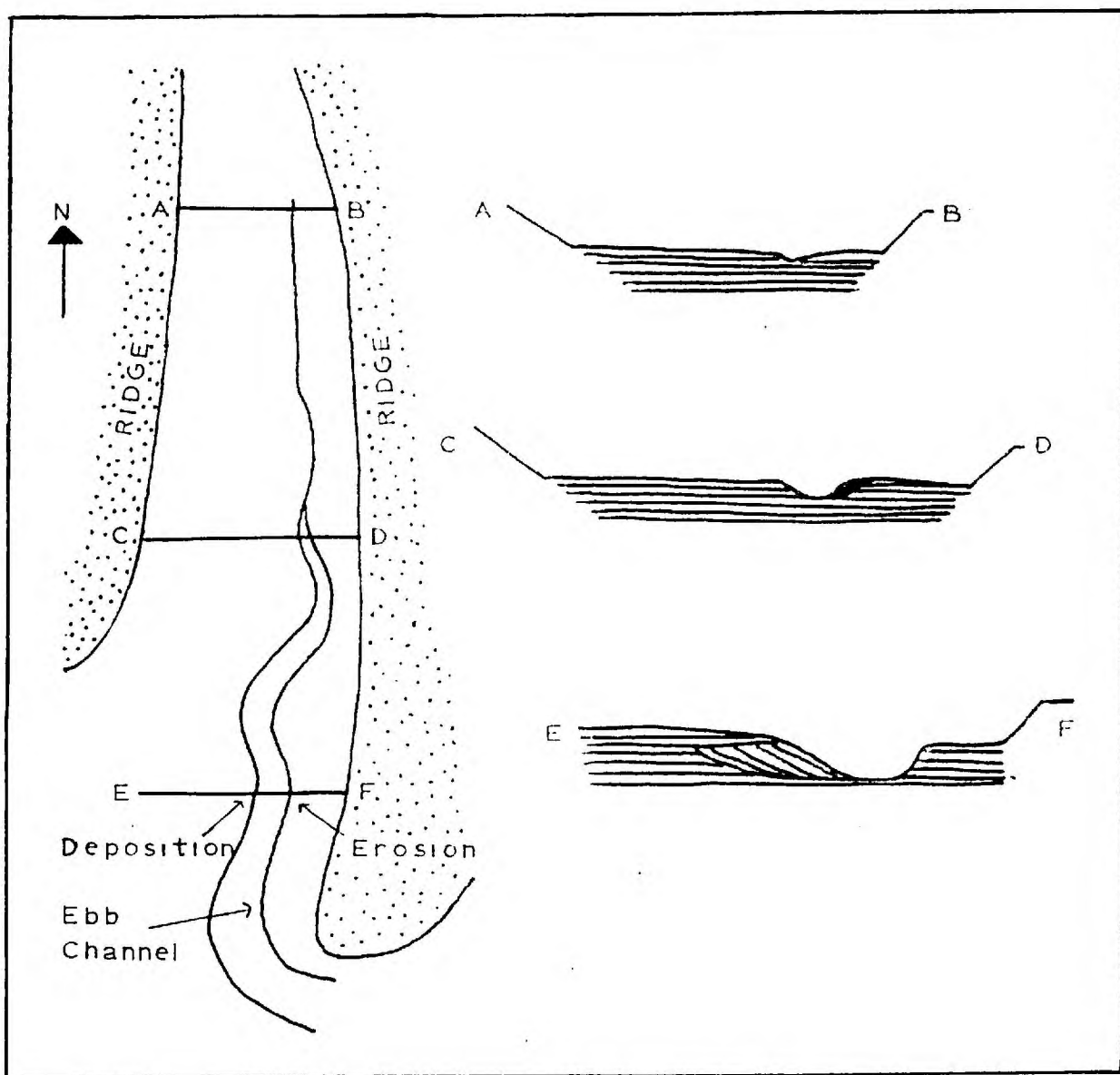


FIG.43. Diagram showing nature and origin of the trough cross stratification associated with the ebb channels in the runnels.

deposition of cross strata on the prograding convex sides (see Fig.43).

The upper surface of erosion (See Plate C) cuts across the channel deposits and is parallel to the upper set of gently inclined laminae. It probably marks the depth to which these deposits were reworked by later wave action.

An interesting feature of the more steeply inclined ebb channel deposits is the occurrence of pebbles and shells, all of which tend to have a common orientation: their long axes being parallel to the dip of the laminae giving rise to a characteristic imbrication.

The orientation of cross stratification and the imbrication of pebbles are often used to reconstruct the current directions in palaeogeographic interpretations of sediments. The assumption usually made is that the direction of dip of the cross strata and the alignment of the long axes of pebbles coincide with the current direction. This^{is} probably true in many cases but in the deposits of the runnels, the cross stratification and imbrication of pebbles produced by the ebb current tend to show a net dip across the runnel at right angles to the current direction.

Stratification of the Spit.

Unfortunately it was not possible to make wax impregnated sections of the spit deposits because of the larger amounts of gravel sized material. Consequently the following interpretation of its structure is based largely on sections dug in the field. These revealed that the deposits of the



PLATE 39



PLATE 40.

CUSP FORM OF ASYMMETRIC RIPPLE MARKS.



PLATE .41. GENERAL VIEW OF ASYMMETRIC
MEGA RIPPLES ON BACKBEACH
SOUTH OF THE SPIT.

spit are thinly bedded and laminated in accordance with the nomenclature of McKee, and the present writer believes, as a result of a study of the sections, that the internal structure of the spit is essentially similar to that of the beach ridges. The strata on the seaward side appear to dip gently seaward at angles of about 5° , becoming horizontal on the crest and dipping away from the sea on the landward side at angles up to 30° .

The stratification is again typical of the planar cross stratification of McKee. This suggests, as in the case of the beach ridges, that swash action plays a considerable part in the building up of the spit.

Stratification of Mega Ripples.

Symmetric and asymmetric mega ripple marks are often found at different localities on the backbeach.

The asymmetric mega ripple marks develop and disperse on the highest part of the backbeach, south of the spit (See Plates —, 39, 40 and 41). They possess an irregular cusped form with their crests aligned approximately parallel with the long axis of the spit to the north. They have an average height of about 1 foot and they may be as much as 8 feet wide.

Similar features have been described by Kindle (1917) and have been called "sand waves" by Vaughan Cornish (1914) "metaripples" by Bucher (1919) and "transverse mega ripples" by Van Straaten (1953).

The internal structure of these transverse mega ripples

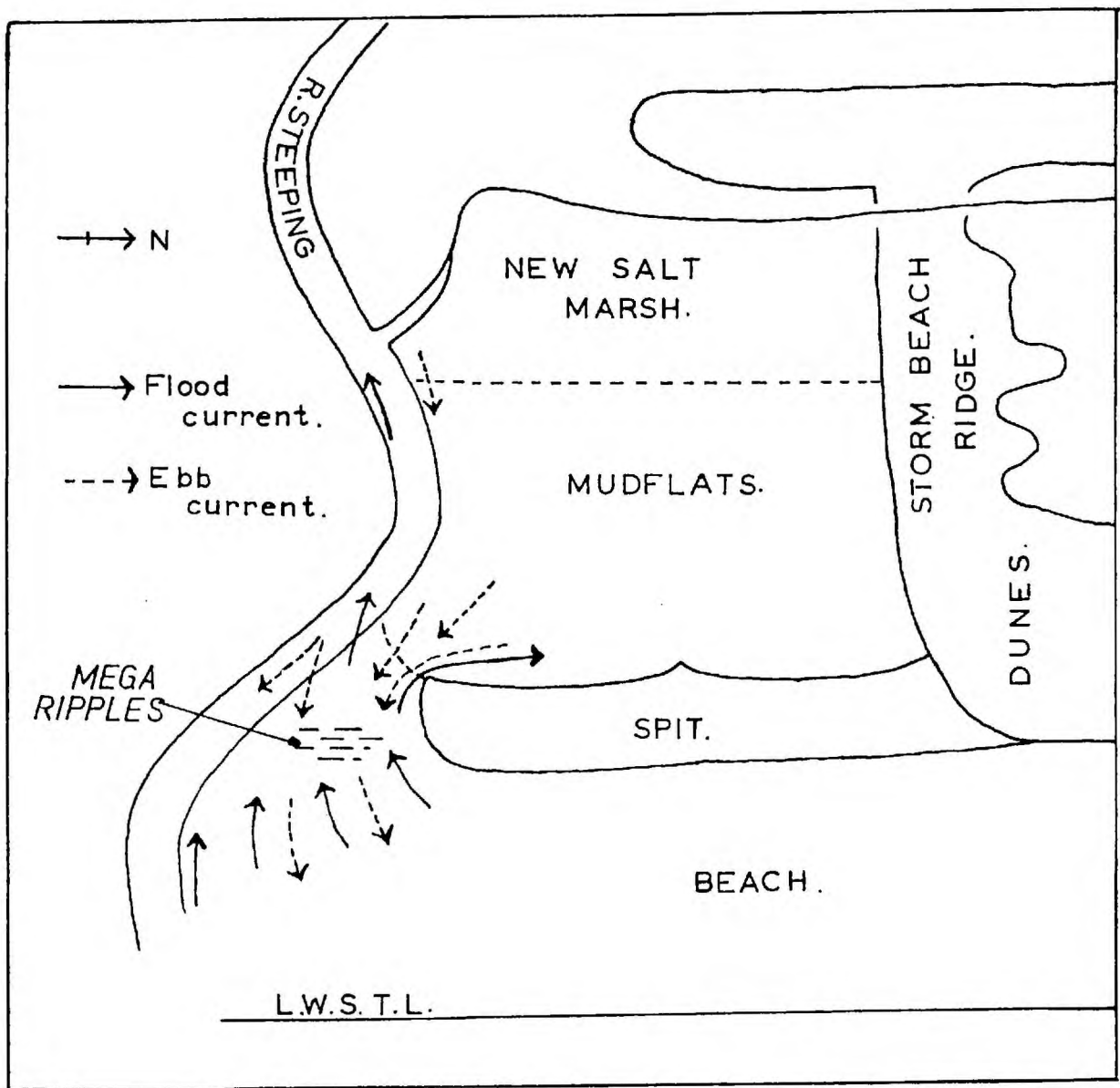


FIG44. Diagram showing possible mode of origin
of transverse mega ripples by tidal
currents.

is much more complicated than an examination of their exterior form would suggest. They are made up of several sets of variously inclined laminae; each lamina is about $\frac{1}{4}$ inch thick and each set is separated from the one above and below it by a surface of erosion (See Plate D at back of the thesis). The strata may dip in the direction of the steep or gentle slopes of the mega ripple giving rise to a "herringbone" type of stratification, or they may be curved in a manner typical of "festoon" stratification.

Although no precise measurements were made, examination of these mega ripple marks, over a period of time in which they were affected by many tides, suggests that they do not move but appear to build up and break down on the same spot. However, whereas the main mega ripple form remains relatively static it appears that the surface layers of sediment are often reworked. This is indicated by the complicated internal cross stratification and it is suggested that this is the result of alternate erosion and deposition.

The location of the mega ripples suggests that they have been produced by strong tidal currents (See Fig. 44). During periods of high spring tides the flood tide waters spread rapidly over that part of the backbeach where the mega ripples occur, as they pass inland up the River Steeping and into the embayment behind the spit. The large volume of water which thus accumulates inland flows rapidly seaward as the tide ebbs. These strong currents would be capable of forming the mega ripples. This agrees with the

suggestions of other writers and is supported by the fact that the long axes of the mega ripples are aligned at right angles to the current directions and during low tide periods, following the ebb tide, their steep slopes face seaward.

The various sets of differentially inclined laminae suggest that both flood and ebb currents play a part in eroding and depositing material on the crests of the mega ripples. However, wave action may also be an important modifying agent.

Symmetric mega ripple marks are occasionally found on the lower parts of the runnels. As stated in an earlier chapter, these are aligned with their crests at right angles to the long axis of the runnel, that is, normal to the flood and ebb current directions and it is suggested that these currents are responsible for the formation of the mega ripples. Unfortunately, due to their infrequent appearance, it was not possible to make a detailed study of their internal stratification.

Ripple Marks.

The surface of the backbeach, like that of the forebeach, is conspicuously ripple marked but there is a greater variation in the types found.

Asymmetric ripple marks are by far the most common. They are found on the tops of the ridges and in these places their crests are long and orientated roughly parallel to the long axis of the ridge. Their steep or stoss slopes face landward and their heights and lengths are comparable with

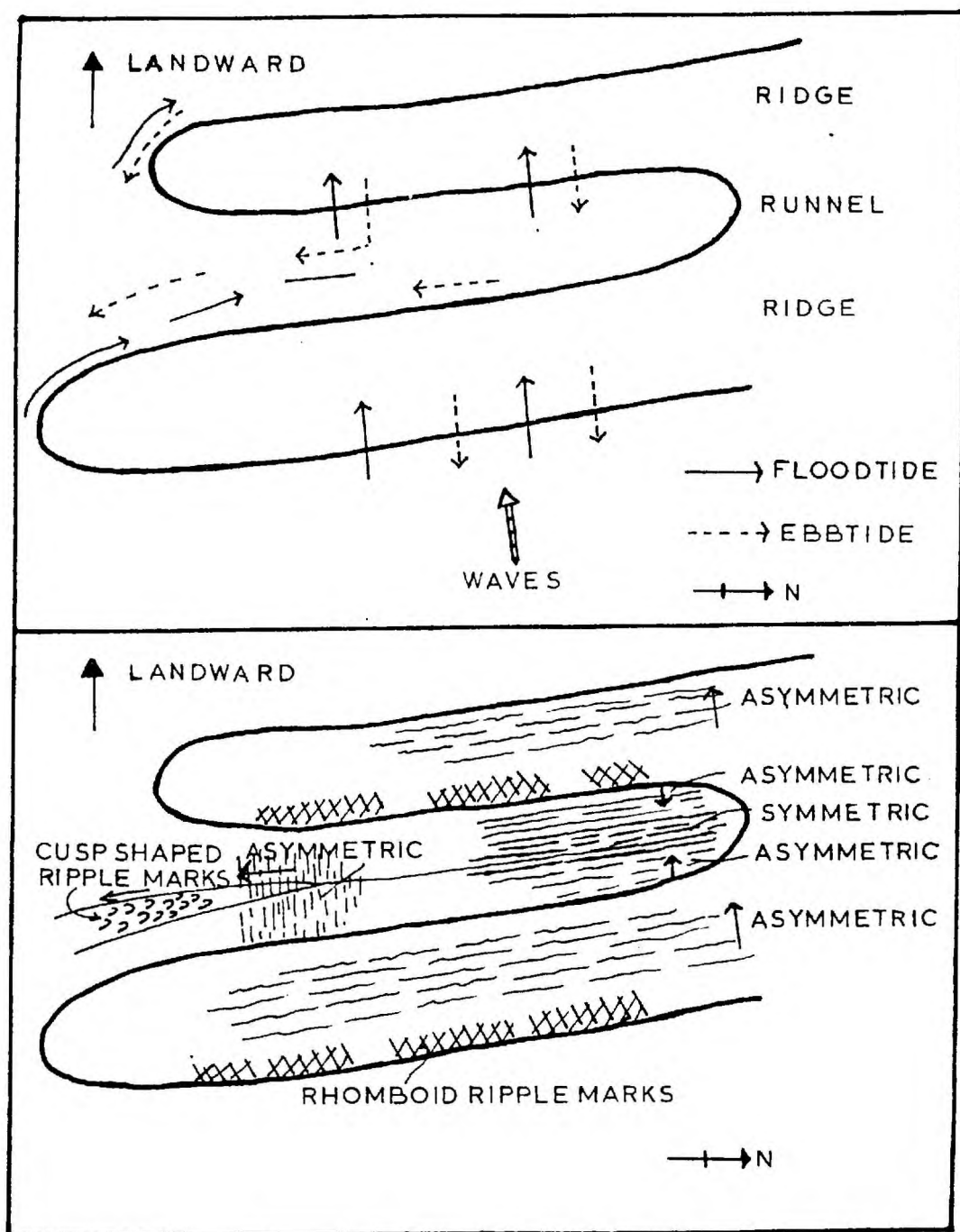


FIG.45. Diagram showing the distribution and variation of major types of ripple marks on the backbeach and their relationship to wave and tidal current directions.



PLATE.42. ASYMMETRIC RIPPLE MARKS
IN BEACH RUNNEL.

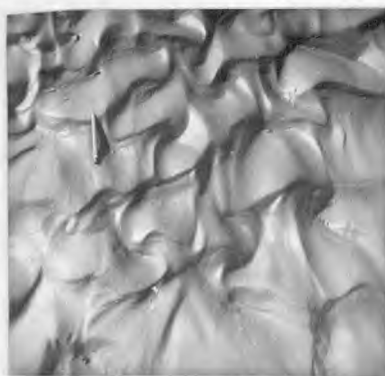


PLATE.43. CUSP SHAPED RIPPLE MARKS
IN BEACH RUNNEL.

those found on the forebeach. It is suggested that they are formed by wave action during high spring tide periods and their asymmetric form as observed at low tide periods, is due to swash action as the tide ebbs. Like those on the forebeach they are equivalent to the transverse asymmetric current ripples of other writers.

Similar ripple marks are found on the surfaces of the runnels. Their crests are orientated parallel to the long axes of the runnels but whereas those on the landward sides of the runnels possess steep slopes facing seaward, those on the seaward sides have steep slopes facing landward. The ripple marks between these two types tend to symmetric in form (See Fig. 44). These ripple marks are probably formed by oscillation of the waters within the runnels during high spring tide periods.

Two other types of asymmetric ripple marks are found in the runnels. They occur on the lowest parts and are closely related to the ebb channels. The first type possesses parallel crests which are orientated at right angles to the long axes of the runnels (See Plate 42 and Fig. 45). They have wavelengths of about 7 inches and heights of about 0.25 inches. Their steep slopes face southward towards the mouths of the runnels. The second type possesses short cusped shaped crests (See Plate 43) with the same orientation at right angles to the long axes of the runnels. These ripple marks are undoubtedly produced by the ebb tide currents which flow southwards within the



PLATE.44. RHOMBOLD RIPPLE MARKS ON
SEAWARD SLOPE OF BEACH RIDGE.



PLATE.45. RHOMBOLD RIPPLES, TROUGHS
INFILLED WITH COAL AND SHELL
FRAGMENTS.

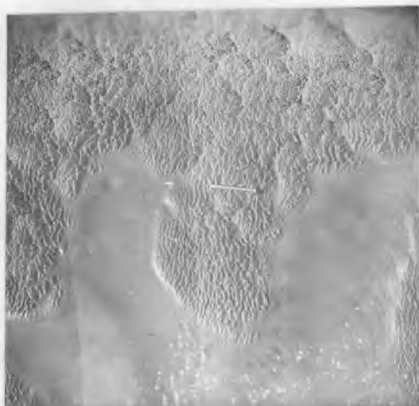


PLATE 46. WIND ANTI-RIPPLETS.



PLATE 47. BEACH CUSPS.

confines of the funnel.

Asymmetric ripple marks are also found on the crests of the mega ripples south of the spit. They have the same orientation as the mega ripples. They probably form as a result of the decreased water velocities when the mega ripples cease to develop. In the troughs of the mega ripples both asymmetric and symmetric ripple marks are found and are probably formed by oscillation of the water in the troughs.

Rhomboid ripple marks are periodically found on the flat seaward facing slopes of the ridges (See Plates 44, 45). Their origin has been explained by Woodford (1935) and appears to be connected with the diagonal patterns of standing waves.

Wind-anti-ripplets, so called by Van Straaten (1953), are found on the moist surface of the backshore, particularly in the runnels during low tide periods when strong winds are blowing. They may be as much as $\frac{3}{4}$ inch in length and $\frac{1}{4}$ inch in height. (See Plate 46). They are asymmetric with their steep slopes facing the wind direction. The wind deposits dry grains on their steep sides, thus adding to their development.

Swash and Backwash Structures.

Structures produced by the swash and backwash of the waves are commonly found on the backbeach after the tide has retreated.

Beach cusps are commonly found on the seaward facing slopes of the beach ridges (see Plate 47). Most writers agree that they are formed by the swash and backwash of

breaking waves and that the size of the cusps is related to the size of the waves, but some doubt exists concerning the actual method of formation.

Johnson (1919) collected most of the earlier theories on their origin and reached the conclusion that they are formed by the selective erosion of the swash working on irregular initial depressions. Evans (1938) who classified cusps suggested that they are formed by erosion of small breaks in beach ridges by the waves. However, Bagnold (1940) notes that the swash piles up against the horns of the cusp and is divided into two streams which flow around the head of the bay and unite to flow back as backwash (~~see fig. 10~~). Kuenen (1948) who re-examined the problem stressed the importance of deposition as well as erosion; the horns being built up of material washed from the bays. This is effected by the refraction of the swash which carries material towards the horns. The sideways component of the swash helps to concentrate the backwash along the edges of the horns (~~see fig. 10~~). Cusps appear to be formed by waves approaching the coastline both normally and obliquely. The present writer found that they generally form at points where there was previously no evidence of a break or irregularity, in fact on the backbeach in the area studied, they tend to form only on the seaward facing slopes of the ridges which are smooth and regular; thus suggesting that the theories of Johnson and Evans are not strictly valid. The writer agrees with Bagnold and Kuenen that the lateral movement of water



PLATE 48. SWASH MARKS ON SEAWARD
FACE OF BEACH RIDGE.



PLATE 49. STRIATED PEBBLE PRODUCED
BY SWASH AND BACKWASH.



PLATE 50. WIND ETCHED FEATURES - NOTE

INCLINATION OF PEBBLES.

within the cusp is of great importance but after cursory observations in the field tends to favour Kuenen's theory for the development of beach cusps.

Lines marking successive stages of retreat of the swash as the tide falls, are regularly found on the seaward facing slopes of the beach ridges. They are fine ridges of light minerals and shell fragments. These are winnowed from the surface sediment by the quiet swilling action of the swash as it climbs the seaward slopes of the ridges and are deposited at the upper limit of the swash action (See Plate 48). Froth and air bubbles are often left stranded at the upper limit of swash action. These burst as the sediment dries producing small circular pits in the underlying sandy surface.

The backwash of a wave often produces marked striations on a sandy or pebbly surface. These striations are always orientated in the direction of the backwash. (See Plate 49).

Structures Produced by Wind Etching.

These are common features on the backbeach when a strong wind is blowing during periods of low tide. Under such conditions the sediment dries quickly and the sand is rapidly winnowed away by the wind. Larger particles such as pebbles and shells of molluscs may not be transported. All the sand is carried away except for that beneath and to leeward of these large particles. The material to leeward, which is shielded by the pebbles or shell, forms a small "spur" or "tail" sloping downwind (See Plate 50).

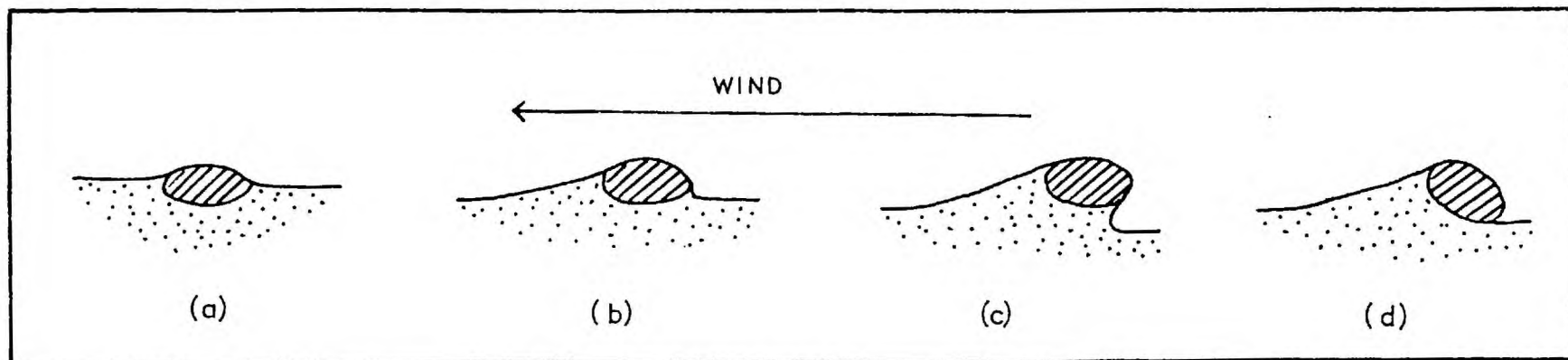


FIG 47. Diagram showing development of sand spurs and inclined pebbles by deflation.

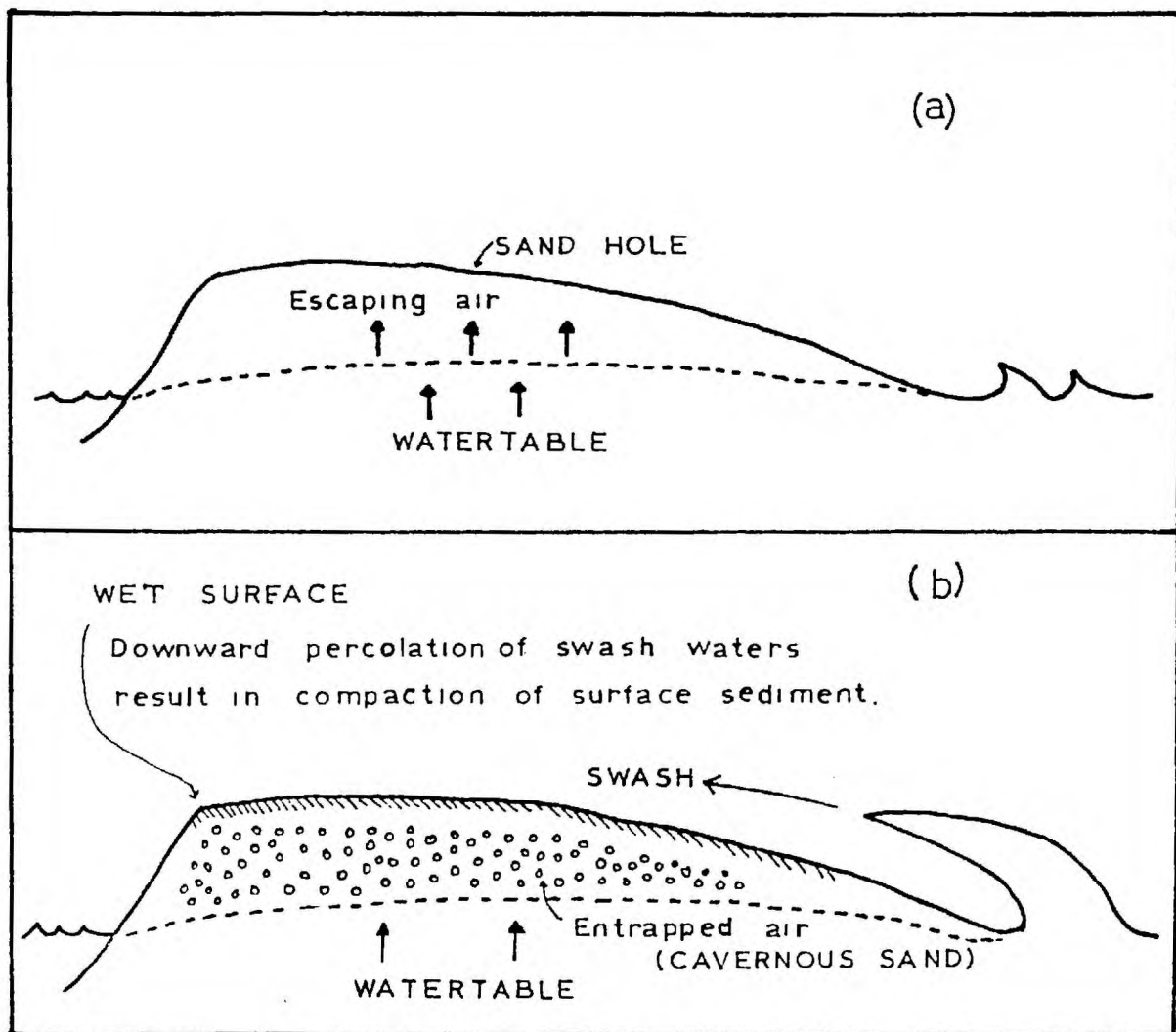


FIG48. Diagram showing development of sand holes and Cavernous sand on the Beach Ridges as the tide rises.



PLATE 51. SAND HOLES.

As deflation continues sand is slowly eroded from beneath the windward side of each pebble or shell, until the degree of undercutting reaches a critical point and the pebble or shell tips over to become steeply inclined in a windward direction (See Fig. 47 and Plate 50). On pebble rich surfaces such as those of the crests of the spit and beach ridges marked imbrication may be produced in this way.

Air Entrapment Structures.

Structures produced by escaping or entrapped air or gas are sometimes found in the deposits of the beach ridges. Similar features have been described by Kindle (1935) and Emery (1945). Two types were observed in the area studied. The first called "sand Holes" are produced by the expulsion of air or gas from the pore spaces of the beach ridge sediment as a result of the pressure set up by the rising water table as the tide comes in. The escaping air tends to be concentrated in steady streams flowing upwards. These form sand holes varying from $1/10$ - $\frac{1}{4}$ inch in diameter on the surface (See Fig. 48a and Plate 51).

The second type of structure called "cavernous sand" is formed during periods when the swash action of the waves spreading rapidly over the flat crest of the ridge, wets the surface sediment above the rising water table. Air is often trapped between these two wet layers as small pockets, giving rise to a loosely packed sand with a characteristic honey comb or cavernous texture. (See Fig. 48 b).

Miscellaneous Inorganic Structures.

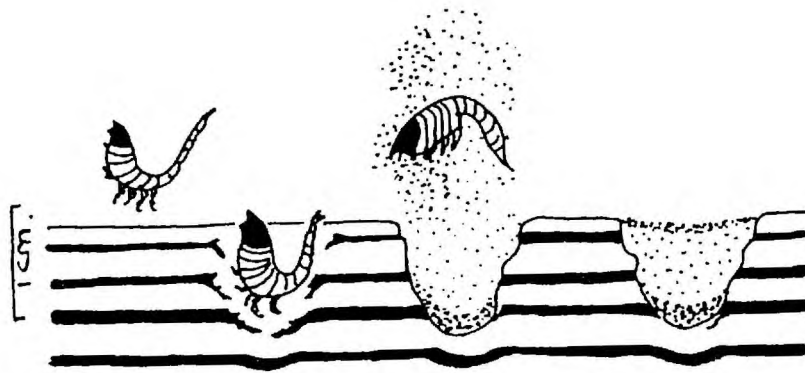


FIG49 Sand hoppers (Cumacea):- structures.
after Schäfer (1956).



PLATE 52. SEAL TRACTS.

Miscellaneous Inorganic Structures.

Many other structures, other than those already described, are found from time to time on the backbeach. These are:-

rill marks.

raindrop prints.

armoured mud balls.

Organic Structures.

The backbeach is practically devoid of organisms except for the occasional appearance of sand hoppers and seals. These have practically no effect upon the stratification but do produce characteristic surface trails. (See Fig. 49 and Plate 52).

The sand hoppers sometimes occur in immense numbers along the strand line where they burrow in the damp sand under weed and other debris. They may jump for distances of several feet by a sudden straightening of a normally bent body producing small irregular pits on the surface.

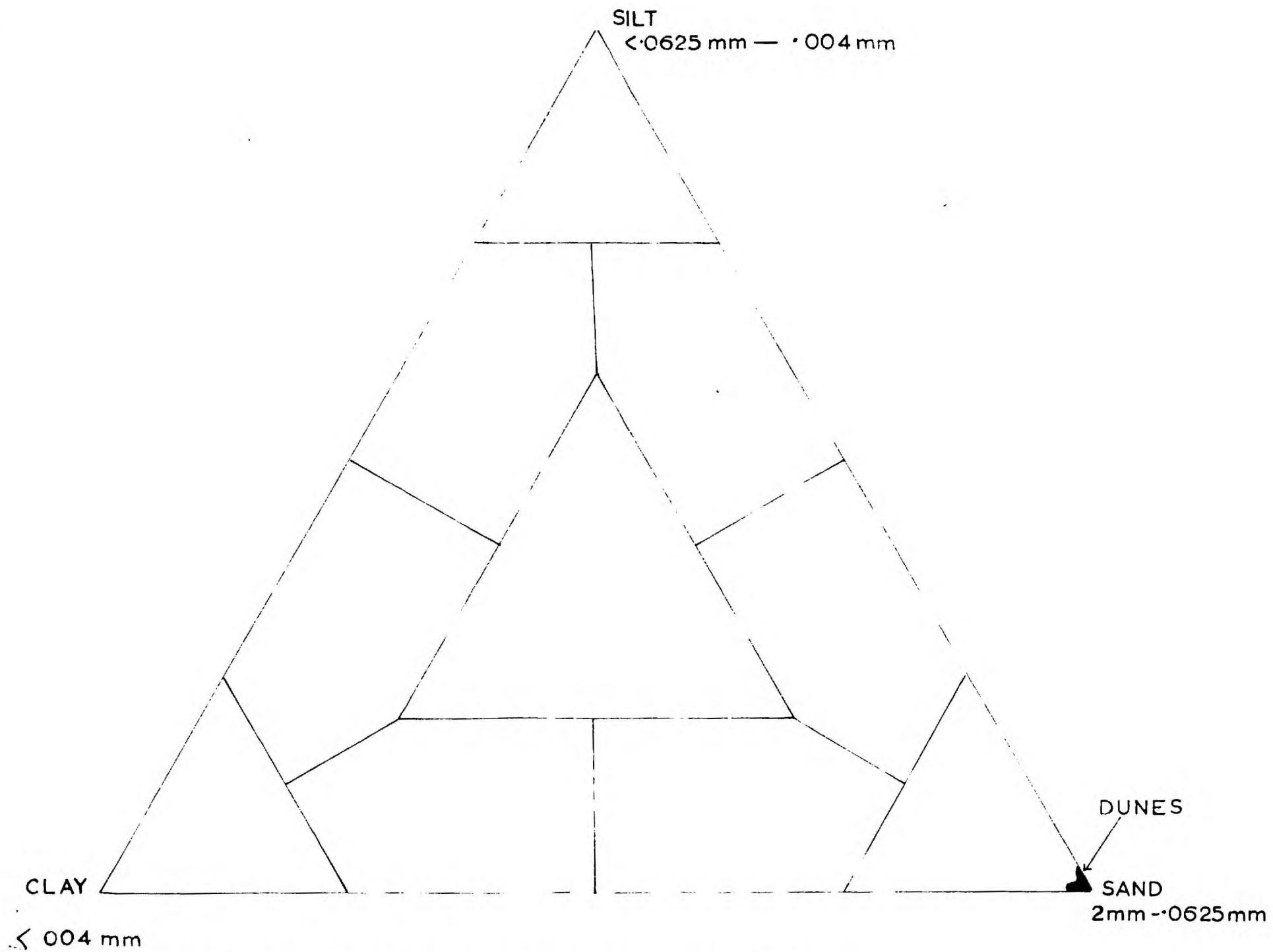


FIG 50. SAND/CLAY/SILT RATIOS OF DUNE DEPOSITS.

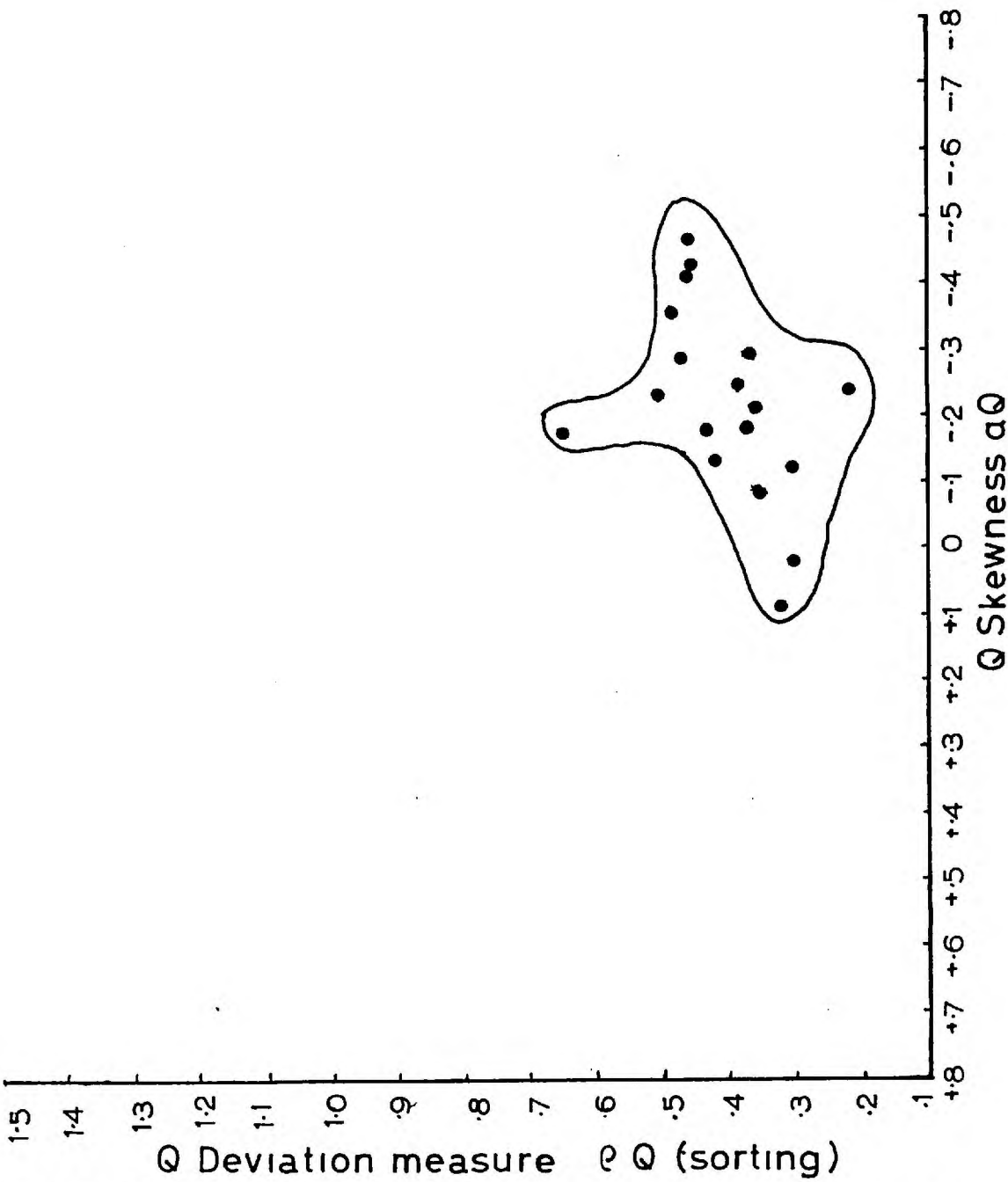


FIG53 Sorting against Skewness for Dune deposits.

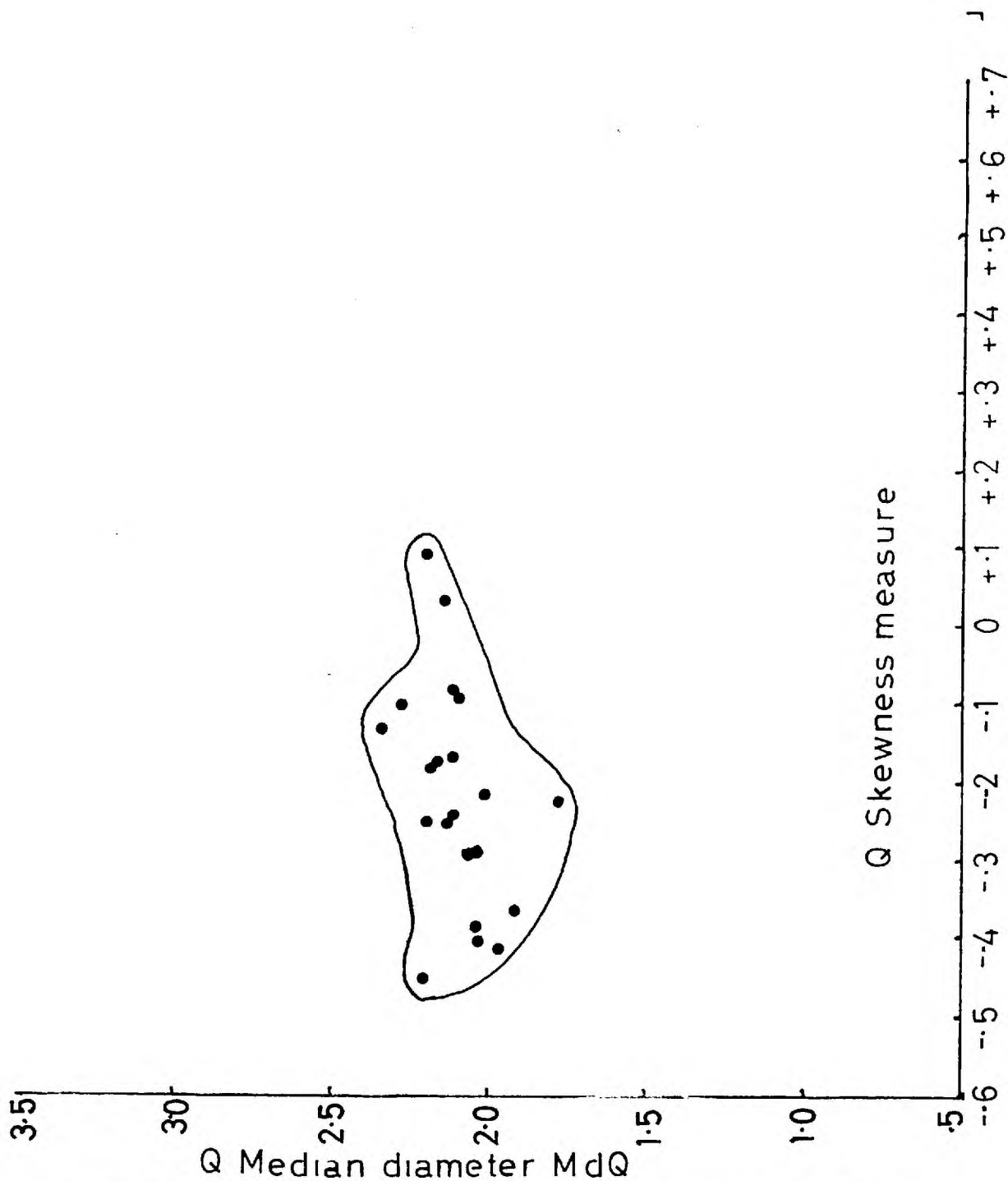


FIG52 Median diameter against skewness for Dune deposits.

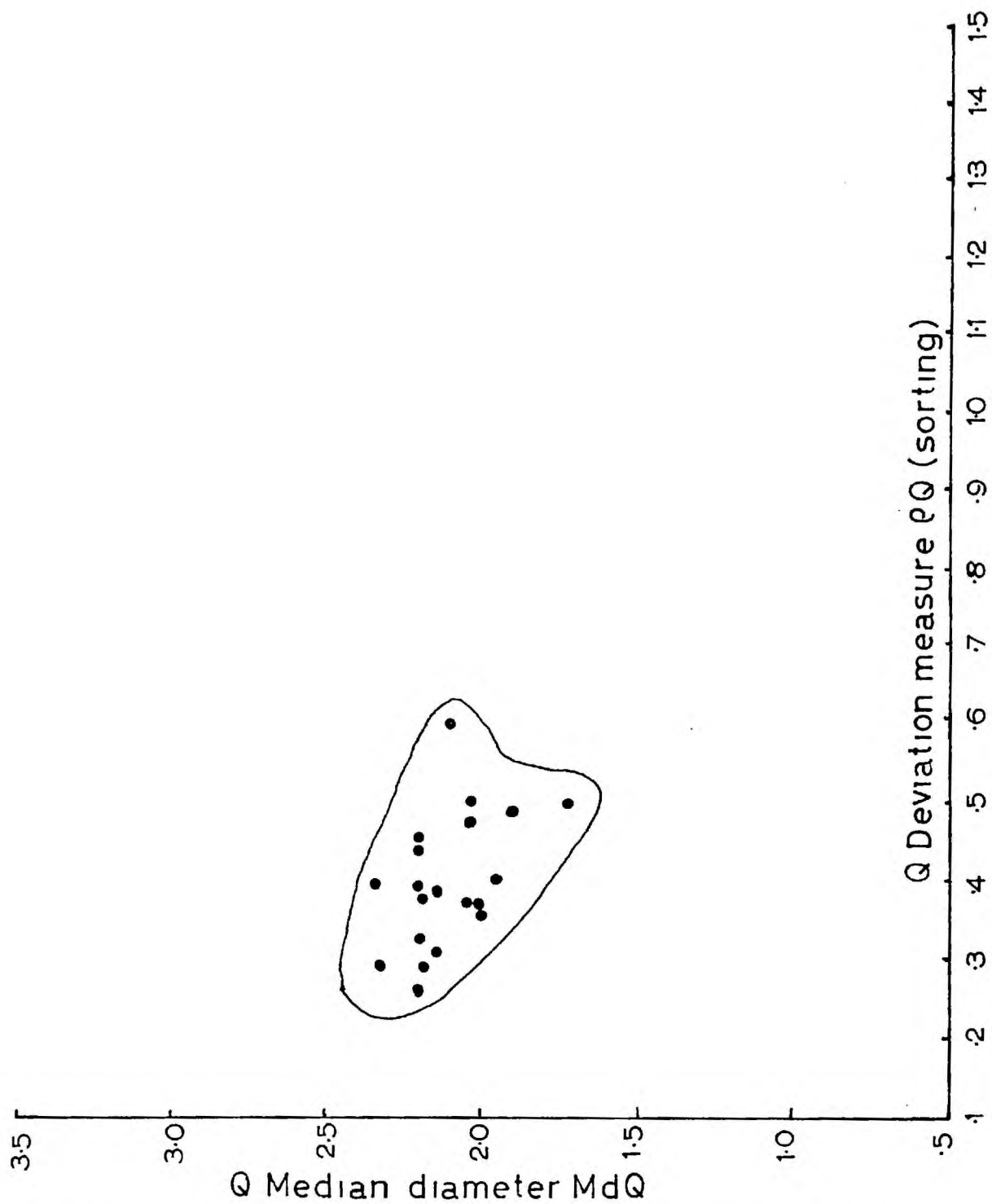


FIG 51. Median diameter against sorting for Dune deposits.

CHAPTER 6.

Dunes.

The deposits of the dunes are generally much better sorted than those of the beach. They are easily distinguished from those of the forebeach but it is not always possible to distinguish them from the backbeach deposits by grain size alone, except when pebbles are present in the latter.

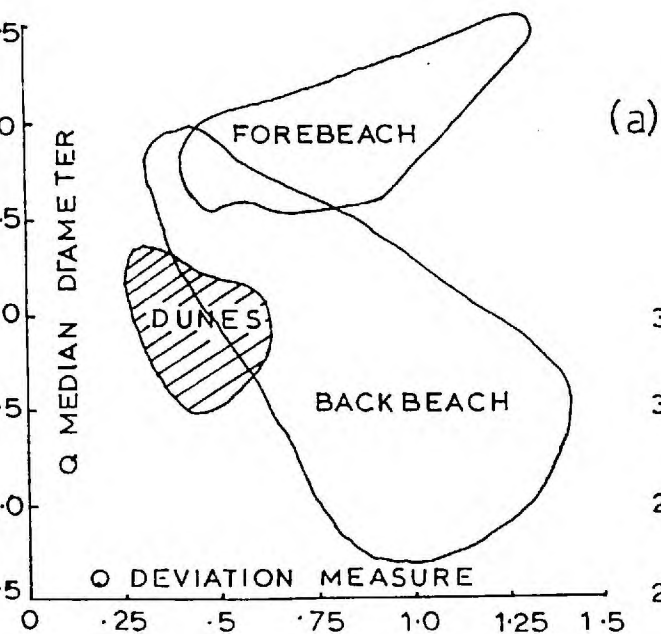
The stratification of the dunes is distinctive. Apart from local variations the morphological shape of a dune is the exterior expression of its internal structure.

Granulometric Analyses.

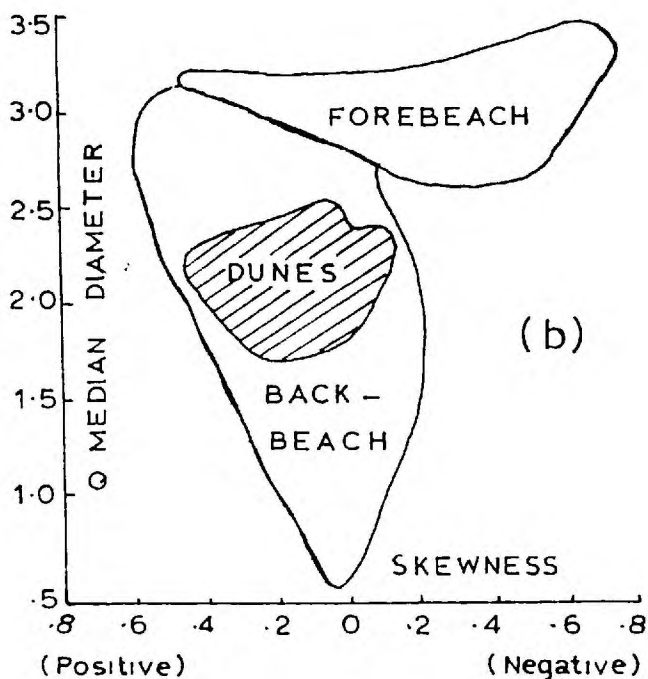
The dune deposits are sands (Shepard and Kruit)(See Fig 50). They contain very small amounts of very fine grained material which rarely exceeds 1% of the total and most of it is less than .004 mm in grain size. All the samples studied consist in the main of material between the grade limits 0.125 - 0.25 mm, that is fine sand (Wentworth).

These deposits have ϕ median diameters ranging from 1.75 - 2.35 with an average value of 2.11. The ϕ deviation measures have a similar narrow range from 0.22 - 0.65 with an average value of 0.4. The ϕ skewness measure values are usually negative but range from +0.08 to -0.48 with an average value of -0.22 (See Figs 51, 52 and 53).

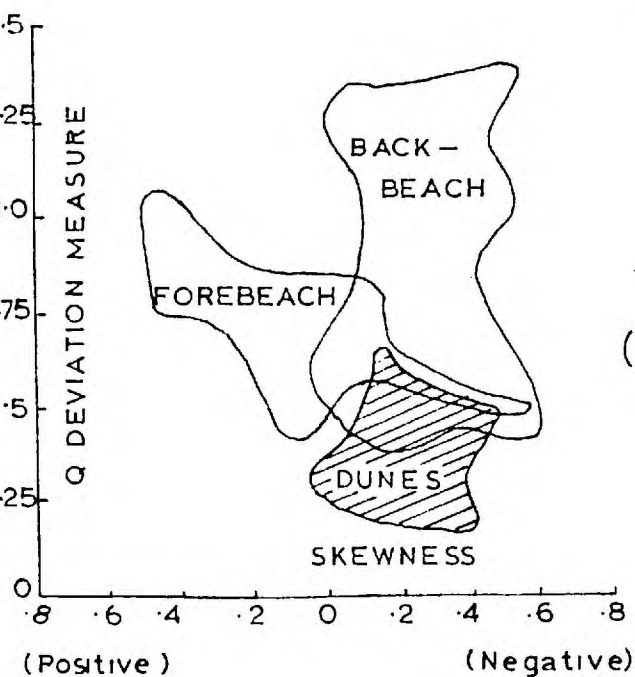
Plots of ϕ median diameter against ϕ deviation and skewness measures and ϕ deviation against skewness show that the dune sands are easily distinguished from the forebeach deposits, whereas only plots of ϕ median diameter



(a)



(b)



(c)

FIG.54.

Diagram showing ranges of Q median diameter, deviation measure, and skewness values for sand fraction of Dune, Forebeach and Backbeach deposits.

against ϕ deviation measure proved to be useful in distinguishing between dune and backbeach deposits (See Fig. 54). Some of the backbeach samples appear to be intermediate between those of the forebeach and dunes, but an examination of the ϕ median diameter ranges shows that the backbeach completely overlaps the dunes. This suggests that the dune sand is derived only from the backbeach. Observations in the field show that during low tide periods, the surface deposits of the forebeach remain extremely wet, whereas those of the backbeach dry out rapidly and so can be easily affected by the winnowing action of the wind.

Similar distinctions have been observed by Mason and Folk (1958) who studied beach and dune deposits on Mustang Island, Texas; and by Friedman (1961). Shepard and Young (1961) however, who compared beach and dune sands from various parts of the world show that it is generally only possible to differentiate between these deposits in areas where there are predominant onshore winds. The dunes in the area studied are, as shown by King (1959) formed by onshore winds.

Mason and Folk and Friedman found that dune sands usually show positive skewness values, whereas Shepard and Young and the present writer generally observed negative skewness values. As pointed out by Shepard and Young this may be caused by the effects of the settling tube method of analysis used by them and the present writer, as

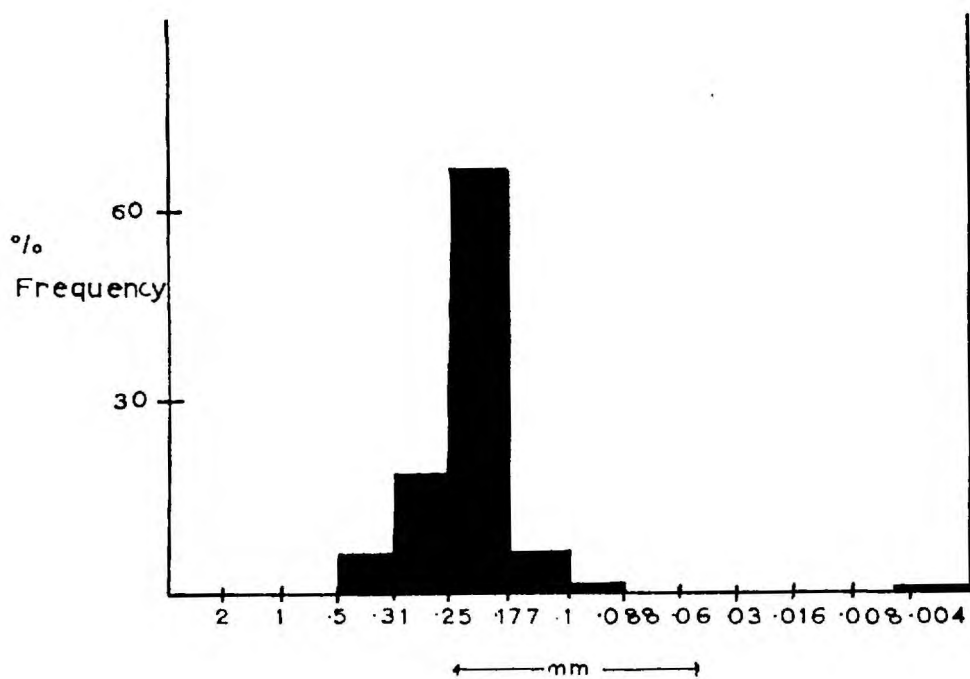


FIG.55 Histogram showing grain size distribution of sample PSA 52 from the dunes.

compared with the sieve method used by the others. However providing only one method is used it affects the analysis of both beach and dune samples in the same manner so that a comparison is justified.

Unlike the present writer the others found that the beach and dune sands showed similar ranges of ϕ median diameter and ϕ deviation measure and plots of these parameters rarely proved useful in distinguishing between the two. This similarity is probably due to the fact that in the areas they studied, the variations in wind, wave and current velocities are very much the same.

In the Gibraltar Point area however, the ranges of ϕ median diameter and ϕ deviation measure of the dunes are much smaller than those for the beach. This is due in part to the fact that the sediments are derived largely from nearby, Pleistocene fluvio-glacial deposits (See last chapter). The short distance of transport, the wide range of grain sizes available in the source areas and a considerable variation in wave and current velocities result in poorly sorted beach sediment with an extensive range of grain sizes. The variation in wind velocity is probably very limited when compared with the variation in wave and current velocities with the result that the wind winnows only material within a small grain size range from the beach.

The dune sands show unimodal grain size distributions (See Fig 55). An examination of the cumulative curves

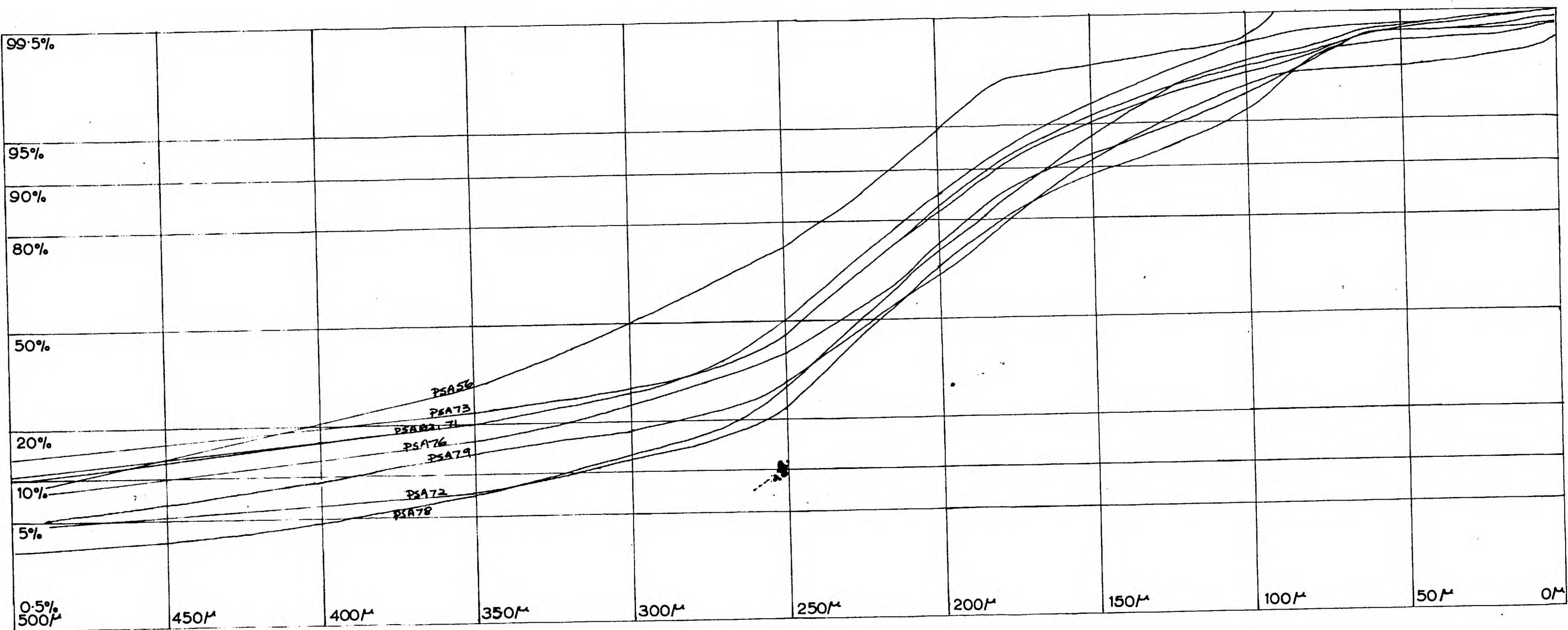


FIG56b Grain size frequency distribution of old dune deposits.

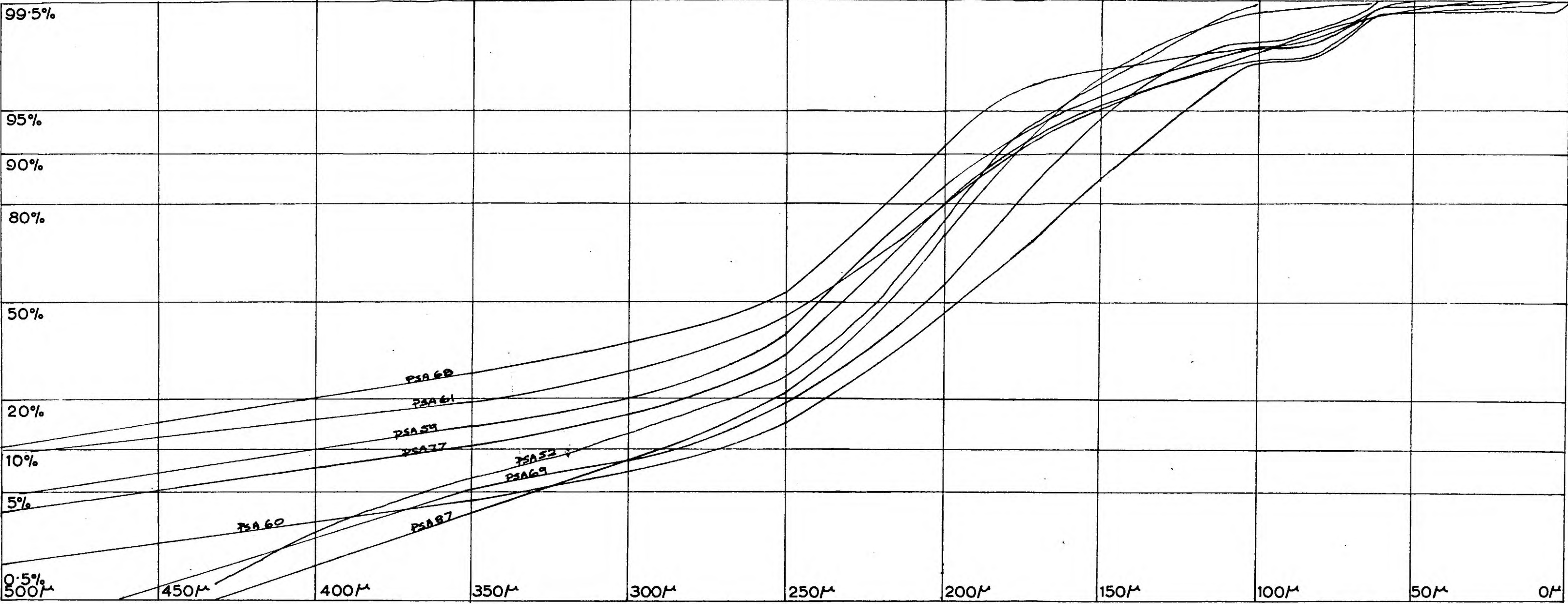


FIG56a Grain size frequency distribution of new dune deposits.

shows that although the lower grain size limits are fairly sharply defined, there is a marked variation in the upper grain size limits (See Fig. 56a,b). Although relatively very much better sorted than the backbeach sands, the dune sands are not quite as well sorted as one might expect. This at first is surprising for one might anticipate that the wind blowing over the beach would pick only the smaller grains and hence a dune sand could be easily distinguished from the parent beach material by its smaller grain size. The process is obviously not so simple and the wind is evidently capable of transporting large grains as well as smaller.

The absence of finer grain sized material, and in particular silt, is undoubtedly due to the fact that the smaller grains are kept in suspension by even slight air turbulence (Bagnold (1940) and entirely by-pass the dunes. If silt is deposited the dune sediment being dry is subject to more sorting from the wind which may remove these finer grains. The small amounts of fine particles less than .004 mm are probably carried into the dunes while adhering to the surfaces of sand grains.

Composition.

The coarse fractions (2mm - 1/16 mm) of the dune deposits consist of quartz grains in the main with smaller amounts of feldspar, rock, shell and coal fragments. Occasionally foraminifera tests and bryozoan fragments are found. Surface samples from the older dunes are stained.

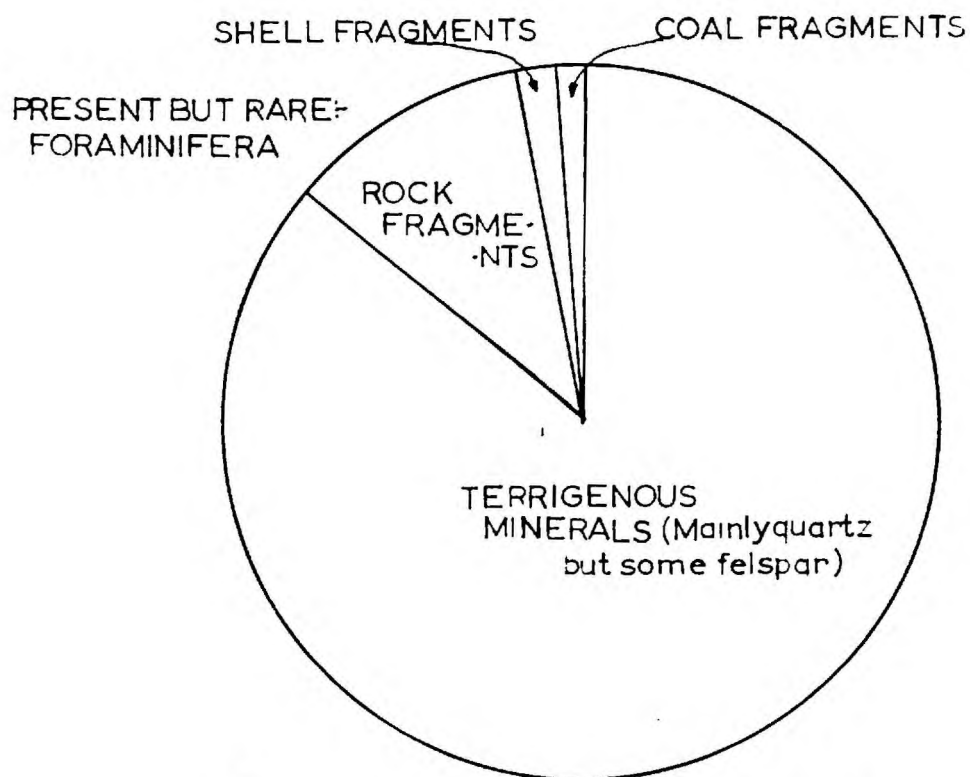


FIG 56^c COMPOSITION OF THE COARSE FRACTION,
(greater than 0.0625 mm), OF DUNE DEPOSITS.

brown by humus. There is an absence of mica but this does not strictly indicate that the wind picks up rounded rather platy grains because mica is also absent from the backbeach deposits! (See Fig 56c)

Frosting of Grains.

Although the shell fragments and foraminifera tests showed evidence of abrasion, frosting of the mineral grains appeared to be practically non-existent. This agrees with the results of Kuenen (1960) and Shepard and Young (1961).

Structures.

Stratification.

All the dunes as far as could be deduced were entirely laminated. The laminae vary in thickness from about 1/10 to 1 inch in thickness. Many were found to be more than 10 feet in length. The inclination of the laminae rarely exceeded 30° and is considerably less near the base and crest of any dune (See Plate E at the back of thesis).

A correlation exists between the direction of inclination of the laminae and the dominant winds. Although the dune ridges are generally affected by winds from two directions that is, onshore and offshore, the gross structure of the dunes is simple and symmetrical. The general dip of the laminae is to landward or seaward and the angles of dip in both directions are approximately equal. This arrangement may be explained by the fact that the dunes sands are rapidly colonised by vegetation which stabilises the dune and prevents any migration. This structure contrasts



PLATE 53. WIND FORMED ASYMMETRIC
RIPPLE MARKS.

markedly with that of migrating dunes described by various other workers. Any diversity of direction of inclination of laminae results from deposition on local surfaces of erosion. Truncating surfaces are formed as the result of deflation or by storm waves. The wind erodes the dunes in places where the vegetation cover is sparse and storm waves cut small cliffs in the seaward faces of new dunes forming behind the backbeach. These surfaces are later obliterated by slumping and deposition of more sand.

An interesting feature of the dunes at Gibraltar Point noted by King (1953) is the fact that the new dunes develop on masses of debris, deposited along the strand line by waves. This material consists largely of the remains of bryozoa (*Flustra* sp.) echinoderms and driftwood etc. (See Plate 53). Occasionally a bed 6 inches or more in thickness made up of this wave borne debris mixed with wind blown sand separates the basal dune laminae from the underlying backbeach ridge deposits. Where dunes can be seen to rest on old backbeach ridges, there is a disparity between the angles of inclination of dune and backbeach laminae. These exposures show that the dune stratification is equivalent to the "planar cross stratification" of McKee and Weir (1953).

Ripple marks.

Wind formed asymmetric ripple marks are found periodically on the more exposed surfaces of new dunes (See Plate 53).



PLATE. 54. CONCENTRIC DRAG MARKS
ON DUNE SURFACE.

As shown by Kindle (1917) and Thompson (1937) these ripple marks are easily distinguished from water formed ripple marks by the fact that the ratios of their heights to their lengths is very small. Also coarser sand is concentrated on the crests as a result of the winnowing action of the wind which carries away finer grained material from the crests, depositing it in the troughs to leeward. When strong winds occur, the finer material from the crests is carried completely out of the area but that in the more sheltered areas of the troughs remains.

Structures produced by Plants.

Plant roots do not extensively disrupt the stratification and the only evidence of their presence are the remains of cylindrical root burrows (See Plate E sections C and E).

The vegetation cover on the new dunes consists largely of marram grass. In many places the cover is thin and the tips of individual leaves tend to rest on the surrounding surface and drag backwards and forwards when disturbed by the wind. This movement produces concentric grooves which may be preserved for considerable periods of time (See Plate 54).

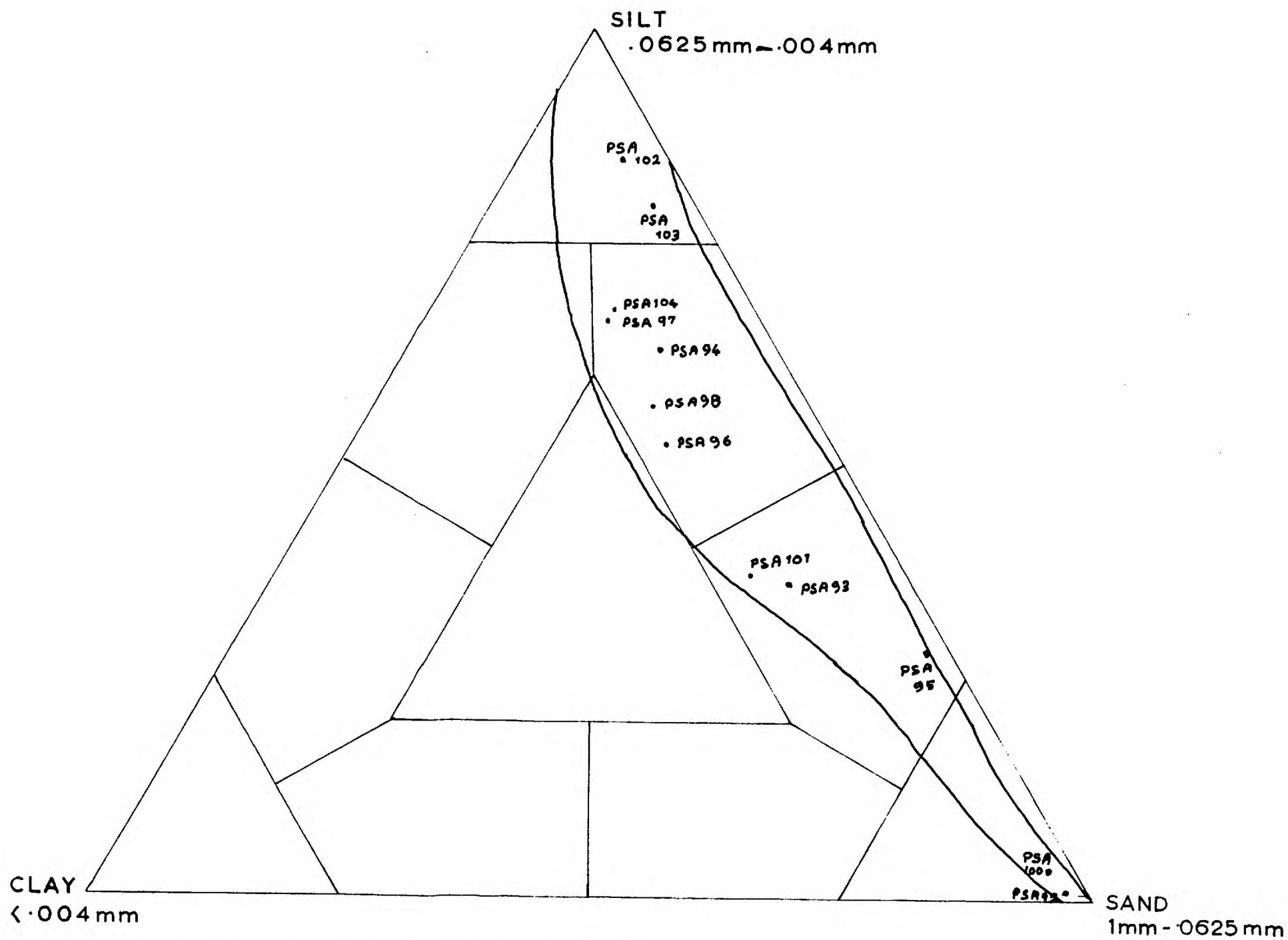


FIG.58. SAND/SILT/CLAY RATIOS OF MUDFLAT DEPOSITS.

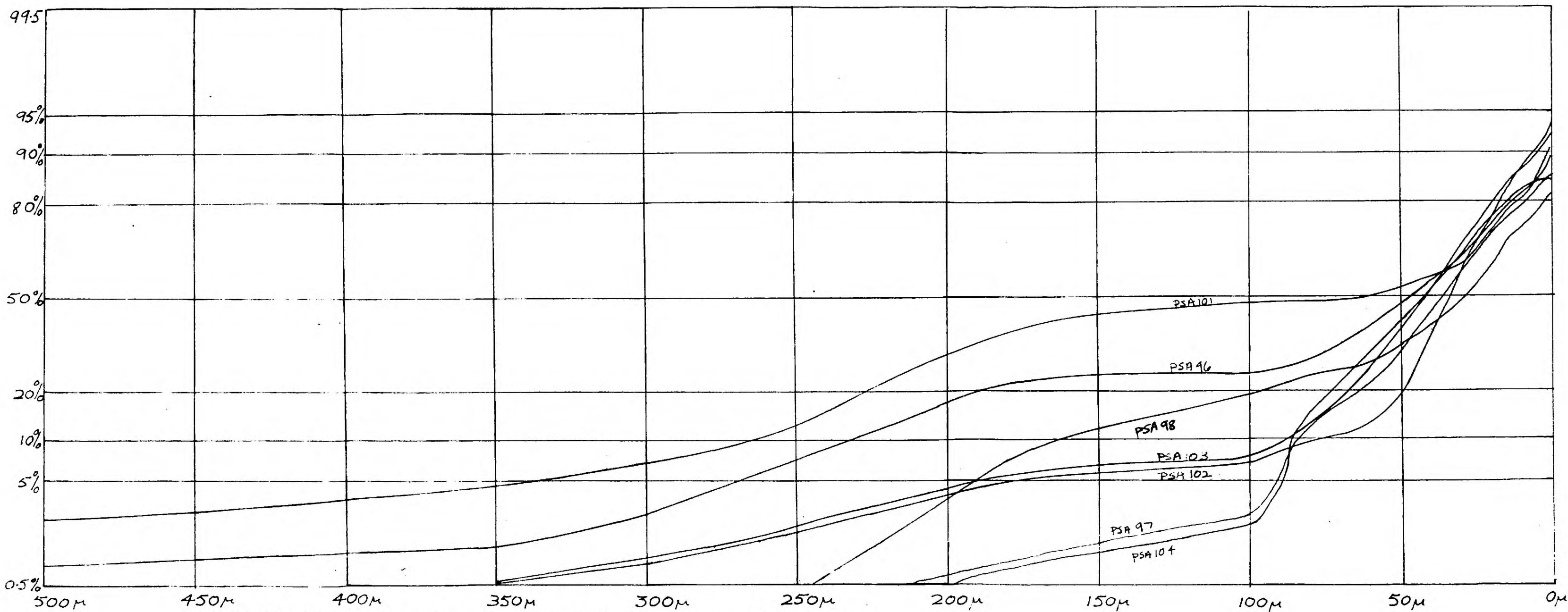


FIG 59 Grain size frequency distribution of mudflat deposits

CHAPTER 7.

Mudflats.

The deposits of the mudflats are similar to the deposits of the intertidal flats of the Wash embayment described by Evans (1960). They are generally much finer grained than the deposits of the beach and dunes and their stratification is often almost completely destroyed by burrowing organisms.

Granulometric Analyses.

The deposits of the mudflats are sandy pelites according to Kruit (See Nota 1958). In the terminology used by Shepard (1954), they are largely sandy silts and silty sands despite the fact that they sometimes contain as much as 20% clay, (less than .004 mm in grain size) (See Fig. 58). Shepard's nomenclature therefore provides an inadequate description of these sediments.

They have ϕ median diameters ranging from 4.99 - 2.3 with an average value of 4.0. Unfortunately in many cases the ϕ deviation and skewness measures could not be accurately calculated because of the difficulty in determining the 84th percentile.

The lower limits of the grain size frequency distribution curves are very well defined but the upper ones are extremely variable (See Fig. 59).

Curves for samples collected from the mudflats near the stormbeach ridge and spit (e.g. PSA 96, 95, 101) show extended coarse tails due to the presence of material coarser than 0.16 mm (160μ) and even sometimes coarser than 0.5 mm

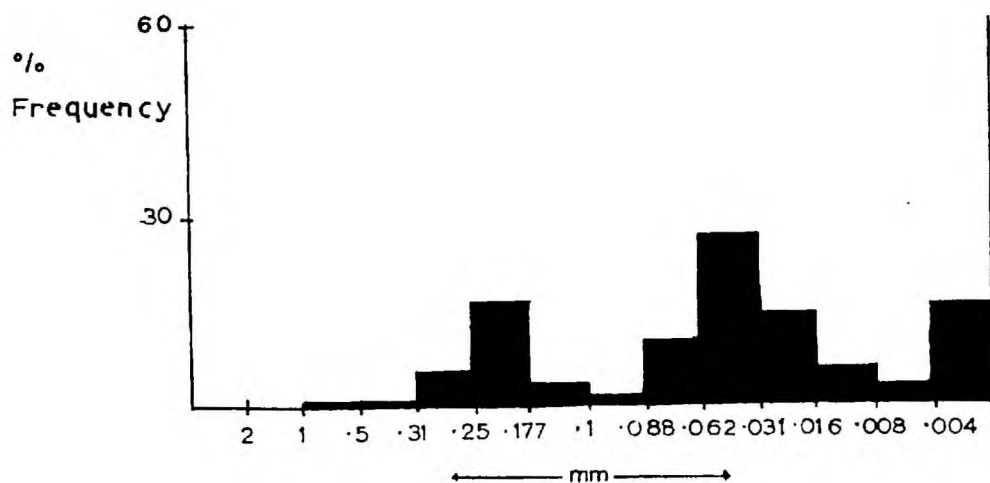


FIG.60. Histogram showing grain size distribution of sample PSA 96 from mudflats near spit.

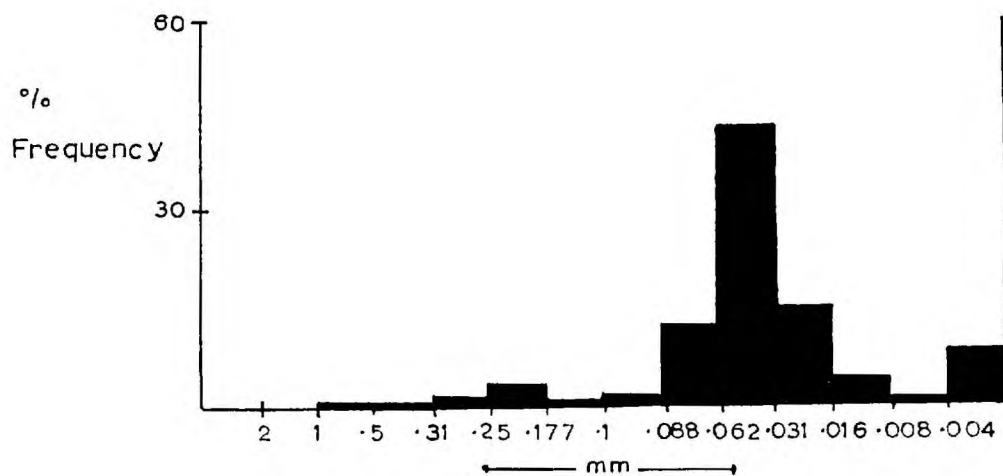


FIG.62. Histogram showing grain size distribution of sample PSA 103 from mudflats.

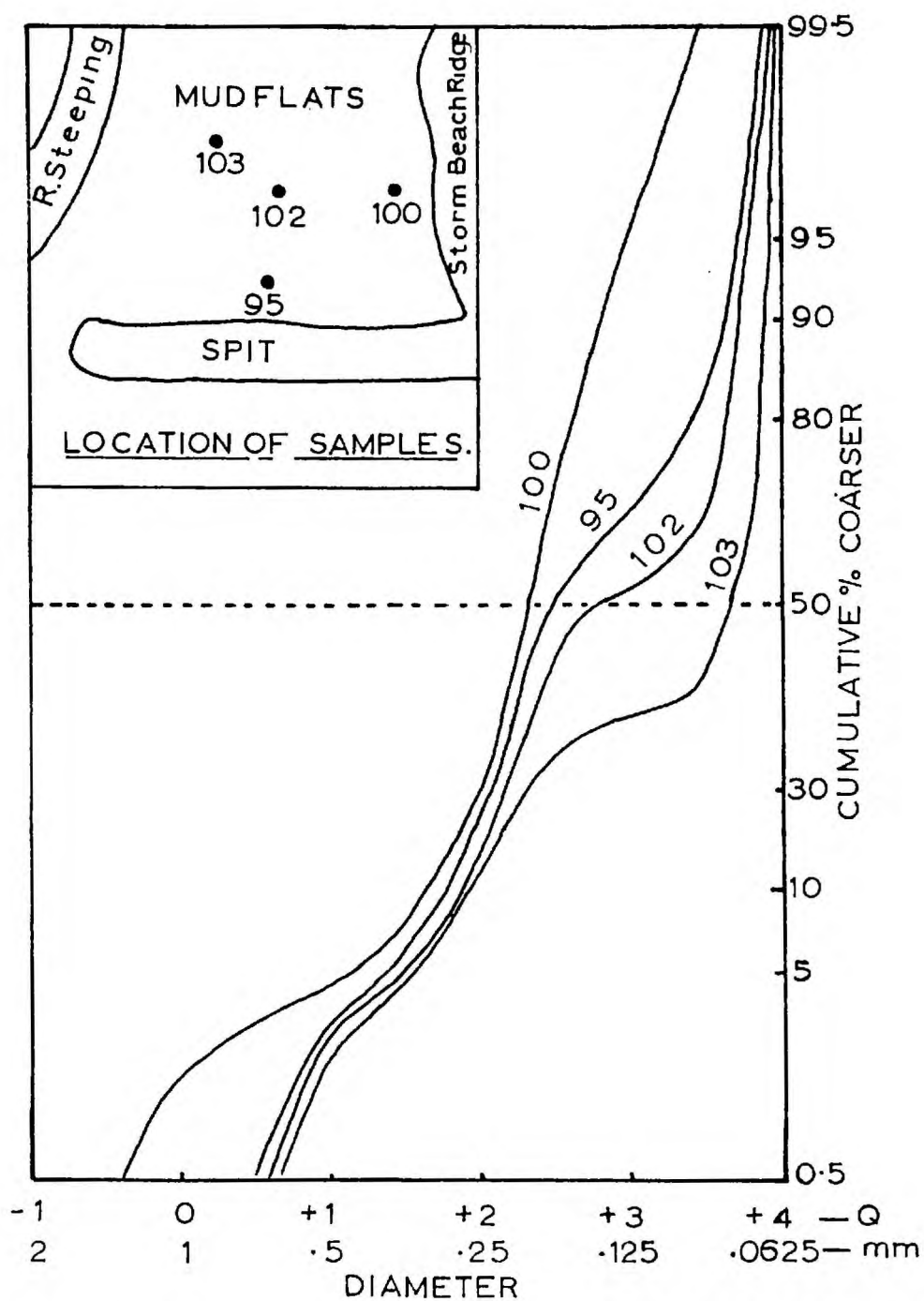


FIG. 61. Decrease in Q median diameter of sand fractions away from the spit and storm beach ridges.

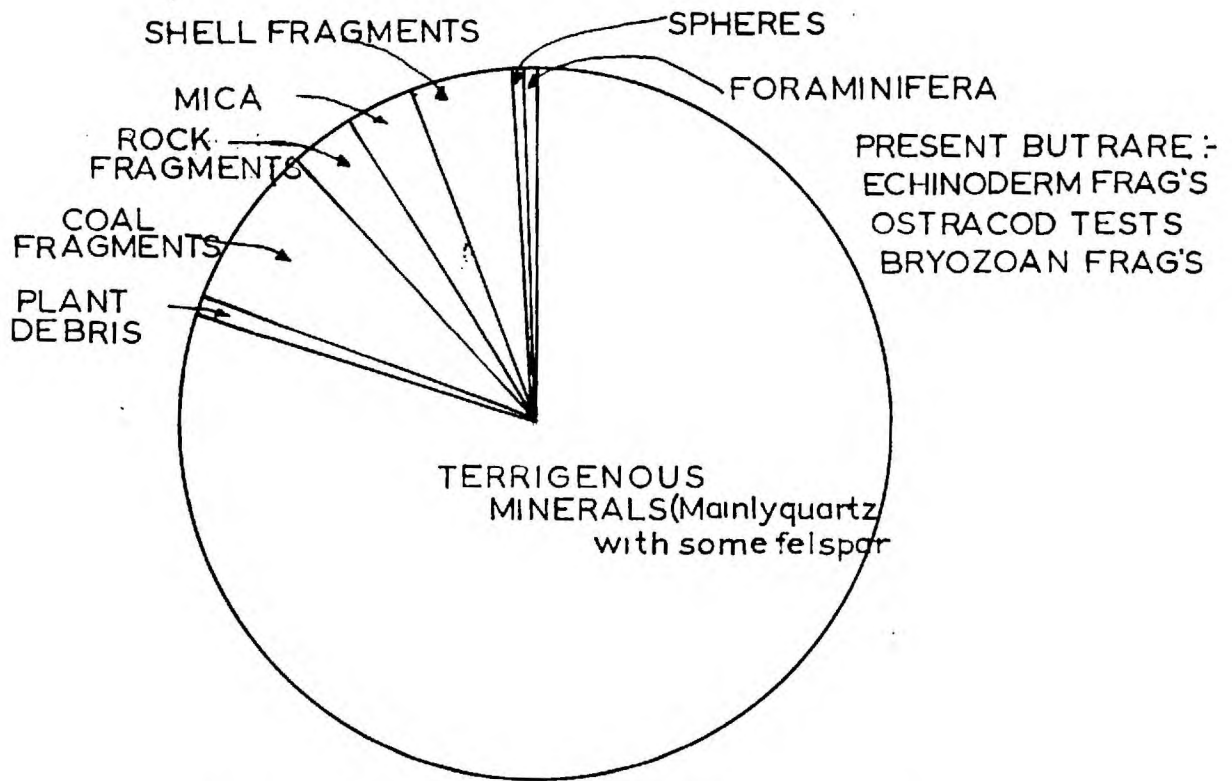


FIG 63. COMPOSITION OF THE COARSE FRACTION
(greater than 0.0625 mm) OF MUDFLAT DEPOSITS.

(500 μ). These coarser materials are carried from the stormbeach ridge and spit during periods of strong wave and wind action. They are mixed with the finer materials deposited by the tidal waters during calmer periods. The resulting deposits are poorly sorted and have marked bimodal distributions (See Fig. 60), comparable with mixtures of r, s and t type deposits of Doeglas (1946, '50).

The amounts and the median diameter values of the coarser sandy material diminish away from the stormbeach ridge and spit (See Fig. 61), until the deposits consist in the main of silt with small amounts of fine and very fine sand (0.25 - 0.062 mm(Wentworth)) and clay (less than .004mm). They are much better sorted (e.g. PSA 97, 104) and less bimodal in their grain size distribution (See Fig. 62). They approximate to mixtures of s and t type deposits of Doeglas.

The mudflat sediments are deposited as "composite" sediments, composed of separate laminae of sand and silty clay but they are subsequently mixed by the burrowing activities of organisms, particularly Corophium volutator, and to a lesser extent Scrobicularia plana and Nereis diversicolor.

Composition.

The coarse fractions (2mm - 0.0625 mm) of the mudflat deposits consist mainly of terrigenous material, dominantly quartz with smaller amounts of felspar, mica, coal and rock fragments. They also possess small amounts of plant and shell fragments, foraminifera tests and spheres. Occasionally echinoderm and bryzoan fragments and ostracod tests are found (See Fig. 63).



PLATE.56. STRATIFICATION OF MUDFLATS.

Structures.

Stratification.

The deposits of the mudflats are generally well stratified and consist mainly of laminae and thin laminae of mud and sand. The proportion of sandy laminae increases towards the spit and storm beach ridge (See Plate E c.f. Sections D and E and Plate 55). The stratification is often interrupted or destroyed by the action of burrowing organisms. The laminae are separated by stratification surfaces resulting from the drying of the surface before the deposition of the succeeding lamina. They may be uniform in thickness across the width of a core or sampling box but sometimes are lenticular or have a rippled form. Generally it is the sandy laminae which are rippled. The thin muddy laminae which usually cover them show negative ripple-marked bases, which are the impressions of the underlying ripple marks (See Plate 56).

Van Straaten (1954) suggested that the sand laminae of the intertidal flat deposits of the Dutch Wadden Sea may be direct products of sedimentation, or they may be residual concentration of an original mixture of sand and mud; that is mixed sand and mud deposited by a tidal current may be further sorted by gentle wave action to produce laminae of well sorted sand. On the Dutch intertidal flats it appears that mud is largely deposited as faecal pellets, which because of their higher effective densities may be deposited with the sand. However, no faecal pellets were found in the mudflats deposits in the Gibraltar Point area and the present writer believes

that the laminae and thin laminae of mud are, unlike the sand, probably formed by deposition from suspension under calm conditions when wave action is at a minimum.

Transitions from sandy to muddy laminae are usually sharp, except in the places where burrowing organisms have destroyed the stratification.

"Cross Stratification" is a common feature of the sediments associated with the creeks. The sets of cross strata are wedge shaped or like sigmoidal lenses in cross section. They may be inclined at varying angles up to 60° depending on the inclination of the surface on which they are deposited; are ~~1-30 feet in~~ 1- 30 feet in length and usually 2 - 4 feet approximately in thickness.

The base of each set of cross strata is marked by a thin horizontal bed made of blocks and pebbles of marsh or mudflat sediment mixed with shell debris. (See Plate F Section F and accompanying Fig.). At the base of this bed is an irregular surface of erosion. This is produced by the undercutting action of the creek on the concave banks of meanders before deposition begins on the prograding convex bank. The sets of cross strata which develop in the prograding bank meet the basal bed at an angle. The cross stratification is often interrupted by slump phenomena. The latter will be discussed later in the chapter.

Similar structures in Dutch and German tidal flat deposits have been described by Van Straaten (1950, 54) and Reineck (1958). It has generally been assumed in most



PLATE 57. SYMMETRICAL (LONGITUDINAL)
RIPPLE MARKS.

palaeogeographic reconstructions that the dip of cross strata coincide with the current direction. Although this may be true in many cases, the examples of cross stratification found in the creek deposits of the mudflats are always normal to the current direction.

Ripple Marks.

Asymmetric ripple marks of the types described in chapter 5 on beach sediments are found in the sandier deposits of the mudflats. They also occur in the sandy deposits of the bottoms of creek channels. Their crests are orientated normal to the channel sides with their steep stoss sides facing downstream in the direction of ebb flow. They are probably formed by the ebb tide current.

Occasionally symmetric ripple marks are found on the muddier surfaces. They are generally orientated with their crests approximately normal to the coastline. The crests are long and straight and the ripples have short wavelengths and low amplitudes and show round troughs (See Plate 57). They may be formed by the tidal currents flowing across the mudflats roughly at right angles to the coastline at higher stages of the spring tides (See Fig. 96 Chapter 13). The crests are sometimes quite sharp but usually become rounded by later wave or current action.

Other writers including Richter (1926) Frebold (1928) Trusheim (1929) and Van Straaten (1957) have described similar symmetric ripple marks. They are termed longitudinal ripple marks. They may be formed by small

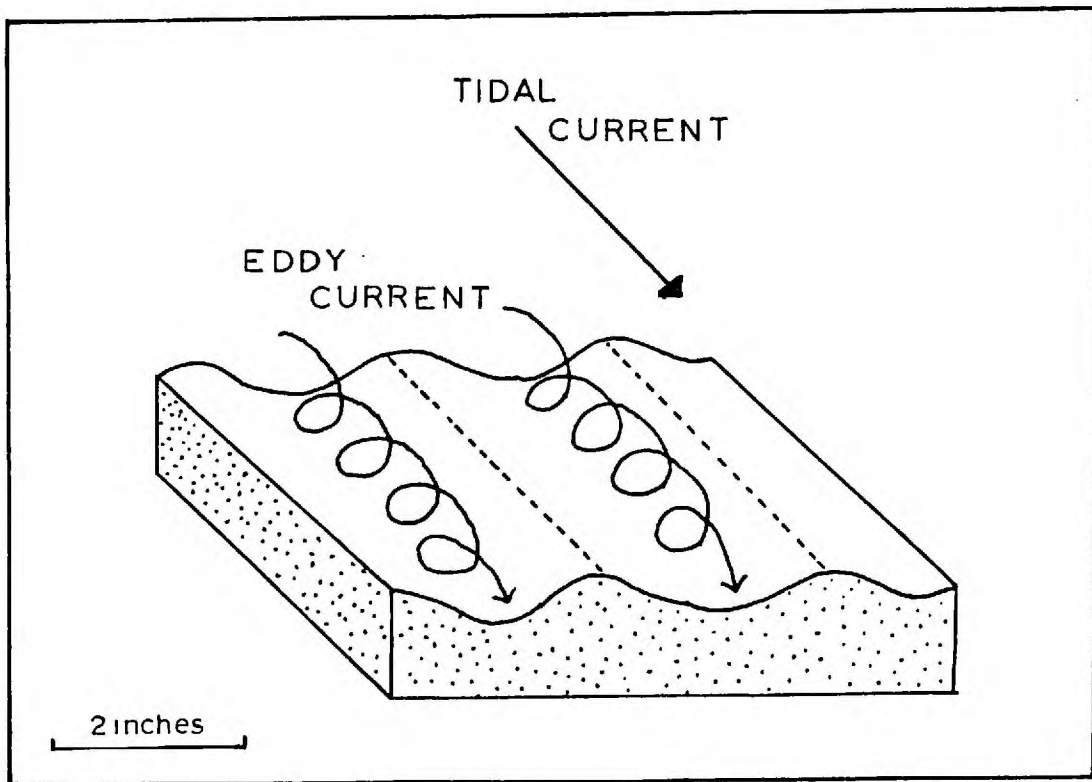


FIG64 Diagram to show possible mode of
origin of symmetric (longitudinal) ripple
marks.



PLATE 58. MUDCRACKS.



PLATE 59. SALICORNIA SP. IN MUDCRACKS.

eddies developed during the flood or ebb tide current due to friction between the muddy surface and boundary layers of water (See Fig 64).

Mudcracks.

Mudcracks are common features on the mudflat deposits. They are formed by dessication and attain their maximum development when hot dry weather coincides with periods of neap tides. At these times the higher parts of the mudflats may be continuously exposed to the air for periods of a week or more.

The cracks usually show a polygonal or chequered pattern. Under very dry conditions and fairly long exposure, the cracks may widen and the upper most laminae curl over^{at} the edges (See Plate 58). The cracks sometimes extend as much as 9 inches or more below the surface. Ferric hydroxide may be deposited on the walls of the fissures. This appears to age to form ferric oxides which are relatively more resistant to erosion than the sediments and often protrude above the surface where a local phase of erosion has occurred.

Seeds of Salicornia sp. are often washed into newly formed mudcracks and may lead to a polygonal pattern in the vegetation cover (See Plate 59). Burrowing organisms often concentrate along the cracks in search of moisture during very dry periods and colonise the soft mud which infills the cracks.

Mud Aggregates.

Muddy sediments rapidly develop cohesion and tend to



PLATE 60. ANGULAR MUD BLOCKS ON
SIDE OF CREEK CHANNEL.



PLATE 61. TRANSPORTED MUD FLAKES.

resist break down into constituent particles when eroded. They often form what have been referred to as "muddy aggregates" (Pettijohn 1949), Shrock 1948). During the present study several types were observed on the mud flats. They are:- angular mudblocks, mud flakes and mud pellets.

Angular mudblocks are formed by the undercutting action of tidal waters on the concave banks of creeks. The blocks break off and accumulate, sometimes in large quantities, in the creek channels at the base of the bank (See Plate 60): because of their size they are rarely transported and often retain their angularity.

Mud pellets or small rounded pebbles of mud, produced by erosion of the mudflat deposits, often accumulate on the sides and in the bottoms of creek channels. These when preserved give rise to characteristic mud conglomerates (See Plate F section F).

Superficial laminae of mud often peel away from the underlying sediment when mudcracks form. They are often picked up by later tidal currents and transported elsewhere on the mudflat surface (See Plate 61)..

Air Entrapment Structures.

Entrapped air or gas often produces characteristic dome like features on the surface of the mudflats. These mud blisters as they are termed, have been described by Schafer (1954). They may be as much as 6 inches in diameter and $\frac{1}{2}$ inch in height. They are produced by the doming up of the surface laminae by an air pocket which has a characteristic



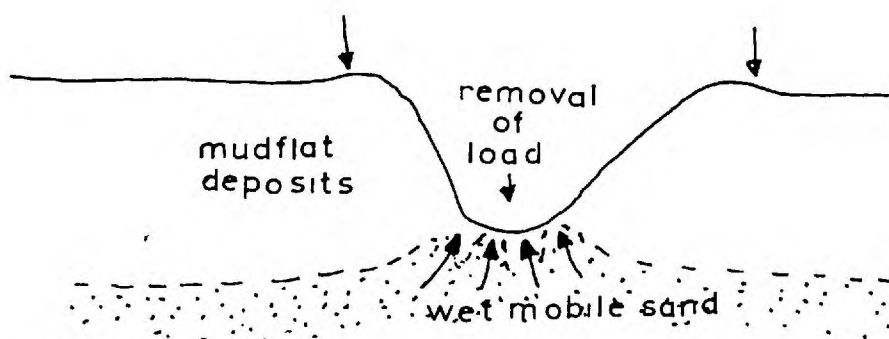
PLATE 62. MUD BLISTER.



PLATE 63. ROTATIONAL SLIPS IN SIDE
OF CREEK CHANNEL.



(a) Rotational slips on side of creek



Intrusion of sand beneath creek.

FIG 65.

0 1 2
FEET.

laccolith like shape (See Plate 62).

They occur near the spit where thin muddy laminae often cover sand. Air or gas escaping upwards through the sand as the tide rises tends to collect under the moist, plastic surface layer of mud. If the pressure inside the dome so formed becomes excessive, the crest of the dome splits and the entrapped air or gas escapes. Under such conditions the domes may deflate or sometimes, when the release of pressure is sudden, may burst open and form round saucer like depressions with irregular raised rims.

Pene-contemporaneous Deformation.

Structures produced by penecontemporaneous deformation have been described by Shrock (1948), Pettijohn (1949) and Kuenen (1950). They are usually produced under the influence of gravity by differential loading or by the movement of water or gas through the sediment. Features produced by the latter process have been described separately because of their particular mode of origin.

Penecontemporaneous faulting often occurs along the sides of creek channels due to erosion by creek waters. As a result of the removal of supporting masses of sediment, slumping occurs and small rotational slips or normal faults develop (See Plate 63 and Fig. 65).

As described earlier undercutting of the banks may also result in the production of angular blocks and they may be included in this category.

"Valley bulges" produced as a result of release of

load, often develop in the bottoms of creek channels (See Fig. 65A). Their formation is often accompanied by the vertical intrusion of sand from below into the muddy deposits of the channel floor. (See Plate K core 24). As pointed out by Evans (1960) differential loading may play a part in the formation of these features in as much as the weight of the extra thickness of sediment on both sides of the channel, in comparison with the channel floor, will result in a downward pressure on both sides of the channel, with a corresponding upward pressure beneath the channel.

Organic Structures.

Structures Produced by Molluscs.

Scrobicularia plana.

This bivalve mollusc is a deposit feeder. It is commonly found living in the muddier sediments and is particularly abundant along the sides of creeks. The organism burrows beneath the surface by means of a foot. It seldom changes its position and moves upwards and downwards rather than laterally. It generally lives a few inches below the surface. (See Plate G cores 2 and 7).

Two retractable siphons are extended upwards to the surface when the organism is feeding. They form a V shape diverging upwards from the shell. When the deposits in which it lives are uncovered by tidal waters the siphons are retracted deep into their cylindrical cavities or even entirely into the shell. During High tides the siphons are extended to the surface and one of them protrudes into the

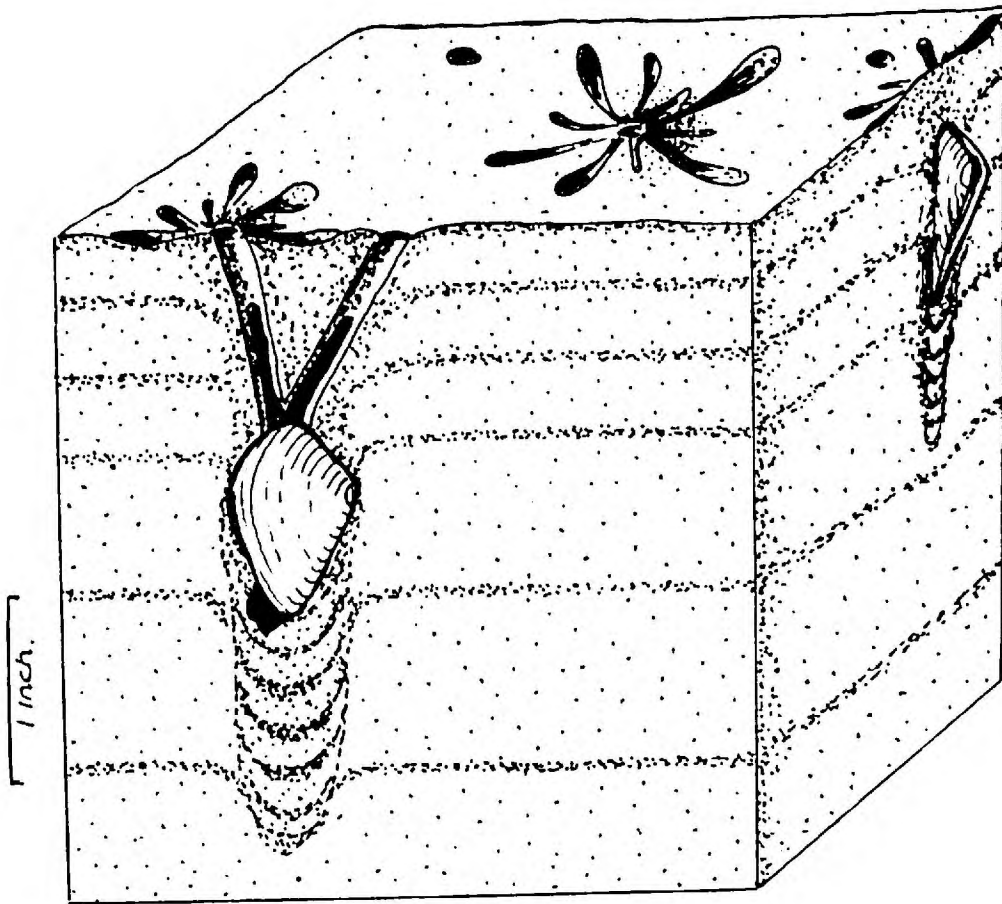


FIG.67. Scrobicularia :- burrows and surface markings .



PLATE 64. SURFACE MARKINGS OF
SCROBILARIA PLANA.



PLATE 65. BURROWS OF SCROBICULARIA,
COROPHIUM VOLUTATOR IN
MUD FLAT DEPOSITS.

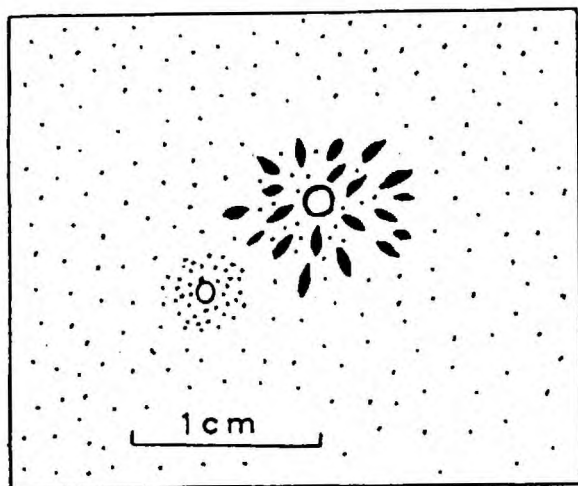


FIG.68.(a). Surface markings made by Macoma.

(After Seilacher 1956).

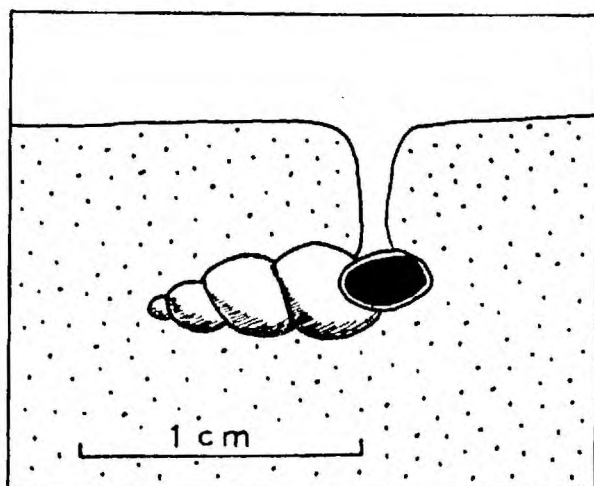


FIG.68.(b). Hydrobia and burrow.

(After Thamdrup 1935).

water while the other moves over the surface sucking up the sediment in search of food. These two siphons produce two circular apertures on the surface around one of which is found a characteristic stellate pattern made up of small scours radiating outwards from the aperture of the siphonal cavity (See Fig. 67 and Plates 64) (5).

The organism produces a wide vertical burrow. The laminae on all sides of the burrow as shown by Van Straaten (1954) and Seilacher (1953) Reineck (1956) are characteristically drawn downwards forming excellent "bottom and top" criteria.

The walls of the siphonal cavities are platered with mud cemented by mucus and often are coated with iron hydroxide. This renders them more resistant to erosion and they often project as tubes above the surface after tidal scouring has removed the surrounding sediment. The tubes and burrows remain after the death of the organism and often become filled with sediment deposited at a later date (See Plate 65) Macoma balthica.

This is less commonly found in the mudflat deposits than Scrobicularia plana. It is smaller than the latter and lives at lesser depths below the surface. It is also a deposit feeder and produces similar burrows with two siphonal cavities but on a small scale. The surface markings are different (See Fig. 68); instead of the stellate pattern

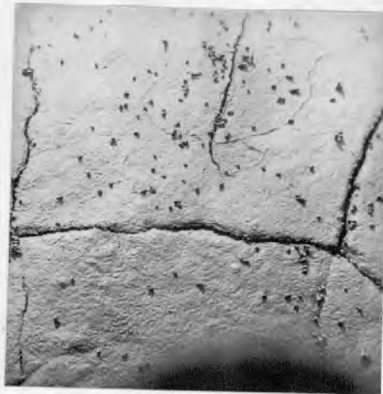


PLATE 66. HYDROBIA TRAILS.



PLATE 67. SURFACE MARKINGS PRODUCED
BY HYDROBIA.

around one of the siphonal cavities there are a series of small depressions which are irregular in distribution (Seilacher (1953) and Yonge (1940)).

Lutraria elliptica.

This is the largest of the lamellibrachⁿs living in the area but is only occasionally found. It is restricted in distribution to the sides of creek channels and lives buried in the sediment at depths up to 6 inches or more. It possesses two siphons which are enclosed in a single fleshy sheath. This reaches the surface along a single vertical channel. The organism is a suspension feeder and the siphons project above the surface and consequently do not disturb the sediment around the elliptical aperture of the siphonal cavity whilst feeding. During periods of low tide the siphons are retracted and the only indication of the organism's presence below the surface is the elliptical aperture of the siphonal channel. Moore (1939) reported faecal pellets formed by Lutraria but none have been found by the present writer.

Hydrobia ulvae.

This small gastropod is individually insignificant but frequently impressive in its abundance in the mudflat deposits. In places the surface may have a granular appearance due to the vast number of these creatures. The organism feeds on organic debris of all kinds.

Their burrows are shallow, usually less than 5 mm in depth and they are only found below the surface when tidal

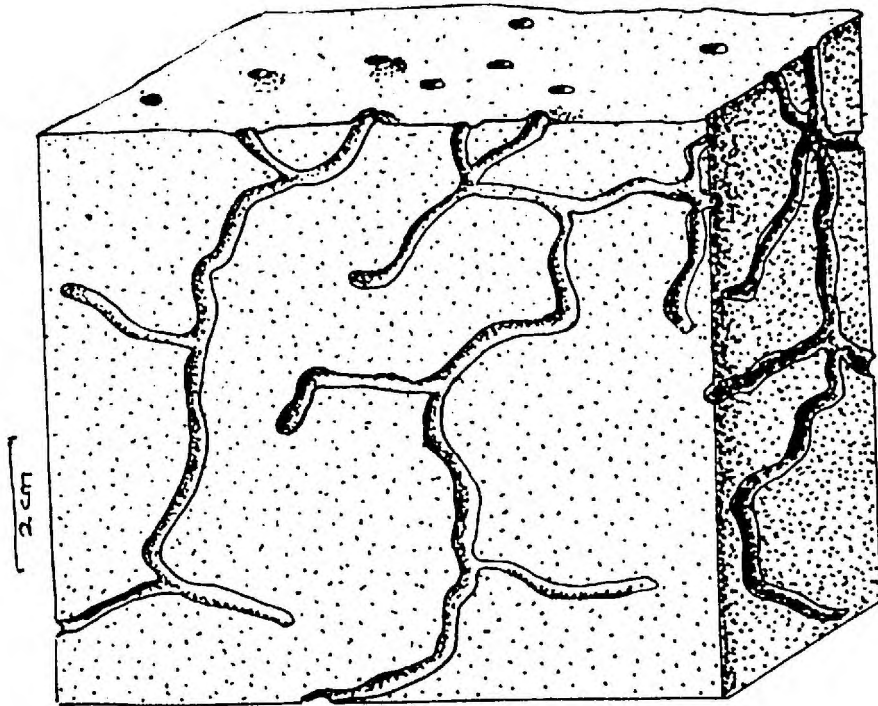


FIG 69. Nereis diversicolor:- burrows and surface markings.

waters cover the area. When below the surface Hydrobia ulvae takes up a horizontal position (Reineck 1956). During periods of low tide it returns to the surface and often moves about producing characteristic surface trails (See Plates 66 and 67). Since the burrows are shallow the sediment is not greatly disturbed except when they occur in large numbers. When below the surface a characteristic pepper pot structure surrounds the aperture to the burrow. This was also observed by Yonge (1949) and Thamsdrup (1935).

Structures Produced by Annelids.

Nereis diversicolor.

Nereis diversicolor is found in considerable numbers in the deposits of the mudflats. It is a deposit feeder but does not live in a single burrow like Arenicola marina and Lanice conchilega (Schafer 1956); the burrows have a branching Y shape near the surface but below this level show no regular pattern and ramify in all directions (See Fig. 69).

The walls of the burrows are mudlined and ill defined "drag structures" are often found associated with them. The worm drags muddy sediment along the burrows which are preserved as mudlined tubes. These may be infilled by sediment washed in at a later date.

Structures Produced by Arthropods.

Corophium volutator.

Corophium is found in great numbers in the muddier parts of the mudflats and in the sides of creeks.

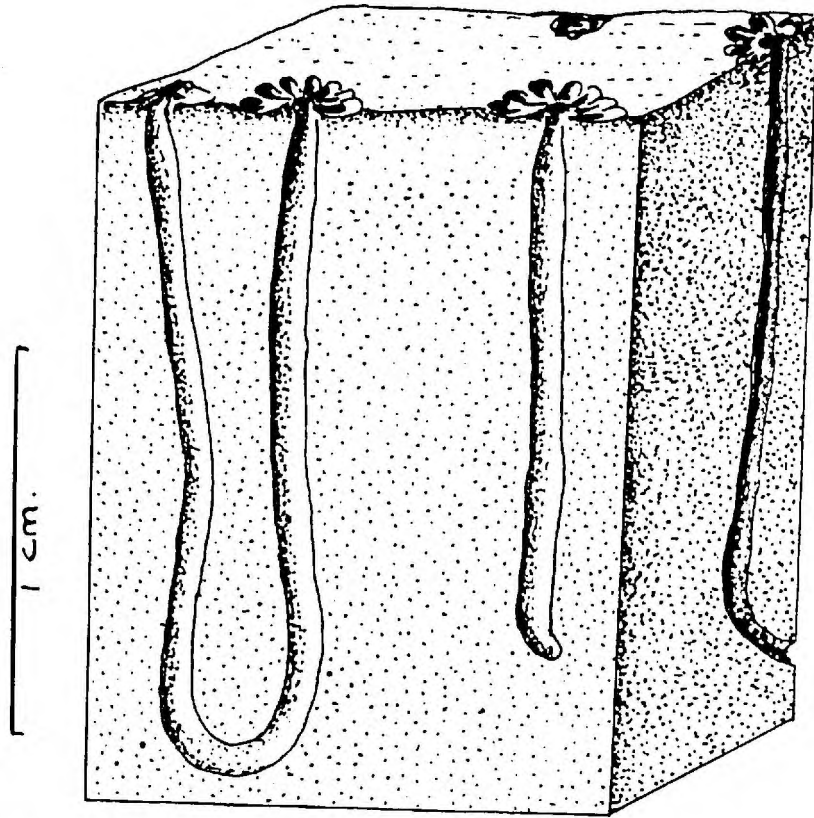


FIG70 Corophium volutator :- burrows and surface markings .



PLATE 69. SURFACE MARKINGS PRODUCED
BY COROPHIUM VOLUTATOR.

Structures produced by this creature have been described by Thamdrup (1935) and Hantzshel (1939). It's burrowing activity is so intense that the lamination is almost completely destroyed. (See Plates E and G sections A, B and C and cores 1 to 7). The burrows have a characteristic U shape and are lined with mud and often with iron oxide and hydroxide. On the surface, the apertures to the burrows are surrounded by small turret like accumulations of sediment (See Plate 69 Fig. 70). At periods of high tide the animal crawls out onto the surface to feed producing irregular surface trails.

Decapods.

Crab burrows are common along the sides of creeks. Similar features have been described by Schäfer (1956) from the mudflats of the German Wadden Sea. They vary in form from almost cylindrical burrows to irregularly shaped pits which may be 9 inches or more deep and about 4 inches wide (See Plate 70).

Structures produced by birds.

Many types of wading birds are found in the Gibraltar Point area. They walk about over the area during periods of low tide in search of food, leaving abundant bird foot impressions on the surface (See Plate 71). Some feed on molluscs, and occasionally small mounds of broken shell fragments are found on the surface of the mudflats and spit. These are accumulations of regurgitated material

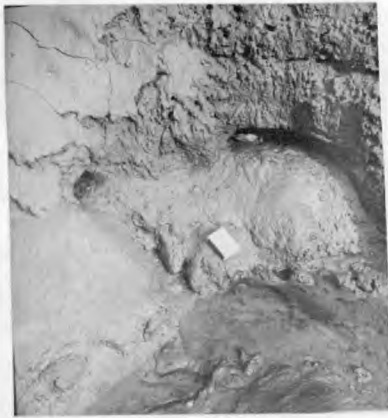


PLATE 70. CRAB BURROWS.

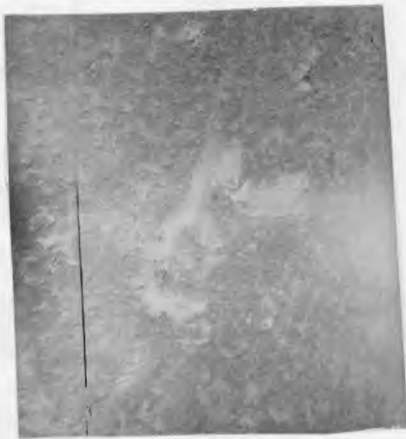


PLATE 72. MOUNDS OF
REGURGITATED SHELL
DEBRIS PRODUCED BY
BIRDS.



PLATE 71. BIRDS FOOTPRINTS.

after the birds have digested the soft parts of the organisms
(See Plate 72).

Structures produced by plants.

On the lower parts of the mudflats colonies of Enteromorpha grow in scattered mats, each consisting of a large number of filaments. They form well developed mounds, sometimes as much as 4 inches high and several square feet in surface area. The algal mat probably protects the underlying sediment from erosion and possibly accentuates accretion on the mounds by filtering fine sediment from the sea water.

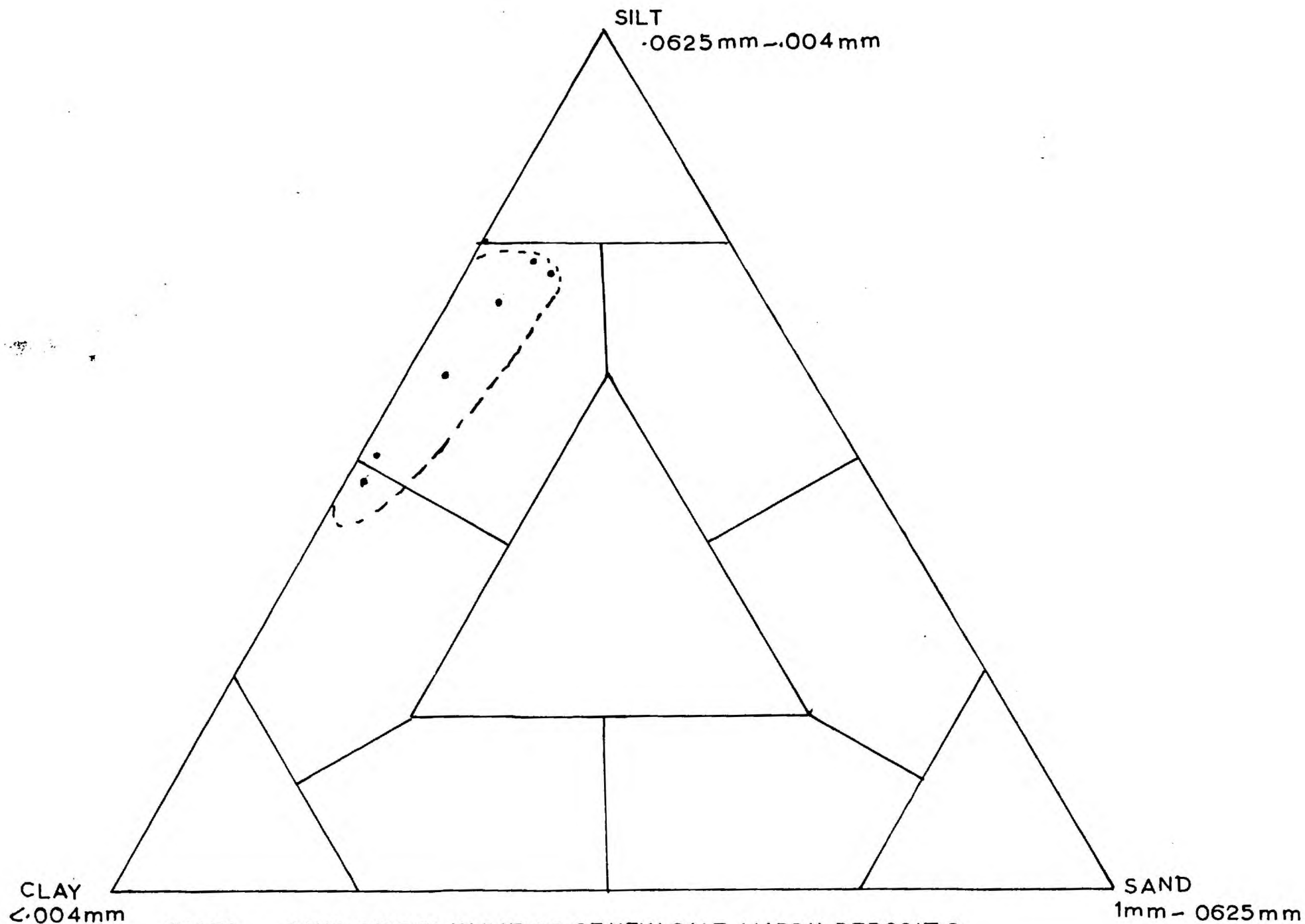


FIG 71 SAND SILT CLAY RATIOS OF NEW SALT MARSH DEPOSITS

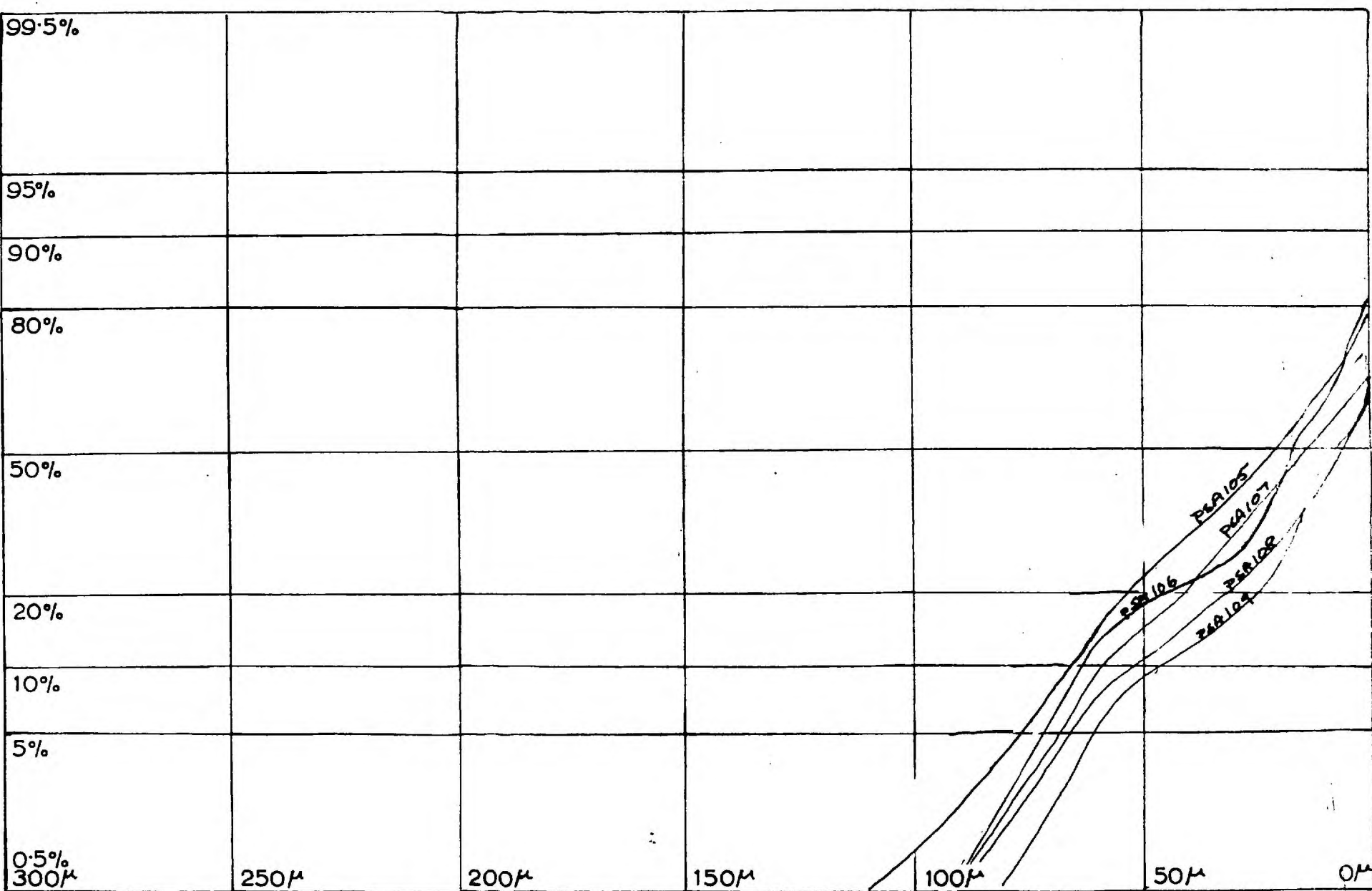


FIG 72. Grain size frequency distribution of salt marsh deposits.

CHAPTER 8.

New Salt Marsh.

Granulometric Analyses.

In the terminology proposed by Kruit the deposits of the new salt marsh are pelites, but in that used by Shepard they are silty clays and clayey silts (See Fig. 71). They do contain small amounts of very fine sand. The median diameter can only be defined approximately and often may be less than 8ϕ . The 84th percentile is unobtainable because of the high percentage of materials less than .004 mm (4μ). Consequently neither the ϕ deviation nor the ϕ skewness measures can be determined.

The grain size frequency distribution curves show well defined coarse and fine limits (See Fig. 72). They are directly comparable with those described by Evans (1960) as being characteristic of the outer part of the saltmarsh near the Witham outfall in the Wash. However one difference is noticeable; Evans found that there are small tails on the coarse ends of several of his distribution curves due to the presence of coal and mica. The absence of such tails in the samples studied by the author results from the different method of analysis used in the present study. Whereas Evans separated materials coarser than .062 mm by sieving; the present writer used a settling tube, so that grains of coal and mica although often of sand size were sorted hydrodynamically with the silt and clay because of their low effective densities. If sieves had been used, as they were by

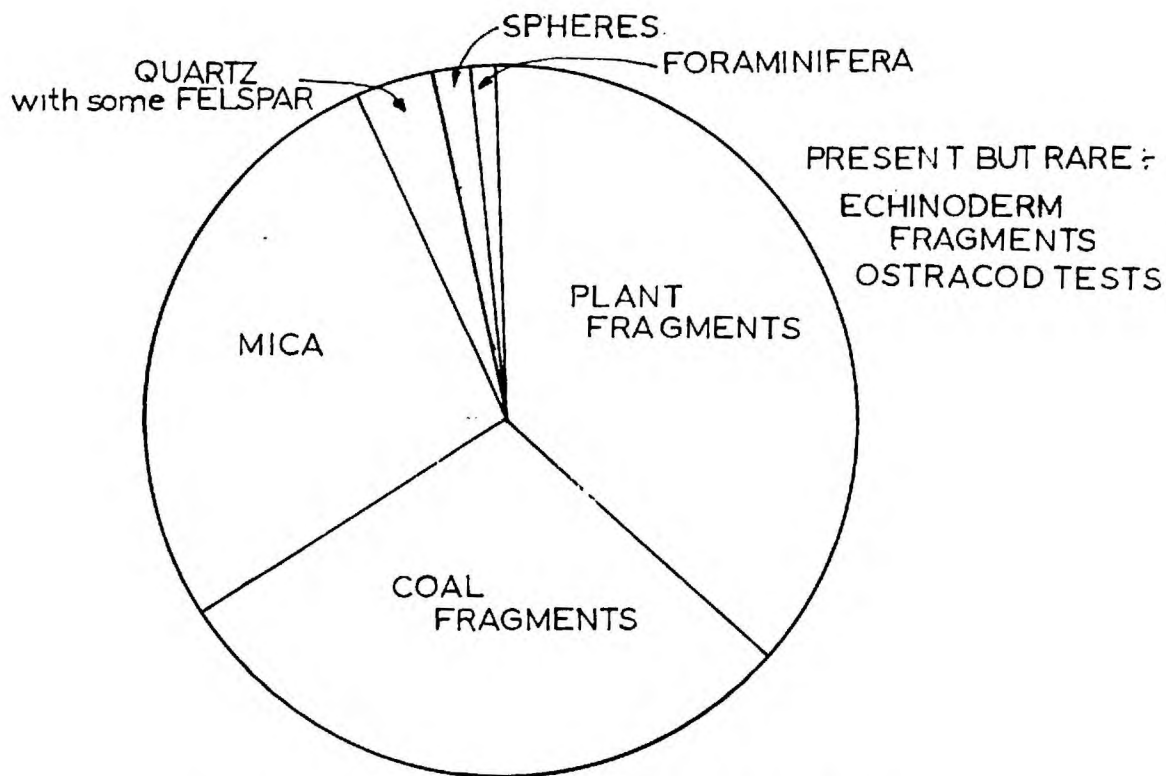


FIG73 COMPOSITION OF THE COARSE FRACTION
(greater than 0.0625mm) OF NEW SALT MARSH DEPOSITS.

Evans, these grains would have been separated with the sand fraction.

The curves are essentially similar to those of "simple sediments" of the 't' type of Doeglas (1940 etc.). The sediments result from the deposition of the fine grained load remaining after the tidal waters have deposited the coarser fractions on the mud flats to seaward.

The fairly dense cover of vegetation in this sub-environment not only helps to prevent erosion of these deposits by storm waves, but also increases the rate of sedimentation by filtering fine grained material from the tidal waters.

Very little sand is carried into this sub-environment because the currents are so weak; the small amounts present are probably carried in during stormy periods.

Composition.

The coarse fractions (between 2mm and 1/16 mm in size) consist mainly of the three components mica, coal and plant fragments (See Fig 73). They also contain small amounts of quartz, felspar, shell fragments and foraminifera tests. Considerable numbers of hollow spherical bodies termed "spheres" described in an earlier chapter are also found. (See p. 39.)

Echinoderm and bryozoan fragments and ostracod tests may or may not be present.

Structures. Inorganic.

Stratification.

The sediments of the new salt marsh are finely

laminated. They differ from the mudflat deposits in as much as there are less sandy laminae and they are less disturbed by burrowing organisms. Individual laminae may be either uniform in thickness over a distance of several inches or lenticular in form. There is a general absence of ripple marked laminae. This is due, in part, to the fact that wave and current actions are generally not strong in this sub-environment and the surface sediment is largely protected from these agents by the thick cover of vegetation.

Cross stratification of the type commonly found in the mudflat deposits, produced by meandering creeks, is found in association with Main creek. Erosion is constantly taking place on the outer concave bends and is accompanied by deposition on the inner convex bank producing sets of cross strata inclined at angles up to 30° (See Plate K core 25). The meandering creek produces a bevelled planar surface of erosion which is met at angle by the overlying cross strata. This surface is generally covered by a shell and mud pellet bed approximately 3 - 6 inches thick. The sets of cross strata have been observed to have in places a horizontal extent of 35 feet or more. The total thickness of the cross stratified unit may be as much as 6 feet. Since the lower bounding surface is a planar surface of erosion this structure is equivalent to the planar cross stratification of McKee and Weir (1953).

Cores and sections from the new salt marsh show that these deposits rest uncomfortably upon older mud flat

deposits (See Plate E sections A, B and C). The sections show that the surface between the two is usually quite sharp, but in places it is penetrated by plant roots and the borings of worms and molluscs.

Ripple Marks.

Ripple marks are occasionally found in areas where there is a lack of vegetation. The surface in these areas is slightly lower than that of the surrounding marsh. Although poorly developed the ripple marks are generally symmetric in form with wavelengths of 3 - 4 inches and heights of about $\frac{1}{4}$ inch. The orientation of the crests varies from time to time and they are probably formed by oscillation of water retained on these parts by wind action after the tidal waters have retreated.

Mudcracks.

These are commonly found during dry spells, particularly on the exposed surfaces along the sides of Main creek. They are similar in every way to those found in the mudflat deposits.

Organic Structures.

The fauna of the new salt marsh is similar to that of the mudflat except that there is marked decrease in the numbers of various forms found. Scrobicularia plana and Nereis diversicolor are common only in areas where the vegetation cover is poor and in the deposits along the sides of Main creek. Corophium volutator, and crabs have a

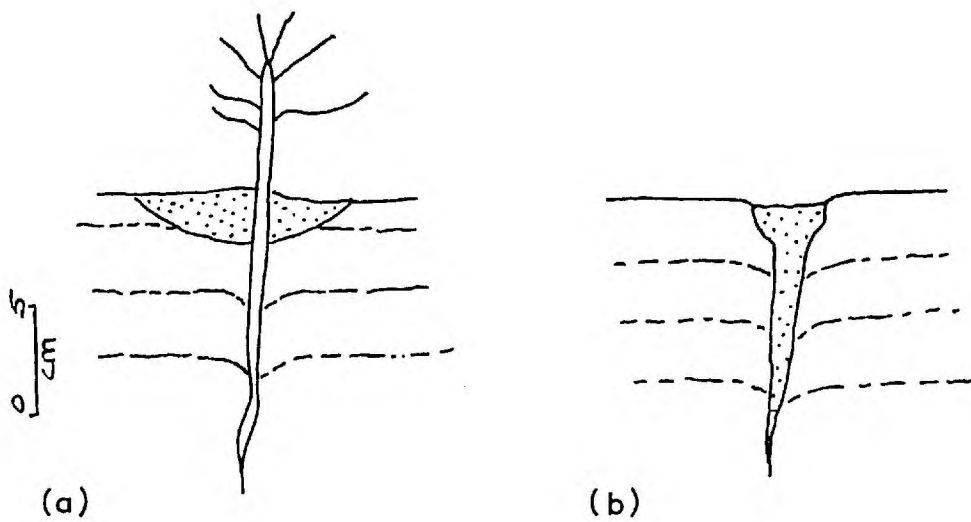


FIG 74. Diagram showing sediment infilling
scours round plants and old plant root
cavities.

similar distribution. Consequently the subsurface and surface structures produced by these organisms are more common in the sediments in these areas and less common in vegetated parts of the marsh away from them. This is due to several factors (Yonge, 1949). Although all the organisms are deposit feeders and prefer muddy sediment, they also required an environment having a high degree of water saturation. The degree of saturation is reduced in the new salt marsh as opposed to the mudflats and the sides of creek channels because the new salt marsh is not so regularly inundated by tidal waters and the dense population of plants is responsible for taking considerable amounts of moisture from the sediments.

However unlike the mudflat deposits structures produced by plants are very common. Around the outer fringe of the new salt marsh, where the vegetation cover is sparse, the plants are often greatly affected by water movements. Currents and the streaming motion of flood and ebb waters often induce a swirling movement in these isolated plants, particularly Salicornia. The plants are bent over to touch the surface of the surrounding sediment and their swirling motion produces a series of concentric drag marks.

Sometimes swirling water currents scour the sediment around isolated plants, forming small circular depressions. These later become infilled with sediment brought in by succeeding tides and if preserved appear as small lens like structures (See Fig. 74 a).

Annual plants such as Salicornia die out during the autumn and their roots decay leaving cavities in the sediment which also become infilled with sediment (See Fig. 7+ b). The cavities so formed are often wider than the actual plant root, probably due to the motion of the plants under the influence of waves and wind (Van Straaten 1954).

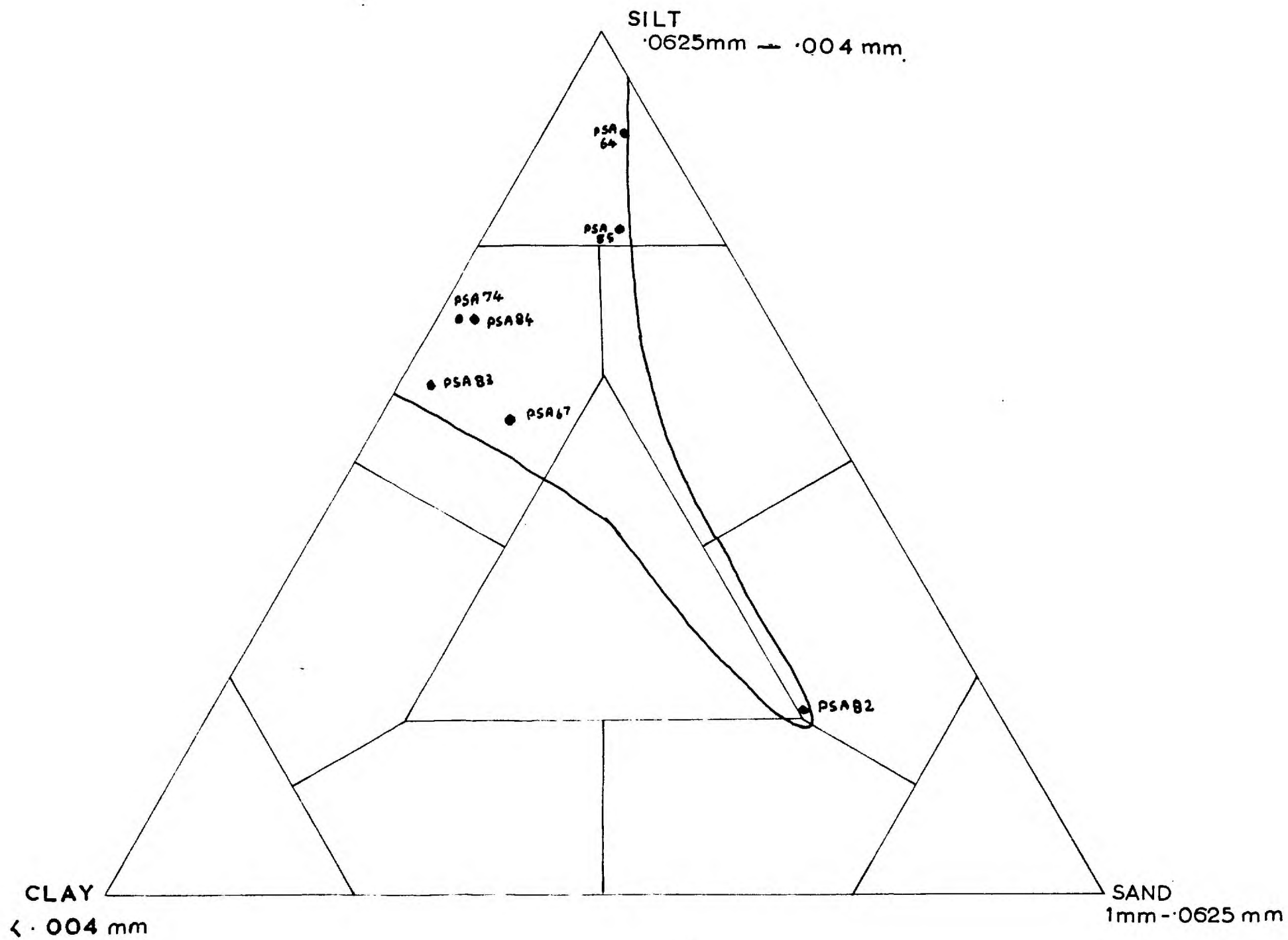


FIG75 SAND/SILT/CLAY RATIOS OF MATURE MARSH DEPOSITS.

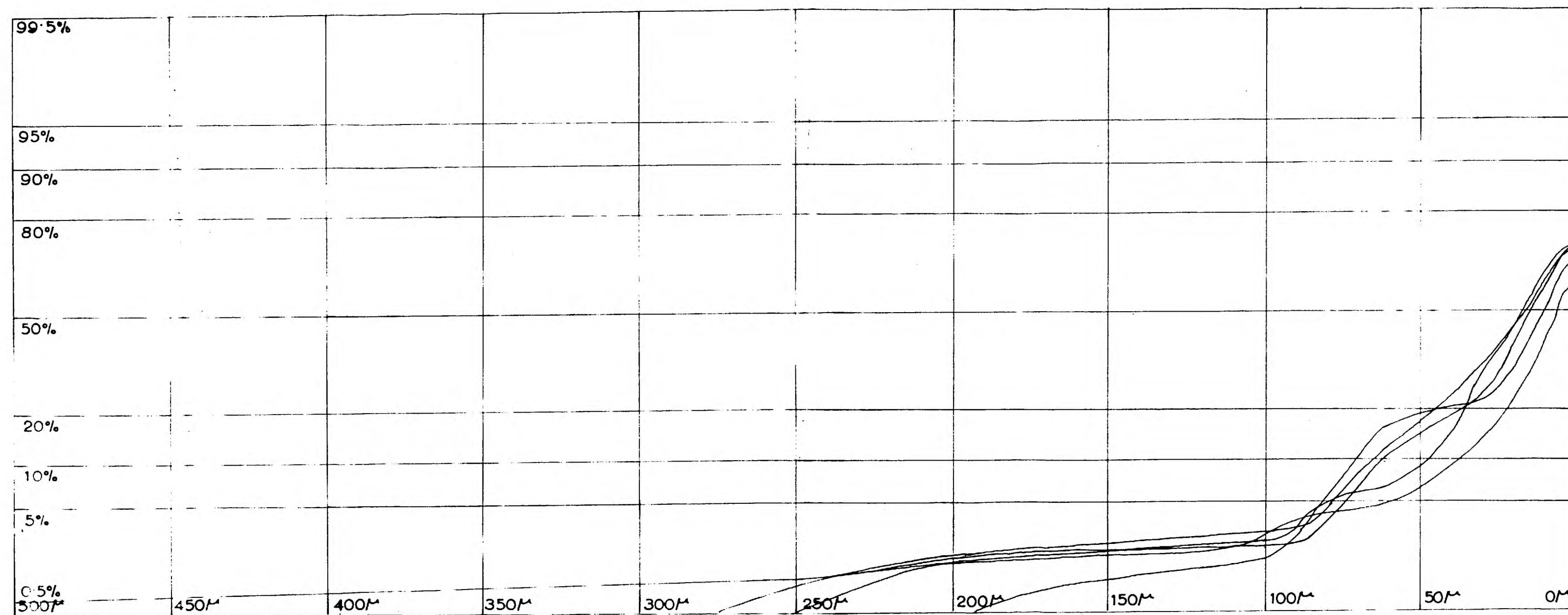


FIG 76 Grain size frequency distribution of mature marsh deposits.

CHAPTER 9.

Mature Marsh.

Granulometric Analyses.

The deposits of the mature marsh are pelites and sandy pelites (Kruit) or clayey silts, silts and sandy silty clays (Shepard)(See Fig. 75). They have ϕ median diameters ranging from 2.5 to 6.8 with an average value of 5.62. The 84th percentiles are again unobtainable so that the ϕ deviation and skewness measures cannot be calculated.

The grain size frequency curves usually have well defined lower limits. Curves of certain samples, however, such as PSA 84 and 79 (See Fig. 76) possess marked 'tails' at their coarser ends: these are due to the presence of small amounts of fine and very fine sand.

The sediments are largely the result of the deposition of the fine grained load carried by the high spring tidal waters which rise up Main creek and flood over the mature marsh. The dense cover of vegetation in this area again acts as an effective filter for this material.

Occasionally when very stormy conditions coincide with high spring tides the storm beach ridge is eroded and sandy materials are swept over it onto the ^smature marsh. Strong winds blow small amounts of sand into the area from surrounding dunes but because these are now stabilised, very little material is introduced in this fashion.

The deposits are mainly "simple" sediments comparable with the 't' type of Douglas, but when small amounts of

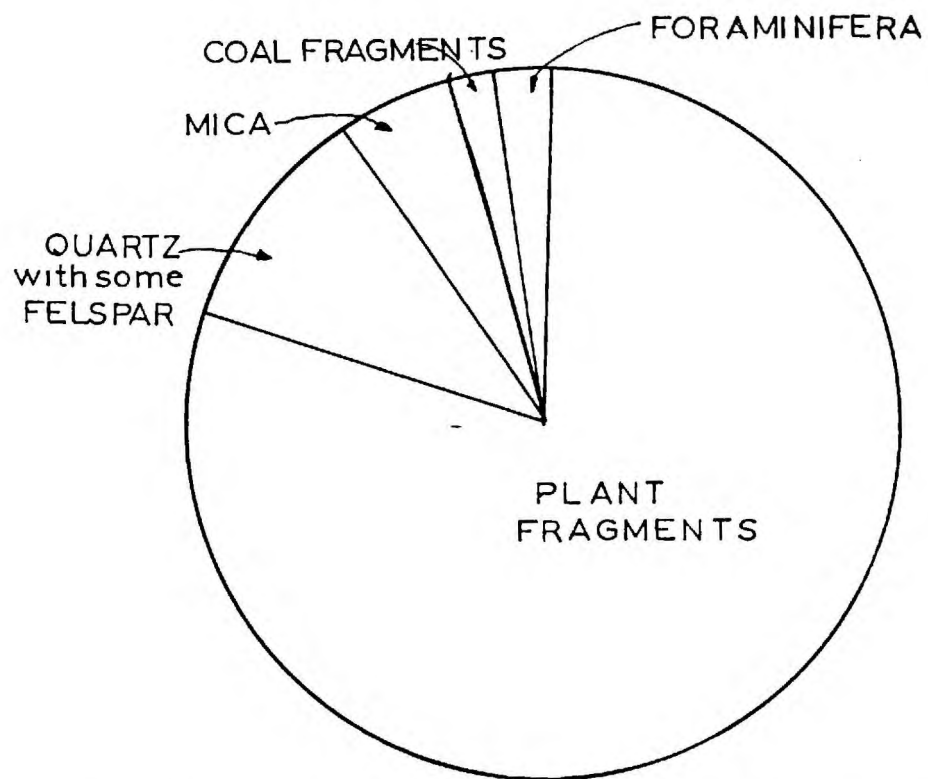


FIG 77 COMPOSITION OF COARSE FRACTION
(greater than 0.0625mm) OF MATURE MARSH DEPOSITS

coarser materials are present they are comparable with mixtures of 's' and 't' types.

Composition.

The coarse fractions consist mainly of plant detritus which has accumulated in situ. Small percentages of terrigenous materials - quartz, feldspar, mica and lithic fragments, of which mica is by far the most abundant, are found (See Fig. 77). Other components present are coal fragments, and to the lesser extent ostracod tests and echinoderm fragments. These and the mica are deposited from slow moving spring tide waters when they flood the area. The other components are carried from the dunes and storm beach ridge by strong wind and wave action during occasional stormy periods.

Foraminifera tests are found to be slightly more abundant than in the coarse fractions of the deposits of the other sub-environments. Many of these belong to species living in the mature marsh e.g. Trochamina sp.

Structures: Inorganic.

Stratification.

The deposits of the mature marsh are finely laminated (See Plate J at back of the thesis). However the transitions from ~~sandy~~ to silty clay laminae are not as sharp as they are in the mudflat and new salt marsh sediments. This is probably because the area is sheltered to such a degree by the storm beach ridge that, unlike the mudflat deposits, the deposits of the mature marsh are rarely, if ever, reworked and sorted by gentle wave and current action.

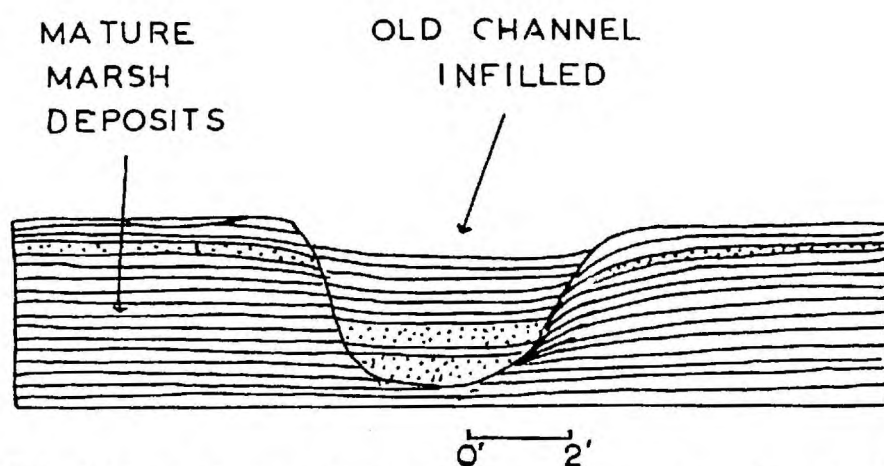


FIG 78. Diagram of section dug in the field across old creek channel in mature marsh.

Also unlike the new salt marsh, the vegetation cover is so dense that particles can rarely settle out evenly onto the underlying surface.

Large Scale Structures.

An interesting feature in this connection is the infilling of the head of the stream which suffered a reversal of drainage as a result of the formation of the storm beach ridge. This channel is now filled by well/laminated deposits to produce a type of "Scour and fill" or "washout" structure (See Fig. 78).

The primary and secondary salt pans also become infilled with well laminated deposits.

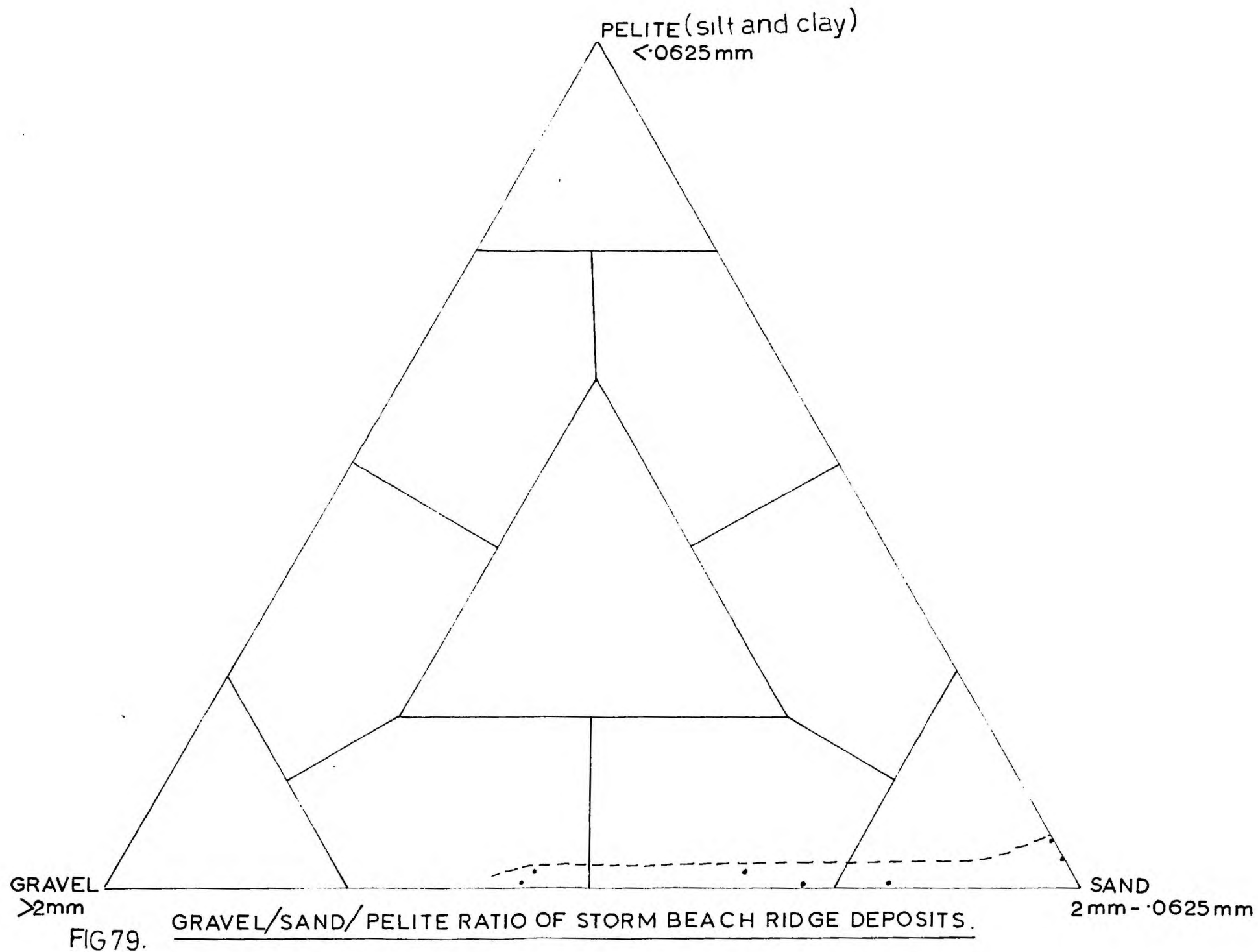
Mudcracks.

The salt pans and sides of creek channels are often mudcracked during periods of neap tides when the weather is hot and dry.

Organic Structures.

Practically none of the organisms which flourish in the mudflat deposits are to be found in the mature marsh. The stratification is not disturbed by burrowing except locally in the salt pans where Hydrobia and Nereis, which can withstand a certain amount of dessication, are found, and in the sides of creeks where occasionally Scrobicularia are seen.

The stratification is however interrupted by ramifying plant roots.



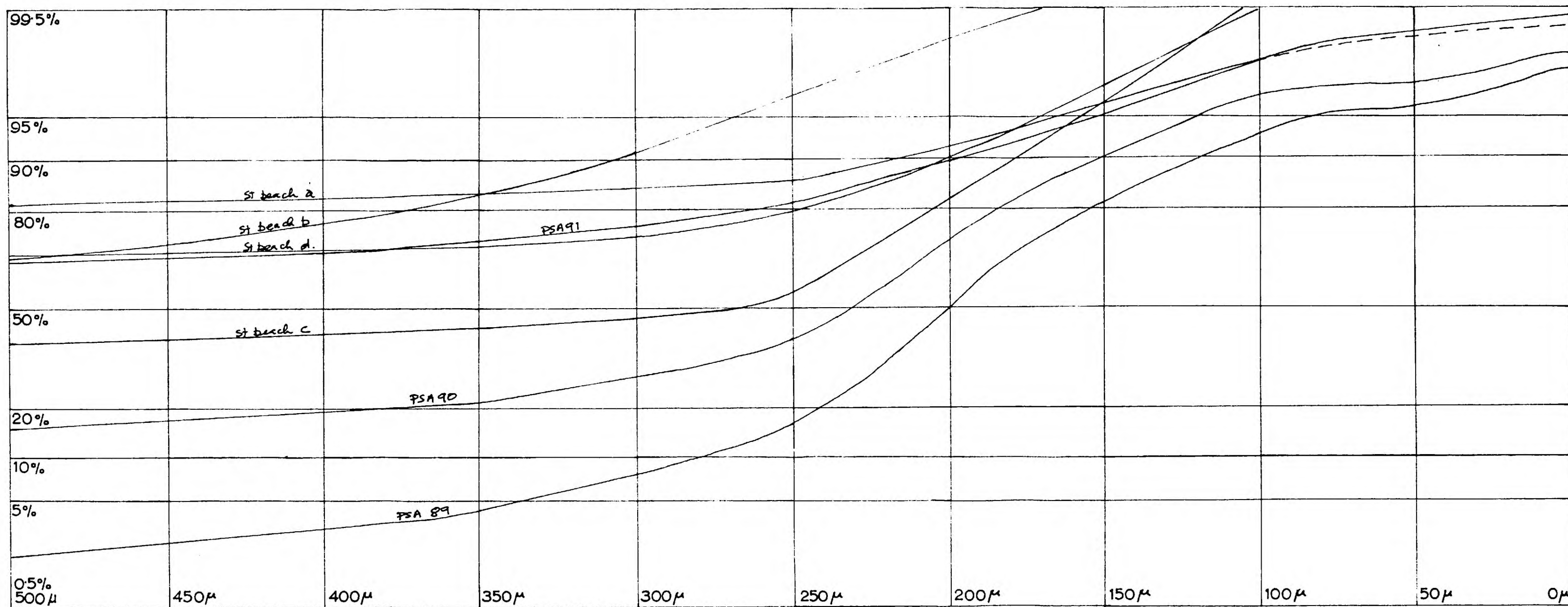


FIG80 Grain size frequency distribution of storm beach ridge deposits

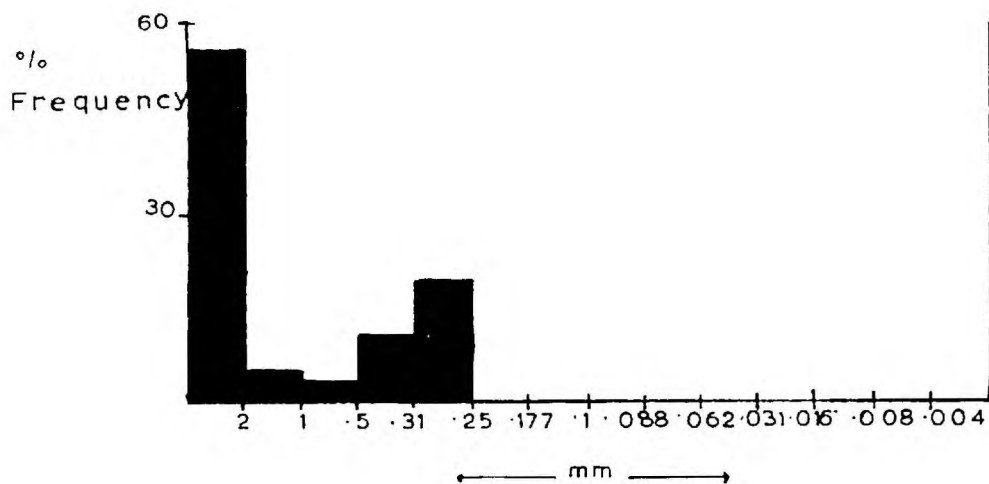


FIG.81. Histogram showing grain size distribution of sample PSA sd from storm beach ridge.

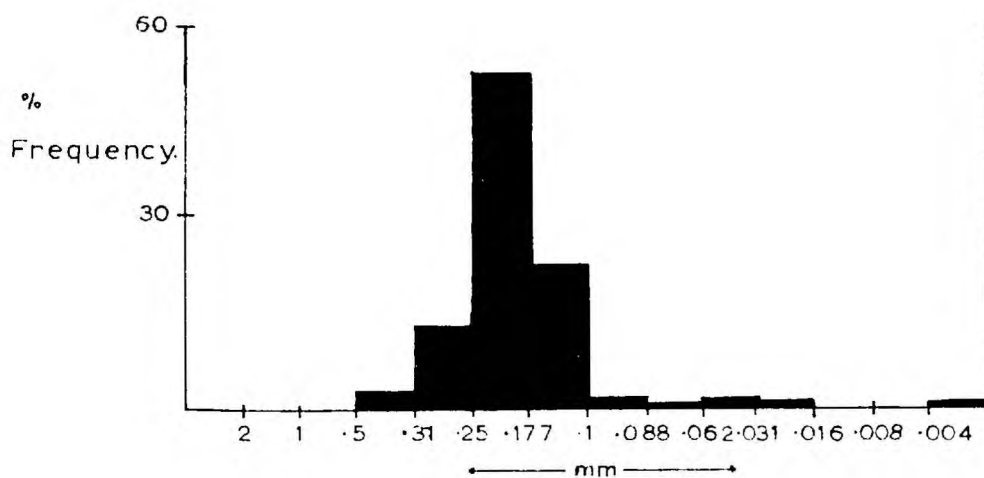


FIG.82. Histogram showing grain size distribution of sample PSA 89 from washover fan behind storm beach ridge

CHAPTER 10.

Storm Beach Ridge.

Granulometric Analyses.

The deposits of the storm beach ridge are generally very similar granulometrically to those of the spit. According to the nomenclatures of Kruit and Shepard they are sandy gravels, gravelly sands and sands (See Fig. 79). They have an average ϕ median diameter 0.52, but as in the case of the spit deposits the 16th percentile is not always obtainable and so the ϕ deviation and skewness measures cannot be calculated.

The cumulative curves show that the deposits cover a wide range of grain sizes (See Fig 80). The deposits of the south facing slop of the ridge are rich in gravel and show distinctive bimodal grain size distribution (See Fig. 81).

Curves for the deposits of the washover fans behind the ridge show that they are relatively well sorted fine sands. They show marked unimodal distributions (See Fig. 82).

The cumulative curves are similar to the 'r' or mixtures of 'r' and 's' types of Doeglas.

The material forming the storm beach ridge was probably carried in and deposited by storm waves during periods of high spring tides. The high concentration of gravel is attributed to the winnowing action of such waves and the wind which carry finer sand inland depositing it on the mature marsh as washover fans and small dunes.

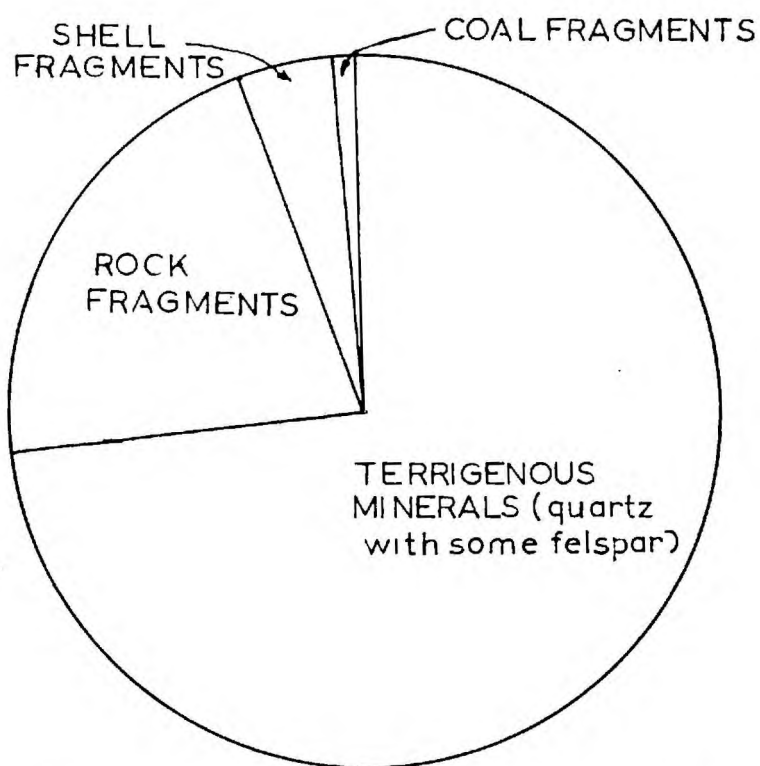


FIG 83 COMPOSITION OF THE COARSE FRACTION
(greater than 0.0625mm) OF STORM BEACH RIDGE

Composition.

The sand fractions of the storm beach ridge are very similar in composition to those of the spit deposits (See Fig. 83).

They consist largely of terrigenous material, particularly quartz grains with smaller amounts of feldspar, rock and coal fragments. Molluscan shell fragments are also frequently found. As in the case of the spit deposits, the absence of more fragile particles of low effective density such as mica, foraminifera etc. is probably due in part to crushing and in part to the winnowing effects of waves and wind.

Structures: Inorganic.

Stratification.

Unfortunately due to their coarseness, it is not possible to take cores or impregnated sections of the storm beach ridge deposits. However sections dug in the field reveal that they are well stratified, bedded and thinly bedded deposits. The strata on the southern side of the ridge tend to dip at angles of 10° or more southwards, becoming horizontal on the crest and then dipping very gradually northwards towards the mature marsh at angles of less than 4° .

Other Structures.

Beach cusps are found occasionally on the southern slope of the ridge after high spring tide periods. The distance between the tips of the horns being as much as 3 - 5 feet, and heights of the horns above the bays being about 6 - 9 inches.

Organic Structures.

The storm beach ridge is characteristically devoid of structures produced by organisms except for plant root burrows. These are rarely discernable and have little or no effect upon the stratification. Some concentric drag marks, formed by the leaves of marram grass scratching the surface when blown by the wind, are occasionally found on the accumulations of wind blown sand behind the storm beach ridge.

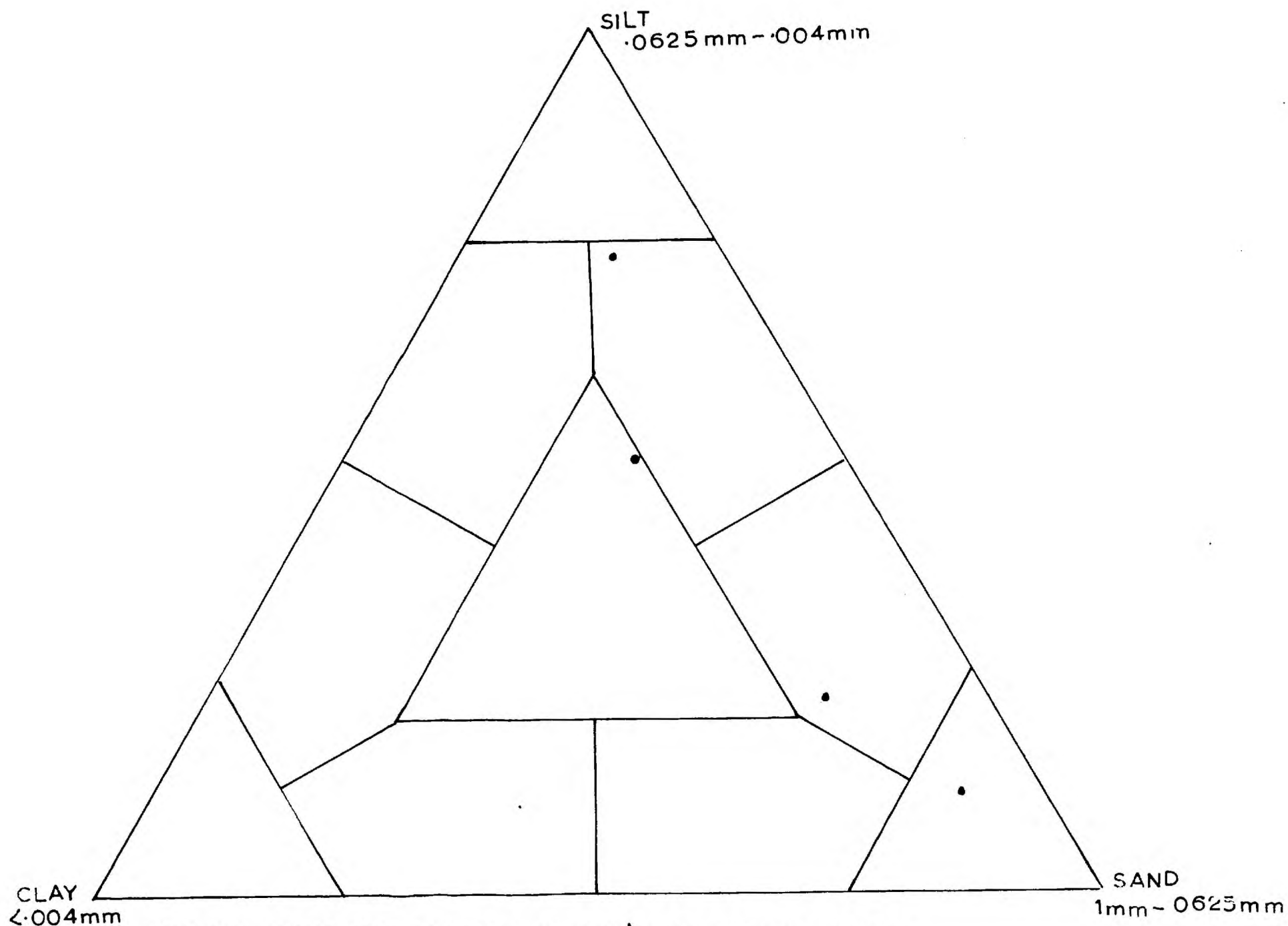


FIG 84 SAND SILT CLAY RATIOS OF MARSH STRIP DEPOSITS

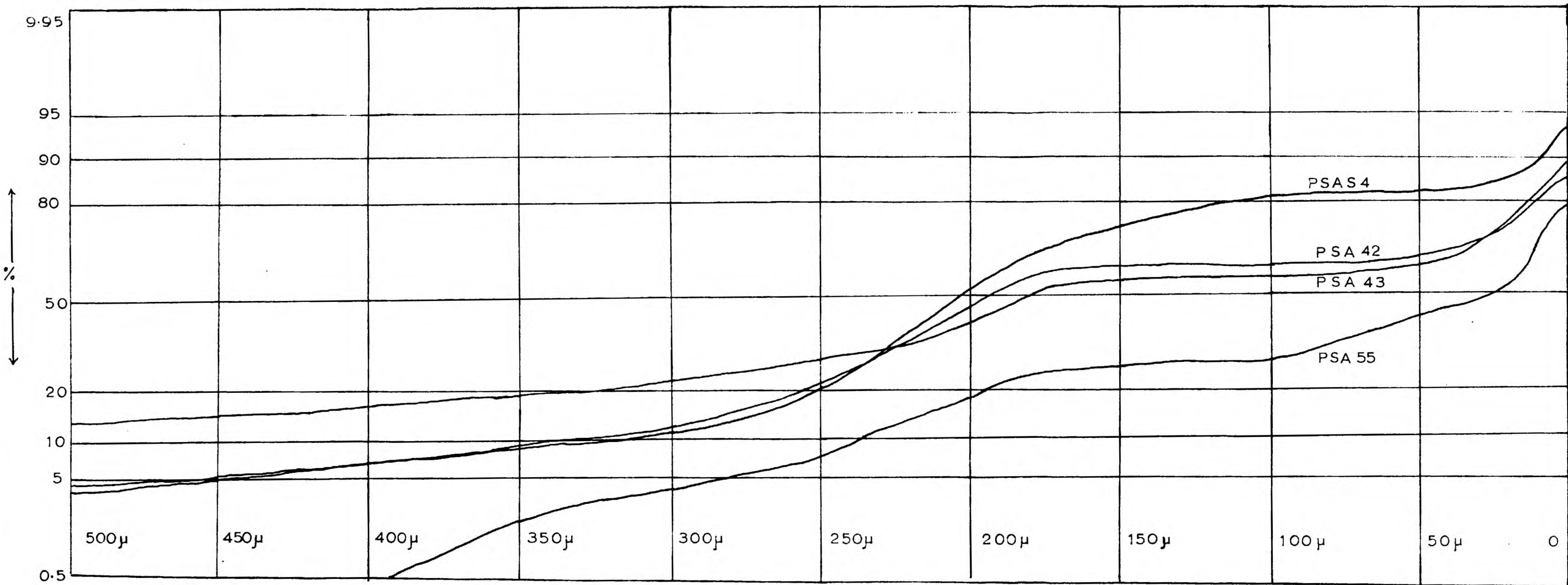


FIG. 86 Grain size frequency distribution of marsh strip deposits.

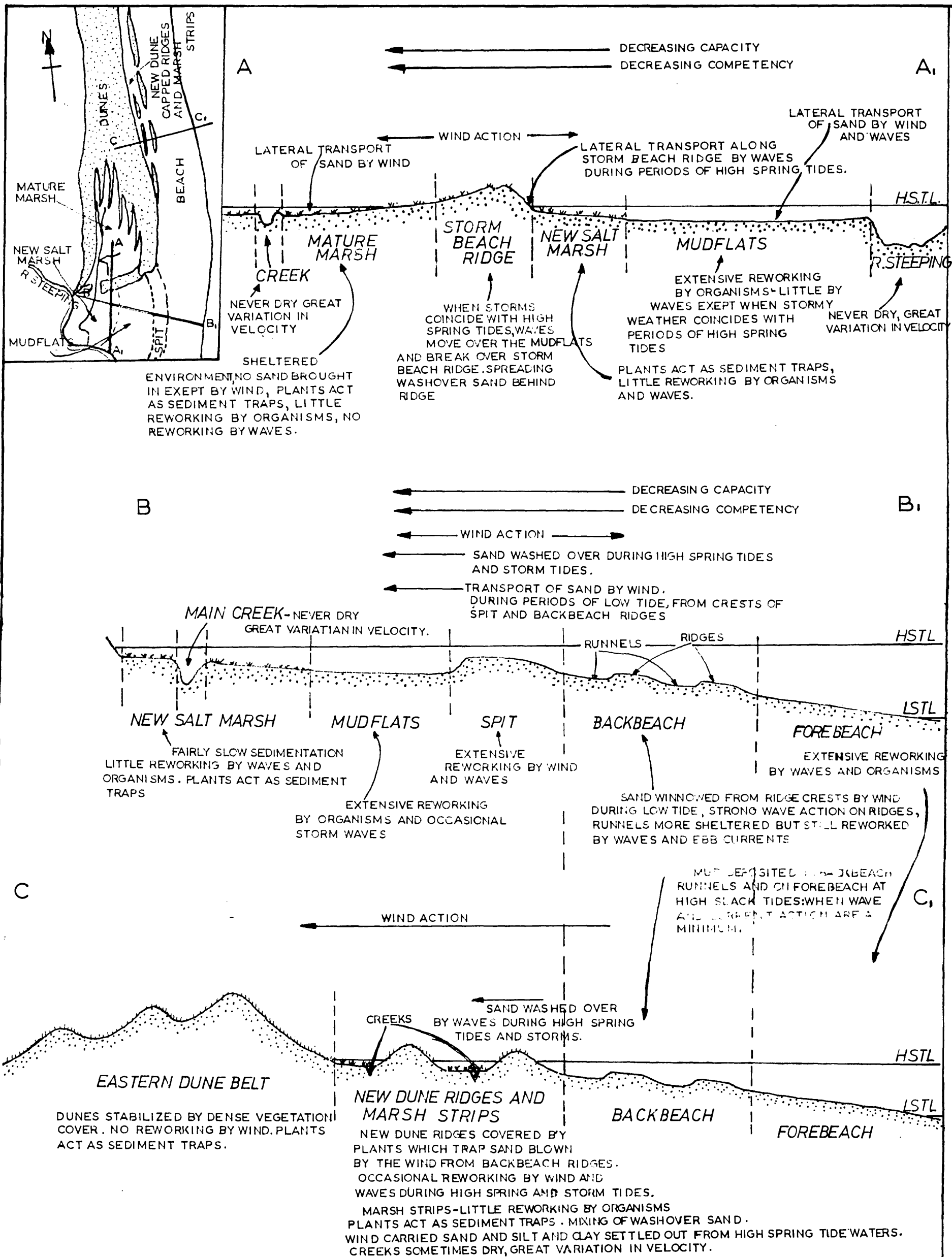


FIG 94 SCHEMATIC PRESENTATION OF THE DYNAMICS OF SEDIMENTATION IN THE GIBRALTAR POINT AREA

CHAPTER 11.

New Dune Ridge & Marsh Strips.

The sediments of the new dune ridges as far as texture, composition and structure are concerned are similar to those of the other older dunes that already have been described in an earlier chapter dealing with the dunes in general. However, their close association with the new marsh strips has a considerable influence on the development of the latter and it can be shown that much of the marsh sediment has been derived from these dunes.

New Marsh Strips.

Granulometric Analyses.

Although only four samples were analysed they showed that the deposits of the new marsh strips cover a wider range of grain sizes than those of the new salt ^{marsh} and mature marsh. ^{They} are "pelitic sands" and "sandy pelites" (Kruit) or clayey silty sands and sandy silty clays (Shepard) (See Fig 84). The sand fraction consists largely of material between the grades 0.25 mm (250 μ) and 0.175 mm (175 μ) i.e. fine sand (Wentworth). They have an average ϕ median diameter 2.53 but it was not always possible to calculate the ϕ deviation and skewness measures because of the difficulty of fixing the 84th percentile in the predominantly finer deposits.

The sediments are bimodal (See Fig. 85). The cumulative curves possess extended coarse 'tails' due to the presence of small amounts of material coarser than 0.25 mm (See Fig. 86). The relatively high proportions of sand in these deposits

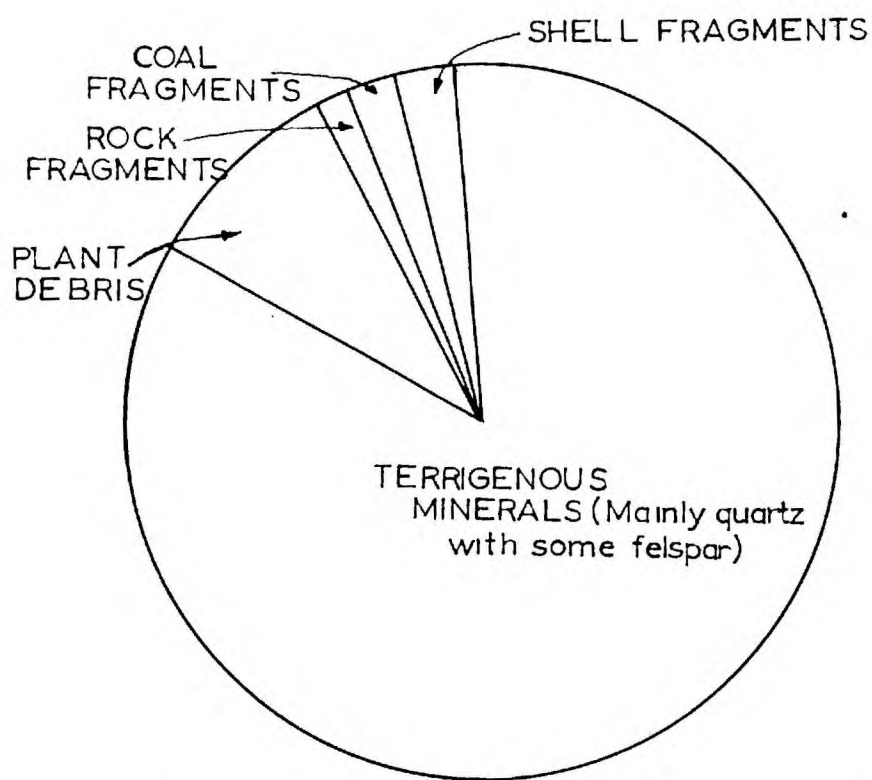


FIG 86a COMPOSITION OF THE COARSE FRACTION
(greater than 0.0625mm) OF MARSH STRIP

are carried from the dune ridges by the wind or washed over by storm waves. The silt and clay are deposited by high spring tide waters which frequently flood the marshes. The dense plant cover acts as an effective trap for these materials. The deposits are composite sediments comparable with 's' and 't' types of Douglas.

Composition.

The coarse fractions consist in the main of terrigenous material in which quartz grains are dominant, with minor amounts of feldspar, rock and coal fragments. Plant fragments are also present in conspicuous proportions and shell fragments, largely molluscan are common. Occasionally echinoderm skeletal fragments and ostracod tests are found. The high proportions of terrigenous material are carried from the dunes by the wind and storm waves. (See FIG 86a)

Structures: Inorganic.

Stratification.

The deposits of the new marsh strips are well stratified, consisting of fine laminae of sand and very fine laminae of silt and clay. There is very little disturbance of the lamination except by plant root structures.

Cross stratification or typical planar "cross stratification" of McKee and Weir (1953) formed by meandering creeks is characteristic of these deposits.

Organic Structures.

Burrowing organisms, particularly Arenicola marina, Hydrobia and Heteromastus sp. are restricted to the areas

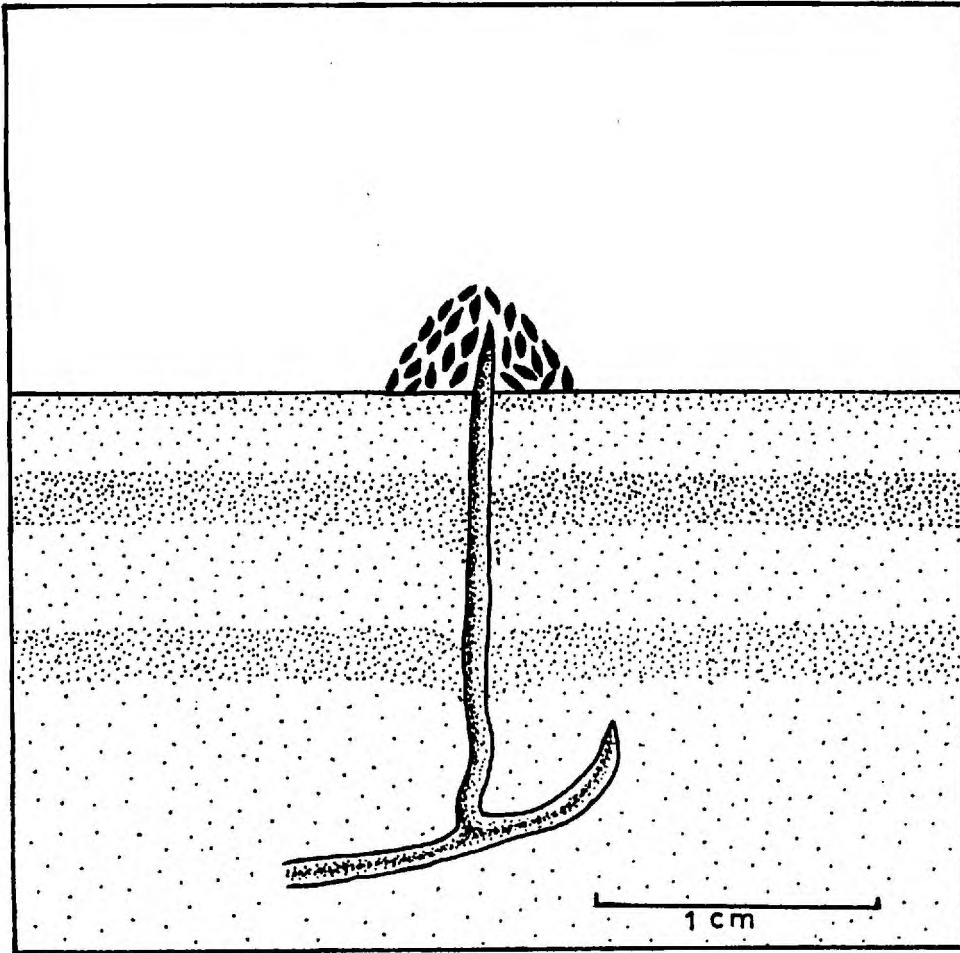


FIG.87. Diagram showing cast and burrows of
Heteromastus filiformis.

occupied by the creeks. The casts and feeding holes of Arenicola are only found on the floors of the creeks and particularly in the lower parts which are rarely uncovered by water. The casts and feeding holes are much larger than those found on the forebeach and due to their poor cohesion tend to lose their irregularly coiled form and take up the appearance of small sand volcanoes (See Plate 13).

The worm Heteromastus sp. is occasionally found in the creek beds. It forms small conical mounds of faecal pellets around the entrance to its burrow (See Fig 87).

Hydrobia are often found in considerable numbers along the sides of creeks and on the marsh strip surface producing abundant trails and small burrows.

CHAPTER 12.

Stratigraphy.

Many geologists have laid emphasis on the importance of three dimensional studies and the spatial relationships of accumulations of modern sediments. These it has been shown yield information most valuable in the stratigraphical interpretation of many ancient sediment bodies. Notable amongst such works are those of Russell (1936), Fisk (1938, '44, '47 etc.), Fisk and others (1954), Fisk and Macfarlan (1955), Kolb and Van Lopik (1958), Scamton (1955) and Van Lopik (1955-'57).

It has been shown in earlier chapters that the Gibraltar Point area is one of particular interest because it can be subdivided into a number of sub-environments of deposition. This account has, so far, dealt with some of the surface and near surface characteristics of the sediments. It has been shown that each sub-environment is characterised by a particular subfacies. This in itself provides a basis upon which similar ancient sediments can be distinguished, but the picture is incomplete and the information already given of little value to the stratigrapher unless the spatial relationships of the various subfacies are given.

In the following pages a three dimensional picture of the Gibraltar Point area will be presented. This picture is based mainly on information gathered from cores, sections, shallow excavations, auger borings, some deep bore holes made by the Lincolnshire River Board and finally historical

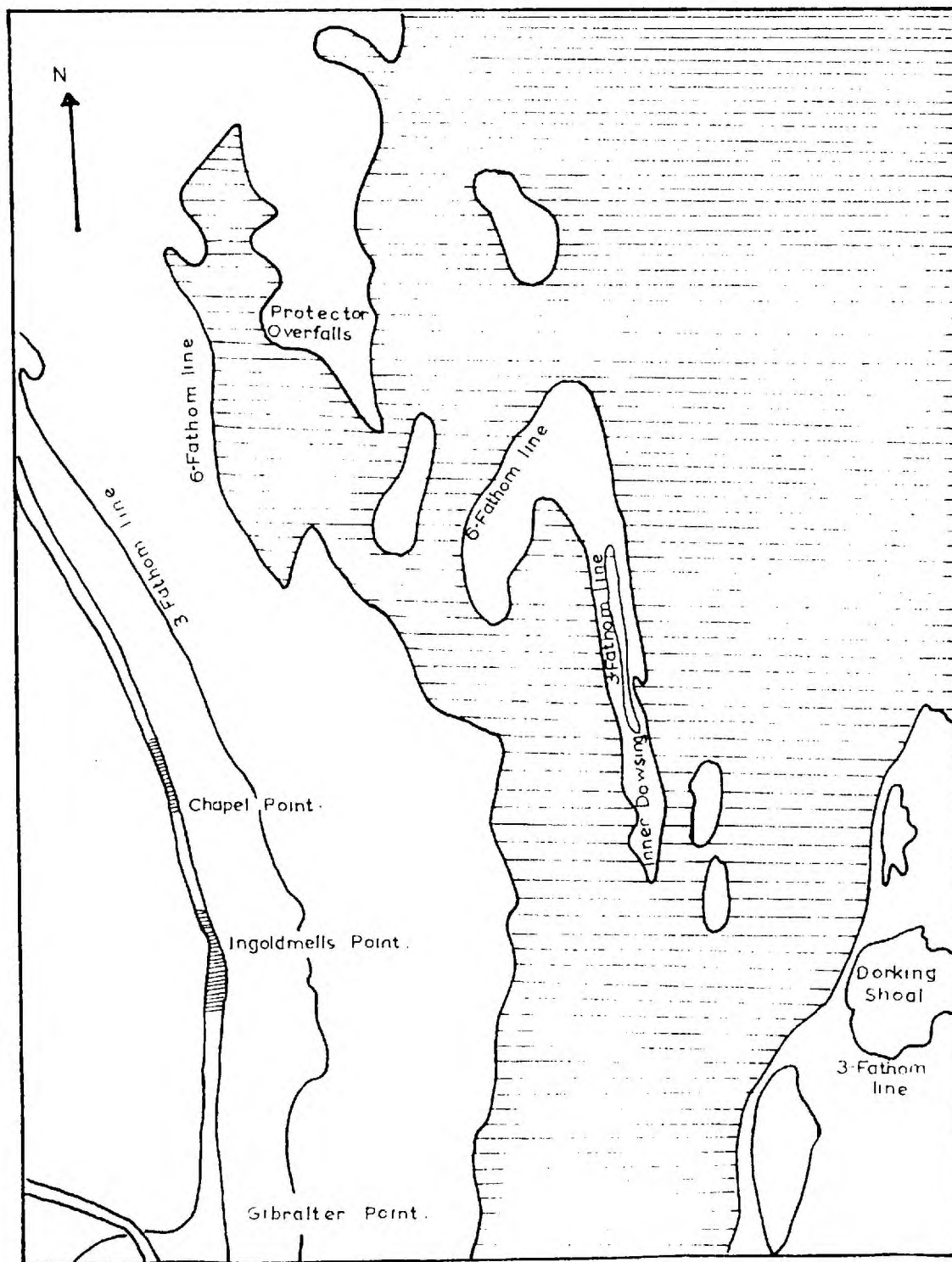


FIG88. The East Lincolnshire Coast including Gibraltar Point and adjacent sea floor. (Afer Swinnerton 1951)

evidence.

Examination of these data has shown that the sediments of the Gibraltar Point area are dominantly sands. These are mainly beach deposits which rest uncomfortably upon older Holocene and Pleistocene sediments. The beach deposits in turn are covered by dune sands, mudflat and marsh deposits (See Fig. 98 at back of the thesis).

Historical evidence suggests that following the deposition of the Pleistocene sediments and during the earlier Holocene the pattern of sedimentation in the area was completely different from that of the present.

Evidence collected by Swinnerton (1936) suggests that during this period the East Lincolnshire region of which Gibraltar Point is part, and much of the present offshore area were shielded from the onslaught of the waves approaching from the open North Sea by some sort of offshore barrier. This barrier probably consisted of a broken range of partially submerged morainic hills which extended from the Norfolk coast to Spurn Point, along the general line of a series of present day offshore barrier islands, called the Protector Outfalls and Inner Dowsing which lie some ten miles seaward of the present coastline (See Fig 88). In the shallow lagoonal area behind this old barrier, tidal flat and salt marsh deposits accumulated.

However, according to Skertchly (1877), during the latter half of the thirteenth century and opening of the fourteenth

century the Lincolnshire coastlands suffered an increasing number of inundations by the sea. Swinnerton (1936) and King (1953) believe that these indicate the destruction and removal of the offshore protective barrier by storms, with resultant erosion of much of the Pleistocene and early Holocene sediments and initiation of the present coastline with sandy beaches and dunes.

Cartographic evidence, shows that accretion, with resultant build out of the beach seawards, has been the dominant process in the Gibraltar Point area over the last ~~two~~ centuries. Many writers including Thompson (1937), Martens (1955) and McKee (1957) have drawn attention to the fact that beach deposits usually possess a characteristic three dimensional form and rarely attain great thicknesses. Barrell (1906, 1909), pointed out that such deposits are generally less than 100' thick while Thompson stated, after examining ancient beaches in California that they rarely exceed 40' in thickness. This is due to the fact that as a beach is forming its thickness is limited essentially by the tidal range. It must develop with one small and two larger dimensions which results in an overall sheet or lens like form. Thompson also showed that ancient beach deposits are usually not continuous for long distances along the outcrop because of the variation in conditions of deposition and erosion along a coastline.

Such undoubtedly is the case in the area studied, which stratigraphically consists in the main of a lens of sand and

UNCONFORMITY AT BASE OF HOLOCENE DEPOSITS.

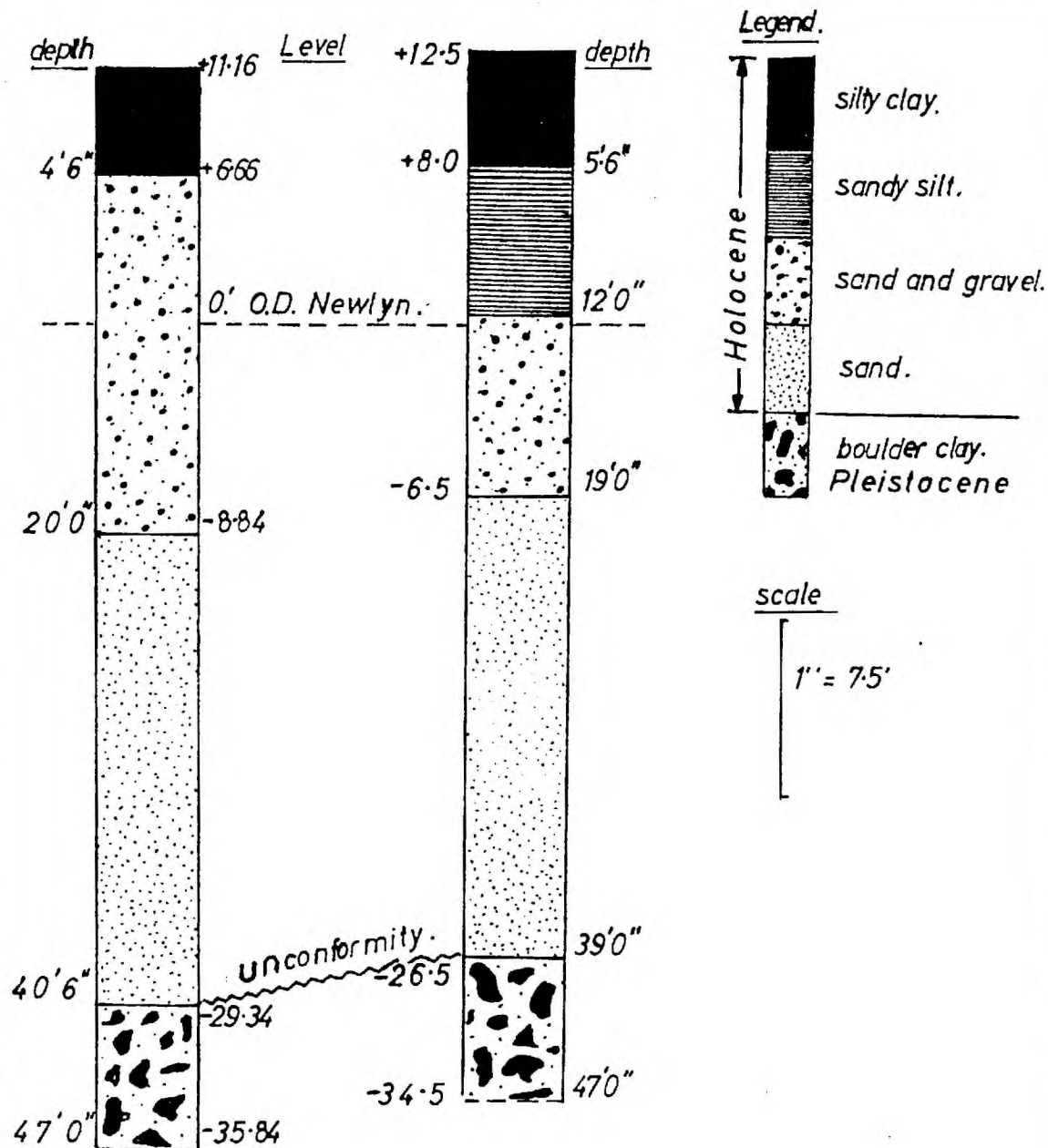


Fig 89. Boreholes on side of R. Steeping at Gibraltar Point.

by kind permission of Lincolnshire River Board.

gravelly sand which according to evidence collected from bore holes (Lincolnshire River Board) has a maximum thickness of slightly more than 30 feet (See Fig. 89). The writer suggests that the present beach is merely the seaward face of the lens. This lenticular body attains maximum development at Gibraltar Point, decreasing in width northwards to Skegness, north of which point and as far as Mablethorpe, the beach is merely a thin covering of sand on a shoreline of erosion, which is receding rather than building out. South of Gibraltar Point, across the Steeping Outfall, the beach deposits pass laterally into tidal flat sediments. It is suggested also, that the lens thins out landwards as it again passes laterally into older tidal flat and marsh deposits, because landward of Gibraltar Point the low lying relief of the ~~Fan~~land appears to be unbroken by dune or gravelly sand ridges. However further information from more bore holes will be necessary before the presence and extent of the subsurface part of the lens can be deduced.

The base of the sand lens rests on Pleistocene boulder clay. This is shown in the two bore holes put down by the Lincolnshire River Board. Further north of Gibraltar Point a surface of erosion separates the beach deposits from the underlying Pleistocene and Holocene deposits. The two boreholes were put down on the sides of the River Steeping, and the present writer feels it is possible that the absence of older Holocene deposits from the two bore holes may be due

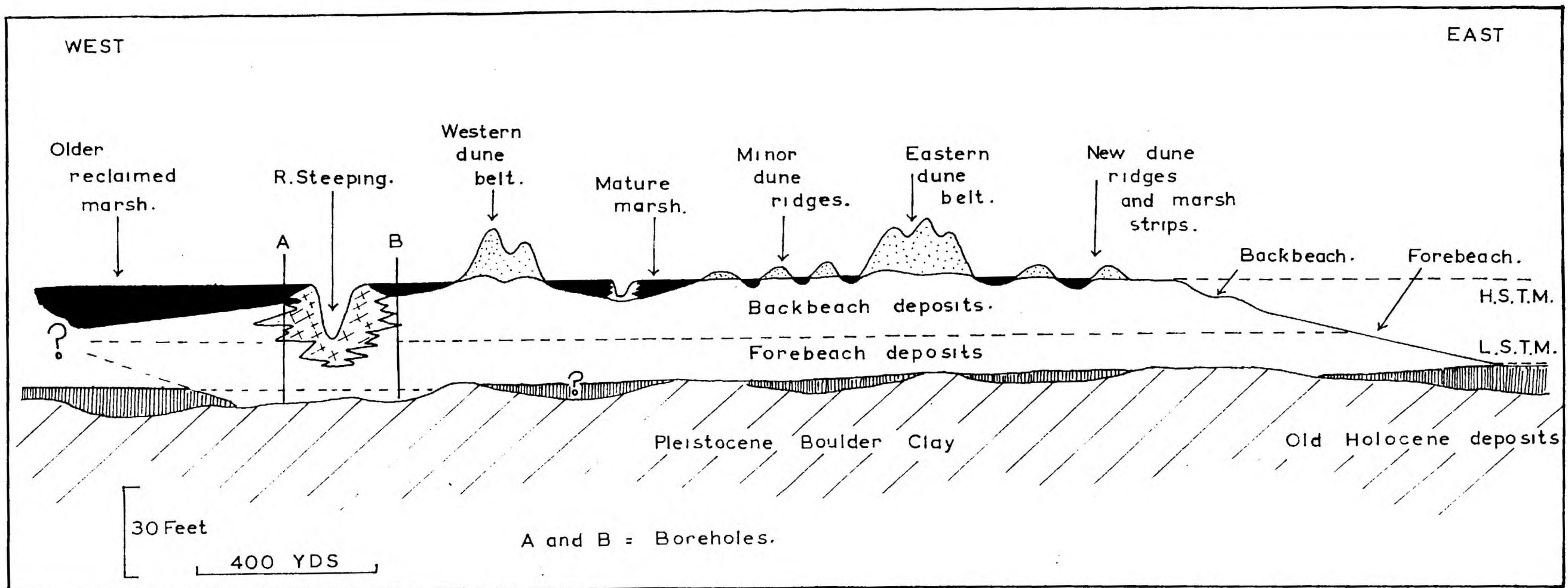


FIG. 90. Hypothetical section through the Gibraltar Point area showing the possible relationship between the deposits studied and older sediments.

to local reworking of the sediments by the River Steeping. If such is the case then further bore holes put down away from the river should reveal remnants of the older Holocene deposits beneath the more recent beach sediments (See Fig. 90). Clayey deposits similar to the Holocene clays observed by Swinnerton at Chapel Point to the north were found below low tide mark at Gibraltar Point.

It is unfortunate that the only complete sequence from Pleistocene boulder clay up to the surface is provided by just the two bore holes, which as already pointed out are not ideal sections, but they do show that the sand lens can be divided into two distinct parts, an upper one consisting of sand and gravel and a lower one consisting of sand. These the author feels are old backbeach and forebeach deposits, although the possibility that they are fluviatile in origin cannot be ruled out.

It has not been possible to demonstrate the boundary between the two in the field except in these bore holes, but as pointed out in an earlier chapter, the evolution of the Gibraltar point area has been characterised by a steady build out and vertical development of the beach.

It seems logical to suggest therefore that the lens of beach sediments which makes up the greater part of Gibraltar Point area consists of two major units. The lower one consisting of sediments typical of the present forebeach, that is, sands which are laminated, the laminae inclined gently seaward since they were deposited on the gentle

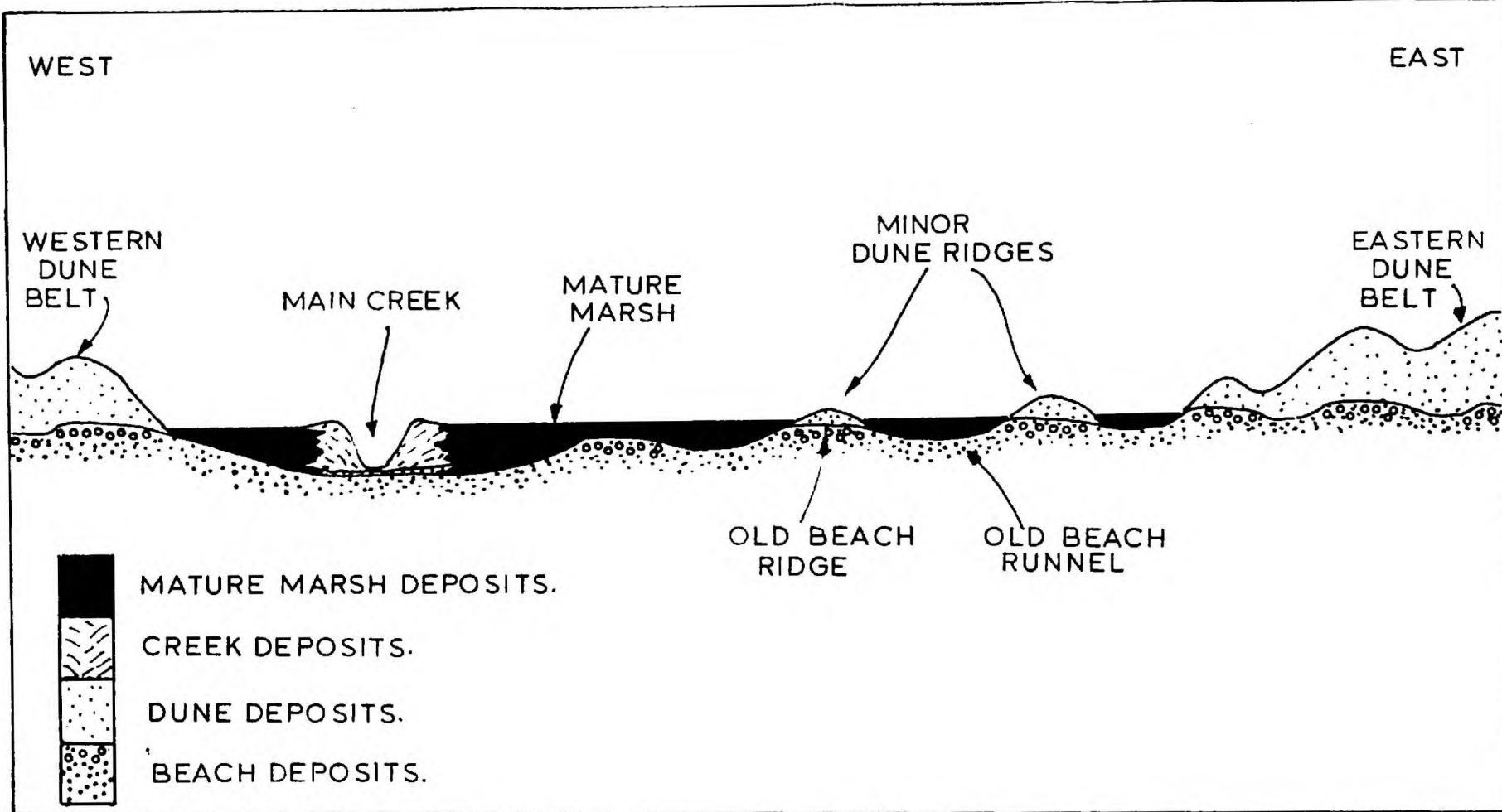


FIG 91

HYPOTHETICAL SECTION THROUGH THE MATURE MARSH.

forebeach slope with occasional ripple formed cross lamination and large numbers of Arenicola burrows. Overlying these, the upper unit consisting of sands and gravelly sands typical of the present backbeach which show a more complex internal structure, of variously inclined and crossed laminae, produced as a result of the development of ridges and runnels, mega ripple marks etc. at various stages of development of the beach. It is suggested that the surface between the two units is equivalent in level to the junction between the forebeach and backbeach at the present.

It has been demonstrated that the ridges become capped by dune sand and the runnels infilled with finer marsh deposits. It was possible to observe the boundaries between these deposits in auger holes, sections dug in the field and cores. In all cases it was found that dune sand rested on the gravelly sand of an older backbeach ridge, while the marsh deposits rested on similar deposits of older runnels (See Fig. 91).

The Upper surface of the lens of beach sand is irregular because of this development of ridges and runnels which have since been incorporated in the succession. The surface in all cases is sharply defined and easily distinguished because of the marked difference in character between the older backbeach and younger marsh and dune deposits.

In the southern part of the area a more complex relationship exists between the underlying beach deposits and overlying new salt marsh, mudflat, storm beach ridge and mature marsh deposits.



PLATE 74. OLD CREEK DEPOSITS

EXPOSED IN SIDE OF R. STEEPING.

Although a spit and ridge and runnel beach exist at present there is little evidence to indicate similar older features preserved beneath these new deposits to westward of the present beach except for the remains of the 1779 spit at the southern end of the western dune belt.

There are two possible explanations for this. First, the River Steeping outfall has continually changed its position over the last two centuries. It may well have been responsible for reworking these deposits and destroying any older beach and marsh features. Older inclined strata similar to those found forming on the prograding banks of the river meanders at present are to be seen exposed by erosion in the side of river channel to the west of the present spit (See Plate 74); suggesting that the river has cut back northwards in the southern part of Gibraltar Point area, at an earlier date. This is also suggested by the cartographic evidence (See Fig 7 Chapter 3).

Secondly, the absence of older ridges and runnels, beneath the present mudflat and new salt marsh deposits, may be attributed to the action of storms, as discussed in an earlier chapter, which affected the area during the nineteenth and early twentieth centuries. These appear to have resulted in erosion of the southern part of the area. The storm beach ridge itself is believed by King (1951) to have been formed as a result of the breakdown of a spit, very much like the present one, which developed further to the west, and the present investigation has shown the great similarity in composition and

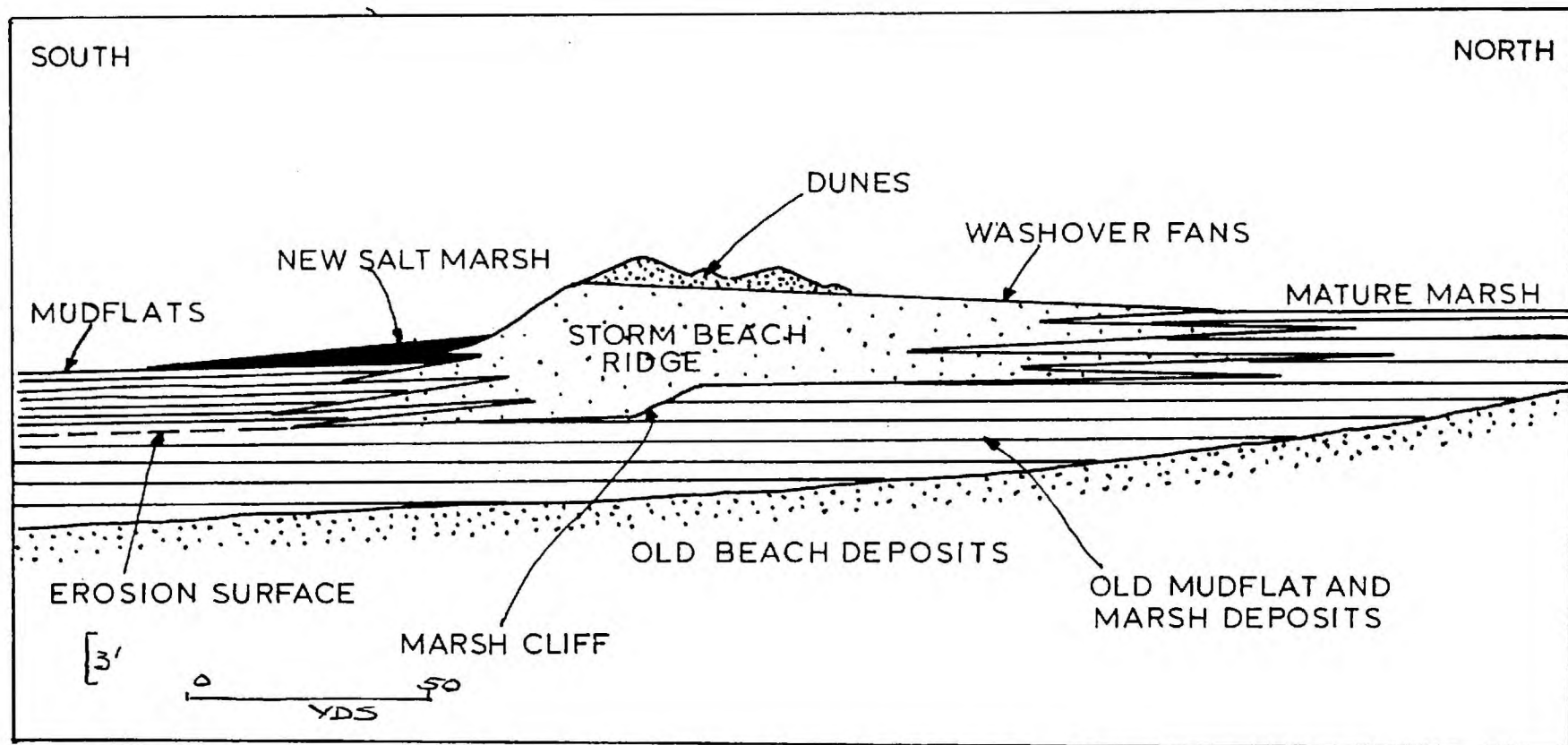


FIG 92. HYPOTHETICAL SECTION THROUGH THE STORM BEACH RIDGE.



PLATE 75. STRATIFICATION OF MATURE
MARSH DEPOSITS, SANDY LAMMINAE
WASHED OVER FROM STORM
BEACH RIDGE.

grain size of material of both storm beach ridge and spit. Sections cut through the storm beach ridge showed that it rests upon an eroded surface and the remains of an old marsh cliff (See Fig. 92).

It is possible that reworking by both the river and storm waves have been responsible for the complex relationship of the various subfacies in the southern part of the area.

Following the formation of the storm beach ridge, new mudflat and salt marsh deposits have developed to the south of it and this development is continuing at present. The storm beach ridge has been further modified by storm waves which occasionally sweep over it spreading much of its material over the mature marsh as washover fans. Sections dug in the mature marsh behind the storm beach ridge show wedges of sand representing a series of washover fans spreading as tongues into the mature marsh and decreasing in thickness away from the storm beach ridge (See FIGS 92 and Plate 75). Similarly, the seaward face of the storm beach ridge is frequently reworked by waves and fans of sand and gravel are often spread out over the mudflats. These form wedges in the mudflat succession and are easily picked out in cores from the mudflats in front of the storm beach ridge. An irregular covering of dune sand covers the deposits of the storm beach ridge, the relationship between the two being similar to that between dune sand and older beach ridge deposits.

Evidence from cores and sections shows that the deposits

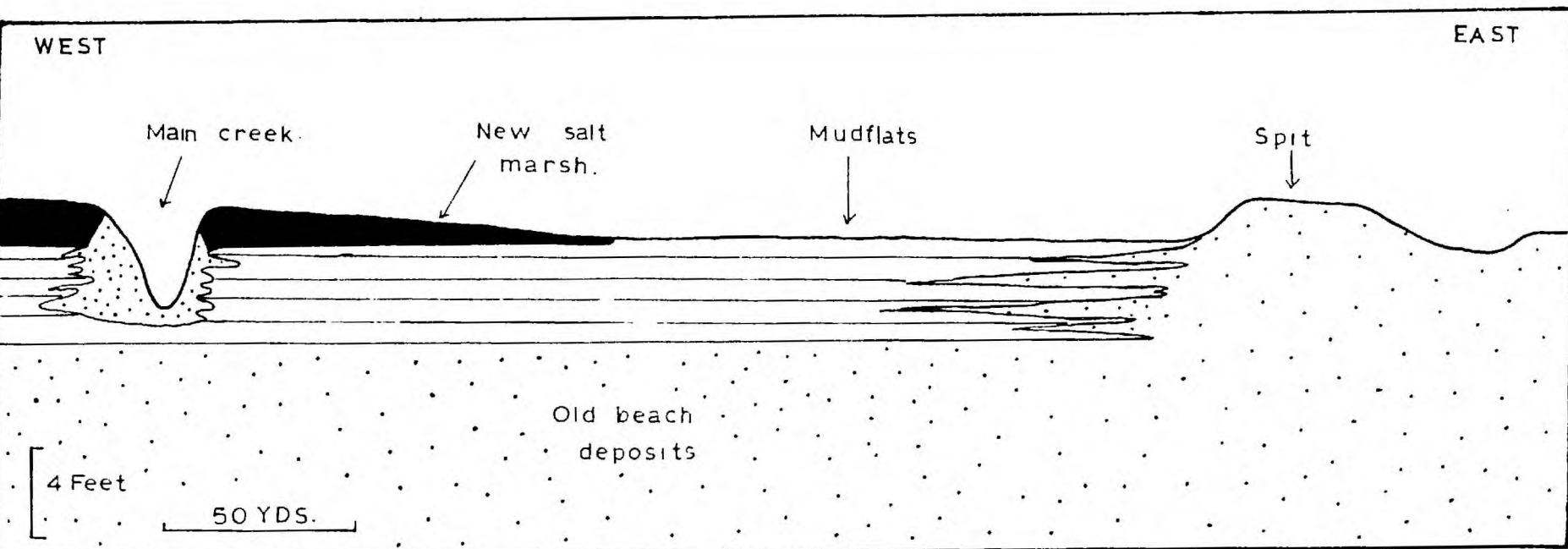


FIG 93. Diagram showing a hypothetical section through new salt marsh, mudflats and spit.



PLATE 76. MUD FLAT DEPOSITS RESTING
ON OLD BEACH DEPOSITS.

of the new salt marsh overlies those of the mudflats. In all cases it is possible to show a well defined boundary between the two subfacies. The new salt marsh deposits are finely laminated fine sands and silty clays and are generally less disturbed by burrowing organisms than the mudflat sediments. The latter are also well laminated but generally have a greater proportion of sandy laminae particularly near the storm beach and spit; in many cases the lamination is almost completely destroyed by burrows particularly those of Gorophium volutator (See Plates E, F, G and H). Evidence collected by repeated ^{2. Survey} surfaces over the last fifteen years or more by King (1951 etc.) indicate that the new salt marsh deposits are building out over the mudflats (See Fig. 93).

It was possible to demonstrate in sections (See Plate 76) that the mudflat deposits south of the spit overlie sandy sediments, which the present writer suggests are older beach deposits because they pass laterally seaward into the present beach deposits without any apparent break. They may, however, be sediments reworked by the River Steeping.

The mudflat deposits pass laterally eastward into the deposits of the present spit: again evidence from cores and sections shows that, as the spit is approached, a number of sandy laminae appear, which increase in thickness towards the spit. These are wedges of sandy sediment representing washover fans from the spit which were formed on occasions when strong wave action washed material from the spit onto the mudflats.

Apart from the River Steeping, the creeks and bordering regions form narrow belts which often cross the boundaries separating different sub-environments. They are interpreted as irregular zones in cross section.

Unfortunately, no survey of the area with particular reference to the heights of boundaries between sub-facies was made during the present investigation, consequently assessments of the thicknesses of the deposits of the various subfacies shown in the accompanying sections are very approximate and are based largely on surveys made by King, observations in the field by the present writer and borehole data.

The beach deposits form a lens which has a maximum thickness of approximately 30 feet in the Gibraltar Point area. The dune sands on the old backbeach ridges vary from a few inches to 10 feet or more in thickness. The deposits of the mudflats are rarely more than 4 feet in thickness, whilst the new salt marsh deposits form a wedge shaped body with a maximum thickness of approximately 2 feet in the west but thinning out eastwards over the mudflats. The deposits of the mature marsh are about 3 - 4 feet in thickness behind the storm beach ridge but thin out northwards between the minor dune ridges, where they are practically only a thin covering of 1 - 3 inches in thickness on older backbeach runnel deposits. The marsh strip deposits are rarely more than 1 foot in thickness, forming thin lenses of fine sediment between the new dune capped ridges and, like the tongues of mature ^amarsh between the minor dune ridges, rest on backbeach runnel deposits.

The boundaries between the various sub-environments are drawn essentially horizontal in the accompanying sections, as they are thought to be related to tidal levels. However, if as it has been suggested by certain workers, including Fowler (1940), Godwin (1940) and King (1953) etc., that sea level is steadily rising, then the boundaries between the various sub-facies will also rise gradually seawards. A feature of significance is the fact that the subfacies are diachronous.

The present author feels that the deposits of the various subfacies are distinctive and could be easily recognised if preserved. It is difficult to point out any one criterion that may prove that a certain formation was a beach, dune or marsh deposit but as shown in the present investigation a careful study of the many features of the sediments can give a very strong indication of their mode of origin.

CHAPTER 13

Processes of Sedimentation.

In the preceding chapters the sediments found in the Gibraltar Point area have been described and it has been shown that there is a remarkable lateral and vertical diversity of sediment type. These differences are a result of a number of factors including direction and intensity of waves and associated currents; tidal variations, wind action and the effects of organisms. In particular, the variation in intensity and relationship of these factors is reflected in the sediments accumulating in the different sub-environments.

In this chapter the area will be treated as a whole and with a knowledge of the grain size frequency distributions of the deposits an attempt will be made to account for the general pattern of sedimentation (See Fig. 94). For such an analysis to be complete, it would be necessary to possess data on the strength of the various currents at various states of the tide, wave amplitudes and periods etc. Although these are not known in quantitative terms it is possible to discuss them on a qualitative basis.

Hydrography.

The dominant direction of wave approach is from the northeast quadrant, the direction of maximum fetch. These waves suffer refraction as they reach the beach but the greatest degree of refraction is at the Point where the trend of the coastline changes from north-south to east-west. As a result of the refraction, the crests of the waves tend to swing

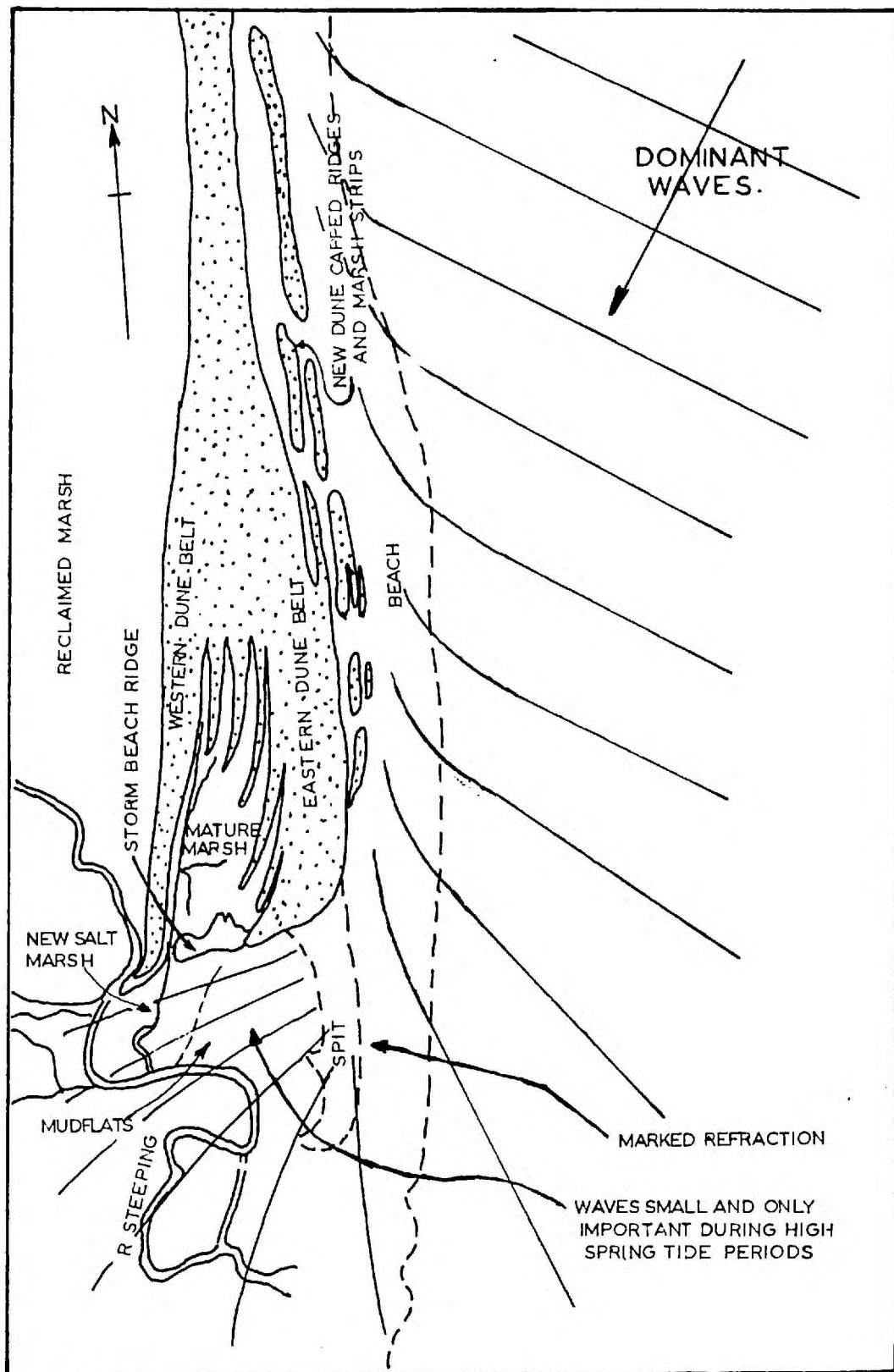


FIG 45 DIAGRAMMATIC WAVE REFRACTION PATTERN FOR THE GIBRALTAR POINT AREA.

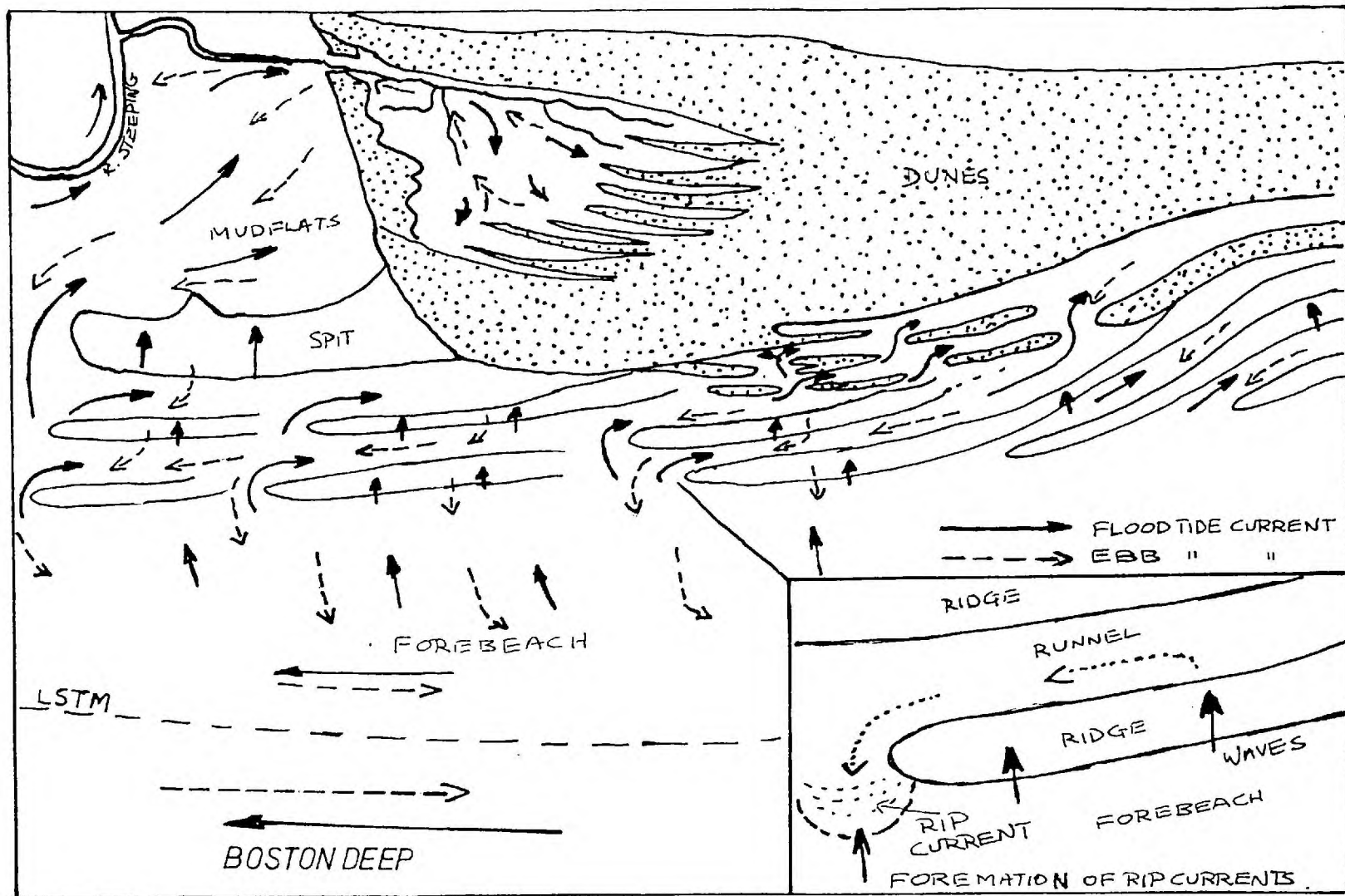


FIG 96 DIAGRAM SHOWING DIRECTIONS OF WATER MOVEMENT OVER THE INTERTIDAL ZONE OF THE GIBRALTAR POINT AREA

around parallel to the coastline and approach the coastline in the southern part of the area from a southerly direction (See Fig. 95).

Tidal waters flood parts of the area twice every 24 hours. According to Admiralty charts mean high spring tides have a range of approximately 20 feet and mean high neap tides a range of 9 Feet. High spring tides inundate the beach, spit, mudflats, new salt marsh, mature marsh and marsh strips, but high neap tides only inundate the forebeach and lower parts of the runnels on the backbeach. The velocity of the flood tide current is generally higher than that of the ebb tide current in the vicinity of Gibraltar Point, (North Sea Pilot 1948).

There is a longshore movement related to the water movements in Boston Deep, a channel to seaward of the forebeach. This is one of several channels along which the tidal waters enter and leave the Wash. As the tide rises the waters move landwards as well as alongshore. Whereas the water movements in Boston Deep are essentially parallel to the coastline, the directions of movement over the intertidal zone form a complex pattern due to the considerable variation in the configuration and morphology of this zone (See Fig.96).

During periods of high spring tides, when maximum inundation occurs, the waters flood across the forebeach in a direction perpendicular to the coastline while south of the spit the waters flow inland and up the channel of the Steeping. Later the rising tide begins to inundate the

runnels on the backbeach and in these the direction of movement is northwards sub-parallel to the coastline. At about the same time the tide floods around the southern end of the spit and overflows the banks of the River Steeping to cover the lower parts of the mudflats.

At a higher stage of the flood tide, the beach ridges become inundated. When this occurs the northward longshore movement in the runnels ends but there is probably still a general longshore movement southwards over the lower part of the beach. The common landward movement of floating objects and the rapid movement in that direction in the breaker zone show that the surface water over most of the area is moving landward. At this stage there tends to be a piling up of water in the runnels as the waves pass over the ridges. This appears to be compensated by a southward movement of water in the runnels. This southward longshore current sweeps seawards through the gaps in the beach ridges and where it meets the general incoming water, rip currents are produced. Similar rips have been observed by Shepard, Emery and Lafond (1941) on the beach at La Jolla, California. These currents may be responsible for cutting the gaps in the beach ridges.

As the backbeach becomes inundated, the waters continue to spread in all directions behind the spit. At the peak of spring tides the waters flood through the gaps in the dune capped beach ridges to cover the marsh strips and the water moving northwards up Main Creek, overflows

its banks to cover the mature marsh in the area behind the storm beach ridge.

After a short period of standstill at high tide the ebb tide begins during which the directions of water are largely reversed, except for the southward flowing current in the runnels which continues in that direction and increases in strength as the tidal level falls.

Aeolian Processes.

Wind action has clearly played a very important part in the development of this area, particularly in the distribution of the dunes. Apart from the knowledge that the prevailing winds are westerly and that there are remarkable variations in wind strength in the dune areas, little information is available at the present. However the observations which are being made by King (See King 1951) with the object of determining the amounts of sand being transported and the variations in wind velocity at particular times on the beach and among the dunes will ultimately be most valuable.

Source of Sediments.

Very little information exists concerning the source of the material deposited in the area. According to the Lincolnshire River Board (Personal communication) relatively no material is contributed by the River Steeping. All the available evidence suggests that the sediment is derived in two ways:-

- 1 By erosion of the coast to the north.
- 2 By erosion of older sediments on the floor of the North Sea.

Many writers such as Sheppard (1912), Kendal and Wroot (1924), Valentin (1954), King (1959) etc. have drawn attention to the fact that apart from small areas in the vicinity of Donna Nook, Spurn Head and Mablethorpe the coastline north of Skegness as far as Flamborough Head is one of erosion, and has been since Roman times. This section of coast consists largely of Pleistocene boulder clays and early Holocene deposits.

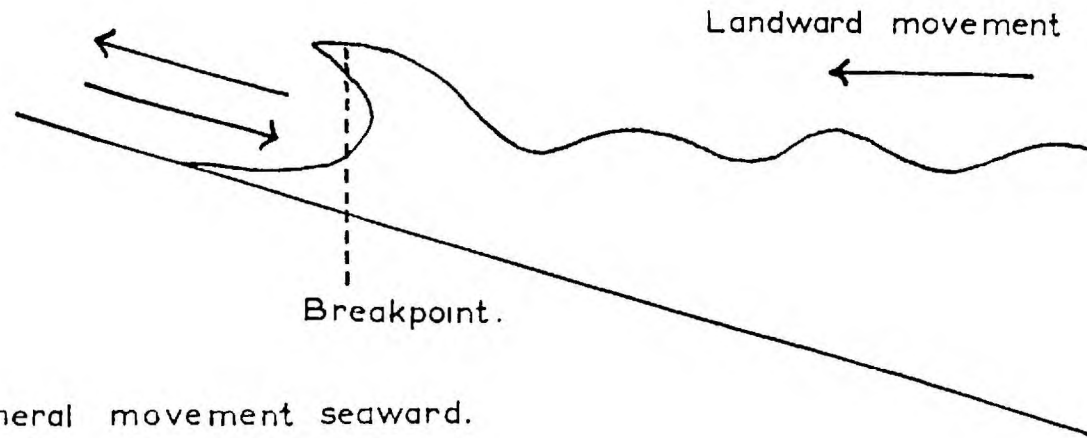
King (1959) believed that the eroded material probably moves offshore or to the south by longshore drift in the littoral zone. In support of the longshore movement of material she stated that the beach ridges in the area studied, move southwards during their development in the summer months.

Stride and Cartwright (1958) and Stride (1959) found that the sediments on the floor of the southern part of the North Sea are being continually reworked by tidal currents, and the reworked material transported landwards. It is possible that waves are also responsible for reworking these deposits since the North Sea is shallow (Luders 1939).

That the sediment comes from these two sources is suggested by the composition of the sediments in the Gibraltar Point area. Peat and mud balls found on the beach are probably transported blocks eroded from older Holocene deposits further north or offshore.

During the present investigation it was found that the results of the heavy mineral analysis agreed with those of Baak (1936), who showed that the suite of minerals which he

Landward or seaward movement
depends on h/l of breaking
wave.



High h/l — General movement seaward.

Low h/l — General movement landward.

FIG 97. Diagram showing directions of movement of material inside
and outside break-point of waves.

called the "E group" is fairly uniform over the whole of the western North Sea and is similar to that found in the Pleistocene glacial deposits exposed on the coast to the north of the area studied.

Differentiation of Sediment in the Area.

The sediment is carried to the area by the flood tide and wave action plays a major role in transporting the material alongshore and from offshore. The transported sediment consists of gravel, sand, silt and clay. Hjulstrom (1935, '36, '39), Inman (1949) and Menard (1950) have shown that gravel and sand usually move as the bed load by traction and saltation, and the silt and clay in suspension. The gravel is only moved under strong wave action.

The material when it reaches the area is probably not differentiated very much because of the short distance of transport from the source areas, and probably at this stage has a grain size frequency distribution of the 'r', 's' and 't' types of Dogglas . However it is markedly differentiated in the area by wave action, wind and tidal currents.

Wave action is the dominant process controlling the pattern of sedimentation on the beach. Experiments described by King (1959) show that under practically all wave conditions sediment is moved shorewards outside the breakpoint. This is because maximum velocity is attained in a shoreward direction under the crests of the waves. Inside the breakpoint swash and backwash become the important elements in transporting and sorting material (See Fig. 97). The

direction of movement may be landward or seaward depending on the ratio between the heights and lengths of the waves. If the ratio of height to length is high, material tends to be moved seaward, if low the movement is generally shoreward.

On ^aprograding beach such as the one studied, it is reasonable to suppose that ^{the}swash is generally stronger than the backwash, with the result that only the finer material of the total load deposited by the swash is moved back seaward by the backwash. As pointed out by King, for such a condition to exist the ratio of h/l of the waves must be small.

Due to the considerable tidal range in the area the effects of swash and backwash are exerted over the complete width of the beach. However, in a complete cycle of neap and spring tides the lower part of the beach, that is the forebeach, is more regularly inundated and therefore affected by wave action to a greater degree.

These conditions are reflected in the areal distribution of the sediments over the beach in as much as there is a gradual increase in the median diameter from forebeach to backbeach and the sands of the forebeach are generally better sorted than those of the backbeach; whereas the former have ϕ deviation measures which range from 0.42 - 1.05 and generally show positive skewness values, the deposits of the backbeach have ϕ deviation measures which range from 0.35 - 1.4 and show negative skewness values.

The areal distribution of the sediments on the beach also appears to be partially controlled by seasonal variations. During Summer time the waves tend to be flat and the swash

action of these waves as described in an earlier chapter results in the production of ridges and runnels on the backbeach. The swash action of gentle waves breaking over the ridges during high spring tide periods removes sand from the crests and deposits it on the base of the steep landward slopes of the ridges and on the runnels beyond. This and the winnowing action of the wind during neap tides and low tide periods result in a concentration of gravel on the crests of ridges and the production of deposits more typical of the 'r' type of Doeglas.

During high spring tides in summer, the water is shallower over the ridges but quite deep over the runnels and forebeach. If the waves are flat, the surfaces of the runnels and forebeach may be well below wave base and silt and clay 't' type of Doeglas, carried in suspension may settle out and be deposited on these areas. Most of this will be removed by wave action as the tide falls, but some will be mixed with the sand by the gentle wave action thus giving rise to mixed deposits of 's' and 't' types of Doeglas.

During winter, storms are common along this coast and the steep waves associated with them tend to flatten the ridge and runnel profile of the backbeach. These waves have high h/l ratios and since the backwash is stronger than the swash generally tend to move sand seaward inside the breakpoint. At the same time however, these waves are responsible for carrying gravel onto the backbeach. Such strong waves are capable of picking up the gravel as suspended load. This

gravel is thrown inland by the swash of the breaking waves and due to the rapid percolation of the waters into the underlying sediment, the backwash moves only finer material seaward, leaving the gravel at the upper limit of swash action.

During high spring tide periods, the waters flood up the Steeping and around the southern end of the spit to spread across the mudflats and new salt marsh. As high spring tide level is approached they flood into the mature marsh and marsh strips between the new dune capped ridges.

Wave action is of little significance in these sheltered sub-environments. The total load transported by these waters has by this time been largely differentiated. All the gravel and sand with grain size frequency distributions of 'r' and 's' types of Doeglas have been deposited on the beach. The remaining load still carried by these waters consists largely of silt and clay with a grain size frequency distribution similar to 'r' type of Doeglas. As the waters move gradually inland over these sub-environments their velocity decreases with a consequent decrease in capacity and competency. As a result of the low velocities; the absence of wave action and the frictional effects of the plants on the marshes, a large amount of this fine material in suspension settles out.

Following the period of standstill at the high water stage, the tidal waters drain off these areas and the ebbing waters sometimes erode and carry away material deposited by the flood. However accretion appears to be the dominant process suggesting that flood tide deposition exceeds ebb tide erosion.

Two factors operate which tend to prevent the erosion of the load deposited by the flood tide, by the ebb currents. They are the "settling lag" of suspended material and "scour lag" of deposited material. These have been discussed by Hjulstroem (1935), Postoma (1954), Sundborg (1956) and Van Straaten and Kuenen (1957; '58).

The "settling lag" is the time between the movement when a current of decreasing velocity is no longer able to hold a particle in suspension and the moment when this particle reaches the bottom. As a result the particle is deposited further inland than the point where the current decreased to such a velocity that it was unable to carry it.

"Scour lag" refers to the difference between the maximum current velocities allowing sedimentation of suspended particles and minimum velocity required to erode the same material from the bottom.

If the scour lag effect is zero then as a result of the settling lag, material deposited by the flood current cannot be eroded by the same mass of water during the ebb period because this attains the required velocity when it has reached a point to seaward. However it may be eroded by a more landward mass of water.

Hjulstrom (1939) pointed out that a stronger current is required for the erosion of material than for its deposition and Van Straaten and Kuenen (1957-58) showed that the scour lag effect is greater for silty or clayey materials because of the smoothness of the bottom and the resulting tendency for

the lowermost layers of water to move in laminary flow.

Therefore both settling and scour lag effects tend to promote the build up of the mudflat and marsh deposits.

Granulometric analyses of these deposits show that the 't' type fractions deposited by the flood tide waters are generally mixed with smaller amounts of sand of the 's' type of Doeglas. These are brought in when storms coincide with high spring tides or by wind action.

Storm surges are common in the North Sea. When these coincide with periods of high spring tides, the actual high tide level may be as much as 10 feet above the predicted level. Under such conditions the spit, storm beach ridge and outer new dune capped ridges are severely eroded and considerable amounts of sand are washed over these features and spread over the surfaces of the mudflats, mature marsh and marsh strips. These conditions are reflected in the grain size frequency distributions of the sediments, in as much as the proportion and median diameter of the sand present in the mudflat deposits particularly increases towards the spit and storm beach ridge (See Fig. 61).

The wind, apart from its major function of generating waves, plays an important role in the transport of the beach sand. The inward and upward surge of the swash following the break of the waves is the agent which places the sand on the backbeach where it is subject to further transport by the wind. At periods of low water, the sediment on the backbeach and particularly on the crests of the beach ridges dries and can then be carried away by the wind. King (1951,59)

drew attention to the fact that the dunes along the Lincolnshire coast are the result of accumulations of sand blown off the beach by occasional onshore winds blowing from the east. The present writer has noted that winds blowing from the north and south will transport sand alongshore and thus become an important agent of longshore movement of sand.

The grain size frequency distribution of the dune sands shows that they are generally better sorted than those of the backbeach, although there is quite a considerable overlap (See Fig. 54). This is to be expected since the dune sands are derived from the backbeach. A comparison of the plots of ϕ median diameter against ϕ deviation and skewness measures shows that the ϕ deviation and, to a lesser extent, ϕ skewness values are a function of the median diameter. In all cases samples having median diameters near 2.5ϕ (0.18mm) are better sorted and the ϕ deviation measure in particular increases in value for median diameters greater or less than 2.5ϕ . This fact is well illustrated by the studies made by Krumbein and Aberdeen (1937) of Barataria Bay sediments, Hough (1942) of Cape Cod Bay sediments, Shukri and Higazy (1944) of Red Sea sediments and Inman (1949) of California beach sediments. Inman points out that particles coarser and finer than 2.5ϕ are more difficult to move, and very fine material is readily carried in suspension so that bottom sediment in the process of transportation tends to become progressively better sorted as its median diameter approaches 2.5ϕ .

The wind as well as being an effective agent in differentiating the dune sands is also an effective mixing agent. It transports material from the spit, storm beach ridge and dunes and deposits it on the neighbouring mudflats, mature marsh and marsh strips. This material is thus added to the silt and clay deposited by the tidal waters and the sand washed over into these areas by storm waves.

Animals and plants act as agents in controlling the grain size frequency distribution of the sediments. On the forebeach, the worm Arenicola marina is continually burrowing through the sediment and probably results in a certain amount of mixing of the deposits, particularly by dragging fine material downwards. Also Lanice conchilega found on the lower part of the forebeach, often occurs in large numbers on well developed mounds of sand and probably acts as a trap for the sediment and may well be an effective agent in preventing erosion in these localities.

On the mudflats, the worm Nereis diversicolor, the mollusc Scrobicularia plana and particularly the crustacean Corophium volutator occur in large numbers. As a result of their burrowing activities these organisms are responsible for mixing the silt and clay deposited by tidal currents with the sand deposited by wave and wind action during stormy periods.

No suspension feeding organisms are found in the Gibraltar Point area, except for an occasional Lutraria sp. This is in contrast with the intertidal flats of the Wash to the southwest where, as Evans (1960) pointed out, Mytilus edulis

occurs in large numbers and may be responsible for filtering considerable amounts of mud from the tidal waters.

The dense cover of vegetation on the salt marsh, mature marsh and marsh strips acts as an effective trap for the sediment carried in suspension by the tidal waters, and by binding the sediments together protects them from erosion.

Marram grass which quickly colonises newly developed accumulations of wind blown sand is an important agent in the development of dunes in the area. It grows best when it is being continually covered by fresh wind blown sand. It not only stabilizes the dunes but promotes their growth by acting as a trap for the wind blown sand.

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Results of the granulometric analyses. Table 1

Number of Sample	Sub- environ- ment	% > 2 mm	% $\frac{2\text{ mm}}{1\text{ mm}}$	% $\frac{1\text{ mm}}{0.5\text{ mm}}$	% $\frac{0.5\text{ mm}}{0.35\text{ mm}}$	% $\frac{0.35\text{ mm}}{0.25\text{ mm}}$	% $\frac{0.25\text{ mm}}{0.177\text{ mm}}$	% $\frac{0.177\text{ mm}}{0.1\text{ mm}}$	% $\frac{0.1\text{ mm}}{0.088\text{ mm}}$	% $\frac{0.088\text{ mm}}{0.0625\text{ mm}}$	% $\frac{0.0625\text{ mm}}{0.031\text{ mm}}$	% $\frac{0.031\text{ mm}}{0.016\text{ mm}}$	% $\frac{0.016\text{ mm}}{0.008\text{ mm}}$	% $\frac{0.008\text{ mm}}{0.004\text{ mm}}$	% < 0.004 mm
	Storm beach ridge.														
PSA 89	"	—	—	0.84	3.43	12.04	53.34	23.22	1.71	0.67	1.2	0.81	0.44	0.16	2.04.
PSA 90	"	—	10.6	4.65	5.88	17.60	44.73	12.90	← — →	0.5 →	0.74	0.48	0.20	—	1.52.
PSA 91	"	55.21	5.61	5.24	← 15.72 →	← 16.43 →	← — →	← — →	← — →	0.63 →	0.19	0.12	0.05	0.09	0.70.
S.a.	"	33.19	45.49	3.45	← 4.33 →	← 11.89 →	← — →	← — →	← — →	0.63 →	0.08	—	—	—	0.92.
S.b.	"	19.08	28.07	20.05	← 28.87 →	← 3.21 →	← — →	← — →	← — →	0.22 →	0.05	0.09	0.02	0.02	0.32.
S.c.	"	28.04	6.69	4.01	← 16.73 →	← 44.16 →	← — →	← — →	← — →	0.13 →	0.02	0.02	0.03	—	0.17.
S.d.	"	56.77	6.48	4.64	← 11.03 →	← 20.30 →	← — →	← — →	← — →	0.1 →	0.04	0.44	0.01	0.005	0.185.
	Spit.														
PSA 16	"	19.06	6.31	2.52	← 10.93 →	← 60.81 →	← — →	← — →	← — →	0.06 →	0.02	—	0.03	0.05	0.21.
S.e.	"	14.48	33.21	14.69	← 18.52 →	← 17.88 →	← — →	← — →	← — →	0.48 →	0.12	0.07	0.16	0.02	0.57.
S.f.	"	34.18	7.53	3.42	← 13.6 →	← 41.26 →	← — →	← — →	← — →	—	—	—	—	—	0.07.
S.g.	"	46.585	15.05	5.19	← 10.90 →	← 21.805 →	← — →	← — →	← — →	0.07 →	0.02	—	0.03	—	0.35.
S.h.	"	34.026	9.59	7.68	← 18.43 →	← 29.95 →	← — →	← — →	← — →	0.12 →	0.04	—	0.02	0.004	0.14.
S.i.	"	54.488	26.29	8.44	← 8.44 →	← 1.95 →	← — →	← — →	← — →	—	—	—	—	—	0.4.
S.j.	"	3.12	6.00	2.77	← 12.00 →	← 73.83 →	← — →	← — →	← — →	2.00 →	—	—	—	—	0.2.
	beach runnels														
PSA 32	"	21.98	16.93	7.72	6.94	13.11	28.54	3.86	← — →	0.35 →	—	—	—	—	0.53.
PSA 38	"	19.64	4.95	4.95	6.37	16.98	41.04	4.25	← — →	0.31 →	0.12	0.04	0.06	0.11	1.18.
PSA 40	"	0.73	4.98	4.98	8.30	19.93	48.16	3.32	← — →	1.67 →	0.59	1.33	0.79	0.62	4.60.
PSA 48	"	9.68	4.86	2.46	4.86	12.95	50.18	9.70	← — →	0.58 →	0.33	0.56	0.48	0.50	2.86.
PSA 50	"	3.40	0.95	2.21	8.43	30.48	48.39	5.37	← — →	0.22 →	0.03	0.04	0.03	0.03	0.42.
	beach ridges														
PSA 4.	"	—	—	0.54	← 8.6 →	← 87.05 →	← — →	← — →	← — →	3.8 →	—	—	—	—	0.01
PSA 5	"	1.12	25.82	31.81	← 35.93 →	← 3.75 →	← — →	← — →	← — →	0.19 →	—	0.14	0.06	0.01	1.17
PSA 6	"	—	—	0.54	← 3.24 →	← 86.47 →	← — →	← — →	← — →	5.76 →	0.77	0.05	0.26	1.00	1.91
PSA 12	"	—	0.48	0.58	← 21.22 →	← 72.58 →	← — →	← — →	← — →	4.33 →	0.04	0.13	—	0.05	0

Results of the granulometric analyses Table 2

Number of sample	Sub-environment	% >2mm	% 2mm 1mm	% 1mm 0.5mm	% 0.5mm 0.35mm	% 0.35mm 0.25mm	% 0.25mm 0.177mm	% 0.177mm 0.1mm	% 0.1mm 0.088mm	% 0.088mm 0.0625mm	% 0.0625mm 0.031mm	% 0.031mm 0.016mm	% 0.016mm 0.008mm	% 0.008mm 0.004mm	% 0.004mm <0.004mm
	fore-beach														
PSA 1	"	—	0.58	0.58	← 0.88 →	← 15.175 →	← 58.30 →	7.31	2.86	2.42	4.65	7.25			
PSA 3	"	—	—	0.51	← 2.55 →	← 73.46 →	← 19.54 →	0.56	0.34	0.29	2.74	—			
PSA 8	"	—	—	0.49	← 2.97 →	← 49.42 →	← 31.26 →	11.80	0.28	0.23	0.43	1.52			
PSA 10	"	—	1.13	1.13	← 2.26 →	← 63.28 →	← 21.34 →	3.02	1.12	0.89	0.92	4.91			
PSA 11	"	—	—	0.39	← 2.98 →	← 84.51 →	← 9.49 →	0.89	—	0.16	0.20	1.38			
PSA 17	"	5.38	2.55	1.28	1.70	5.53	18.72	28.93	14.47	9.60	4.25	1.73	0.70	0.51	4.47
PSA 18	"	—	0.70	← 0.70 →	2.09	16.70	35.48	25.75	6.64	2.02	1.07	1.12	1.07	6.84	
PSA 19	"	—	—	—	← 2.78 →	23.16	57.42	11.12	3.45	0.64	0.15	0.07	0.01	1.15	
PSA 22	"	—	—	—	← 2.01 →	16.07	40.17	28.12	8.84	0.03	0.01	0.01	0.01	4.79	
PSA 23	"	—	—	—	← 0.35 →	2.76	11.73	25.53	23.04	4.51	4.18	7.34	2.09	18.47	
PSA 24	"	3.02	1.49	1.12	0.74	4.10	31.27	52.88	1.12	1.43	0.88	0.05	0.31	0.06	1.50
PSA 28	"	—	0.74	0.74	1.98	4.95	21.76	38.60	14.84	5.38	1.84	1.12	0.84	0.93	6.33
PSA 29	"	0.44	—	1.16	0.58	5.80	30.15	49.87	6.96	2.84	0.44	0.13	—	—	1.63
PSA 30	"	2.46	1.01	1.01	1.51	6.03	30.16	29.15	2.00	23.58	—	—	0.06	3.03	
PSA 44	"	—	—	—	← 1.58 →	3.80	22.18	16.48	3.95	11.67	10.93	5.79	3.20	20.41	
PSA 45	"	—	—	1.35	1.35	2.68	12.08	43.61	31.54	4.61	0.88	0.35	0.10	—	1.45
PSA 46	"	—	—	—	← 1.1 →	4.39	22.53	22.53	6.68	6.84	7.02	6.89	5.68	16.34	
	dunes														
PSA 52	"	—	—	—	6.56	18.74	66.53	7.49	← 0.29 →	—	—	—	0.14	0.24	
PSA 53	"	—	—	5.50	4.40	23.11	60.52	5.50	← 0.05 →	0.15	—	—	0.25	0.50	
PSA 56	"	—	—	7.60	21.56	43.42	24.97	1.23	← 0.87 →	—	0.04	—	0.01	0.30	
PSA 58	"	—	—	4.93	5.76	17.26	57.56	12.34	← 1.34 →	0.18	0.13	0.01	0.05	0.05	
PSA 59	"	—	—	4.77	9.54	24.54	53.16	6.52	← 0.86 →	0.08	0.02	—	—	0.20	
PSA 60	"	—	—	1.27	3.18	10.81	50.90	31.81	← 1.37 →	0.14	0.05	—	—	0.48	
PSA 61	"	—	3.63	6.05	10.29	25.42	45.39	7.26	← 1.41 →	0.02	0.04	—	0.07	0.42	
PSA 62	"	—	1.90	8.56	9.51	24.72	47.53	5.71	← 1.25 →	0.07	0.18	—	0.11	0.48	
PSA 66	"	—	—	3.97	7.94	21.17	53.59	9.27	← 1.04 →	0.07	0.04	—	0.19	0.71	
PSA 68	"	—	—	10.13	17.56	25.66	43.21	2.01	← 0.70 →	0.39	—	—	0.17	0.53	
PSA 69	"	—	—	—	5.36	14.28	58.93	19.64	← 1.12 →	0.01	—	0.09	0.09	0.49	
PSA 70	"	—	—	8.03	13.38	24.98	47.27	5.35	← 0.49 →	—	0.09	0.14	0.03	0.36	
PSA 71	"	—	—	9.9	9.9	28.71	44.55	5.94	← 0.28 →	0.07	0.01	—	0.07	0.57	
PSA 72	"	—	1.86	2.80	2.80	14.91	58.72	14.91	← 3.16 →	—	0.07	—	0.09	0.67	
PSA 76	"	—	—	7.46	8.28	22.37	48.05	10.77	← 2.15 →	—	0.17	0.06	—	0.70	
PSA 77	"	—	—	3.53	7.07	21.20	58.29	8.83	← 0.57 →	0.21	0.06	—	—	0.25	
PSA 78	"	—	—	2.98	3.97	20.89	57.70	12.94	← 0.34 →	0.07	0.24	—	—	0.86	
PSA 79	"	—	—	4.88	8.36	16.03	51.58	16.69	← 0.55 →	0.31	0.21	0.07	0.27	1.04	
PSA 81	"	—	—	2.42	4.04	19.39	56.57	16.16	← 0.26 →	0.17	0.04	0.07	0.06	0.81	
PSA 86	"	—	3.89	5.83	15.55	33.05	36.94	2.92	← 0.69 →	—	—	0.06	0.14	0.92	
PSA 87	"	—	—	—	3.34	17.81	66.81	11.12	← 0.21 →	—	—	—	—	0.70	
	mud-flats														
PSA 93	"	—	—	2.18	2.18	7.41	27.46	11.33	← 1.31 →	13.28	14.56	4.96	3.20	11.62	

Results of granulometric analyses Table 3

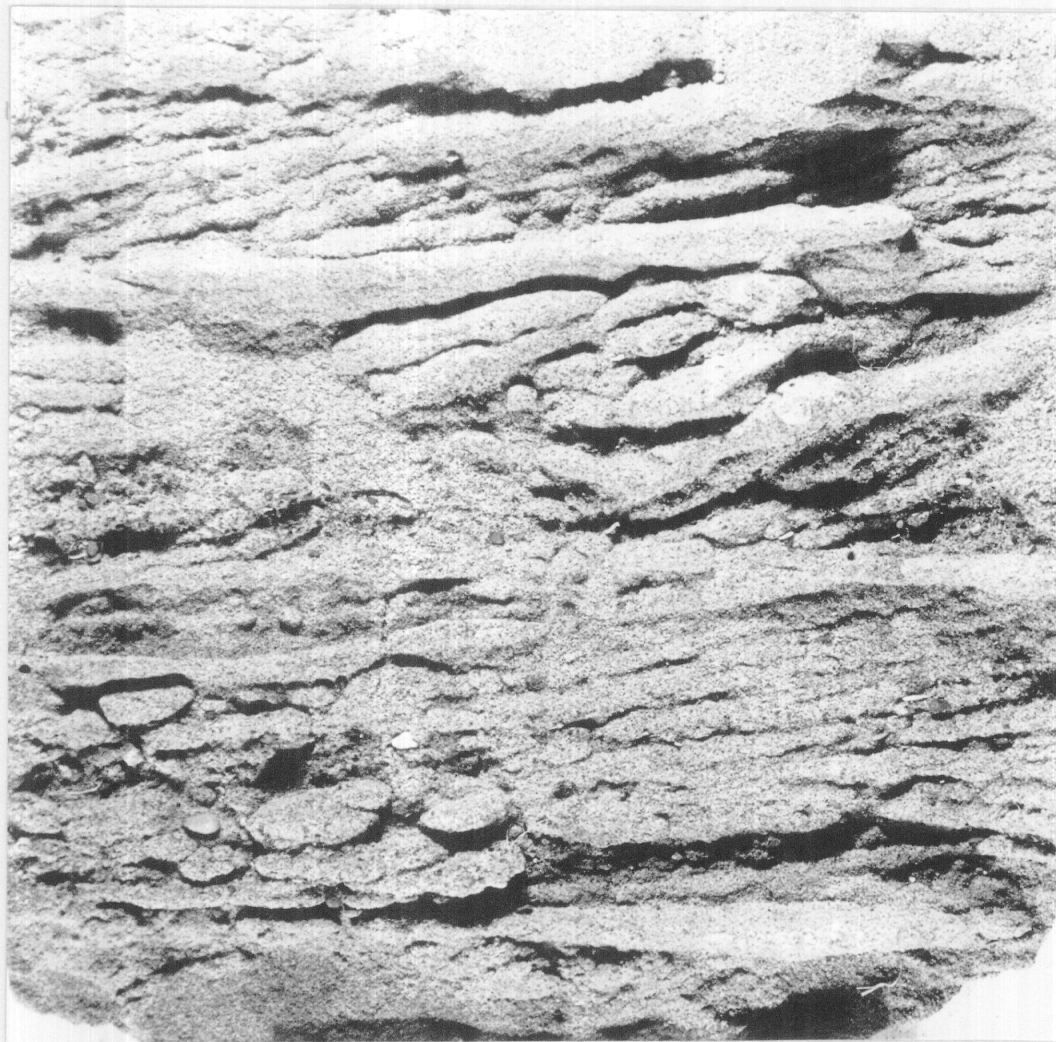
Number of Sample	Sub-environment.	% >2mm	% $\frac{2\text{ mm}}{1\text{ mm}}$	% $\frac{1\text{ mm}}{0.5\text{ mm}}$	% $\frac{0.5\text{ mm}}{0.351\text{ mm}}$	% $\frac{0.351\text{ mm}}{0.251\text{ mm}}$	% $\frac{0.25\text{ mm}}{0.177\text{ mm}}$	% $\frac{0.177\text{ mm}}{0.1\text{ mm}}$	% $\frac{0.1\text{ mm}}{0.088\text{ mm}}$	% $\frac{0.088\text{ mm}}{0.0625\text{ mm}}$	% $\frac{0.0625\text{ mm}}{0.031\text{ mm}}$	% $\frac{0.031\text{ mm}}{0.016\text{ mm}}$	% $\frac{0.016\text{ mm}}{0.008\text{ mm}}$	% $\frac{0.008\text{ mm}}{0.004\text{ mm}}$	% <0.004 mm
	mid-flats. (CONT').														
PSA 94	"	—	—	1.35	1.08	3.77	11.59	4.85	1.08	5.12	26.01	22.32	7.18	3.96	11.62.
PSA 95	"	—	—	2.52	2.11	7.16	35.80	19.79	1.26	25.39	1.25	1.24	1.20	0.22	2.05.
PSA 96	"	—	—	0.84	0.42	5.88	15.94	2.94	1.68	9.46	25.76	14.39	4.62	2.93	15.15.
PSA 97	"	—	—	—	—	—	0.99	1.28	5.38	12.30	36.86	16.65	5.42	3.56	14.02
PSA 98	"	—	—	—	0.33	1.15	8.52	11.79	3.28	4.66	25.53	18.04	6.55	4.71	15.46.
PSA 99	"	—	2.70	2.07	3.22	8.06	29.03	7.86	0.23	32.33	3.04	4.16	1.67	1.08	5.20.
PSA 100	"	—	1.80	2.16	3.24	12.22	49.61	25.17	—	0.25	0.76	1.26	0.59	4.32	15.48.
PSA 101	"	—	0.59	1.78	2.67	7.73	27.35	7.43	0.30	0.44	10.25	15.75	5.91	4.32	15.48.
PSA 102	"	—	—	0.29	0.22	1.32	3.22	1.61	1.32	3.82	46.3	24.75	4.73	2.62	9.78.
PSA 103	"	—	—	0.66	0.44	2.07	3.85	1.63	2.52	13.08	44.18	15.44	4.24	2.74	9.16.
PSA 104	"	—	—	—	—	—	0.56	1.44	5.78	19.65	38.24	13.76	4.50	1.63	15.16.
	new-salt-marsh														
PSA 105	"	—	—	—	—	—	—	0.8	2.71	2.81	9.32	18.61	25.12	20.3	20.13.
PSA 106	"	—	—	—	—	—	—	—	2.10	10.3	38.1	24.91	20.17	9.97	19.31
PSA 107	"	—	—	—	—	—	—	—	0.91	8.2	20.4	18.51	12.3	4.61	33.91
PSA 108	"	—	—	—	—	—	—	—	0.25	6.1	13.8	17.75	11.23	8.90	42.3
PSA 109	"	—	—	—	—	—	—	—	—	4.2	11.97	21.98	14.57	4.53	44.78.
	mature marsh														
PSA 64	"	—	0.32	4.71	0.64	1.12	2.73	1.28	1.12	3.2	9.87	21.38	14.03	39.99	3.73.
PSA 74	"	—	—	—	—	—	0.14	0.12	2.39	7.85	12.44	24.02	13.36	10.44	29.49
PSA 82	"	—	0.41	0.37	4.3	15.61	19.37	10.37	0.91	0.22	7.18	3.88	5.63	3.72	19.59
PSA 83	"	—	—	—	—	1.5	3.2	4.3	1.6	7.00	14.82	21.77	10.98	7.49	31.66
PSA 84	"	—	—	—	—	—	1.3	3.10	—	1.93	19.2	25.3	12.81	7.65	29.33
PSA 88	"	—	—	—	—	0.21	3.91	2.39	0.72	11.33	6.01	15.16	14.34	11.69	33.095
	marsh Strips														
PSA 42	"	—	—	3.61	4.82	12.64	37.33	3.61	—	0.61	6.49	8.27	3.88	3.83	14.88.
PSA 43	"	—	11.03	4.0	3.51	9.52	25.06	4.01	1.00	0.43	5.02	4.95	2.37	1.31	6.46
PSA 54	"	—	—	4.1	2.70	12.44	46.51	15.14	0.54	0.44	1.89	2.94	2.73	3.22	7.10.
PSA 55	"	—	—	—	2.14	5.13	17.95	3.85	1.28	8.05	9.02	14.16	12.63	2.12	23.41.

Results of the granulometric analyses Table 4

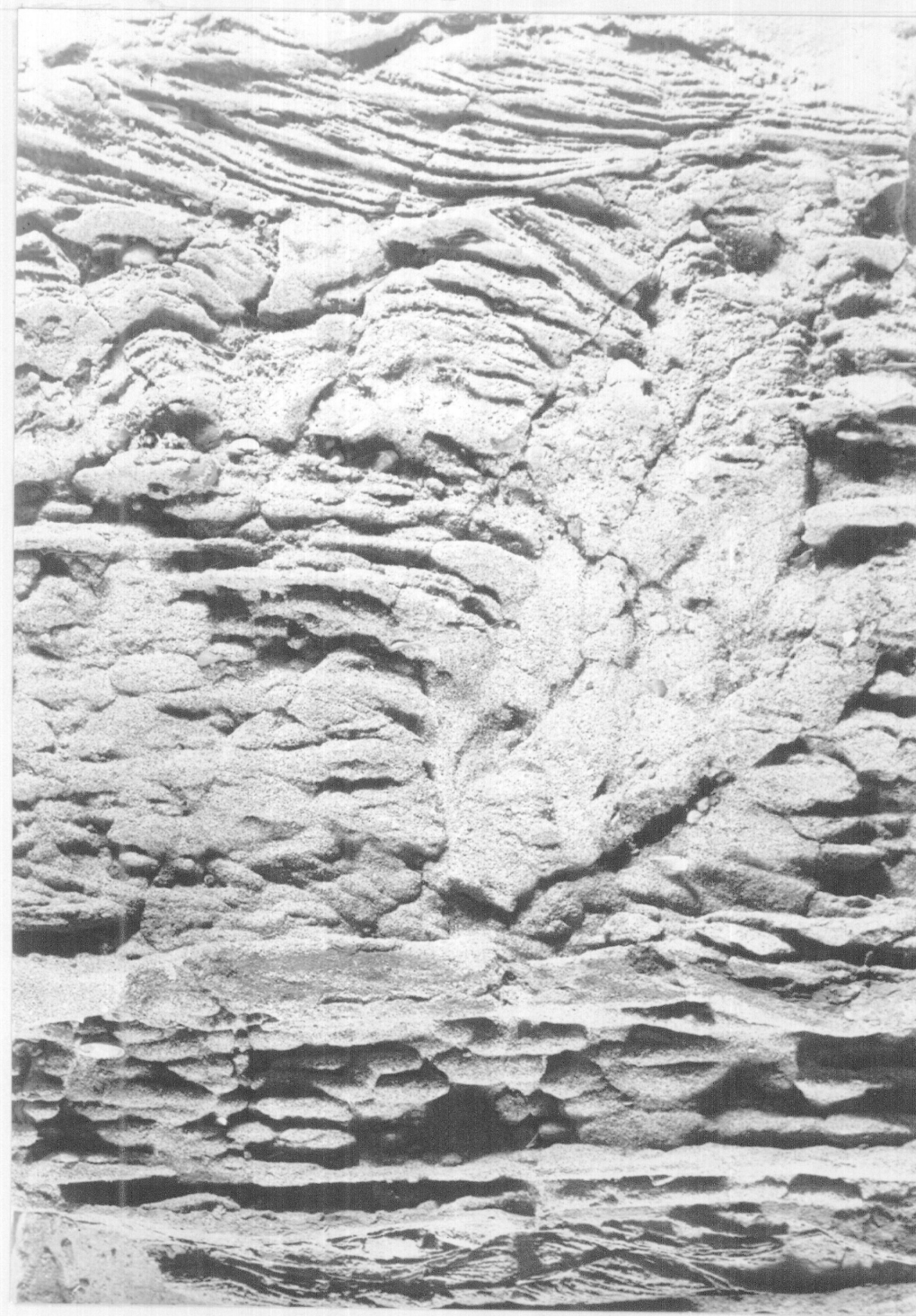
Number of sample	Sub-environment	% gravel	% sand	% silt	% clay	median ϕ (parameters of Inman 1955)	sorting ϕ	skewness ϕ
				pelite.				
	Storm beach ridge.							
PSA 89.	"	—	94.657	5.343		2.32	0.41	+0.216
PSA 90.	"	—	96.645	3.484		2.11	0.73	-0.45
PSA 91.	"	55.208	43.034	1.758		-1.5	—	—
S.a.	"	33.19	65.178	1.632		-0.57	—	—
S.b.	"	19.078	80.194	0.729		0.13	—	—
S.c.	"	28.041	71.592	0.376		1.88	—	—
S.d.	"	56.977	42.647	0.376		-0.75	—	—
	Spit.							
PSA 16.	"	18.06	81.565	0.375		2.125	—	—
S.e.	"	14.478	84.308	1.214		0.145	—	—
S.f.	"	34.698	65.013	0.289		1.69	—	—
S.g.	"	46.585	52.939	0.476		-0.8	—	—
S.h.	"	34.026	65.645	0.329		0.83	—	—
S.i.	"	54.488	45.126	0.386		-1.15	—	—
S.j.	"	3.119	94.596	2.285		2.285	0.555	-0.18
	Beach runnels							
PSA 32	"	21.981	77.14	0.879		1.32	—	—
PSA 38	"	19.636	78.533	1.831		1.97	—	—
PSA 40	"	0.726	89.68	9.604		2.16	0.51	-0.5
PSA 48	"	9.676	84.983	5.341		2.125	0.768	-0.53
PSA 50	"	3.4	95.83	0.77		2.03	0.408	-0.348
	beach ridges.							
PSA 4	"	—	98.221	1.779		2.45	0.355	+0.085
PSA 5	"	1.123	97.31	1.567		0.675	—	—
PSA 6	"	—	95.651	4.349		2.46	0.365	+0.329
PSA 12	"	—	98.27	1.73		2.15	0.208	-0.048
PSA 20	"	—	97.61	2.39		2.585	0.328	+0.009
PSA 21	"	—	97.515	2.485		2.275	0.533	-0.2665
PSA 25	"	—	96.068	3.932		2.455	0.41	+0.0366
PSA 27	"	6.99	91.264	1.778		2.395	0.42	-0.107
PSA 31	"	—	98.154	1.846		2.32	0.785	+0.036
PSA 33	"	2.658	95.81	1.535		2.22	0.318	+0.041
PSA 34	"	5.369	93.88	0.75		2.24	0.578	-0.59
PSA 37	"	4.294	94.34	1.366		2.01	2.135	-0.37
PSA 39	"	13.668	85.937	0.395		1.81	1.03	+0.22
PSA 47	"	4.115	73.74	22.45		2.39	—	—
PSA 49	"	44.55	54.999	0.451		-0.7	—	—
PSA 51	"	4.8825	94.211	0.907		2.225	0.378	-0.164
PSA 57	"	7.760	90.603	1.637		1.775	1.2	-0.52
PSA 63	"	55.705	91.063	3.3665		1.71	1.28	-0.41
	fore-beach							
PSA 1	"	—	57.491	42.509		3.64	1.05	+0.657
PSA 3	"	—	94.885	5.115		2.88	0.54	+0.026
PSA 8	"	—	74.625	25.385		3.25	0.755	-0.0265
PSA 10	"	—	87.015	12.985		3.01	0.66	+0.106
PSA 11	"	—	96.929	3.061		2.75	0.42	+0.119
PSA 17	"	53.832	76.586	18.03		2.915	0.858	-0.087
PSA 18	"	—	86.277	13.723		3.19	0.733	-0.057
PSA 19	"	—	96.361	3.639		2.79	0.49	+0.123
PSA 22	"	—	90.366	9.635		3.19	0.488	-0.486
PSA 23	"	—	54.853	45.147		3.65	—	—
PSA 24	"	3.024	92.725	4.251		2.58	0.81	+0.444
PSA 28	"	—	87.025	12.975		2.855	0.64	+0.039
PSA 29	"	0.4434	96.828	2.7286		2.64	0.50	+0.14
PSA 30	"	24.75	70.878	26.6645		2.665	0.85	+0.1824
PSA 44	"	—	46.895	53.105		4.19	—	—
PSA 45	"	—	95.954	4.046		3.15	0.495	=0.384
PSA 46	"	—	53.84	46.16		3.51	—	—
	dunes.							
PSA 52	"	—	99.325	0.675		2.18	0.285	-0.236
PSA 53	"	—	99.037	0.963		2.12	0.66	-0.1666
PSA 56	"	—	98.775	1.225		1.775	0.51	-0.2255
PSA 58	"	—	97.85	2.15		2.19	0.38	-0.1842
PSA 59	"	—	98.833	1.167		2.065	0.36	-0.2917
PSA 60	"	—	97.97	2.03		2.36	0.418	-0.136
PSA 61	"	—	98.045	1.955		2.04	0.48	-0.2917
PSA 62	"	—	97.92	2.080		2.04	0.5	-0.32
PSA 66	"	—	97.95	2.05		2.13	0.39	-0.256
PSA 68	"	—	98.565	1.435		1.96	0.469	-0.4136
PSA 69	"	—	98.202	1.798		2.28	0.295	-0.102
PSA 70	"	—	99.003	0.997		2.03	0.47	-0.404
PSA 71	"	—	99.01	0.99		2.005	0.368	-0.209
PSA 72	"	—	96.01	3.99		2.2	0.33	+0.091
PSA 76	"	—	97.745	2.255		2.2	0.46	-0.456
PSA 77	"	—	98.917	1.083		2.12	0.33	-0.2424
PSA 78	"	—	98.442	1.508		2.15	0.31	+0.032
PSA 79	"	—	97.547	2.453		2.18	0.44	-0.18
PSA 81	"	—	98.587	1.413		2.21	0.358	-0.084
PSA 86	"	—	98.14	1.81		1.91	0.49	-0.3674
PSA 87	"	—	99.089	0.911		2.205	0.26	-0.096
	mud-flats.							
PSA 93	"	—	51.869	48.131		3.215	2.36	+0.5234
PSA 94	"	—	25.671	74.329		4.83	2.27	-0.062
PSA 95	"	—	69.488	30.512		2.57	0.83	+0.4035
PSA 96	"	—	31.47	68.53		4.43	—	—
PSA 97	"	—	18.555	81.445		4.8	—	—
PSA 98	"	—	28.009	71.991		4.99	—	—
PSA 99	"	—	52.516	47.484		2.68	0.97	+0.299
PSA 100	"	—	94.197	5.803		2.3	0.44	+0.166
PSA 101	"	—	47.853	52.147		4.12	—	—
PSA 102	"	—	10.34	89.66		4.9	0.945	+0.323
PSA 103	"	—	16.357	83.643		4.55	1.13	+0.3274
PSA 104	"	—	18.769	81.231		4.75	—	—
	new-salt-marsh.							
PSA 105	"	—	12.6	87.4		5.86	—	—
PSA 106	"	—	10.13	89.87		5.64	—	—
PSA 107	"	—	7.99	92.01		6.4	—	—
PSA 108	"	—	5.21	94.79		7.1	—	—
PSA 109	"	—	2.34	97.66		7.8	—	—
	mature marsh.							
PSA 64	"	—	8.665	91.335		6.34	—	—
PSA 74	"	—	2.3893	97.6107		6.25	—	—
PSA 82	"	—	59.793	40.207		2.435	—	—
PSA 83	"	—	3.6912	96.3088		6.00	—	—
PSA 84	"	—	4.3406	95.6594		5.9	—	—
PSA 88	"	—	4.1812	95.8188		6.8	—	—
	Marsh STRIPS.							
PSA 42	"	—	62.06	37.94		2.37	—	—
PSA 43	"	—	21.276	78.16		2.03	—	—
PSA 54	"	—	81.666	18.334		2.31	1.51	+0.7484
PSA 55	"	—	31.189	68.811		5.33	—	—

PLATE A

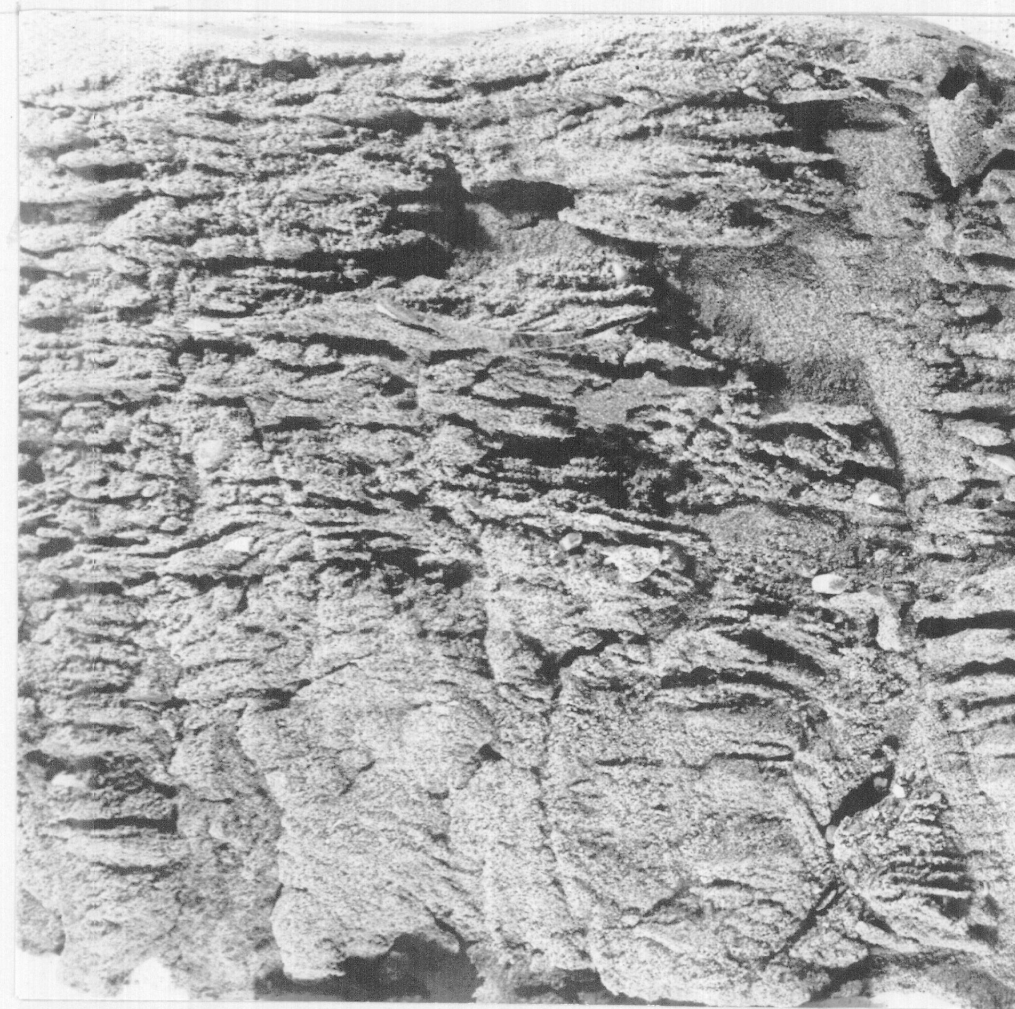
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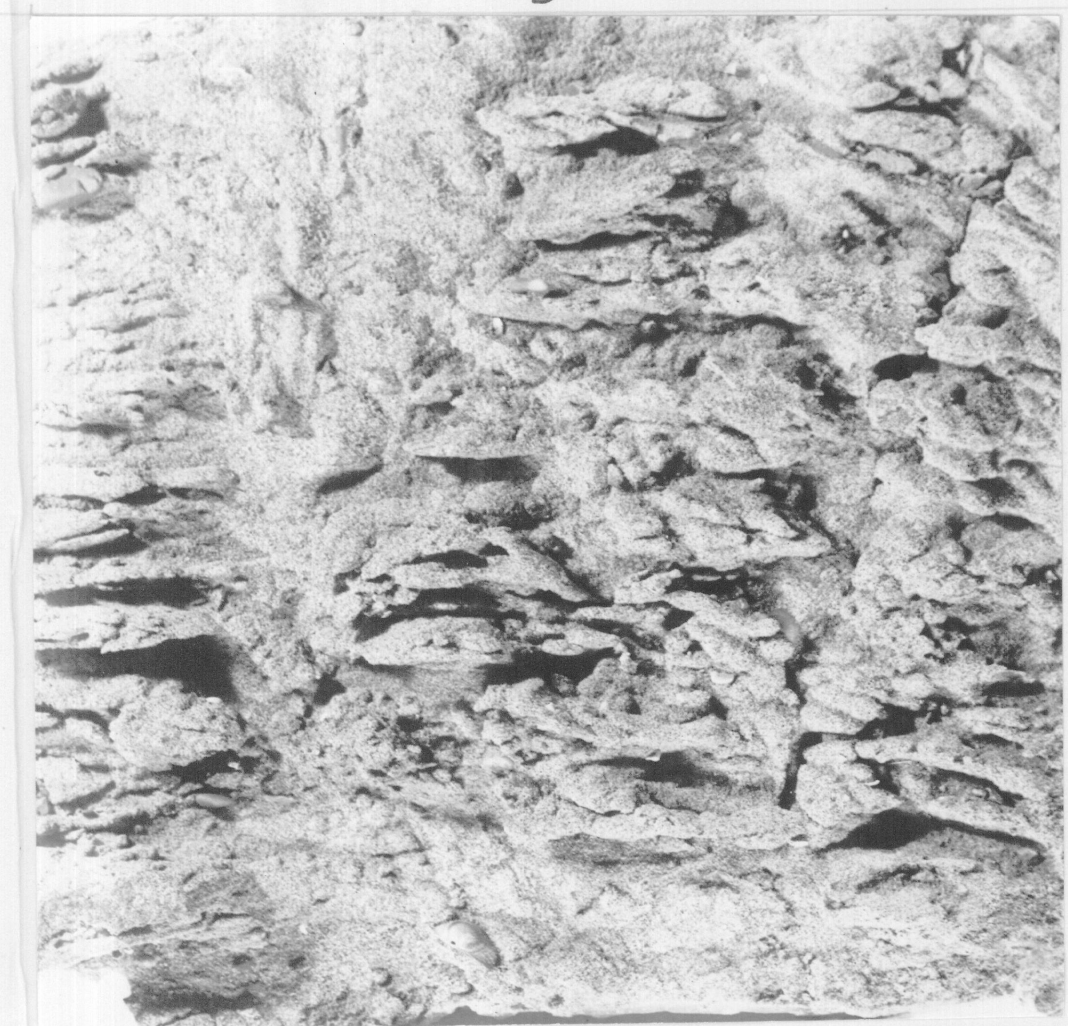
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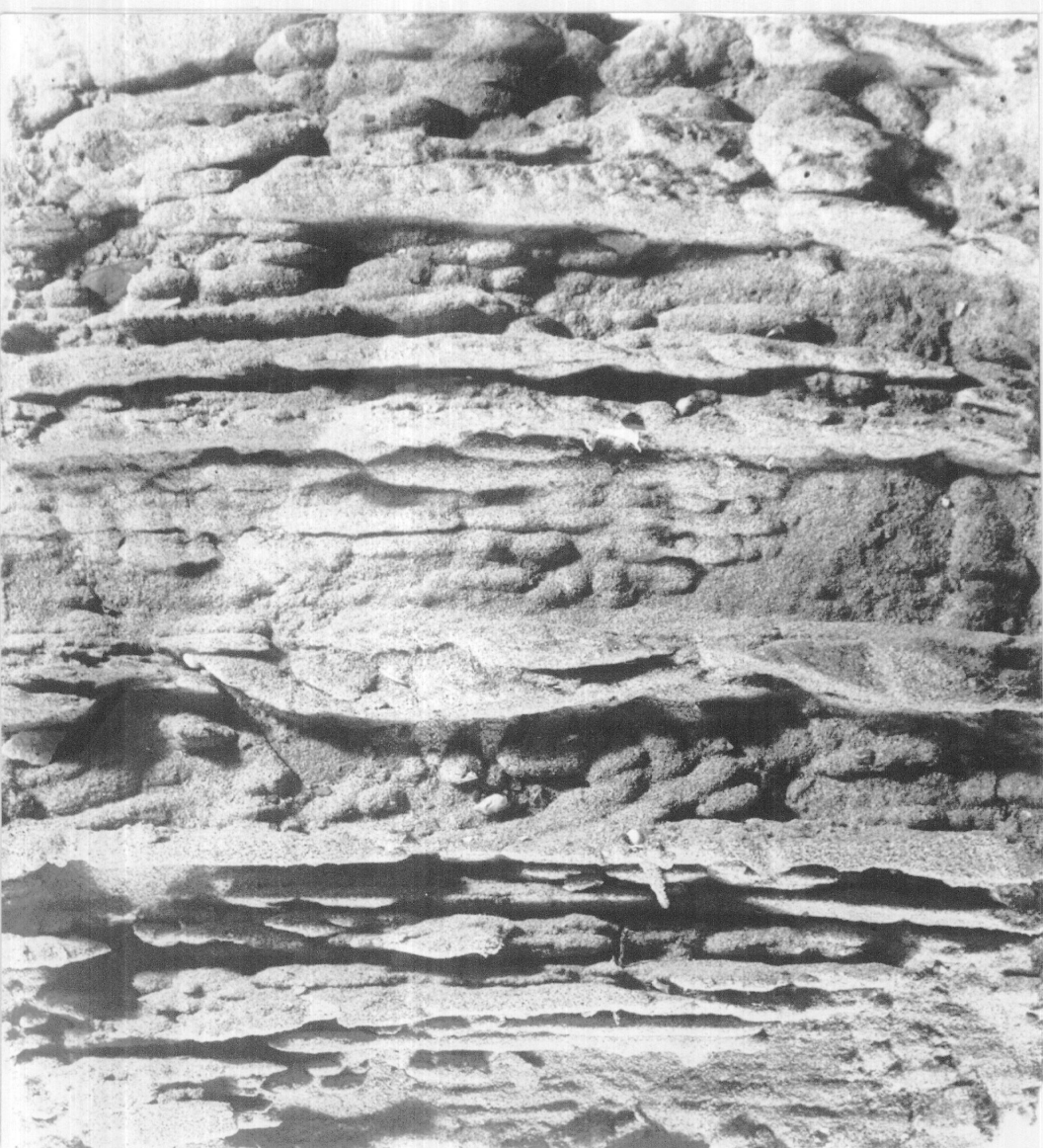
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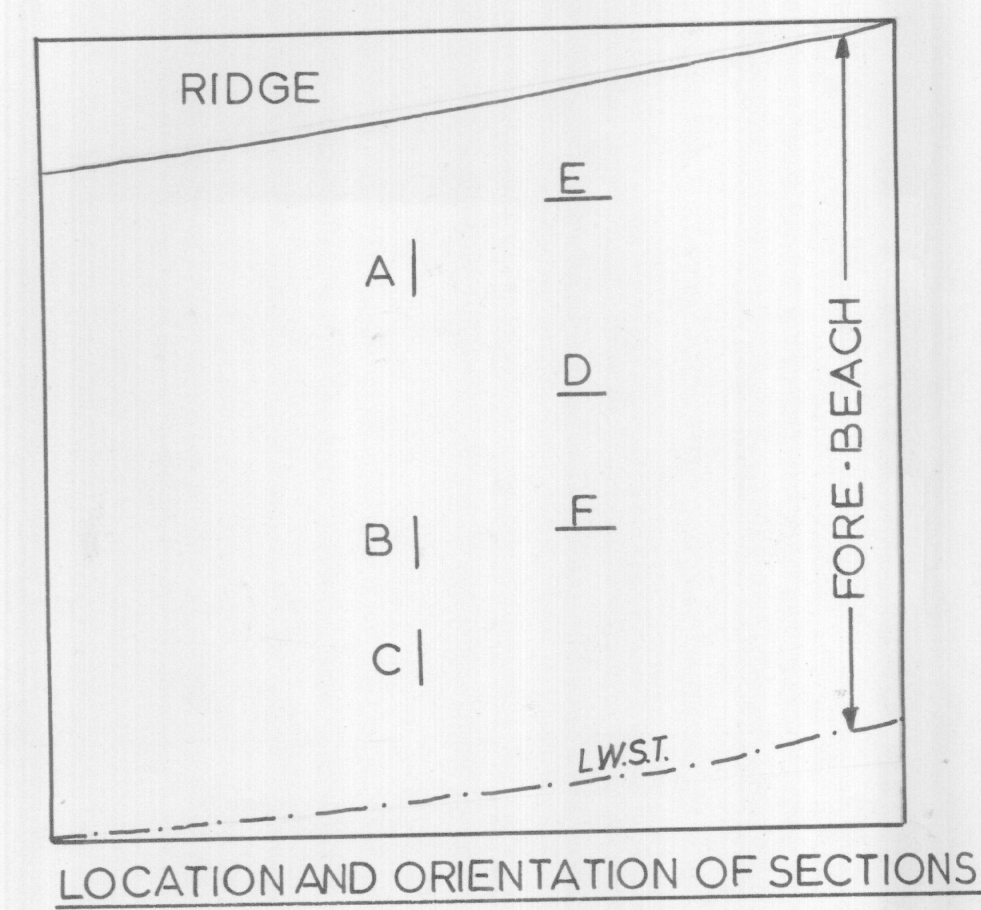
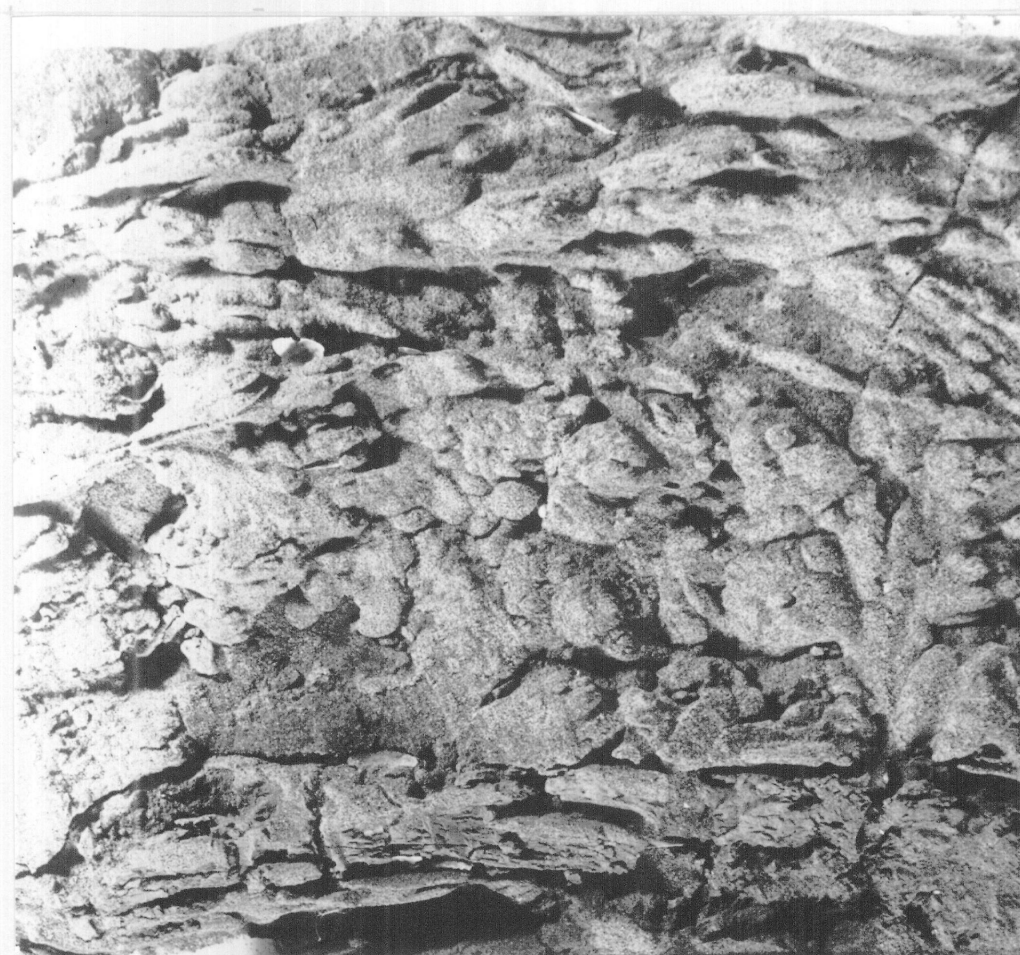
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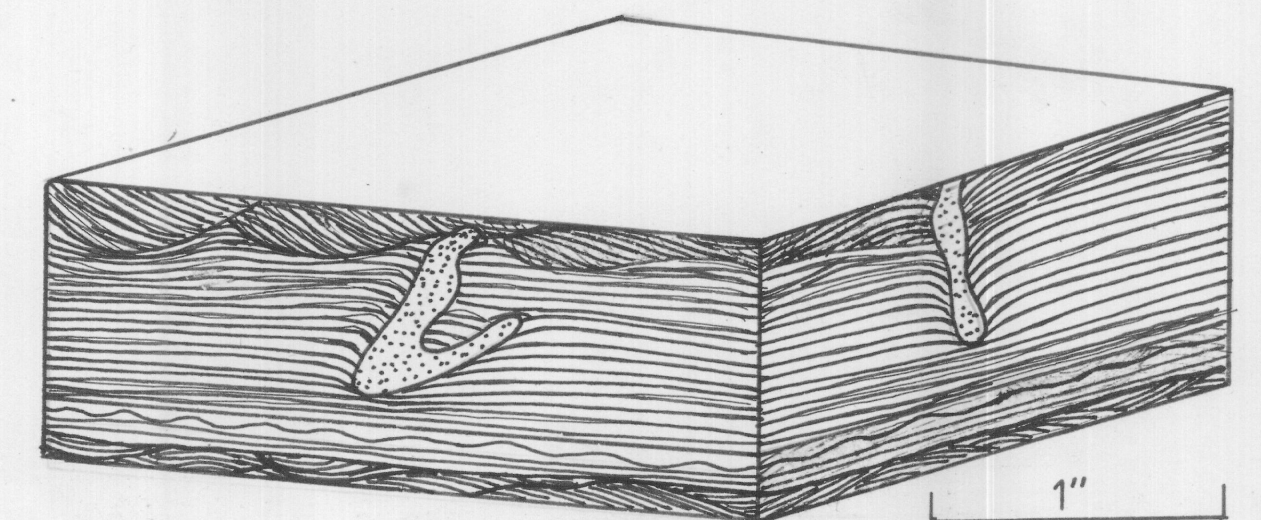
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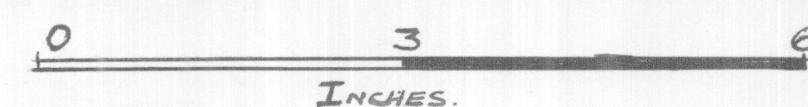
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LOCATION AND ORIENTATION OF SECTIONS.

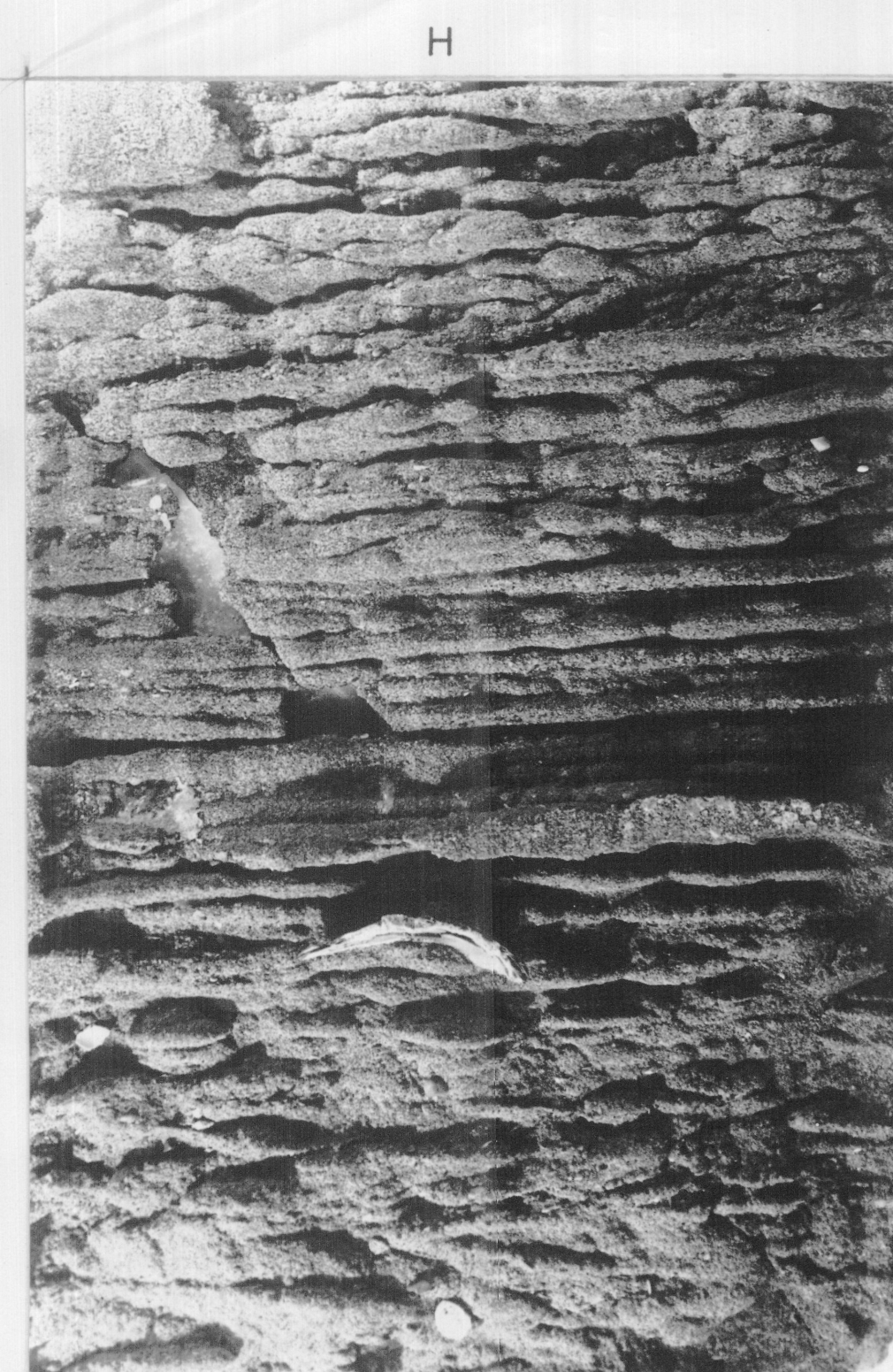
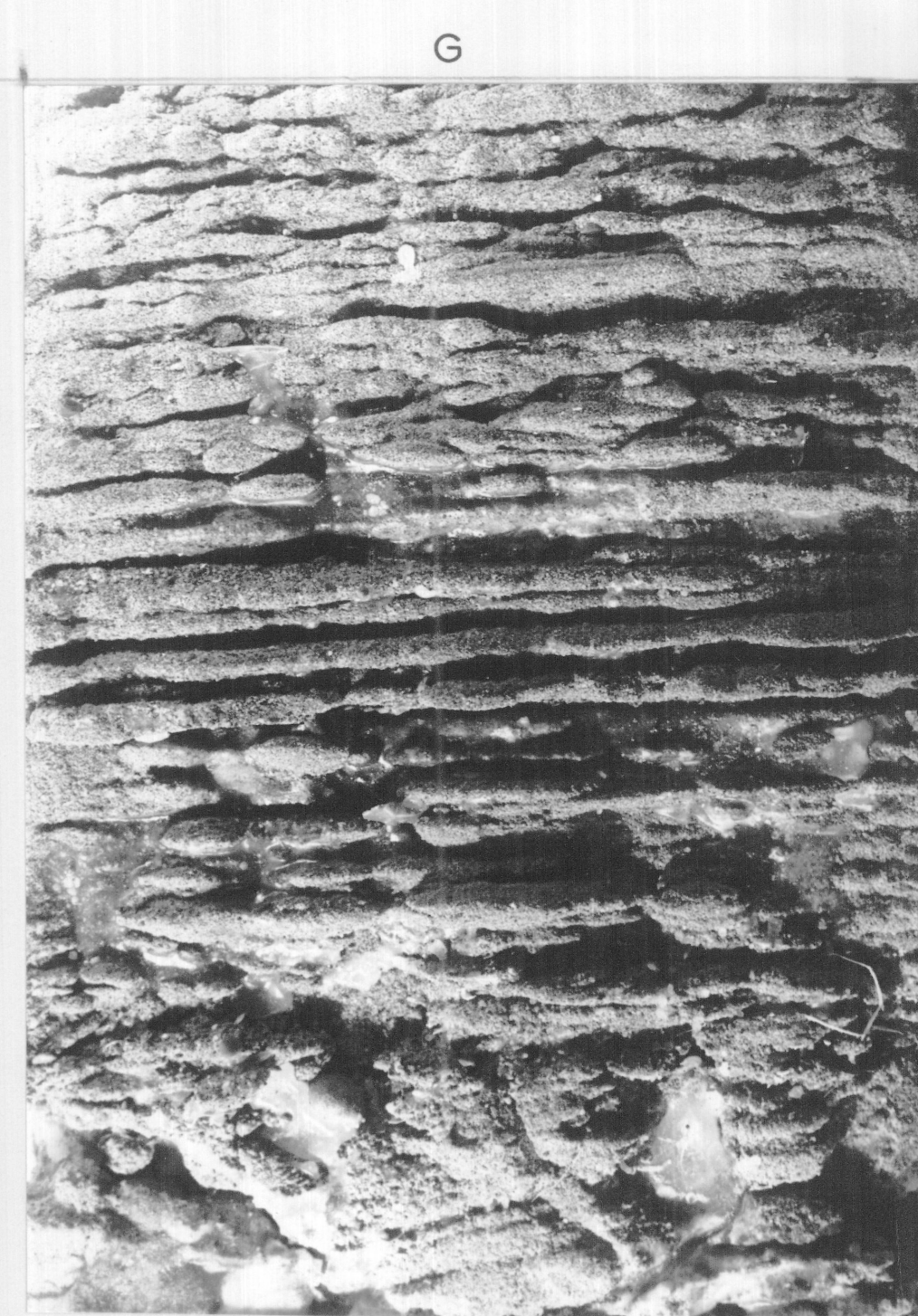
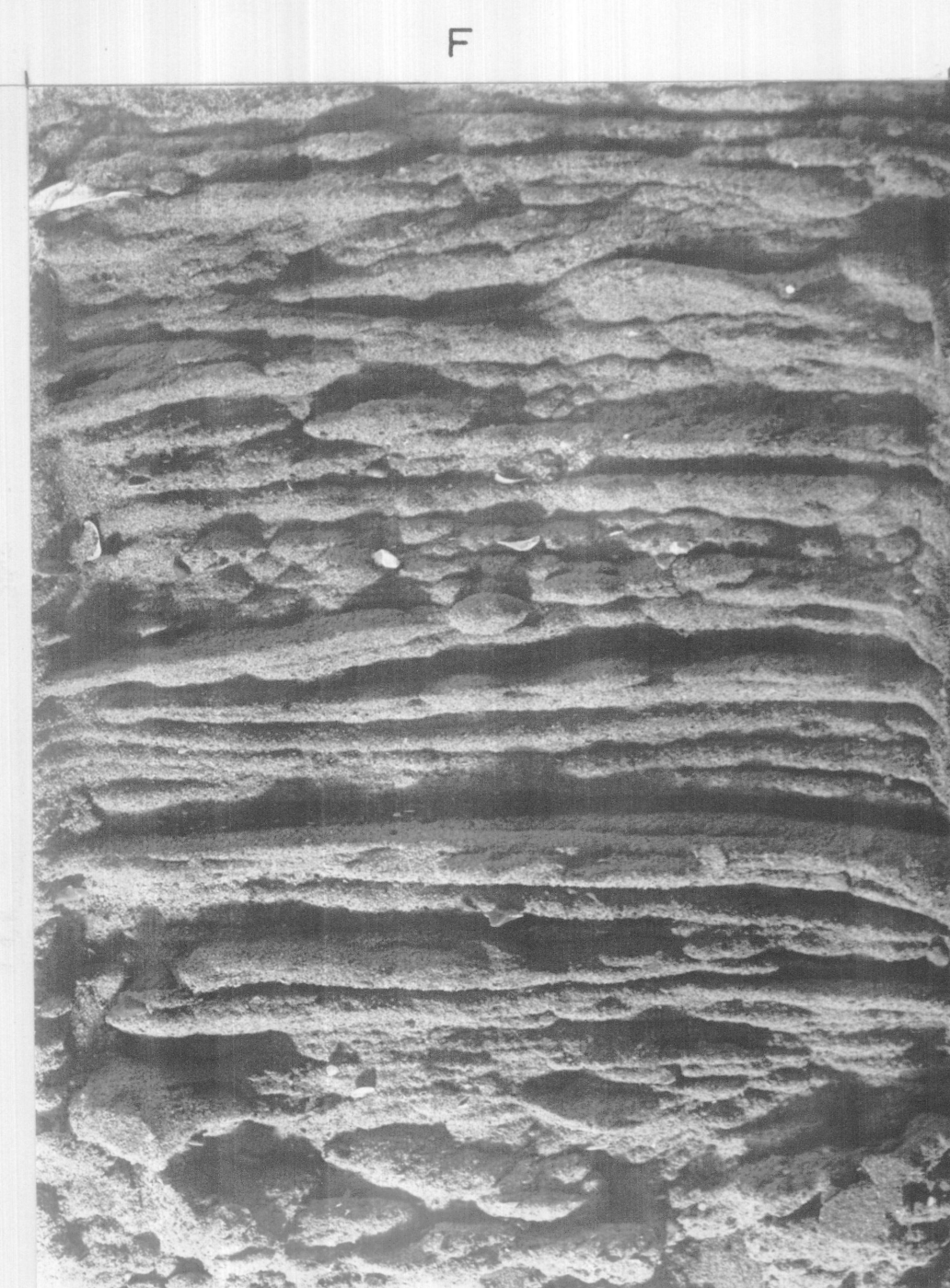
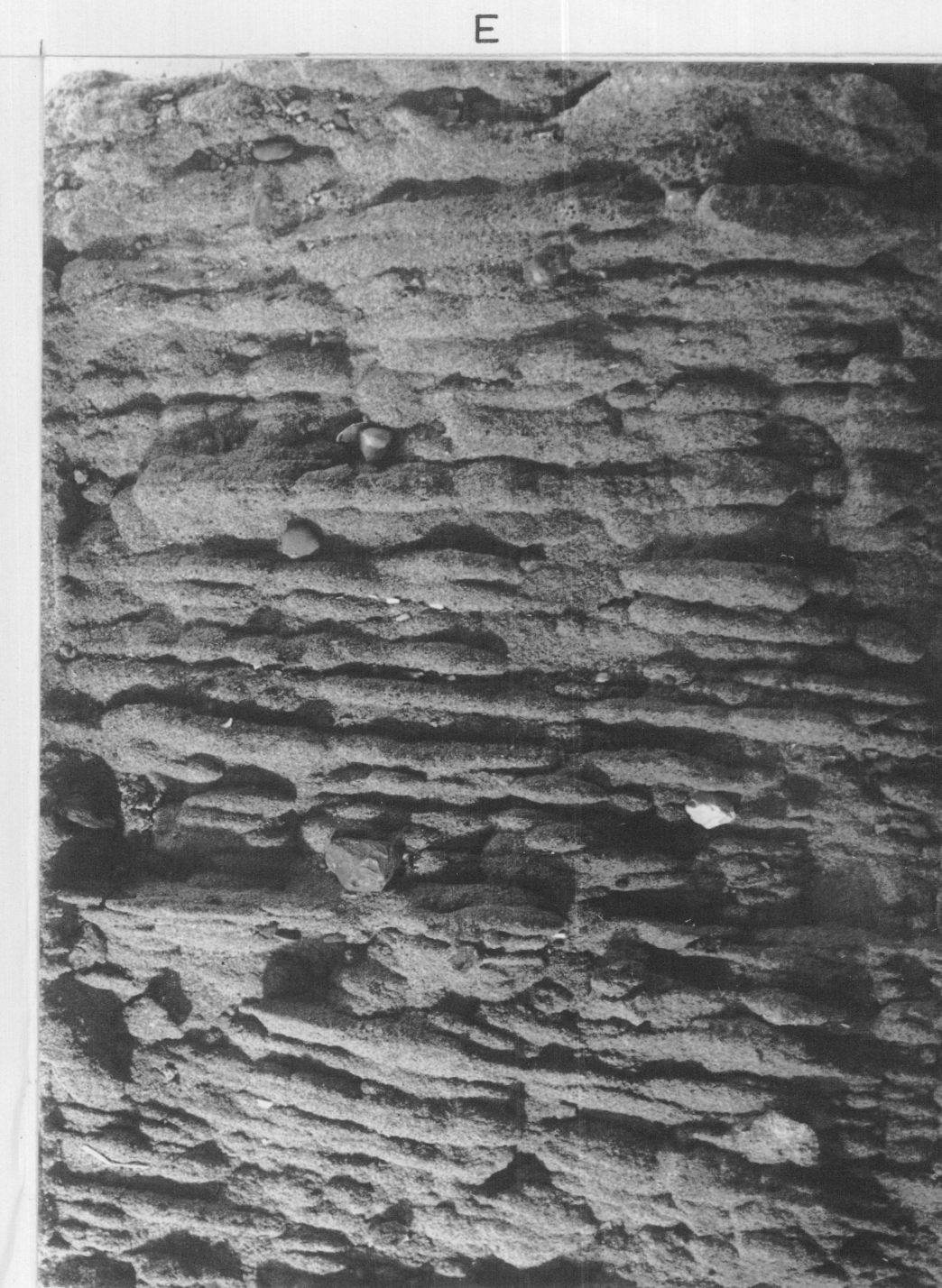
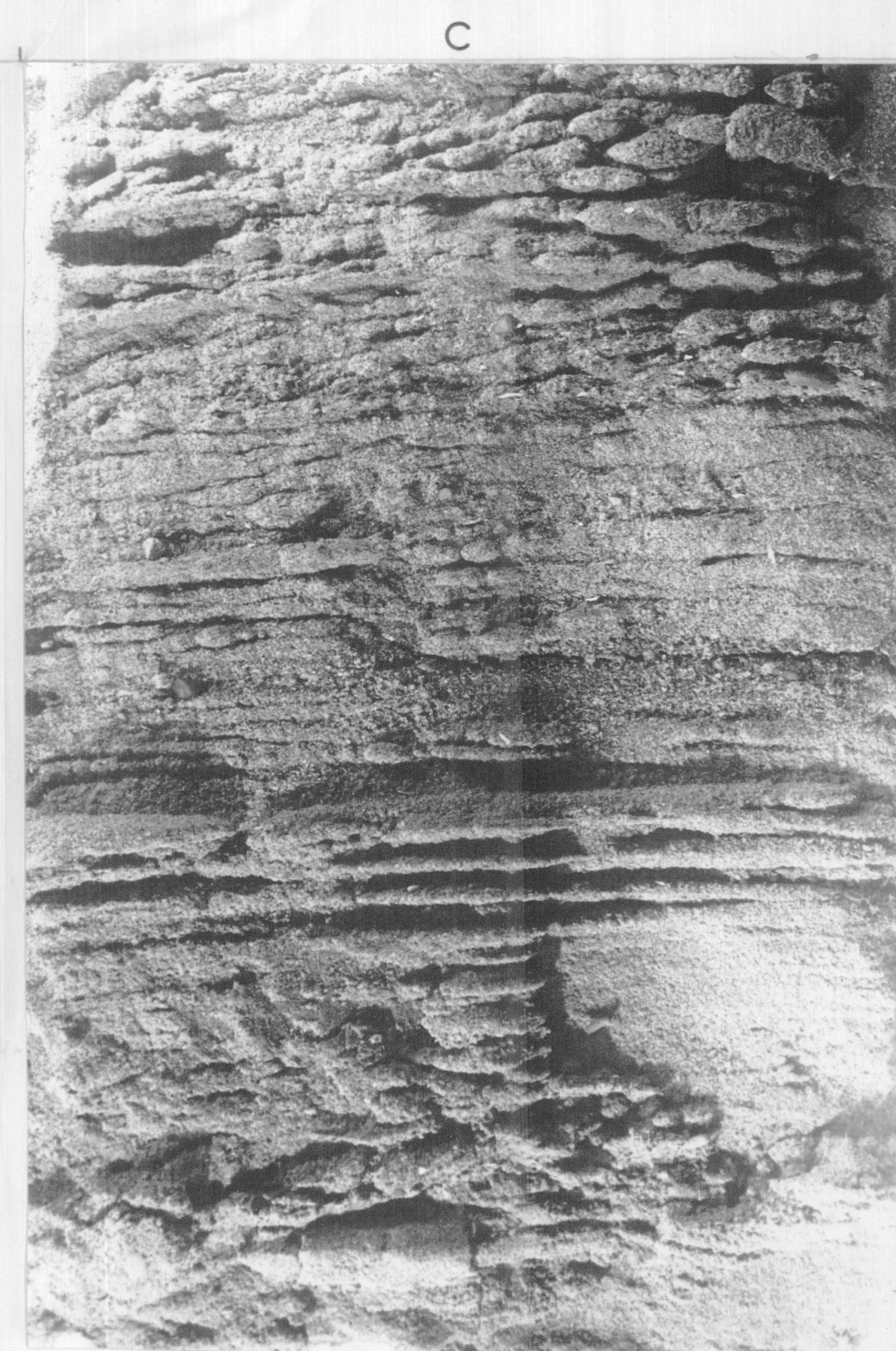
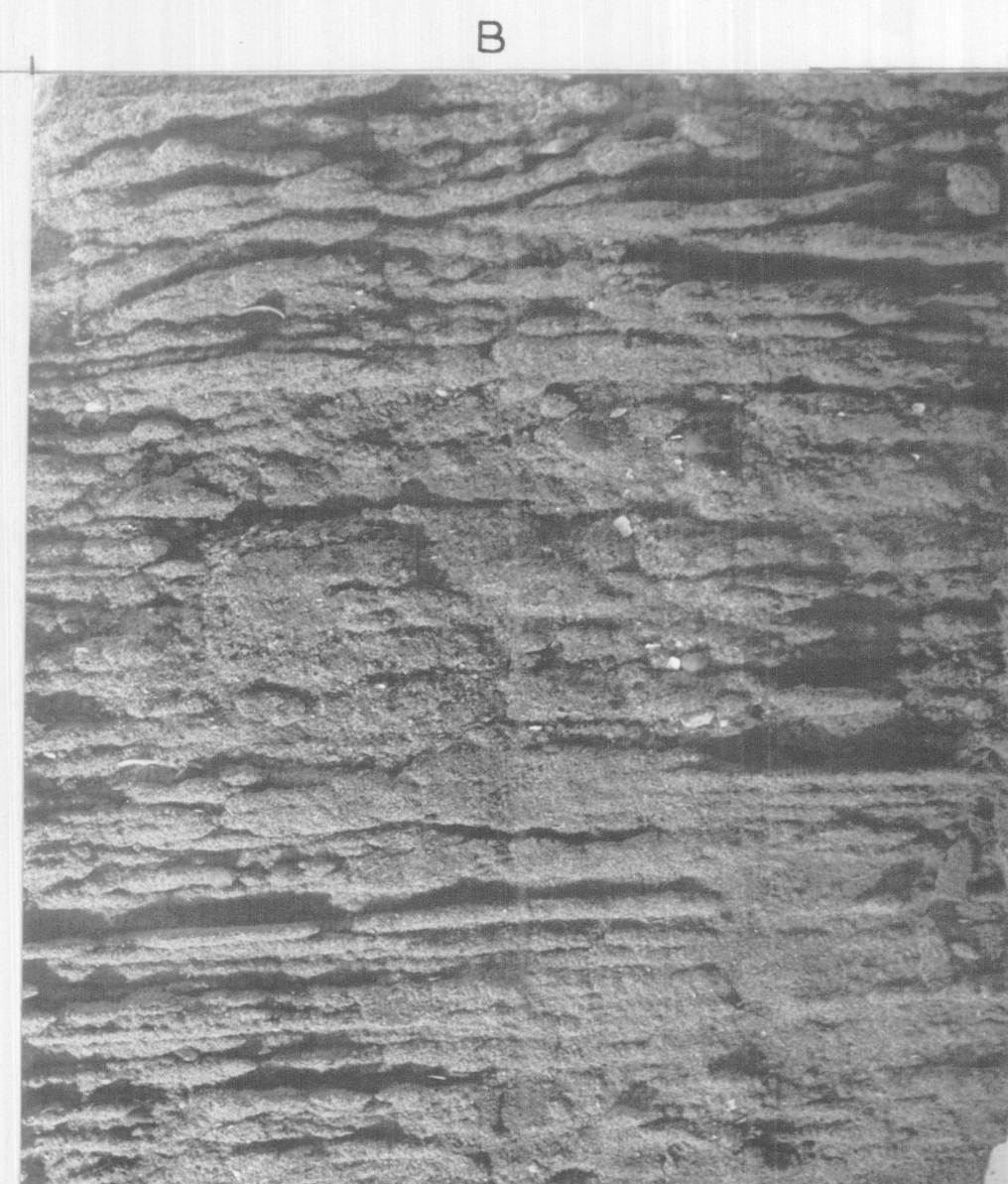
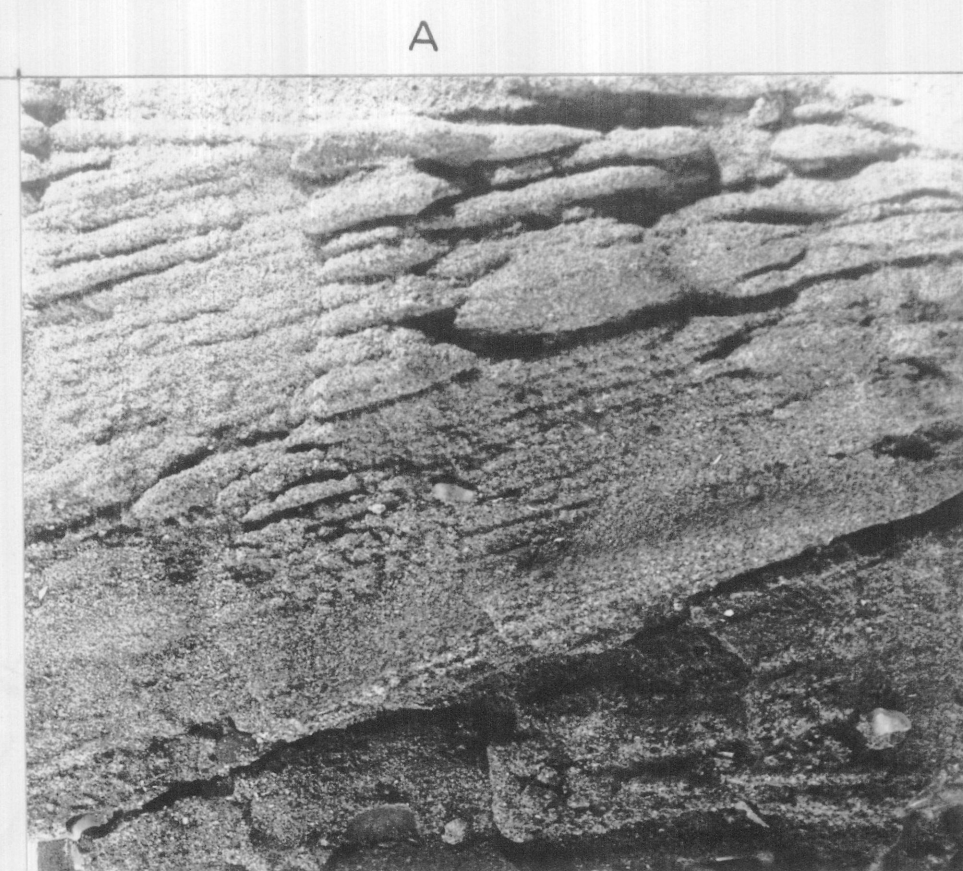


STRUCTURE OF FORE-BEACH DEPOSITS - showing cross lamination and herringbone structure of ripple marks, interlaminated deposits (laminae inclined gently seaward) and burrows of *Arenicola marina*.



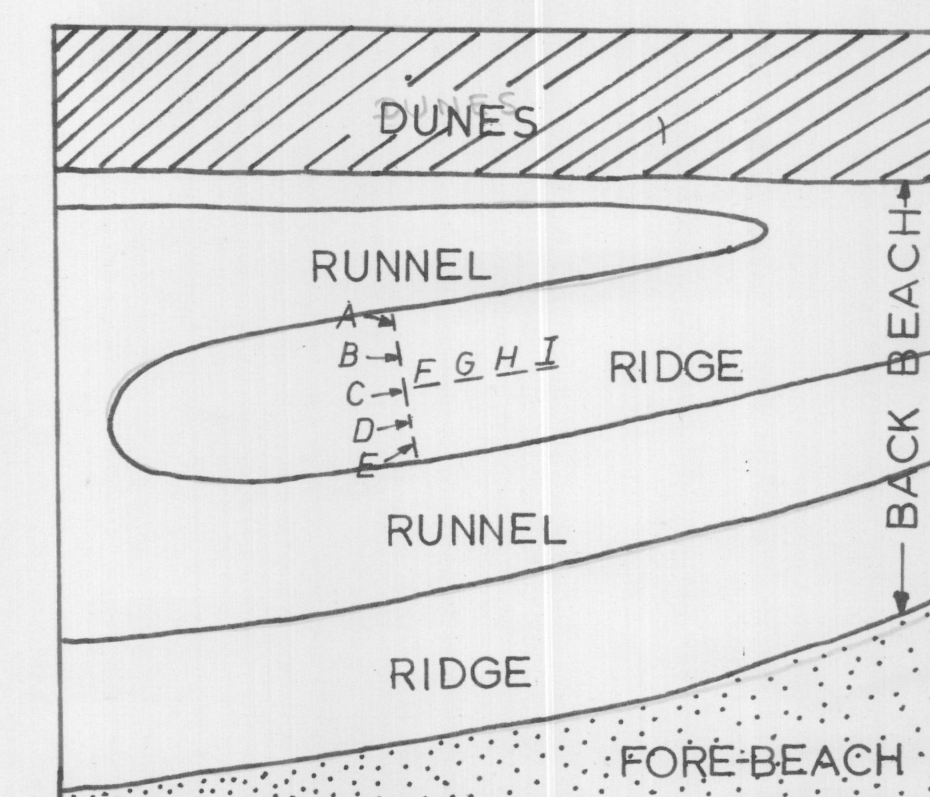
INTERNAL STRUCTURE OF FORE-BEACH DEPOSITS .

PLATE B.

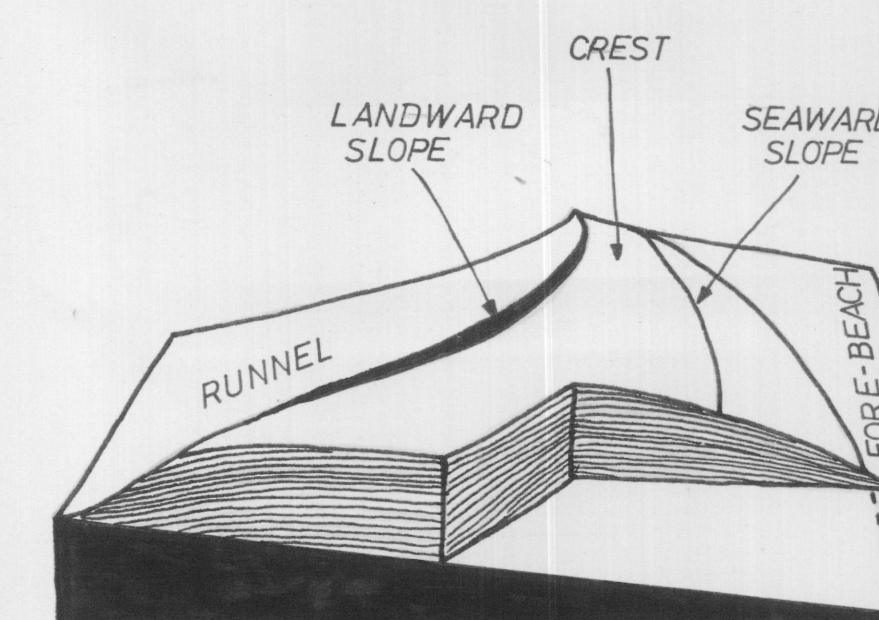


0 3 6
INCHES.

INTERNAL STRUCTURE OF BEACH RIDGE .



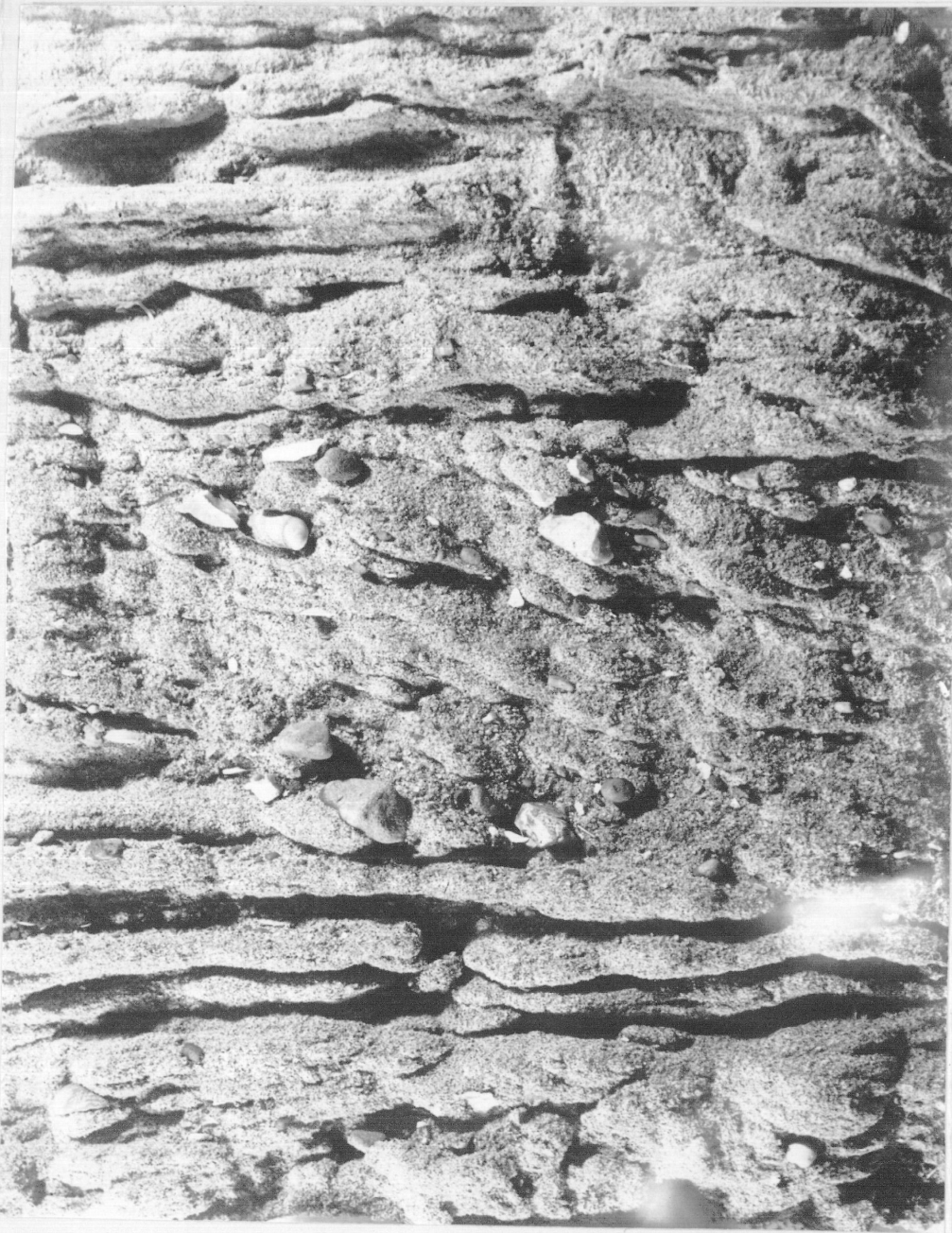
LOCATION AND ORIENTATION OF SECTIONS.



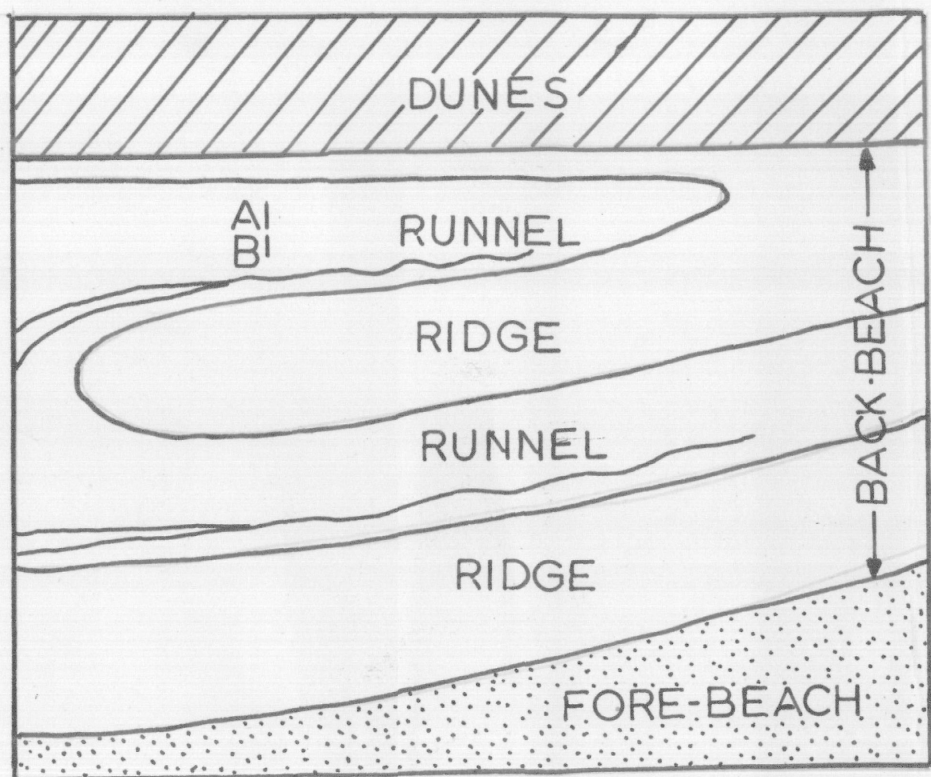
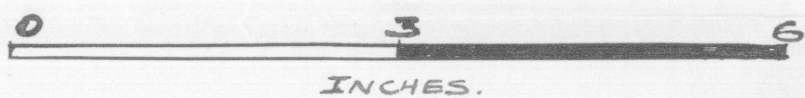
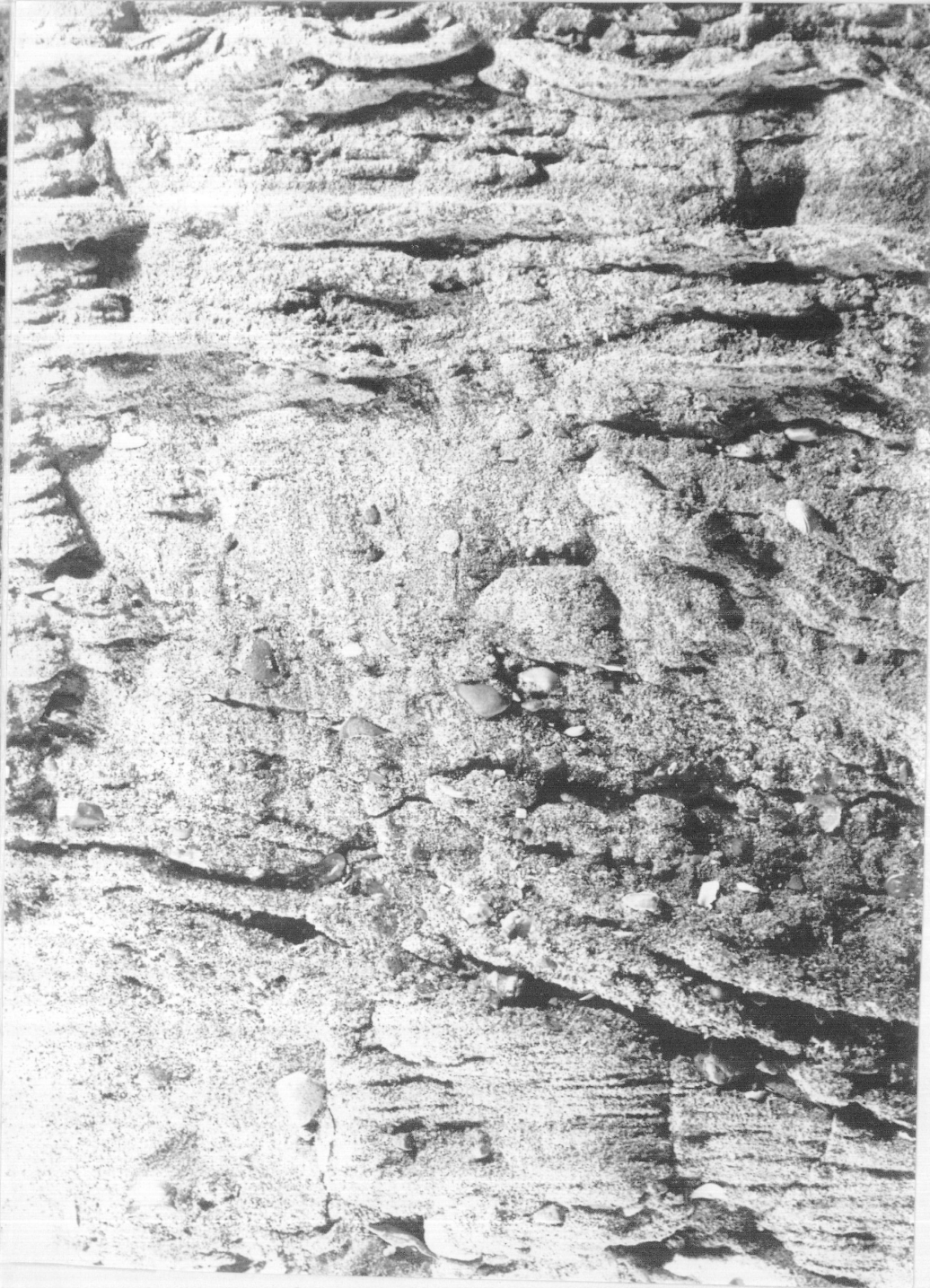
INTERNAL STRUCTURE OF BEACH RIDGE .

PLATE.C.

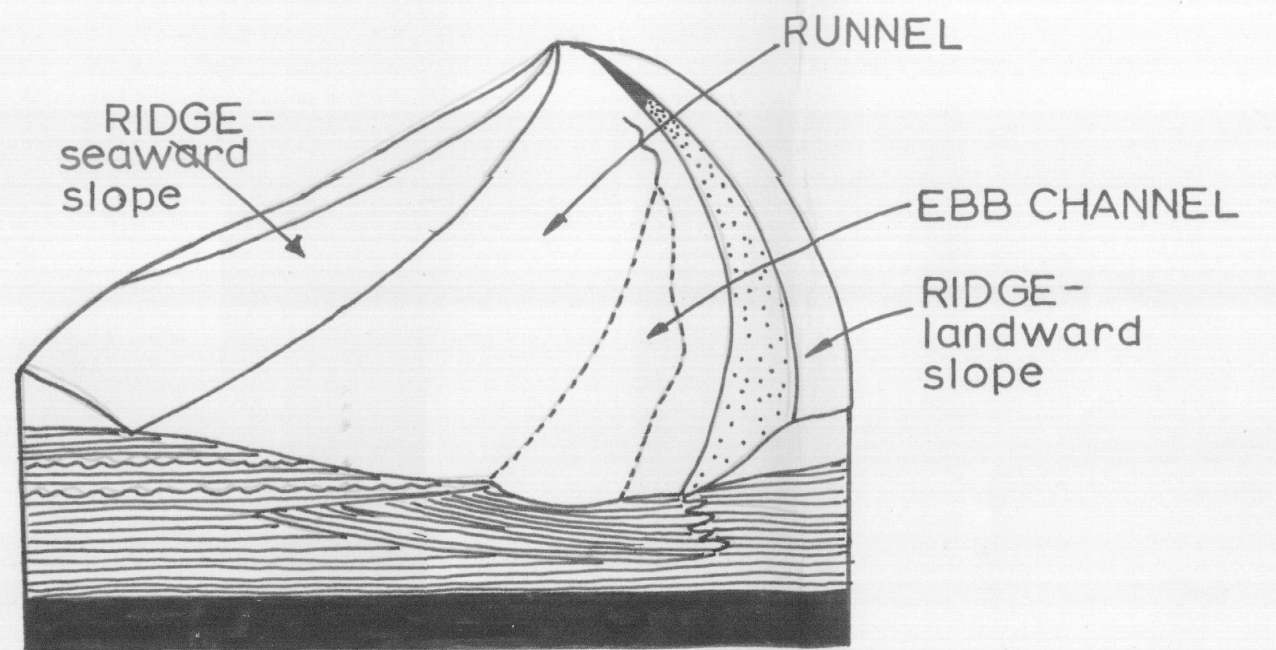
A



B



LOCATION AND ORIENTATION OF SECTIONS.



INTERNAL STRUCTURE OF BEACH RUNNEL
-washout structure formed by meandering tidal creek.

INTERNAL STRUCTURE OF BEACH RUNNEL .

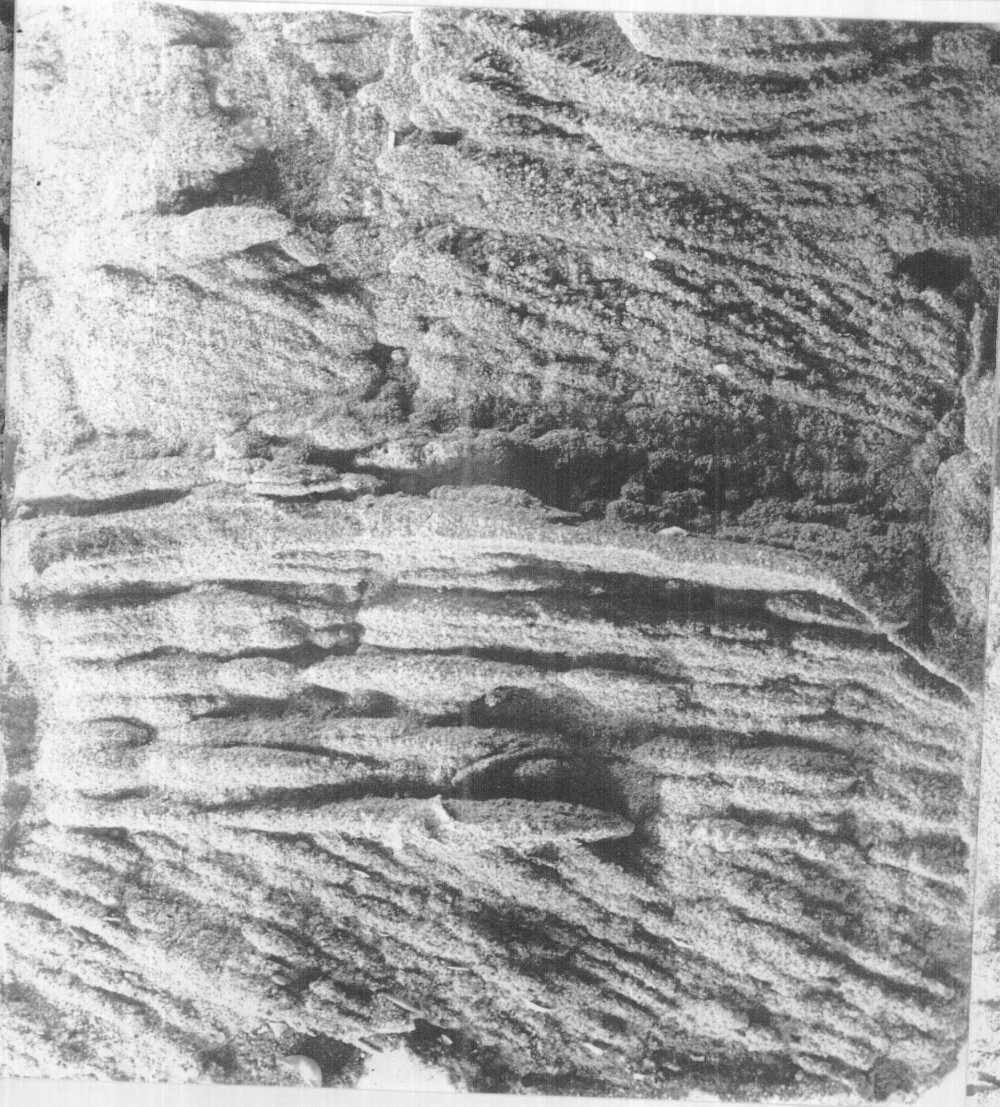
PLATE.D.

A

B

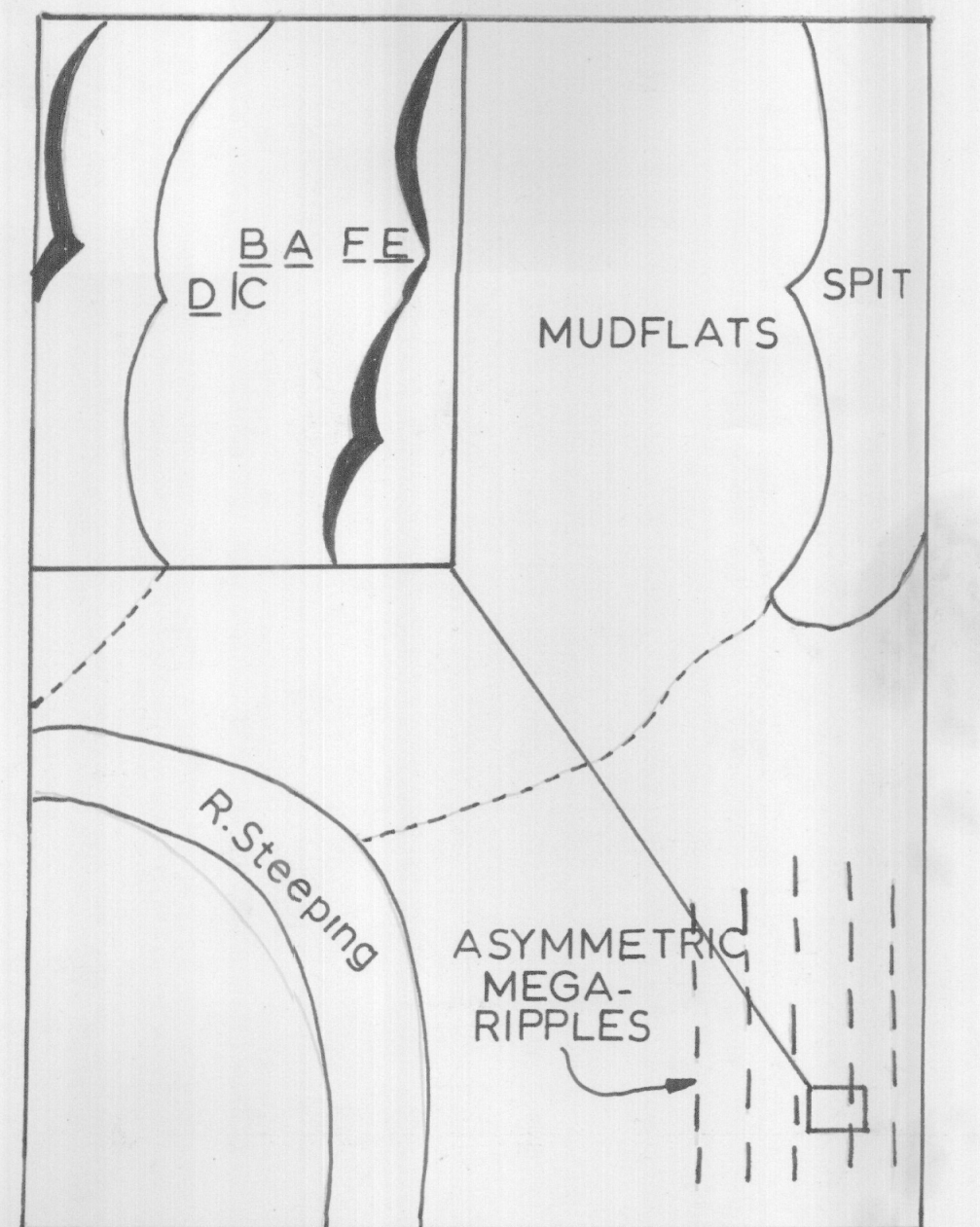
C

D

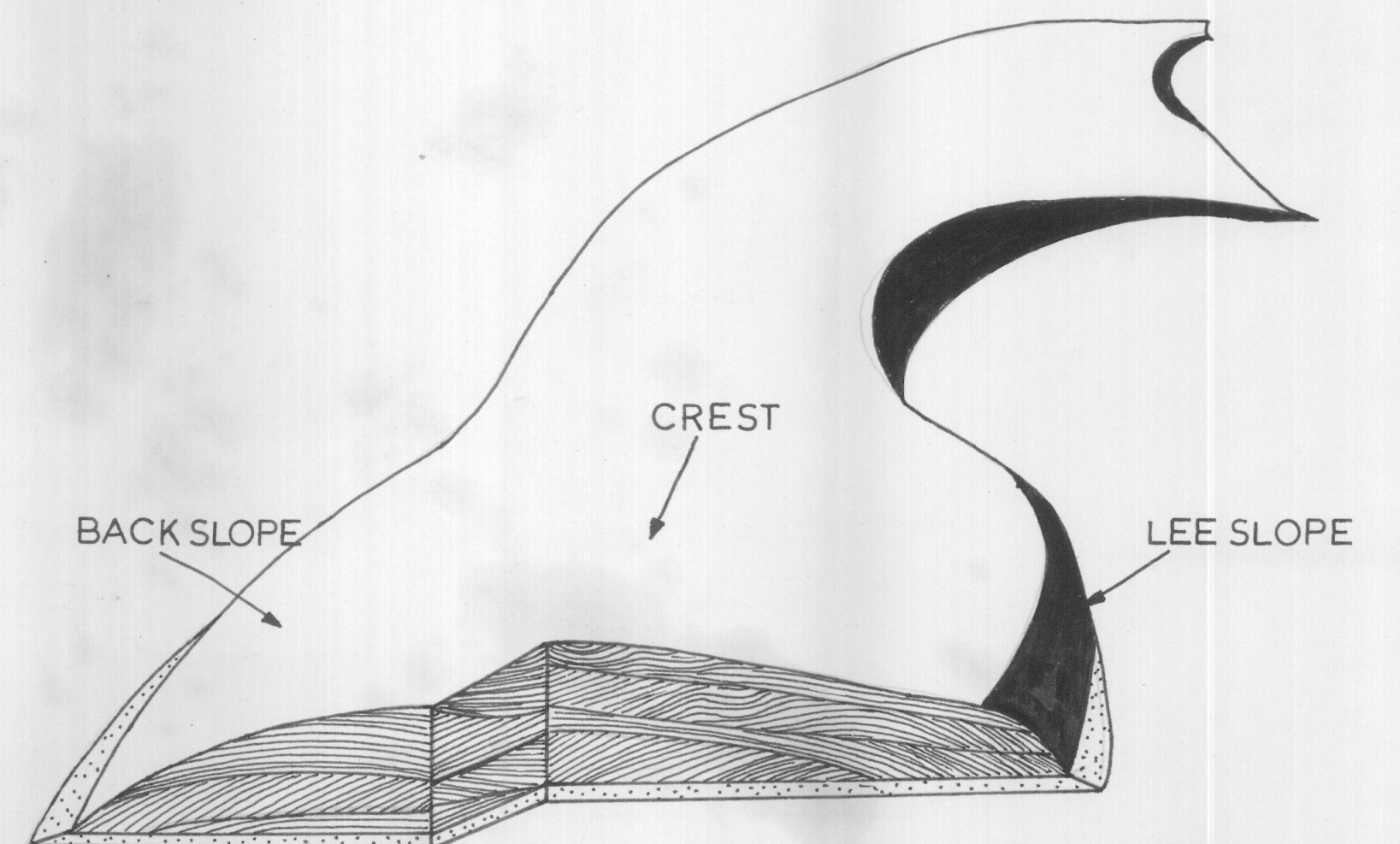
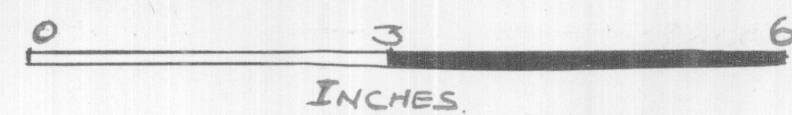


E

F



LOCATION AND ORIENTATION OF SECTIONS.

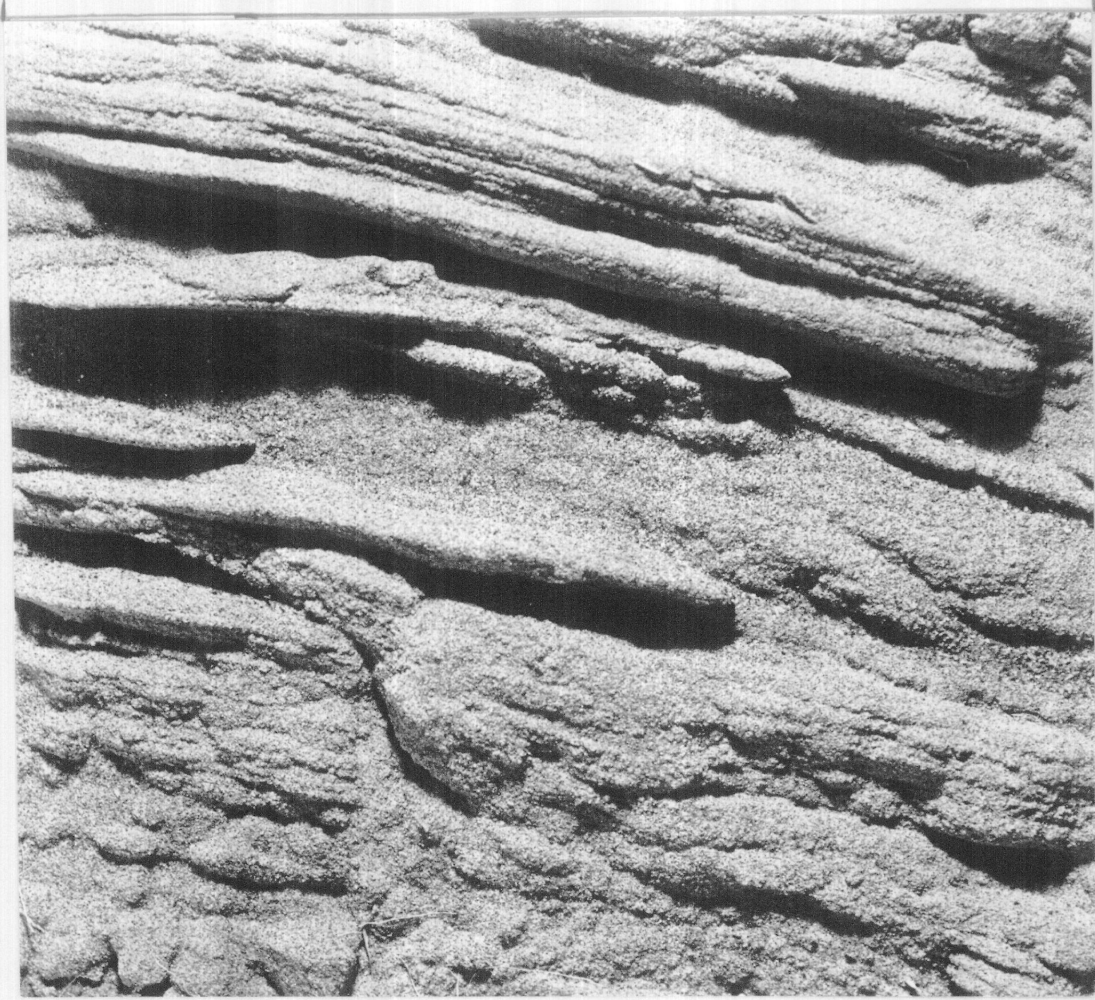


INTERNAL STRUCTURE OF ASYMMETRIC MEGA-RIPPLE, showing "foreset" "herring bone" and "festoon" bedding

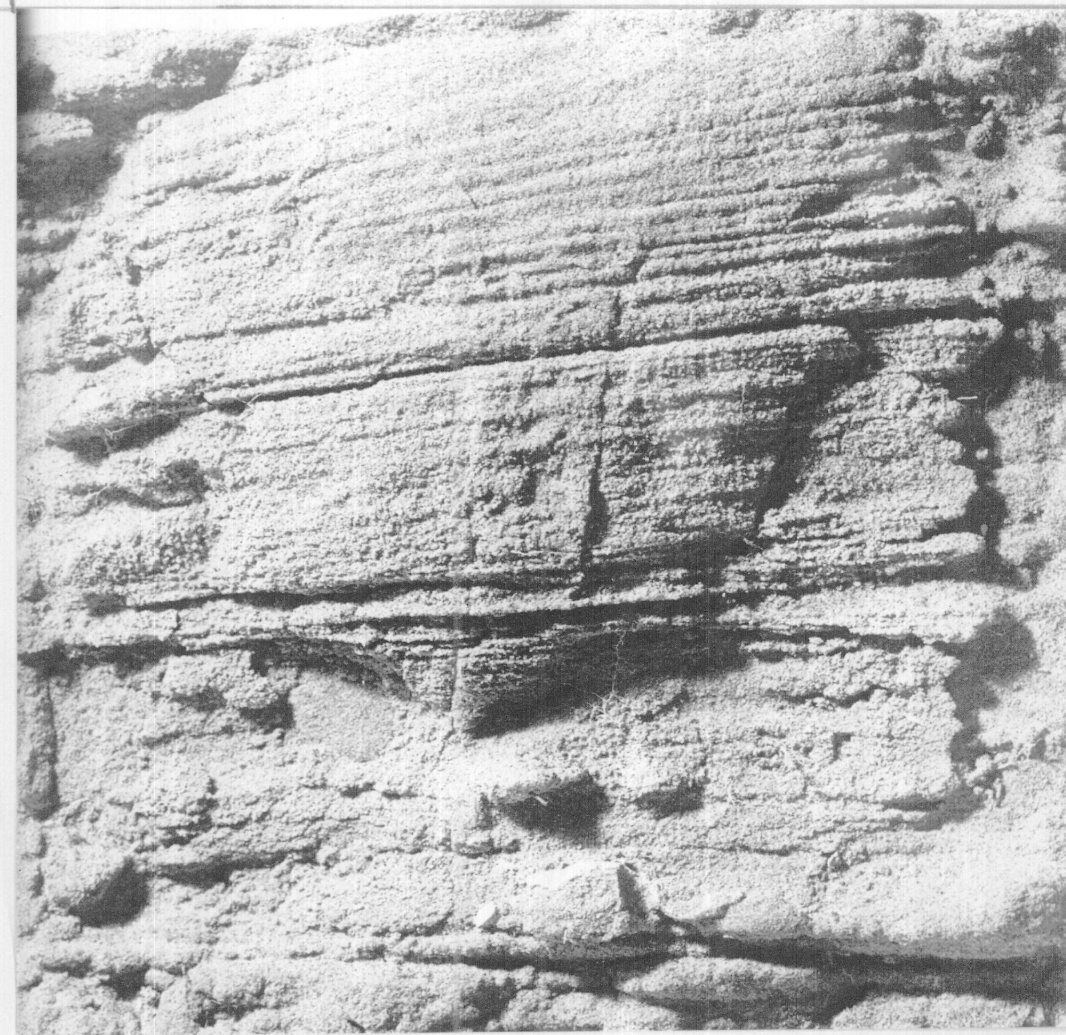
INTERNAL STRUCTURE OF ASYMMETRIC MEGA RIPPLES.

PLATE E.

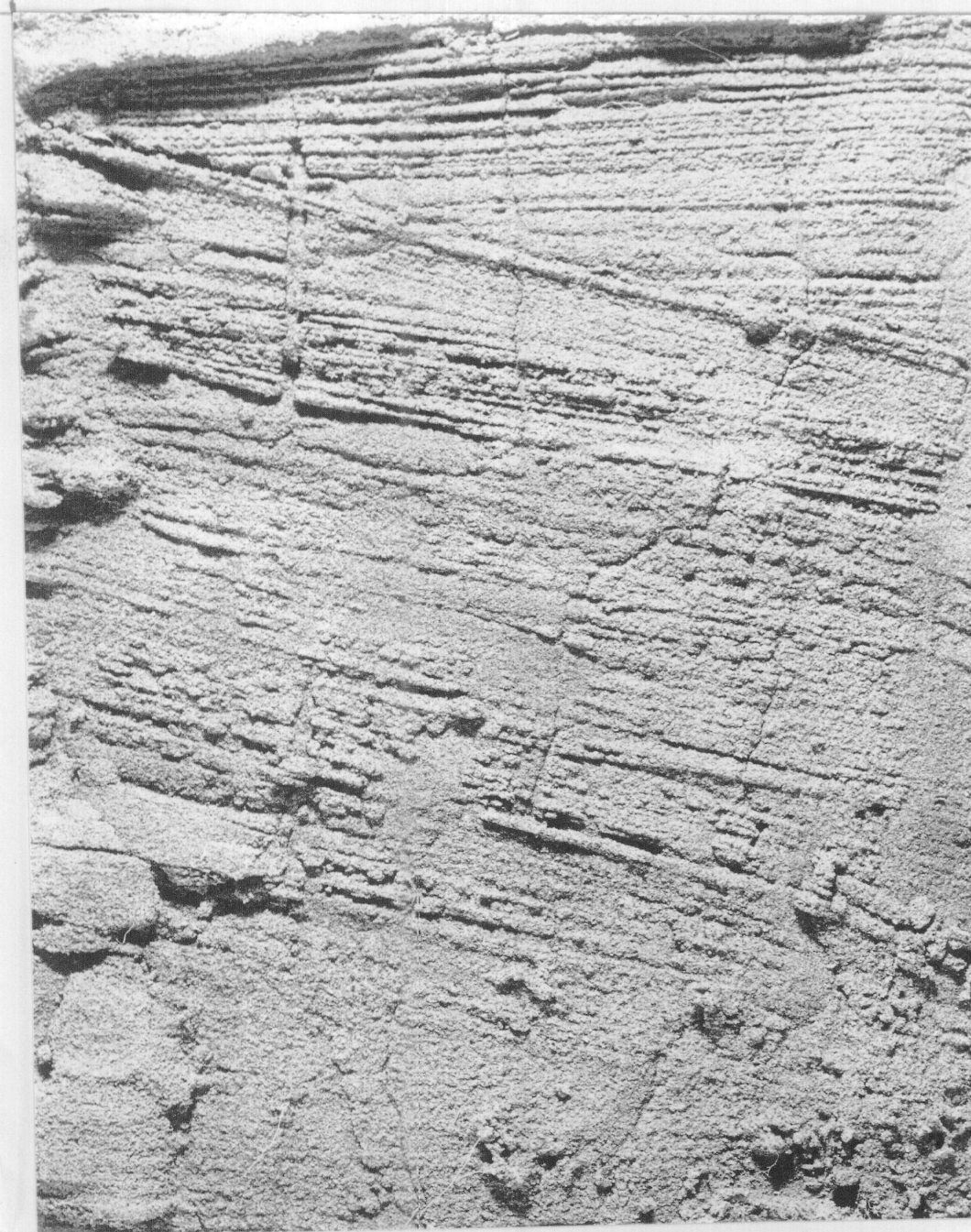
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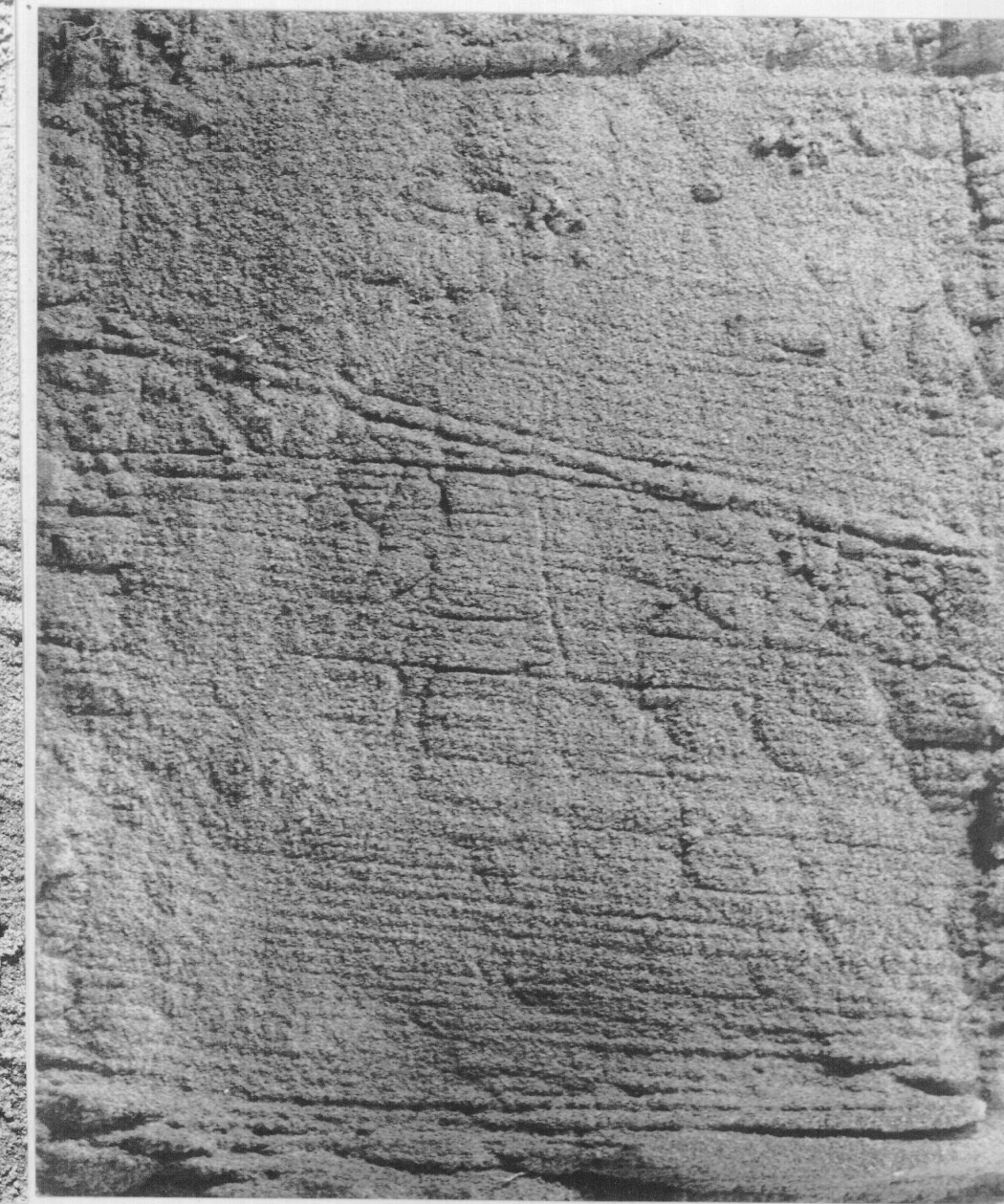
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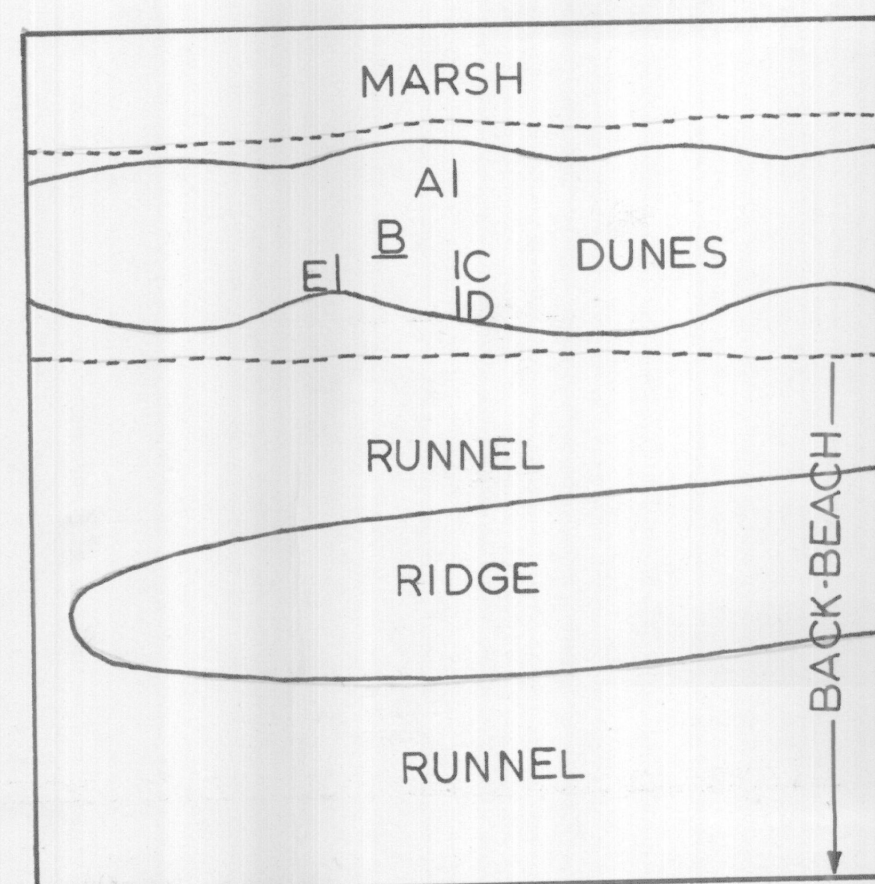
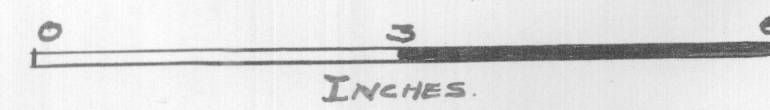
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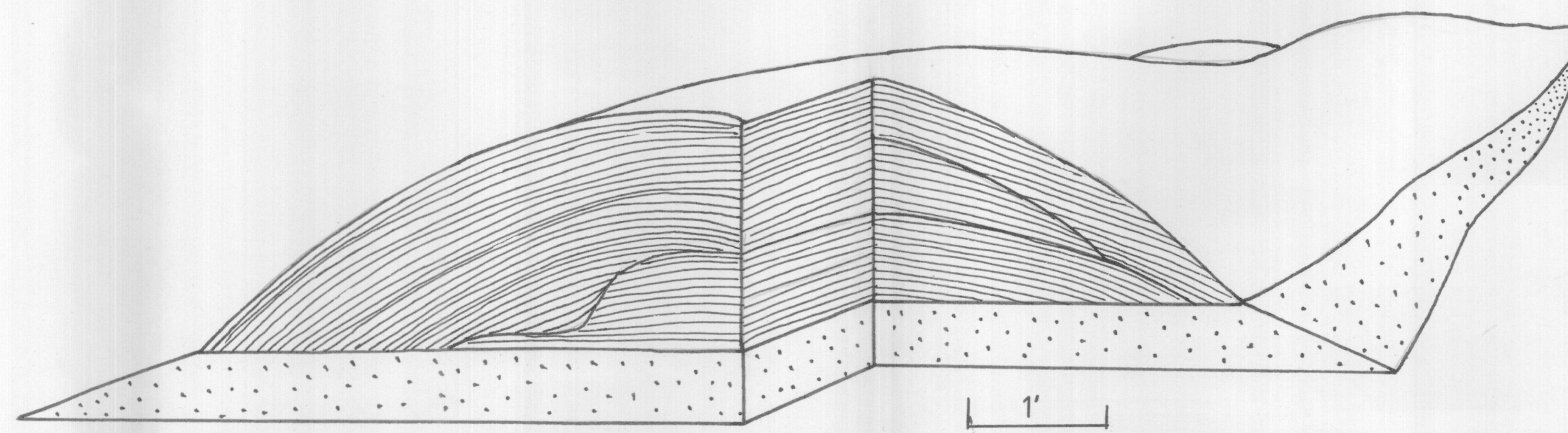
D



E



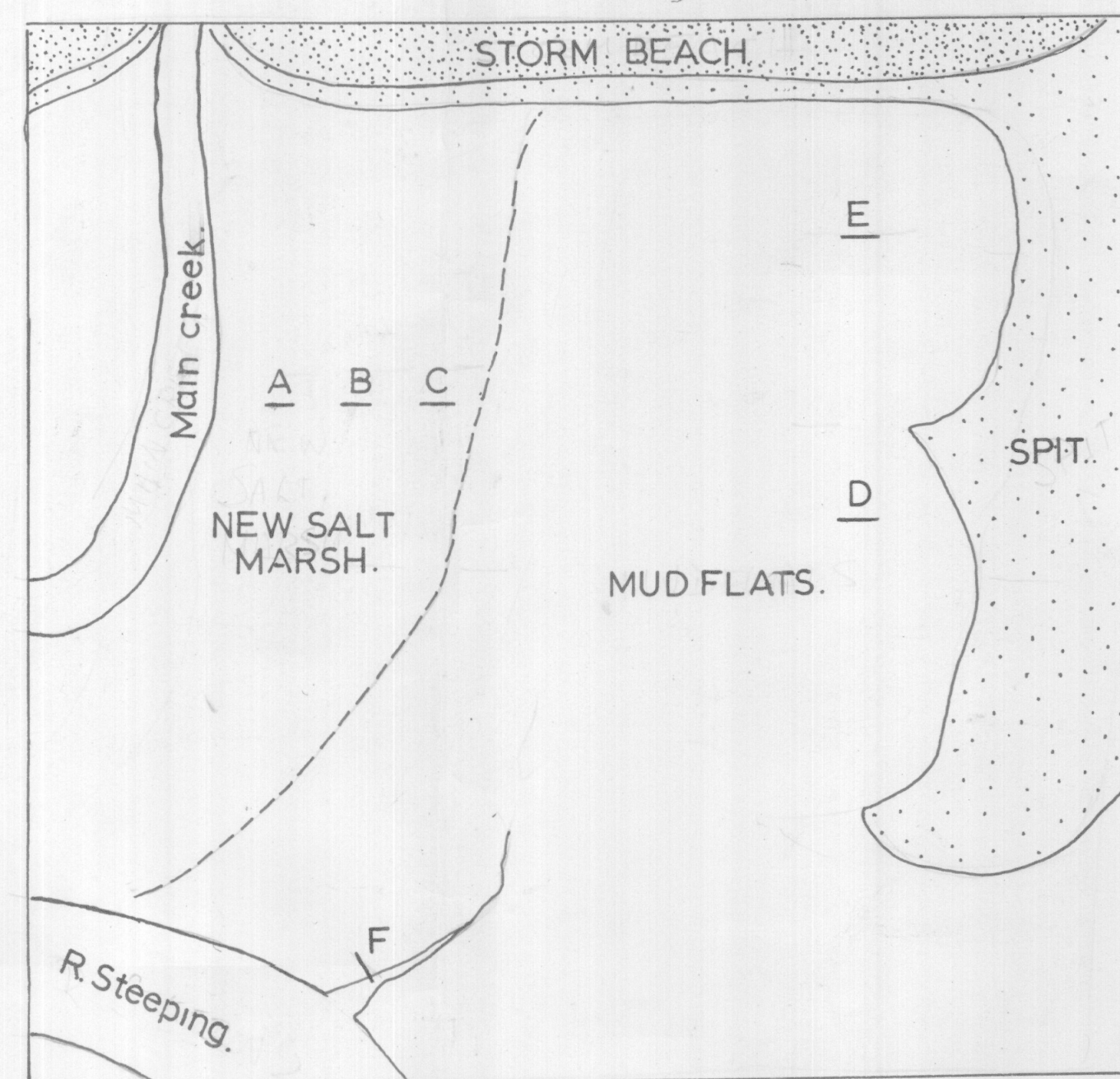
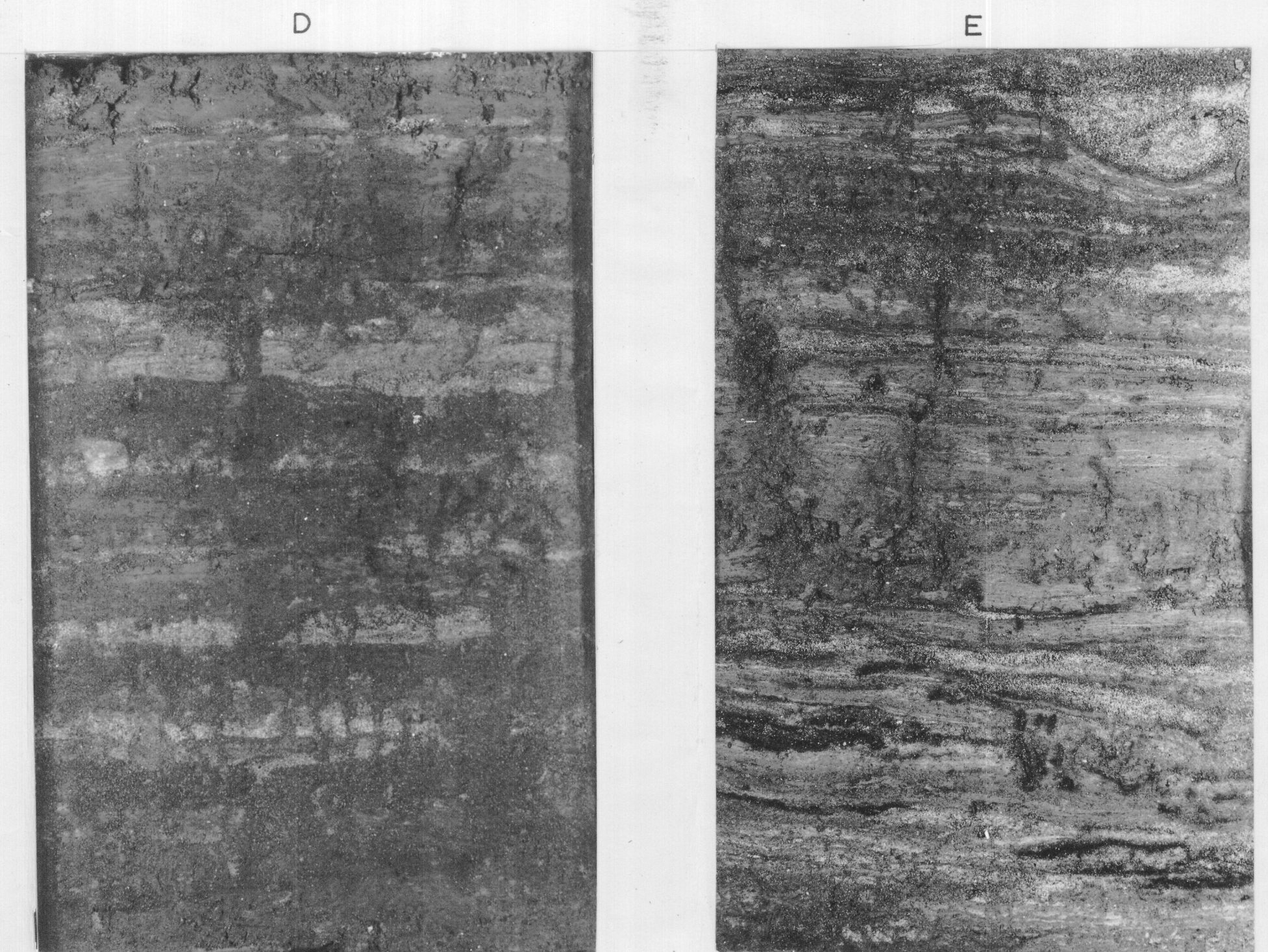
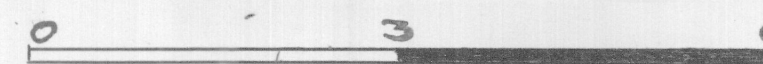
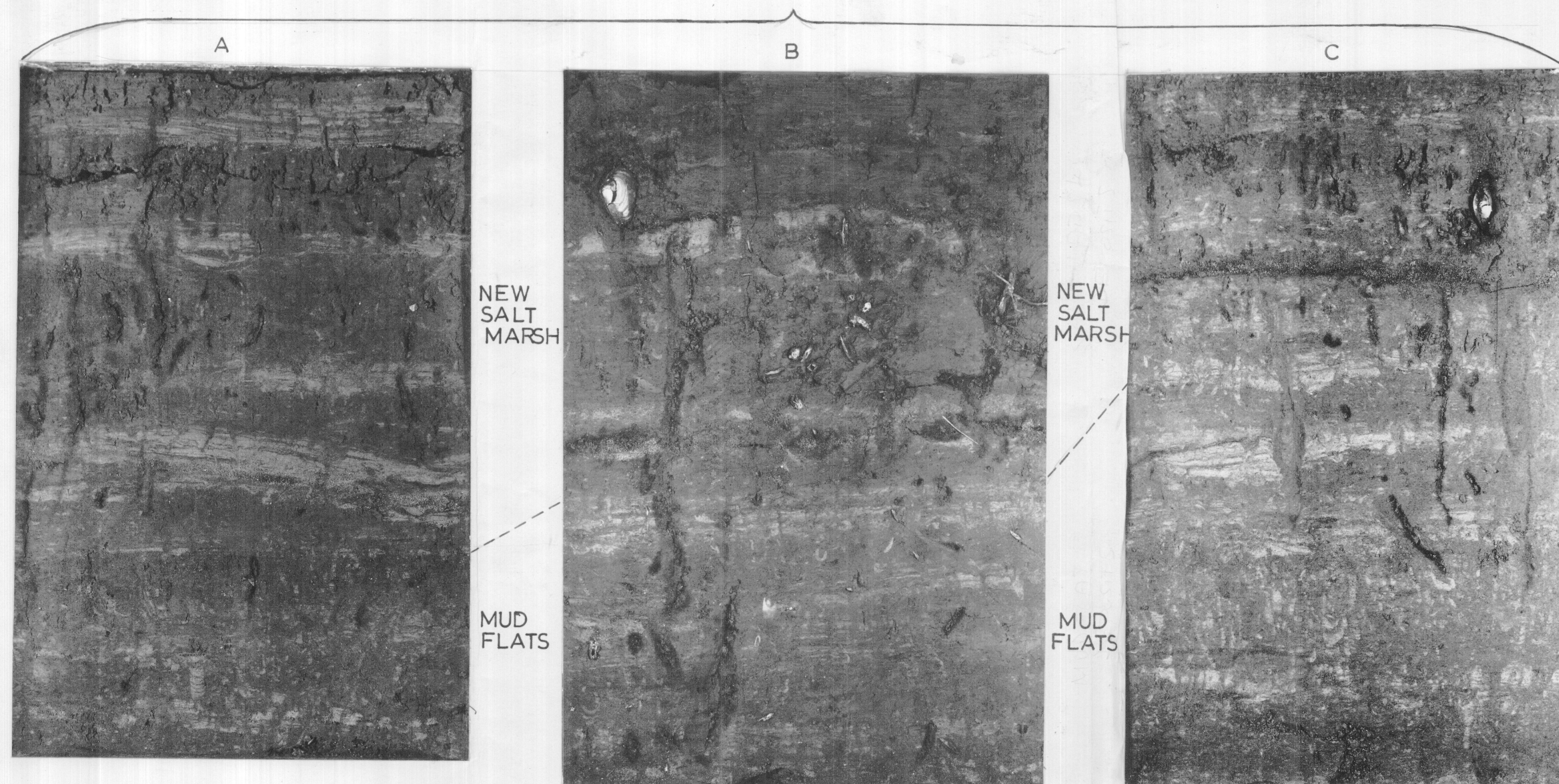
LOCATION AND ORIENTATION OF SECTIONS.



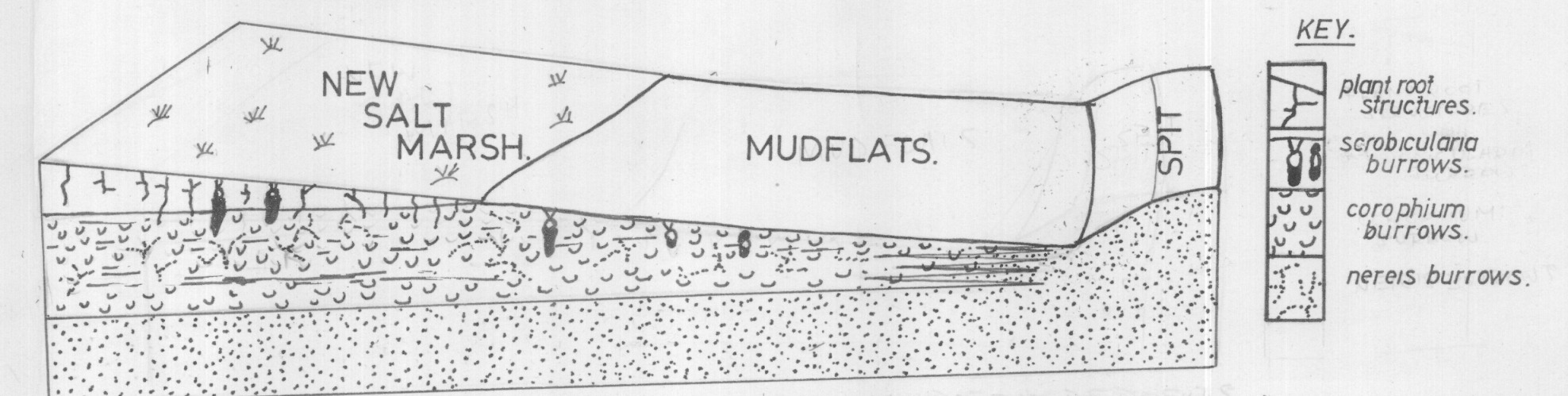
INTERNAL STRUCTURE OF A DUNE - showing lamination and deflation surfaces

INTERNAL STRUCTURE OF A DUNE .

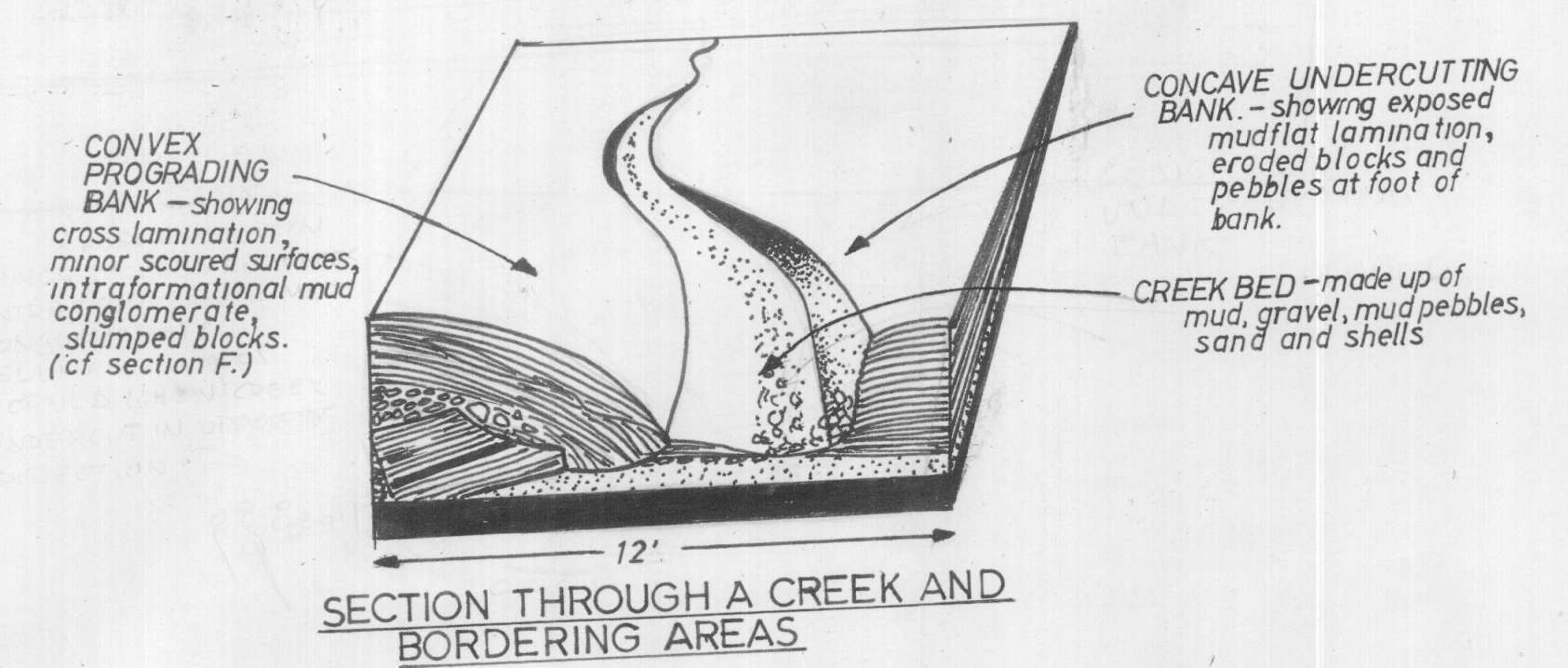
PLATE F.



LOCATION AND ORIENTATION OF SECTIONS.



STRUCTURE OF NEW SALT MARSH AND MUDFLAT DEPOSITS
— mudflat deposits pass laterally into spit deposits and rest on older Holocene sands.



SECTION THROUGH A CREEK AND BORDERING AREAS

INTERNAL STRUCTURE OF NEW SALT MARSH, MUDFLAT AND CREEK DEPOSITS.

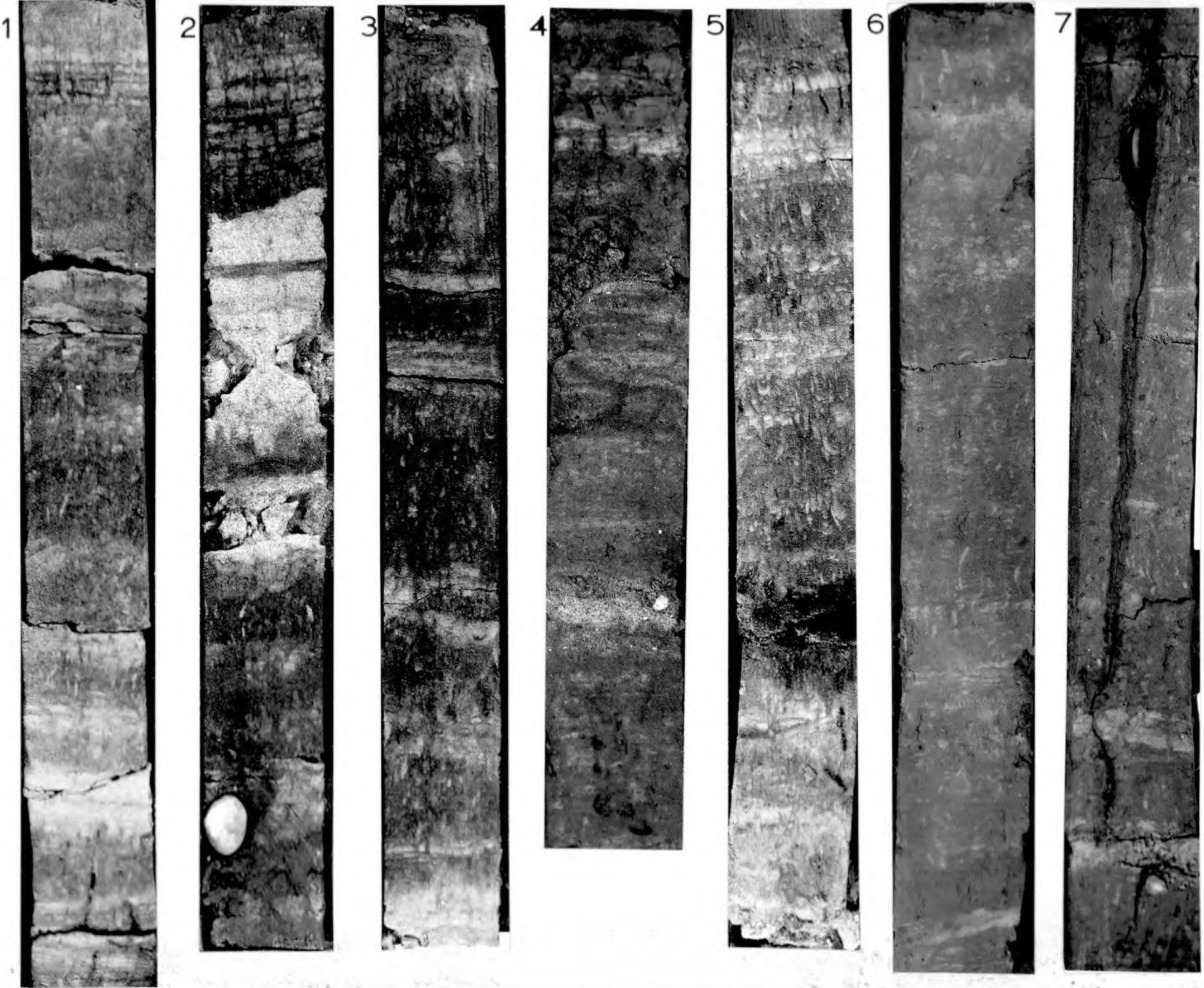
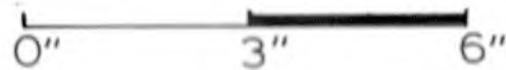


PLATE G.

MUDFLAT DEPOSITS



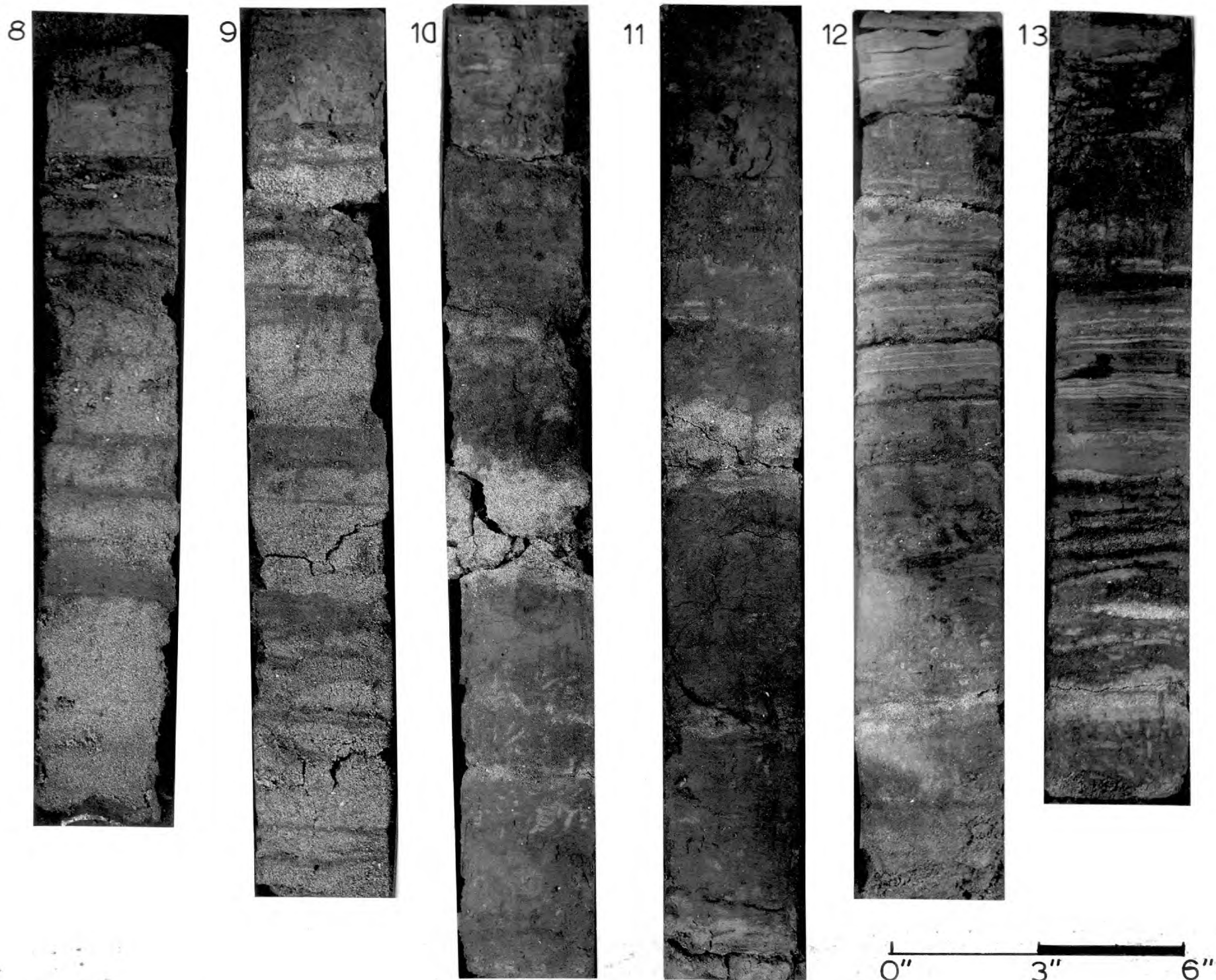
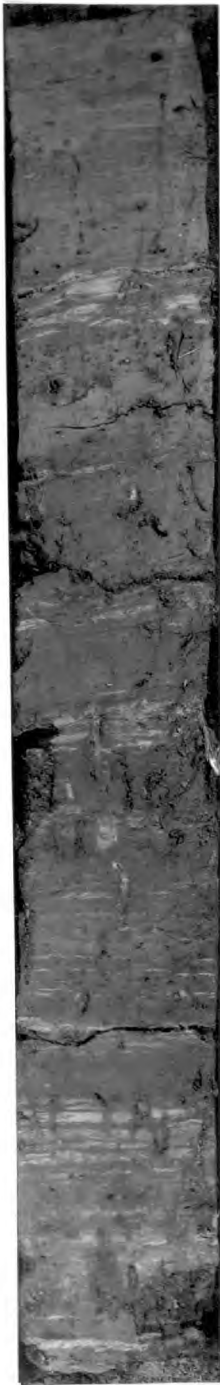


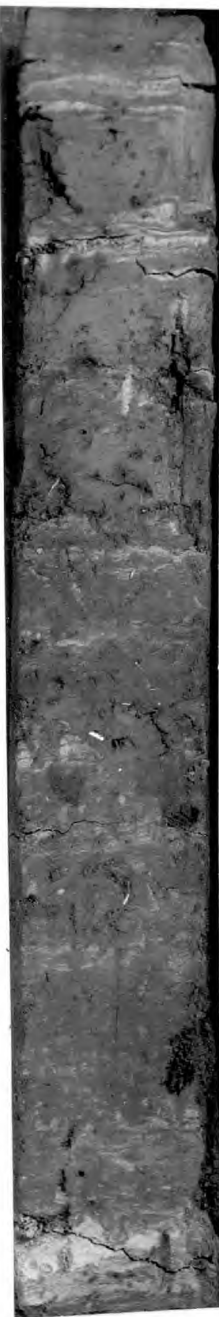
PLATE.H.

MUDFLAT DEPOSITS

14



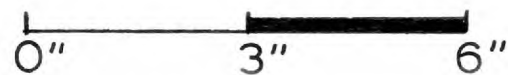
15



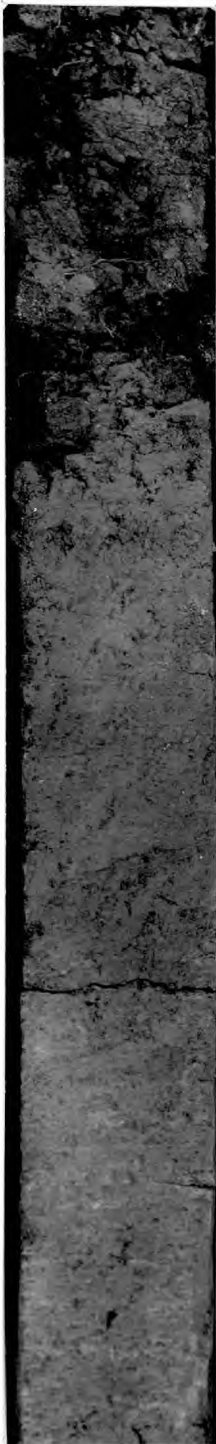
16



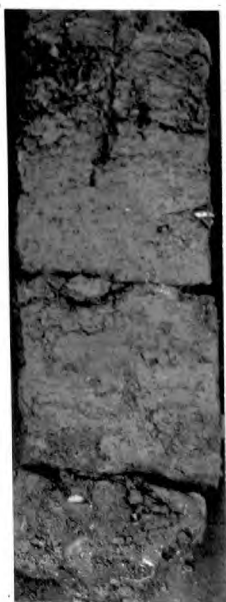
PLATE I

NEW SALT MARSH DEPOSITS

17



18



20



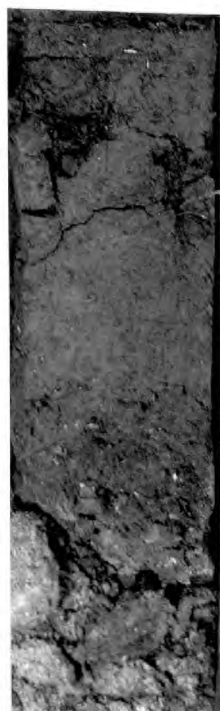
21



22



19



0" 3" 6"

PLATE J.

MATURE MARSH DEPOSITS

23



24



25

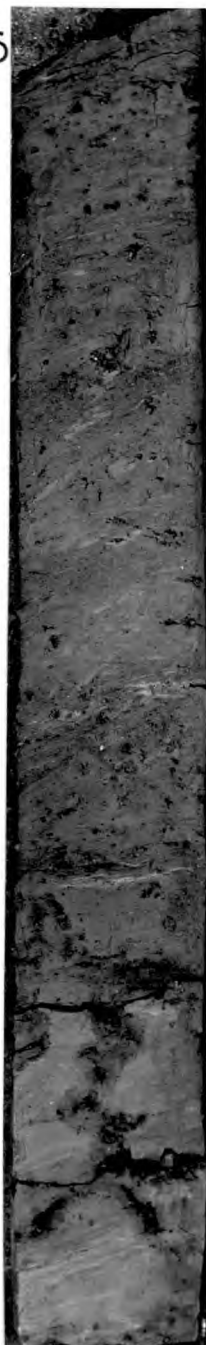
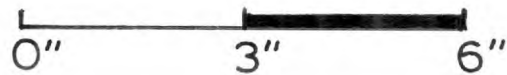


PLATE . K .

CREEK DEPOSITS

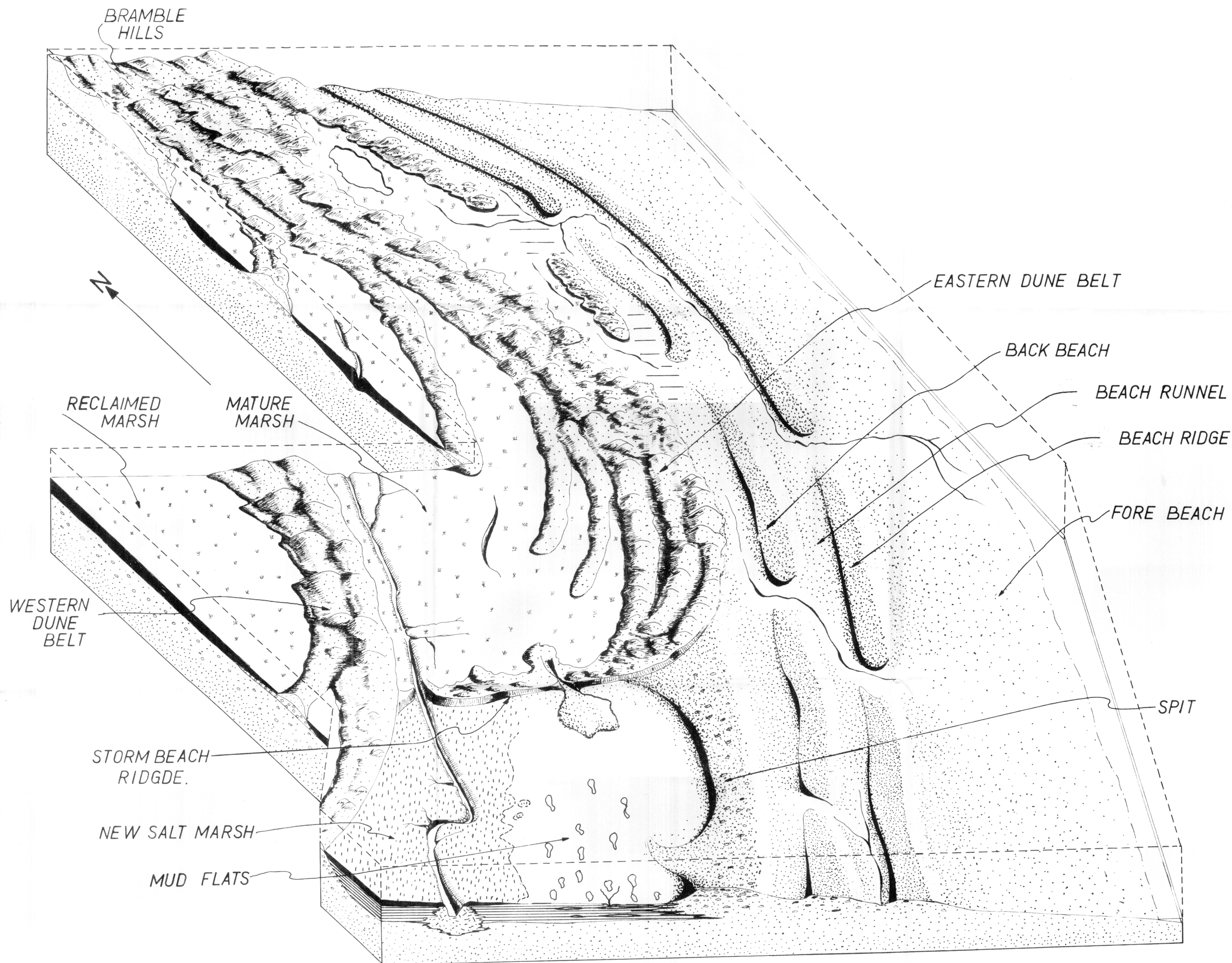


FIG.98. SEDIMENTARY ENVIRONMENTS OF THE GIBRALTAR POINT AREA -(LINCOLNSHIRE)

GIBRALTAR POINT. 1955 .



GIBRALTAR POINT

APRIL 1955

