THE SEDIMENTOLOGY AND PALEOTIDAL SIGNIFICANCE OF A LATE PLEISTOCENE RAISED BEACH, ADVOCATE HARBOUR, NOVA SCOTIA

by

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ABSTRACT

Continuous quarrying of a gravel pit at Advocate Harbour permitted a detailed 3-dimensional study of a raised Pleistocene beach. The beach is divided into two units that are separated by an erosional surface; a lower, progradational gravel unit and an upper, transgressive sand unit.

The progradational gravel unit consists predominantly of poorly sorted foreshore beds, but the low tide terrace, backshore and channel facies are also present. The low tide terrace consists predominantly of cross stratified sand that dips seaward and is interpreted as a subtidal deposit. The foreshore facies consists of low angle (5° - 14°) seaward dipping gravel beds interbedded with discordant high angle cross beds. Gravel in the backshore facies is better sorted and finer grained than in the foreshore facies. Storms deposit gravel either in landward prograding washover fans or in low angle, graded beds that dip seaward. The channel facies consists of channel deposits that occur in the foreshore and backshore facies. Storm runoff and tidal infilling and draining of a lagoon landward of the beach have probably formed the channels. The vertical distance between the low tide terrace and the backshore facies delineates a maximum paleotidal range of 3.4 m. This contrasts markedly with the present maximum range of 12.6 m.

The transgressive sand unit occurs above the gravel unit and consists of a core of well sorted washover fan gravel overlain by sandy foreshore and backshore beds. The sandy foreshore and backshore beds meet at the crest of the beach and define the highest stand of the sea during the formation of the beach, 27.3 m above present sea level. The vertical sequence of sediments is supratidal overlain by foreshore, which indicates a transgression. This transgression is probably the result of the eustatic rise in sea level exceeding glacial rebound for a short period of time. The beach was stranded when glacial rebound again exceeded the eustatic rise in sea level.

A model for gravel beaches is proposed which delineates paleotidal range. The model is a synthesis of the sedimentological data from the raised beach at Advocate and the published data on gravel beaches.

ACKNOWLEDGEMENTS

Many people have helped me with this thesis, and it is hoped that no significant contributor is omitted in this section.

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Last but not least, I thank Dianne Crouse, who typed this thesis. Because the writer is always in a last minute flap, part of the thesis was typed under extenuating circumstances. I'm glad that she's my friend.

CHAPTER 1

INTRODUCTION

The Problem

A raised gravel beach at Advocate Harbour, Nova Scotia (Fig. 1) was studied to determine Late Pleistocene tidal conditions in the Bay of Fundy. The present tidal range in the Bay of Fundy is the largest in the world, reaching 16.1 m at Burntcoat Head. At Advocate Harbour, the maximum tidal range is 12.6 m. However, Swift and Borns (1967) state that in the late Pleistocene "..... the 14 m tide range of the present basin (Bay of Fundy) was greatly reduced .....". Grant (1970) believes that "Tidal amplification in the Bay of Fundy commenced about 6000 years ago". He suggests that early postglacial tides in the bay were very small, probably less than 2 m. The beach at Advocate Harbour was studied to test this hypothesis.

Although the specific purpose of the study was to determine the paleotidal range of the beach, the result of the study is a detailed sedimentological model for gravel beaches that delineates tidal range. The model extends from the nearshore subtidal environment to the supratidal environment.

Pleistocene History

The raised beach at Advocate Harbour is part of a raised fluviomarine outwash terrace extending discontinuously along the south coast of the

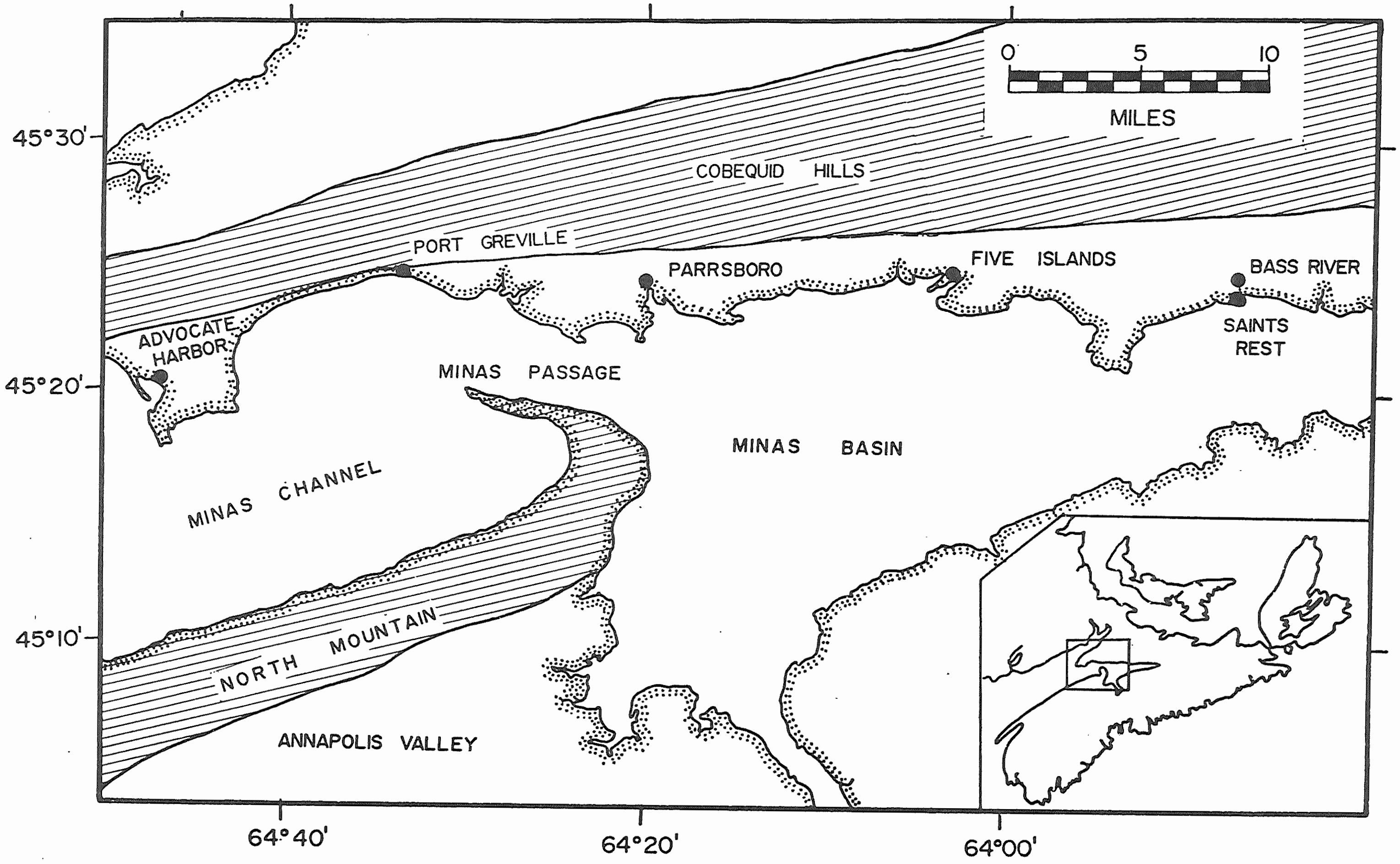


Fig. 1 (from Swift and Borns, 1967). Map showing location of the Minas Basin. Shaded areas are uplands.

Chignecto Peninsula from Advocate Harbour to Saint's Rest (Fig. 2). Chalmers (1894) first described the terrace, and recognized its importance in defining the extent of postglacial marine onlap. Goldthwait (1924) discussed part of the terrace at Parrsboro, and suggested that it might not represent the maximum extent of marine onlap due to post-emergence erosion. However, the first and only detailed study of the terrace was by Swift and Borns (1967).

Swift and Borns (1967) named the deposits of the terrace the Five Islands Formation and divided it into two members: 1. the upper, glaciofluvial Saint's Rest Member, that disconformably overlies 2. the lower, marine Advocate Harbour Member. The Advocate Harbour Member is composed of two marine lithosomes, glaciodeltaic and glaciolittoral. The glaciodeltaic lithosome extends from Spencer's Island to Five Islands, while the glaciolittoral lithosome occurs only at Advocate Harbour.

The glaciodeltaic lithosome is made up of deltas with a tripartite structure (topset, foreset and bottomset beds). The topset beds are coarse, imbricated fluvial gravels that unconformably overlie the foreset beds. Foreset beds are finer grained than the topset beds, and dip from 20° to 34°. The bottomset beds are rhythmites, coarsening upwards from clay/silt through clay/sand to clay/gravel interbeds.

Although Gilbert-type deltas are typically lacustrine (Gilbert, 1890; Ashley, 1972), the deltas of the Advocate Harbour Member are marine. Moulds of the euryhaline pelecypod Portlandia glacialis were found in the bottomset beds of the delta at Five Islands (Borns, 1966). Moulds of the euryhaline pelecypod Portlandia arctica were found by the writer in the

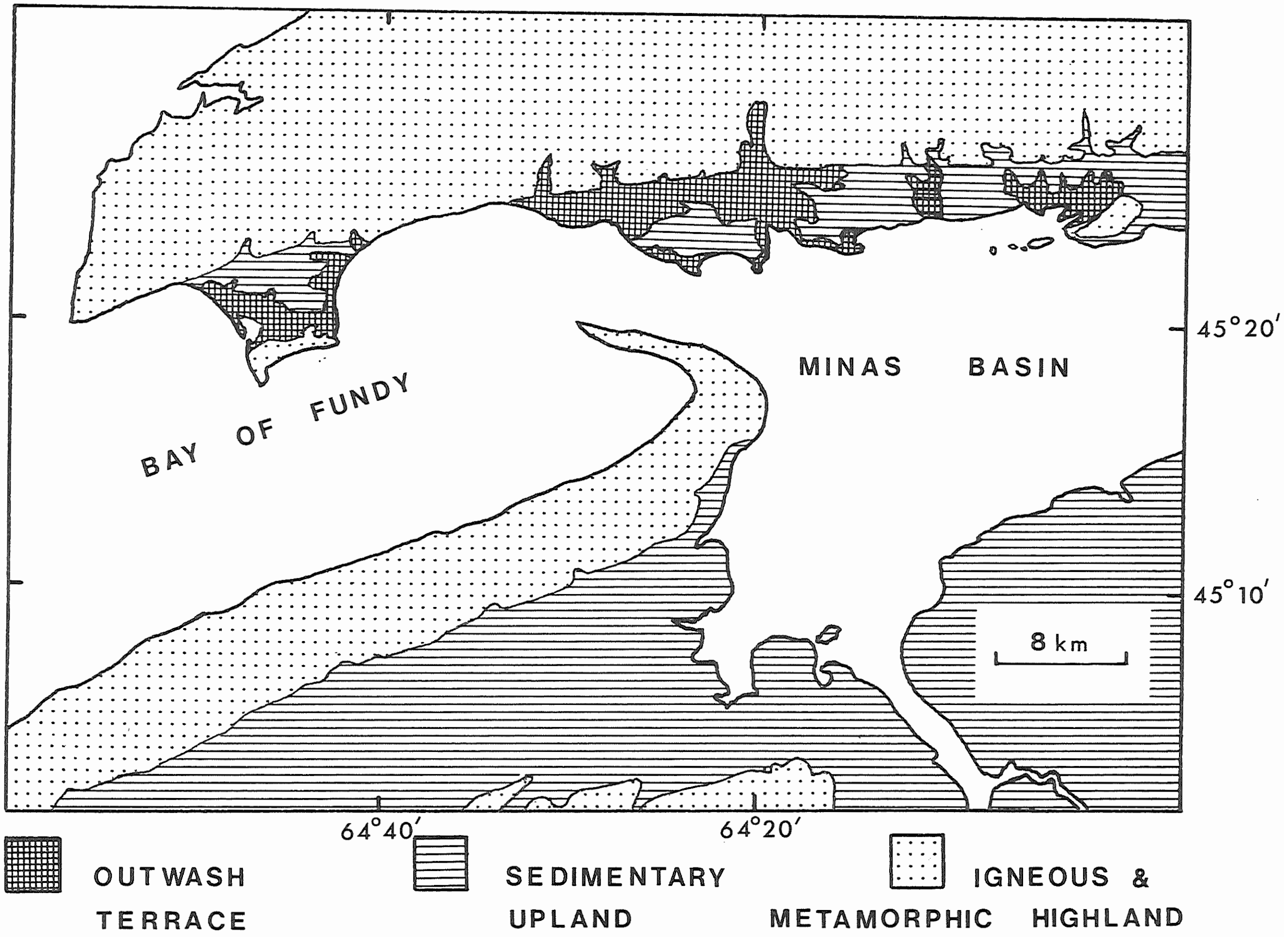


Fig. 2 (from Swift and Borns, 1967). Geomorphic provinces of the Lower Minas Basin.

bottomset beds of the delta at Spencer's Island (Wagner, in press).

The glaciolittoral lithosome at Advocate Harbour consists of several raised spits enclosing a lagoon, similar to the modern Advocate Harbour shoreline (Fig. 3). The internal structure of the spits is typical beach stratification (McKee , 1957), with foreshore beds dipping 5° to 14°S (seaward). The sediment is generally gravel with sand matrix. Wave activity and longshore drift must have been similar to that of today, as the orientation of the spits (fossil and modern) are similar (Fig. 3).

The glaciofluvial lithosome (Saint's Rest Member) of sandy gravel disconformably overlies the marine lithosomes. Sedimentary structures and textures are typical of a shallow braided stream (Eynon, 1974). Numerous kettles occur in this lithosome. Swift and Borns (1967) imply that it is present at all outcrops along the terrace (their fig. 15, p. 709), and envisage it as a separate, later event.

Although they had no direct evidence of age, Swift and Borns (1967) place the deposition of the terrace between Port Huron and Valders time of the classical sequence (13,000 to 11,500 years B.P.). Numerous dates between 13,000 and 14,000 years B.P. from raised marine features on the New Brunswick shore (Gadd, 1973) indicate ice dissipation in the Bay of Fundy at about 14,000 years B.P. Swift and Borns suggest the following sequence of events for the formation of the terrace. As the ice dissipated in the Minas Basin, it was followed by a rising sea level. Ice receded in the valleys on the northern shore of the Minas Basin, and was replaced by prograding deltas as

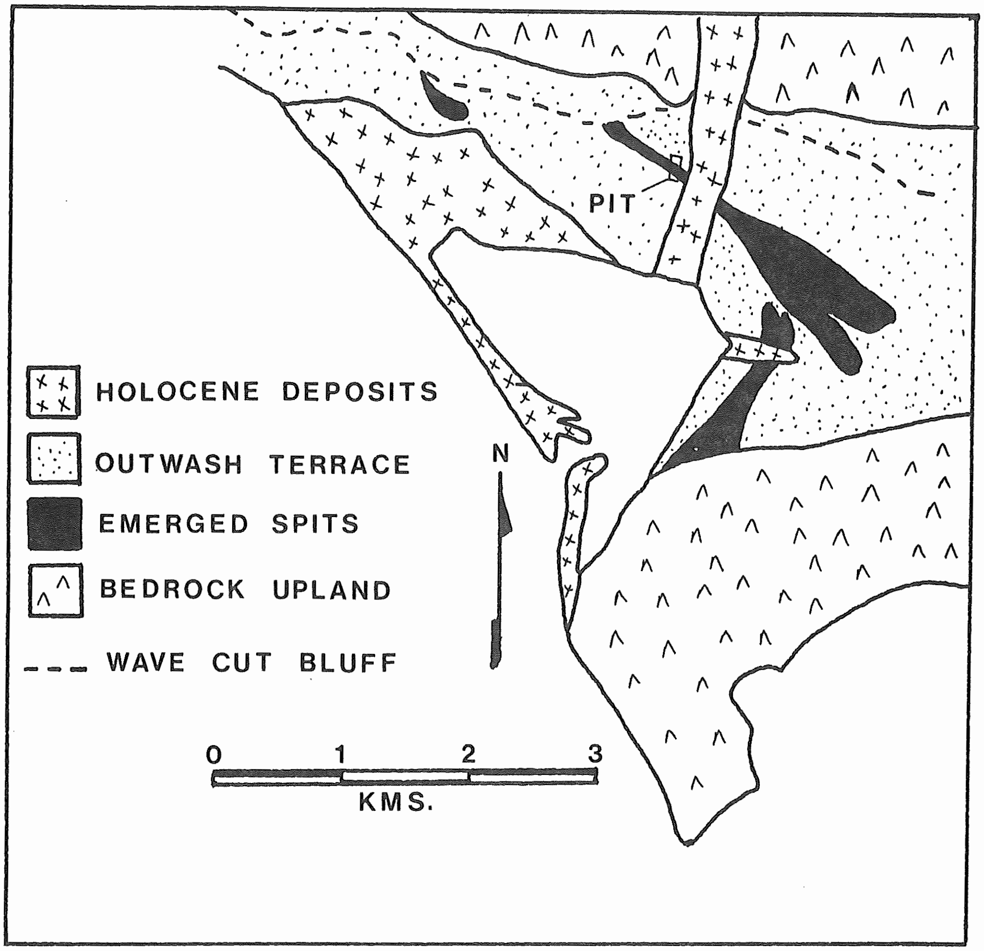


Fig. 3 (from Swift and Borns, 1967). Surficial geology of Advocate Harbour area with location of gravel pit.

far north as the Glooscap (Cobequid) fault (Fig. 4, top). The upper surfaces of the deltas rose with the rising sea level. The zone of rapid isostatic uplift, following the receding ice front, reached the northern shore of the Minas Basin and the deltas emerged. Dissection of the upper surfaces of the deltas produced a maximum of 6 m of relief.

Subaerial alluvial fans then prograded across the dissected delta surfaces, producing the glaciofluvial lithosome (middle, Fig. 4). As the supply of outwash material diminished, the terrace continued to emerge, and underwent a second dissection, forming the present drainage system. When emergence slowed to a negligible rate, the sea advanced to its present position (Fig. 4, bottom).

Previous Work on Gravel Beaches

A complete literature review of beaches will not be attempted, as most of the literature is on sand beaches. Because a paleotidal range model for a beach must be based on sedimentary structures and textures, a review of papers in these fields is appropriate. To conclude the review, Klein's (1971) paper on paleotidal range determinations from tidal flats will be covered because of its relevance to the thesis problem.

Before a review of the literature on beaches is given, it is important to clarify the terms openwork, closedwork, unimodal and bimodal. The terms openwork and closedwork are often used interchangeably with the terms unimodal and bimodal, respectively (Pettijohn, 1957; Hey, 1967) but they are not synonyms. Pettijohn (1957, p. 245) defines openwork gravel as gravel with

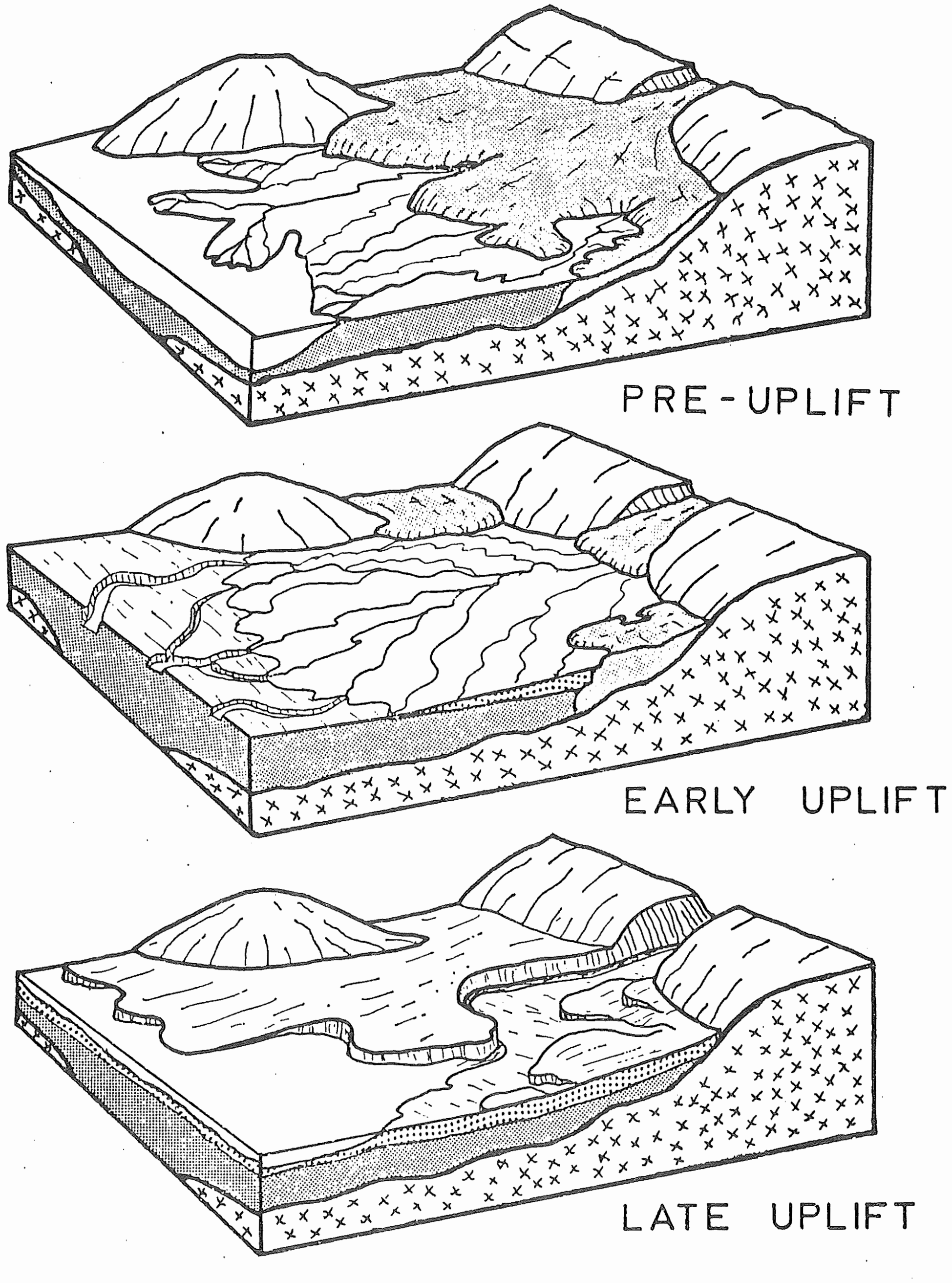


Fig. 4 (from Swift and Borns, 1967). Evolution of the Minas Basin north shore outwash terrace. Top, growth of marine deltas; middle, uplift and erosion of marine plain - growth of subaerial fans based on Cobequid scarp; bottom, modern terrace after uplift, dissection and sea-level rise.

unfilled voids. Closedwork gravel has no voids. Grain size distributions with a single maximum (or mode) are called unimodal distributions (Pettijohn, 1957, p. 35). Bimodal distributions have two modes and polymodal have more than two. Thus, an openwork gravel need not be unimodal; it can be bimodal or polymodal. The terms unimodal and bimodal will be used only when referring to the work of other authors or to specific grain size distributions.

One of the first contributions to the knowledge of fabrics in beach gravel was made by Krumbein (1939). He noticed that pebbles in the backshore zone of a lacustrine beach were strongly imbricated lakeward. Plots of both the a-axis (long) and c-axis (short) of the pebbles revealed that the c-axis (the pole to the maximum projection plane) was more definitive of the imbrication. The strike of the maximum projection plane was parallel to the trend of the beach.

Bluck (1967) studied the textural aspects of several gravel beaches in Wales. He noticed that disc-shaped pebbles increased in abundance landward and conversely, spherical-shaped pebbles increased in abundance seaward. He attributed this to the slower seaward movement of disc-shaped particles, resulting in a lag of disc-shaped pebbles at the top of the beach. Concomitant with the shape sorting was a size sorting, with grain size increasing up the beach. In contrast to Krumbein (1939), he found an imbricate pebble zone in the upper foreshore zone of the beach.

Carr (1969) found that the coarsest gravel was at, or slightly landward of, the beach crest. Bimodal gravel, or gravel with sand, occurred at the low water mark. Below the low water mark, shingle was discontinuous.

Hobday and Banks (1971) reported a similar shape sorting, but the opposite size sorting, to that of Bluck (1967) in the foreshore zone of a gravel beach in Norway. Grain size decreased from the lower to the upper foreshore, and then, in accordance with Carr's (1969) observation, increased in the supratidal storm ridges. They also described swash bars, composed of the finest gravel present, on the beach.

Shepard (1948) noticed that a change in texture could occur at a change in the beach profile. He described the terrace that frequently occurs at the base of the foreshore slope and the accompanying change in grain size from the foreshore to the terrace. The terrace was named the low-tide terrace because of its relative position to the tides. "..... Some gravel and cobble beaches have been found to have low-tide terraces of sand which overlap onto the gravel and cobble zone inside".

Hey (1967) studied several excavations in a prograding gravel beach system at Dungeness, on the south coast of England, that exposed this type of low tide terrace. The deposits are less than 350 years old at the excavations. At the northern excavation, bimodal gravel occurred between the levels of low and high spring tide (Fig. 5). The gravel beds had a constant dip, and unconformities were rare. An unbedded, unimodal gravel occurred above the level of high spring tide, and a sand deposit (low tide terrace) occurred below the level of low spring tide. A step, or break in slope, marked the foreshore/low tide terrace boundary. The upper metre of the sand deposit was cross bedded. In the southern excavation, the bimodal gravel/sand contact extended 3.4 m below the level of low spring tide. Hey has difficulty in explaining this, as he prefers to limit gravel deposition to

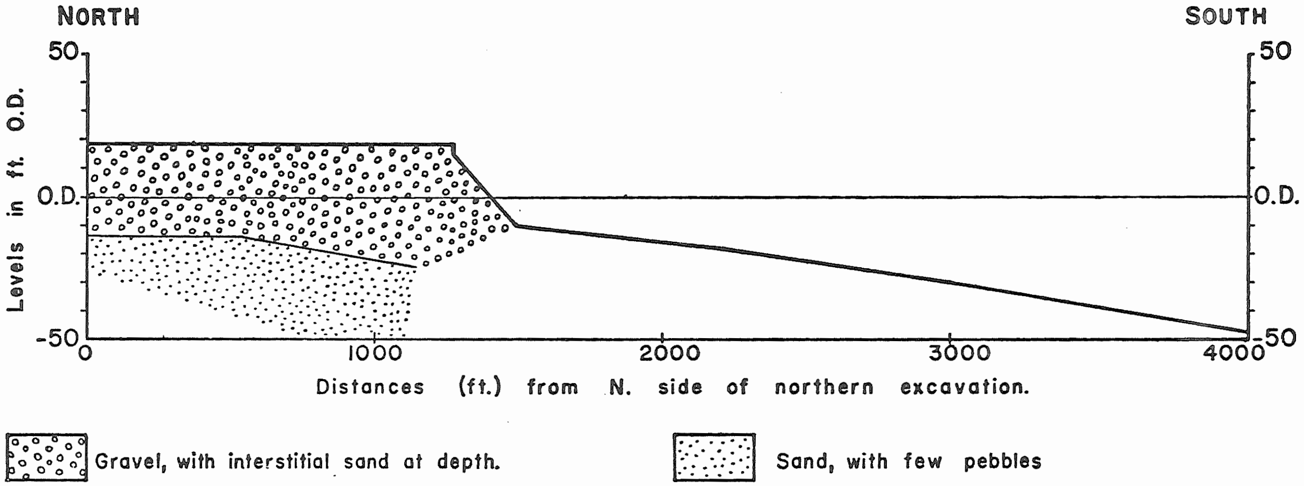


Fig. 5 (from Hey, 1967). N-S section across the southern edge of Dungeness and the adjacent sea floor. The line of the section runs along the eastern sides of the 1966 excavations.

Tides	High Water	Low Water
Ordinary neap	7.3'	-6.0'
Ordinary spring	12.7'	-10.2'
Equinoctial spring	14.8'	-12.8'

the intertidal zone, as it is on the modern beach at Kent. This problem will be discussed more fully in Chapter 5.

From the literature, the textural aspects of gravel beach can be summarized as follows:

1. Grain size may increase or decrease from the lower to the upper foreshore.
2. Supratidal gravel is coarser than gravel in the upper foreshore, and is openwork.
3. Intertidal gravel may be openwork or closedwork.
4. Sand preferentially occurs below, and gravel above, the level of low tide.
5. A terrace of finer grained sediment, that creates a break in the foreshore slope, may occur near the low tide level.
6. Gravel is deposited in the foreshore zone in conformable beds.
7. Disc-shaped pebbles increase in abundance landward, while spherical shaped pebbles increase in abundance seaward.
8. Imbricated pebbles occur in the upper foreshore to backshore zone of a beach. The maximum projection plane, and not the a-axis, is definitive of the imbrication.

Although beaches have not been used for paleotidal range determinations, the zonation of tidal flats based on sedimentary structures and textures led Klein (1971) to conclude that a paleotidal range could be determined from a fossil tidal flat. Tidal flats consist of a classic fining upwards sequence; sand in the lower, interbedded sand and mud in the middle and mud in the upper tidal flat. The upper limit of the tidal flat is marked by a salt marsh. The lower limit is more difficult to determine because of continuous sand from the subtidal to the lower intertidal. Sedimentary structures due to emergence runoff can be used to mark this boundary. These include:

1. ripple cross-lamination at 90° or 180° to dune cross-stratification (due to ebb-oriented ripples superposed on the dune slip face)
2. runoff rills
3. interference and double-crested ripples

Although this model is not applicable to beaches universally, parts of the model are useful. Emergence runoff features, possibly coupled with a change in slope and grain size (Shepard, 1948, 1973; Hey, 1967), could be used to define the subtidal/intertidal boundary. However, the intertidal/supratidal boundary is not marked by a salt marsh on a beach. Clearly, determining a paleotidal range from a beach requires better textural and structural knowledge than that which has been published.

Beach Nomenclature

Although beach nomenclature is fairly well established, definitions of a term vary from author to author. As an example, Shepard (1973) defines the seaward limit of a beach as low tide, whereas King (1972) defines the seaward limit as "..... the zone where the waves, approaching from deep water, first cause appreciable movement of the bottom material". Definitions for the beach nomenclature used in this thesis are selected from various authors on the basis of suitability. Figure 6 illustrates the subdivisions

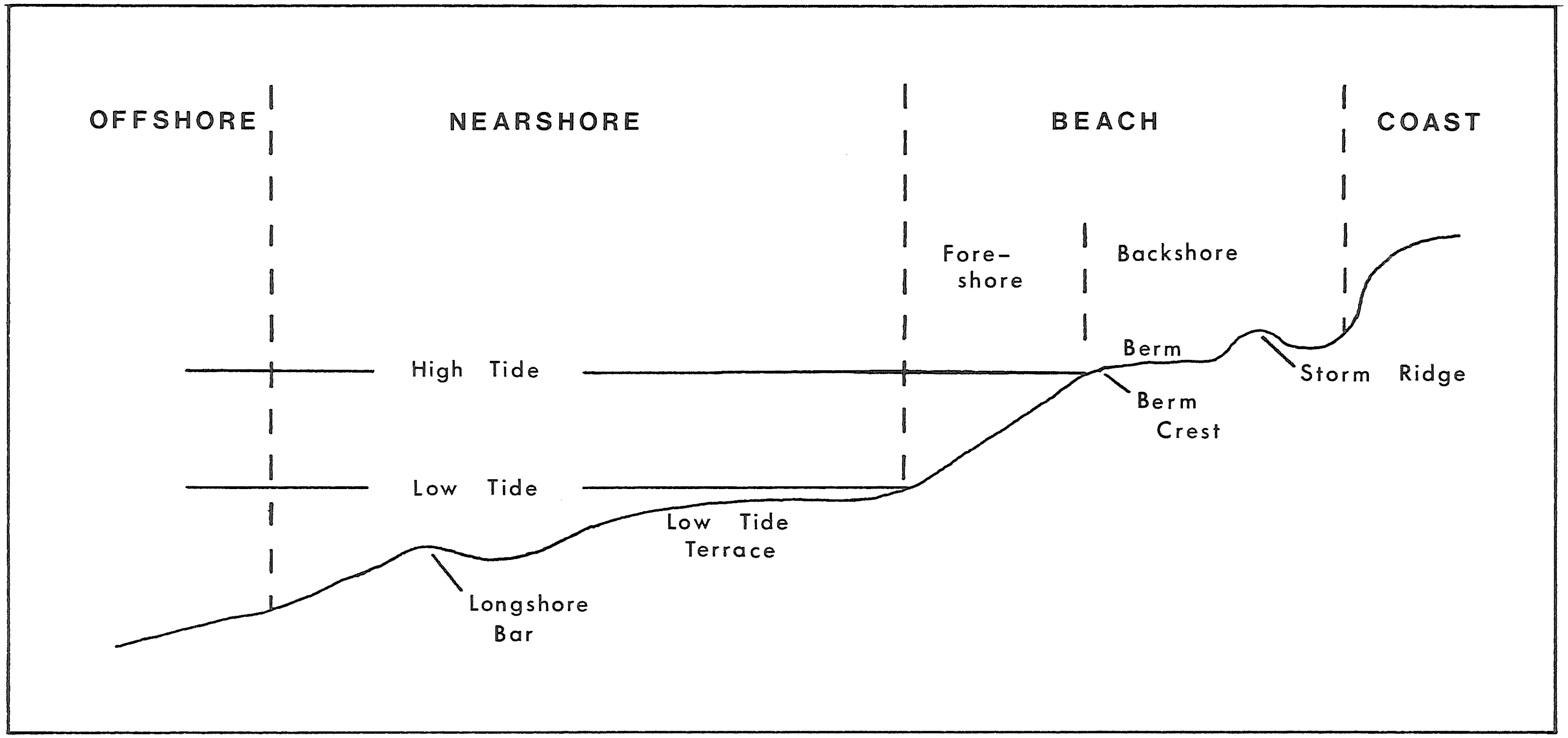


Fig. 6. Subdivisions of the beach and nearshore environment.

of a beach.

BACKSHORE - The zone of the beach lying between the foreshore and the coastline (Shepard, 1973).

BEACH - A sedimentary deposit, generally composed of sand or gravel, formed principally by wave action along the shore of a body of water. It extends landward from the low water mark to the effective upper limit of ordinary storm waves (Curray, 1969; Shepard, 1973).

BERM - A terrace formed in the backshore zone above the limit of the swash at high tide to form a flat terrace, or a ridge with a reverse slope (King, 1972).

BERM CREST - The seaward limit of a berm (Shepard, 1973). It occurs at the junction between the foreshore and backshore.

COAST - The landward limit of the beach, usually marked by a change in material or physiographic form as, for example, a sea cliff. The coastal material is not formed by the wave activity responsible for the beach (adapted from Shepard, 1973).

FORESHORE - All the part of the beach which is regularly covered and uncovered by the tide (King, 1972). This is synonymous with the term Beach Face Slope.

LOW TIDE TERRACE - The gently sloping terrace at the base of the foreshore zone, the upper part of which may be exposed at low tide. A step or break in slope frequently marks the foreshore - low tide terrace junction.

LONGSHORE BAR - A sedimentary deposit, generally of sand or gravel, that may be exposed under the lowest of tide levels, seaward of and parallel to a beach (adapted from Curray, 1969).

LONGSHORE TROUGH - The hollows found on the landward side of the longshore bars (King, 1972).

NEARSHORE - The area lying between the location of the transformation from sinusoidal to solitary waves and the foreshore zone (adapted from Clifton, 1971).

RIDGE AND RUNNEL - A dune-shaped accumulation of sediment in the foreshore with the lee slope facing landward. It is the result of a wave-induced attempt to steepen the foreshore slope to the equilibrium gradient. It can develop subtidally, but will migrate into the foreshore zone. Ridges and runnels are equivalent to King's (1949, 1972) swash bars.

STORM RIDGE - A low, lengthy ridge of beach material piled up by storm waves landward of the berm. Usually consists of coarse sand, gravel or shells. Occurs singly or as a series of more or less parallel ridges. Should not be confused with dune ridges that form particularly where the sand is fine and resemble beach ridges (Shepard, 1973, definition from BEACH RIDGE).

The seaward limit of the nearshore zone as defined by Clifton (1971) basically corresponds to the seaward limit of the beach as defined by King (1972, p. 23). King's definition was not used due to its more subjective nature.

Method of Study

A pit was excavated by the Nova Scotia Department of Highways in one of the raised spits at Advocate (Fig. 3) during the summer of 1974. The gravel was used to pave parts of highway 209 from Fraserville to New Salem. Continuous quarrying afforded three-dimensional exposure of the beach. At several stages during the quarrying, the outline of the pit was traced and the walls of the pit photographed (Fig. 7). A photolog of the final positions of the north and west walls was assembled to enable a facies reconstruction of the beach (see photolog in back, with accompanying facies diagram). This photolog will be referred to throughout the text of the thesis.

During the study, most of the quarrying was on the north wall, with a minor amount on the west wall (Fig. 7). The east wall falls on the property line, precluding excavation to the east. The south wall was unquarried, because of the location of the pit road and asphalt plant. Except for some new exposure on the north end of the east wall, the south and east walls remained unchanged. The photolog does not include the east wall, as it is a mirror image of the west wall, nor the south wall, as it had little exposure.

The modern beach at Advocate was also studied, but in less detail than the raised beach. It provided a useful analogue to the raised beach, especially since it is also a gravel beach. The modern beach will be mentioned in several parts of the thesis for the purpose of comparison.

Wentworth's scale and Folk and Ward's (1957) graphic statistics are used for grain size analysis. Fabric data is plotted on Schmidt equal area nets, using a lower hemisphere projection, and contoured at selected intervals.

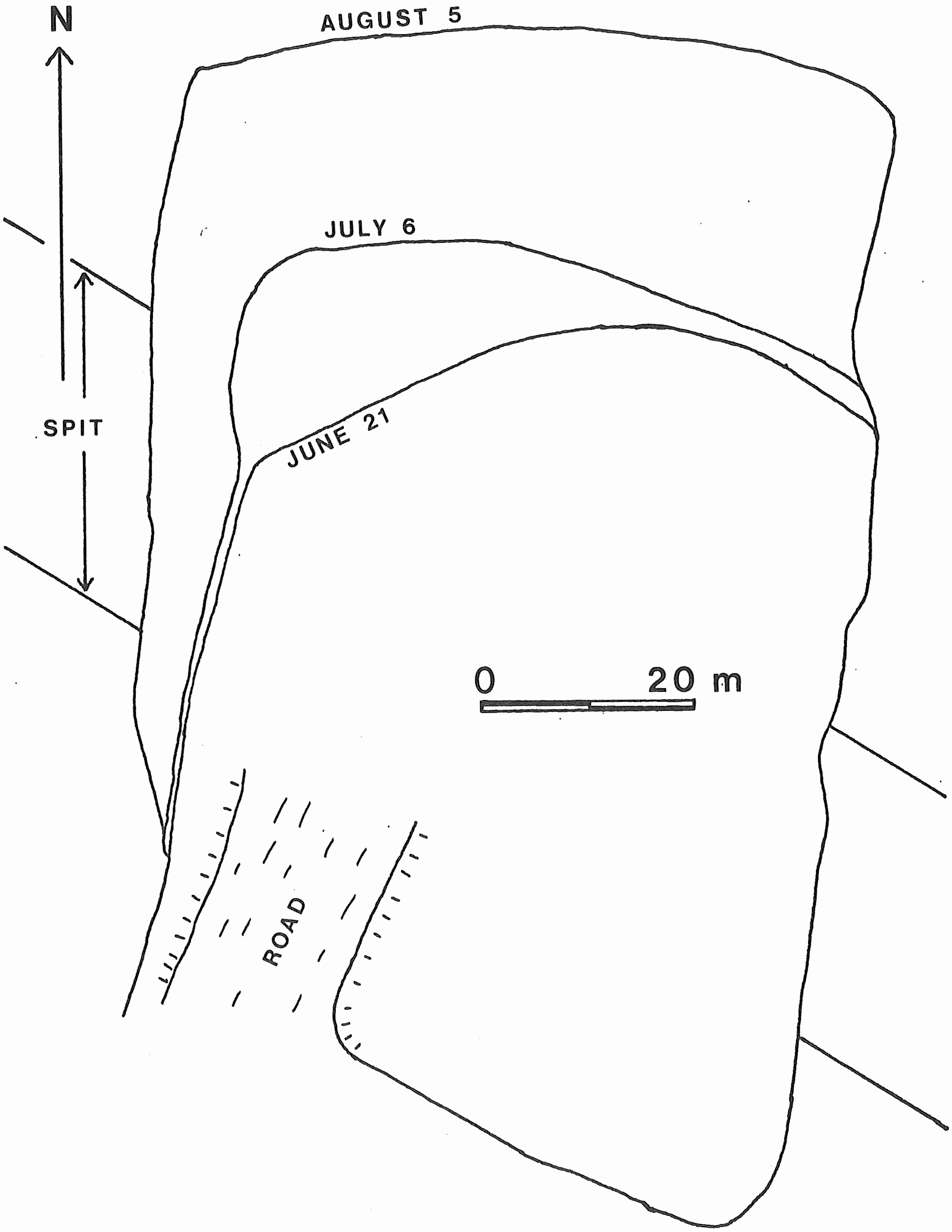


Fig. 7. Outline of pit during several stages of excavation in 1974. The pit was photographed at each stage.

A complete explanation of the methods used in grain size and fabric analyses is given in the appropriate appendices.

Stratigraphy

The beach can be divided genetically into two units (Figs. 8 and 9). The lower unit, Unit 1, is a regressive deposit representing a progradation of the beach. It is very coarse grained and consists predominantly of poorly sorted gravel beds dipping 5-14°S (seaward). In the lower southwest corner of the pit (see photolog) the dip of the beds flattens to 2-5°S, and there is a concomitant decrease in grain size to pebbly sand. In the upper northwest corner of the pit, the gravel beds dip 3-6°S and are finer grained and better sorted. Thus, the overall profile of the beds in Unit 1 is sigmoidal.

Unit 2, the upper unit, is a transgressive deposit that forms the spit described by Swift and Borns (1967) (Fig. 3). The contact between Units 1 and 2 is an angular unconformity in the southern part of the west wall, and a paraconformity in the northern part of the west wall (see photolog). Unit 2 is better sorted and finer grained than Unit 1. The core of Unit 2 consists predominantly of gravel dipping 20°-34°N. Overlying the gravel core is a sand deposit dipping 1°-4°S in the southern part and 1°-3°N in the northern part (see photolog) of the west wall.

To the south, an erosional contact separates Unit 2 from a series of seaward dipping(S) sand beds. The sand beds were probably deposited as the sea level was dropping, stranding the beach, and hence, will be referred to as the regressive sands. They are not included in Unit 2, and will not be

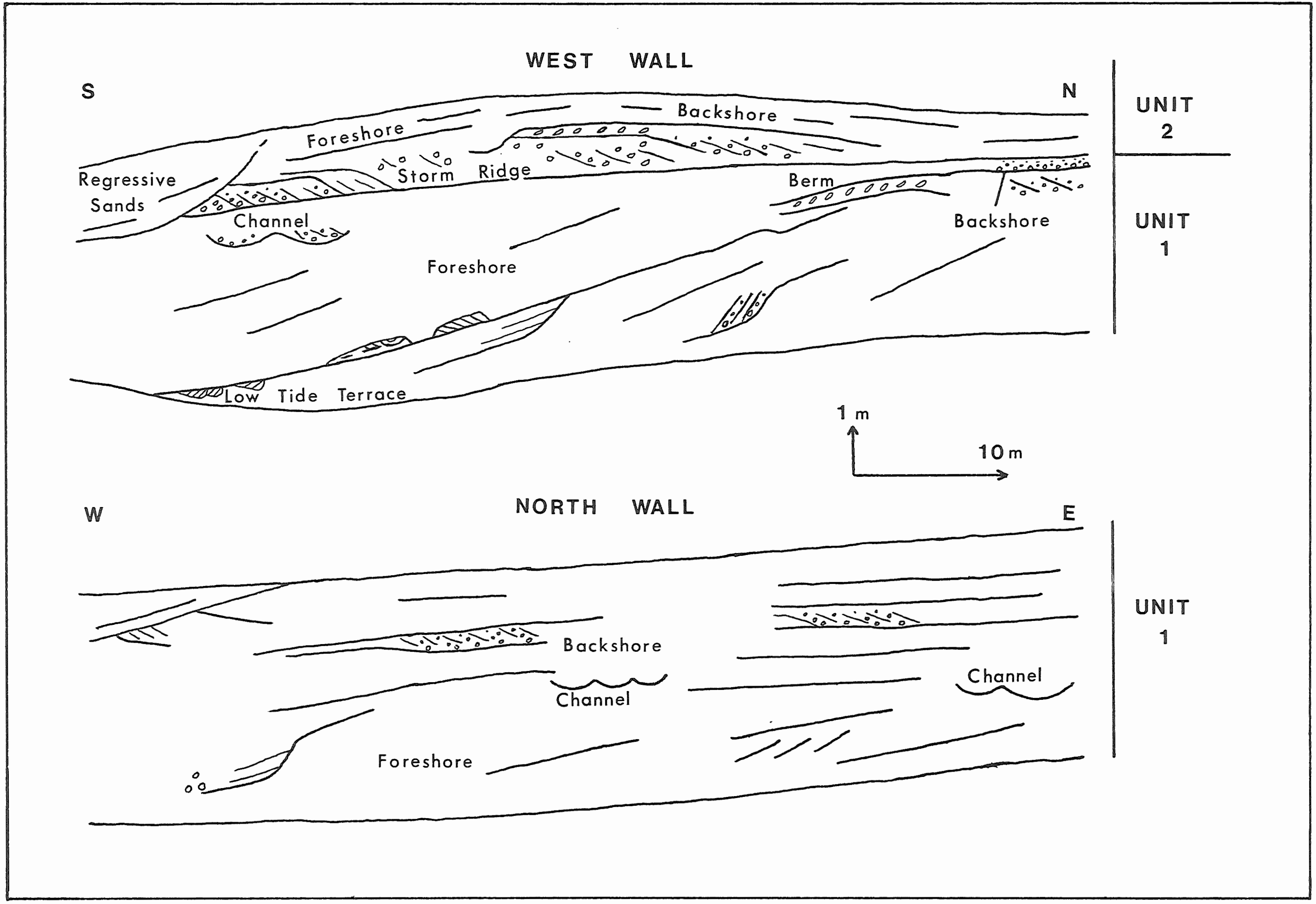


Fig. 8. Stratigraphy and facies of the main part of the west wall and all of the north wall.

dealt with in detail.

The west wall will be discussed most frequently, as it is a well exposed dip section. The azimuth of the west wall on the photolog is 004°. Strike of the beds in Unit 1 is 111°, giving a true dip azimuth of 021°. Strike of the beds in Unit 2 is 122°, the same as the trend of the spit, creating a true dip azimuth of 032°. Thus, the west wall gives a better approximation of true dip for beds in Unit 1 than beds in Unit 2. The azimuth of the north wall is approximately 090°, and hence, is a strike section.

Fig. 9. Looking along the trend of the raised beach at the west wall of the gravel pit. Note the landward (to the right) and seaward (to the left) slope of the land away from the crest of the beach.

CHAPTER II

FACIES OF UNIT 1

Introduction

The facies of the beach have been distinguished by their textures, structures and relative positions within the beach. Genetic names have been given to the facies to facilitate understanding of the text (rather than using terms such as facies A). Two distinctive facies exist in the backshore zone, necessitating the establishment of a sub-facies. The facies are:

Low Tide Terrace Facies

This facies is composed of sandy gravel and pebbly sand with low angle bedding dipping 2°-5°S. The sandy part of the facies is cross stratified, with all the cross stratification dipping to the south, indicating sand movement offshore. It is interpreted as a deposit formed below the level of low tide, in the nearshore zone.

Foreshore Facies

Poorly sorted gravel dipping 5°-14°S is predominant in the foreshore facies. Bedding is imparted by changes in sand matrix content and pebble concentrations. Steeply dipping (20°-27°S) cross beds form angular discordances within the foreshore beds. Sand ridges and runnels occur in the lower foreshore. It is interpreted as an intertidal, or foreshore, deposit.

Backshore Facies

Well sorted, graded beds dipping 3°-7°S are predominantly in this facies. The beds have erosional lower contacts, and are stacked in an overlapping manner as the strike of the beds varies. Lenses of openwork pebble beds dipping 24°-32°N occur within the graded beds. The beds were deposited in the backshore zone of the beach.

Berm Subfacies

The berm subfacies of the backshore facies consists of low angle beds (1°-5°) that dip north and/or south. Coarse pebble beds are common, and the pebbles are strongly imbricated seaward. The beds form a terrace or berm in the backshore zone of the beach.

Channel Facies

Stratification in the channel facies is size specific. Small channel deposits are massive and poorly bedded. Larger channel deposits (>2.0 m wide) have low angle beds with a variable dip direction, or high angle beds dipping 18°-34°N. The larger deposits are interpreted as tidal channel deposits, while the smaller deposits are interpreted as storm runoff channel deposits.

Description and Interpretation

This section contains the description and interpretation of each of the facies in Unit 1. The facies will be described individually under the following headings:

a. Occurrence

b. Stratification

c. Grain Size

d. Fabric (where appropriate)

e. Interpretation

Low Tide Terrace Facies

Occurrence

The low tide terrace is exposed only in the deepest part of the pit, along the south end of the west wall (A, photolog). On the other walls, excavation was not sufficiently deep to expose this facies. It occurs immediately below the foreshore facies (Fig. 10). The foreshore beds are traceable into the low tide terrace, and the contact between the two facies is somewhat arbitrary. Tidal terrace beds dip from 2°-5°S while the foreshore beds dip 5°-14°S. As the dip decreases, so does the grain size. The contact is based both on the change in dip and grain size.

Stratification

The low tide terrace is composed of two parts: 1. gravel with sand matrix dipping 2°-5°S and 2. high angle, cross stratified sand, with occasional pebbles and fine gravel, dipping predominantly south. The sandy part occurs in the extreme southwest corner of the pit (A, photolog).

1. Although foreshore beds are traceable into the gravel low tide terrace beds, there are several differences in stratification. Beds are

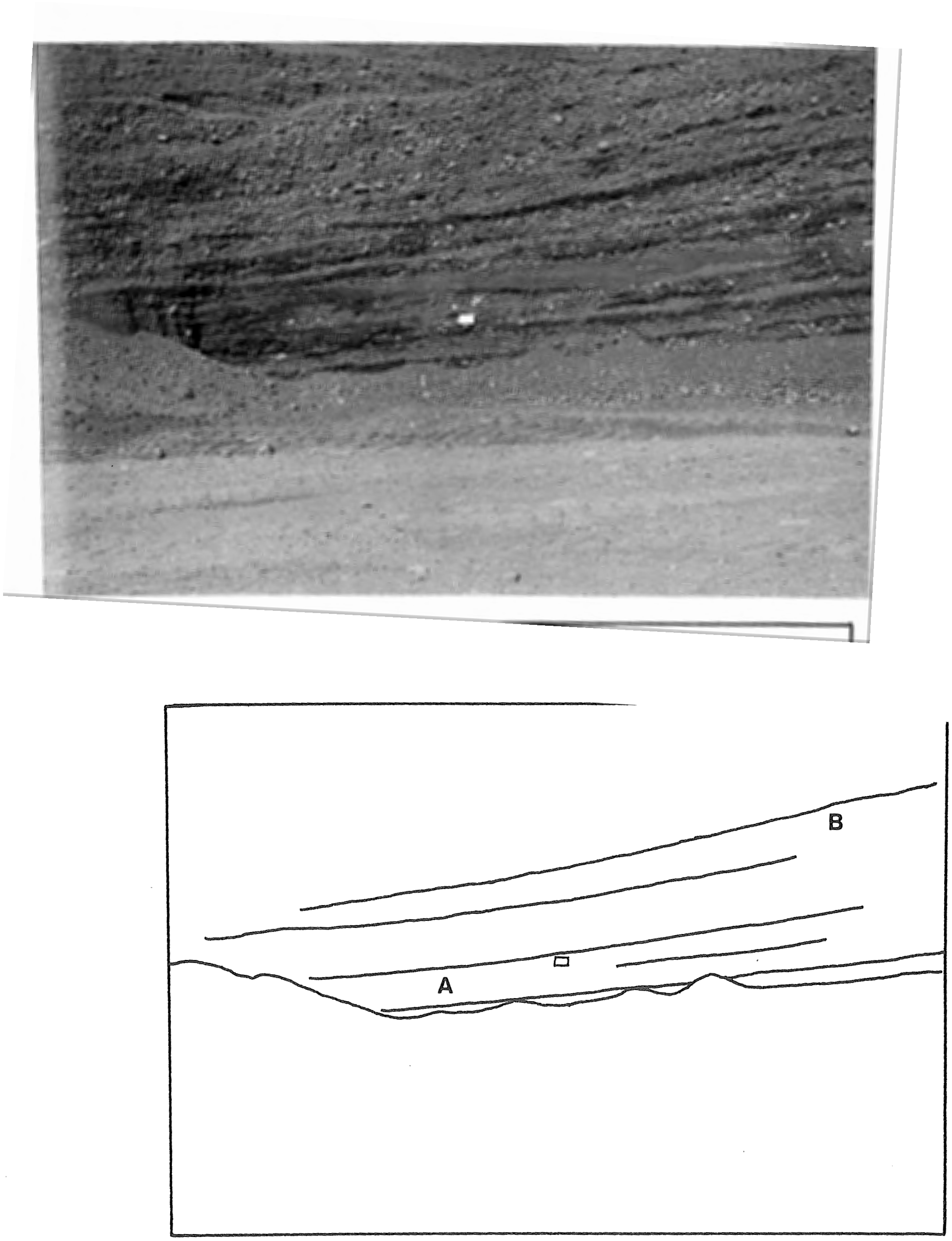


Fig. 10. High angle foreshore beds (B) flattening into low angle beds in the low tide terrace (A). Notebook for scale.

thinner (generally 10-20 cm thick), have lower dips and are laterally more continuous than in the foreshore facies. Erosional surfaces and the large scale cross beds of the foreshore are absent, creating a "layer cake" type of bedding. Bedding is imparted by changes in grain size and matrix content. Sedimentation was less rapid in the terrace facies, as beds less than 1 m apart in this facies are more than 1.5 m apart in the foreshore facies.

2. The sand deposit in the low tide terrace is a marked change from the gravel in the foreshore zone. It is a complex of shallow, dish-shaped depressions, 1-3 m wide and 10-25 cm deep, filled with predominantly southward dipping cross stratified sand (Fig. 11). The depressions are asymmetric with a steep side dipping 12°-21°S and a gently sloping side dipping 4°-8°N. Internal stratification follows the trend of the outer morphology. The initial fill varies from thinly to thickly laminated sand, with scattered pebbles, that dip 12°-21°S. As the depression is filled, the dip of the laminated sand lesses, first becoming asymptotic, than parallel laminated with a dip of 1°-4°S and frequently reverses dip to 1°-3°N to finish the infill. Pebbly sand, with the same structure, is present in the lower part of the deposit.

Grain Size

The gravel in the low tide terrace is generally finer than the gravel in the lower foreshore (Fig. 12), and ranges from poorly to very poorly sorted. The sandy part of the low tide terrace consists of well sorted, medium grained sand (sample 146) and poorly sorted pebbly sand (sample 147). The pebbly sand occurs in the lower right of Fig. 11 and the well sorted sand occurs immediately below the trowel in the center of Fig. 11. Grain

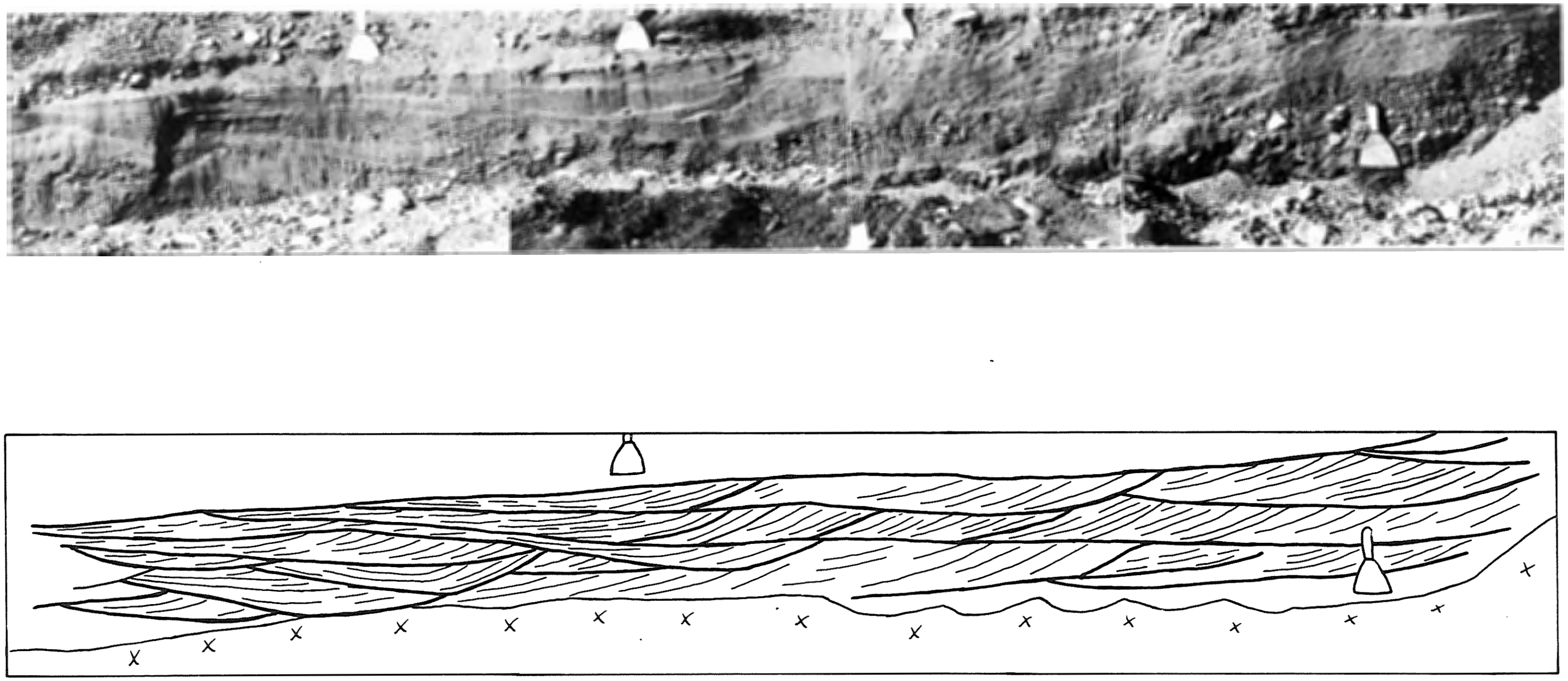
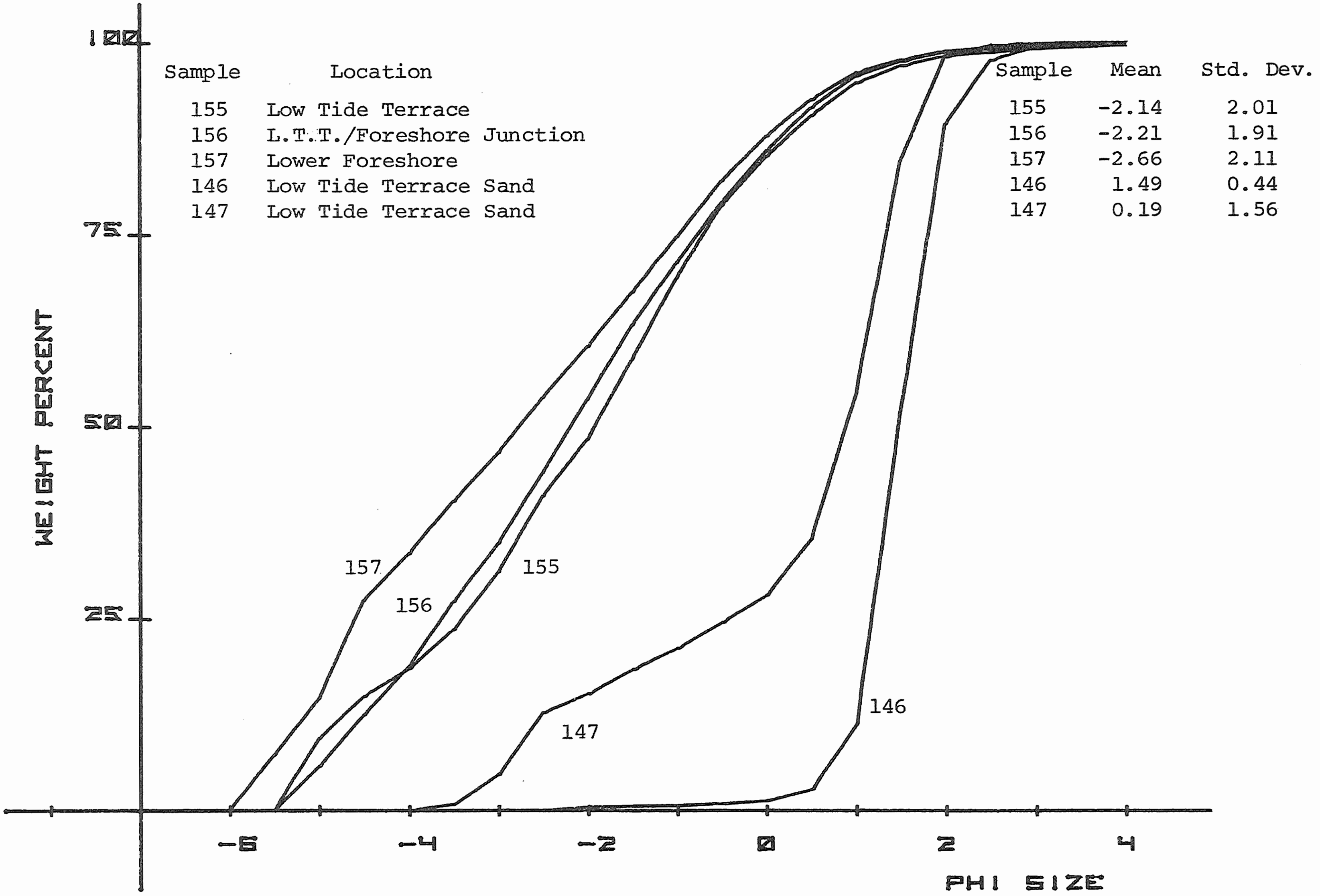


Fig. 11. Sandy part of the low tide terrace facies composed of shallow, asymmetric depressions. Cross stratification dips to the south.



Sample	Location
155	Low Tide Terrace
156	L.T.T./Foreshore Junction
157	Lower Foreshore
146	Low Tide Terrace Sand
147	Low Tide Terrace Sand

Sample	Mean	Std. Dev.
155	-2.14	2.01
156	-2.21	1.91
157	-2.66	2.11
146	1.49	0.44
147	0.19	1.56

Fig. 12. Grain size analyses, low tide terrace.

size analyses of samples 64 and 152 (Fig. 23, foreshore facies) yield cumulative plots of the same general shape as the plots for samples 146 and 147. It would be hazardous to interpret facies solely on the basis of cumulative curves.

Interpretation

The low tide terrace facies is interpreted as a subtidal deposit adjacent to the foreshore zone. As Hey (1967) suggests, sediment deposited in the subtidal zone should show differences from sediment deposited in the foreshore zone, despite their proximity. The criteria for a subtidal origin are:

1. finer grain size
2. lower dips than in the foreshore facies
3. sediment movement offshore
4. absence of exposure features

1. and 2. Foreshore beds can be traced into the low tide terrace, but are finer grained and have lower dips than in the foreshore facies. The reduction in dip cannot be entirely accounted for by the reduction in grain size, as part of the terrace is gravel.

The reduction in dip is related to the different processes acting in the subtidal and the foreshore zones. In the foreshore zone, the swash steepens the face of the beach, particularly in a gravel beach where water loss on the swash results in a relatively weak backwash (King, 1972).

Below the level of low tide, this steepening process does not occur, so dips of beds are less. The change in slope often produces a step at the base of the foreshore zone (Bagnold, 1940; Clifton, 1971). The step is more pronounced when a change in grain size occurs at the foreshore/subtidal boundary.

The literature on gravel beaches suggests that there is a tendency for sand to accumulate in the subtidal zone and gravel to accumulate in the foreshore zone. Why is this so? Why is the low tide terrace finer grained than the foreshore facies?

Rector (1954) found that beach material had a greater tendency to move landward as the grain size increased under given wave conditions. Bagnold (1940) conducted wave tank experiments and observed the same phenomena. He reasoned that since the swash is stronger than the backwash, especially on gravel beaches where water loss is high, large particles are moved landward because the swash is above the critical velocity for the large particles. The accompanying backwash is below the critical velocity for the large particles, and so, can not move them seaward. However, the backwash is above the critical velocity for fine grained sediment, and can return the sand seaward. This results in a segregation of coarse material in the foreshore zone, and fine material in the subtidal zone.

Although this segregation is preferred in nature also, sediment supply ultimately determines whether the subtidal zone will be composed of sand or gravel. If only gravel is supplied to the beach, the low tide terrace will be composed of gravel. If sufficient sand is supplied to the beach, the low tide terrace will be composed of sand. A gravel-starved beach will have the gravel/sand contact within the foreshore zone, but the sand in the foreshore zone will have different sedimentary structures than the subtidal sand (Page 126). The effect of gravel supply is visible on the modern beach at Dungeness, England (Hey, 1967). The gravel/sand contact falls from above low spring tide on the north to below low spring tide on the south end of the beach. Gravel supply is from the south.

3. The southward-dipping cross stratification in the sandy part of the low tide terrace indicates sediment movement offshore. Cross stratification in the sands in the lower foreshore, immediately above the low tide terrace, dip predominantly northward, indicating sediment movement landward. This change in the direction of sediment movement is the main criteria for the low tide terrace being formed subtidally.

Clifton (1971) describes asymmetric depressions, similar to those in the low tide terrace, in the "inner rough facies", immediately below the foreshore zone, off gently sloping beaches. The depressions are of similar size to those in the low tide terrace, and have the steep side facing seaward. Over a period of time, the depressions migrate seaward, producing trough cross stratification from 4-100 cm thick. The resultant internal structure of the inner rough facies is similar to that of the low tide terrace (Clifton, 1971, p. 657, fig. 10).

Wave theory (King, 1972) predicts offshore sediment movement at beaches where wave steepness, wave height (H)/wave length (L), is above a critical value. The critical value increases as the grain size of the beach sediment and/or gradient of the beach increases. Wave steepnesses, calculated by this author from Clifton's (1971) wave data using the modal values, are greater than 0.025 and predict offshore sediment movement at Whalehead Cove. This agrees with Clifton's observations. Thus, during high wave activity, sediment movement is offshore, and during low wave activity, sediment movement is onshore. This is why storms remove sediment from a beach, and ridge and runnel systems return sediment in calmer weather.

In the low tide terrace, the cross stratification indicates that all of the sediment movement is offshore. There are two possible explanations for this; wave steepness was always greater than the critical value or the preservation potential of structures produced by onshore sediment movement is low. It seems improbable that wave steepness was continually above the critical value. More plausible is a low preservation potential for structures produced by onshore sediment movement. High wave activity causes erosion of the low activity bedforms and structures, and produces offshore sediment movement structures and bedforms. Onshore sediment movement bedforms are re-created during calmer periods, but the high wave activity structures are not completely eroded.

4. There is an absence of features formed in the swash zone of a beach. Erosional features, like the cross beds or buried scarps of the foreshore, do not occur in the low tide terrace. Emergence runoff features, such as the runnels, are confined to the foreshore. This evidence is not completely satisfactory, as the thickness of exposed low tide terrace sediments is small. But in the exposed section, these features are absent.

Foreshore Facies

Occurrence

The foreshore facies occurs on all of the walls of the pit. Except in the southwest corner of the pit, the foreshore facies is the lowest facies exposed. It is overlain by backshore beds of either Unit 1 or Unit 2, or regressive sands (see photolog). On the north wall, the contact with the backshore beds is distinct and erosional at the west end (B, photolog), but moving eastward, channel deposits (C, photolog) and a bed deposited near the foreshore/backshore boundary (discussed on page 58) make the boundary less clear. Since the north wall is slightly oblique to strike, the foreshore facies appears as a succession of low dip beds, younging to the west. The maximum height of the foreshore facies increases from 25.9 m above sea level on the east side to 26.4 m above sea level on the west side of the north wall.

On the west wall, the foreshore facies attains its maximum thickness of 3.4 m. In the northwest corner, the contact between the foreshore beds and overlying backshore beds of Unit 1 is obscured by erosional channel deposits (D, photolog). To the south of this a well developed berm deposit (E, photolog) defines the upper limit of the foreshore beds. Farther south, an erosional contact separates the foreshore beds from Unit 2 (F, photolog). In the south corner of the west wall, regressive sands, deposited after Unit 2 was formed, overlie the foreshore beds of Unit 1 (G, photolog). The foreshore beds can be traced into the low tide terrace facies in the southwest corner of the pit (A, photolog). The maximum elevation for the foreshore facies on the west wall is 25.6 m at the berm deposit.

Stratification

The overall shape of the foreshore beds is sigmoidal, going from a concave-up surface in the lower foreshore to a convex-up surface in the upper foreshore. There are three types of stratified deposits within the foreshore facies:

1. coarse, poorly sorted gravel dipping 5°-14°S
2. alternating beds of graded openwork and closedwork gravel dipping 20°-27°S
3. well-sorted,stratified sand with a predominantly northward component of dip.

1. The bulk of the sediment in the foreshore facies is poorly sorted gravel. Bedding is imparted by changes in a) pebble concentrations, b) fine grained matrix content or c) both. Generally, the changes occur gradually and do not produce well-defined beds; the facies is rather massive. The exception is beds with a marked concentration of pebbles and fine grained matrix in which the intermediate grain sizes are absent. These beds (hereafter called pebble beds) stand out as dark areas on the pit face (Fig. 13) due to the moisture content of the matrix. The upper contact of the pebble beds is usually sharp and planar, while the lower contact is gradational and irregular. Many of the beds are discontinuous and grade into more massive intervals up and/or down dip.

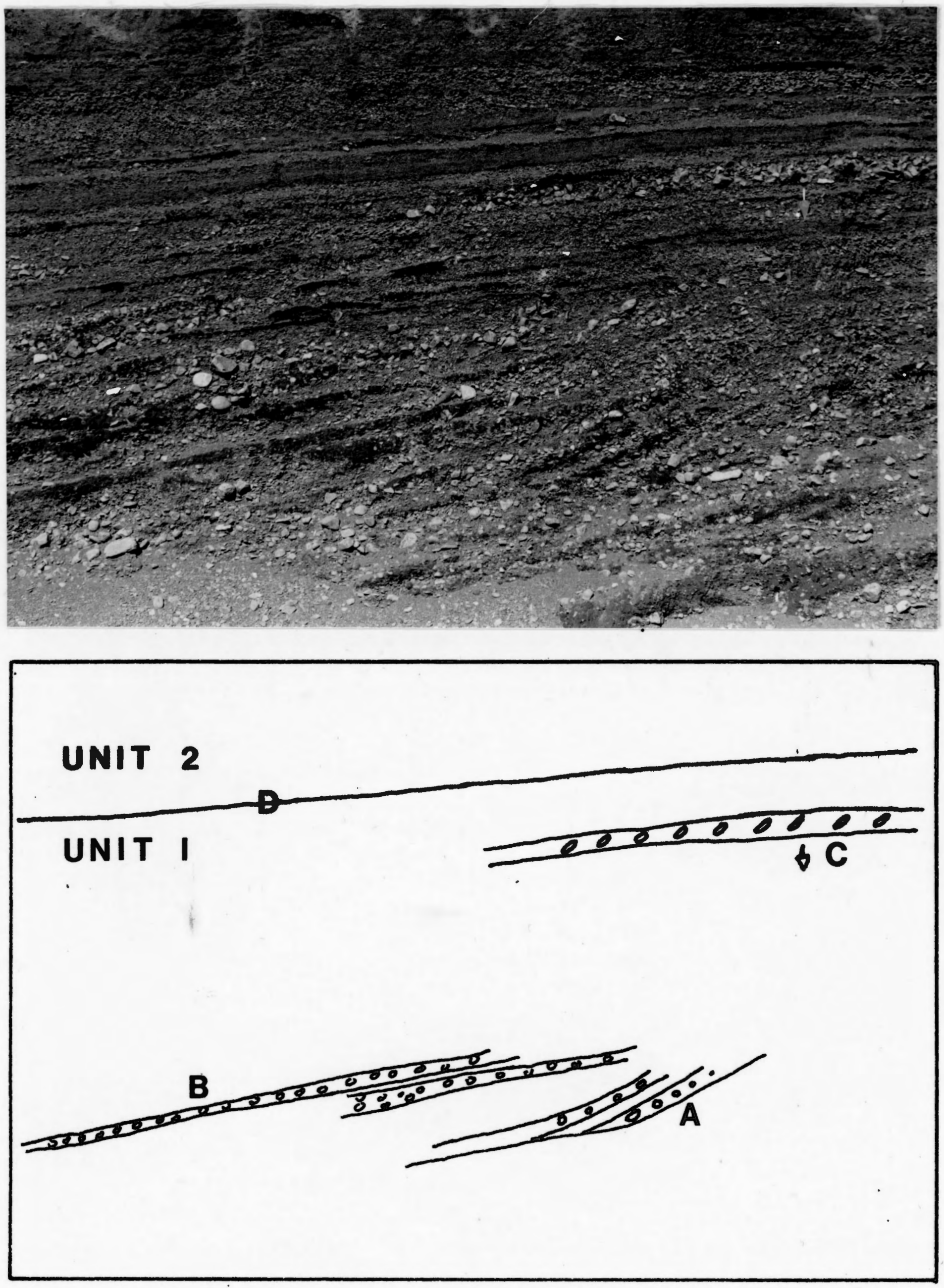


Fig. 13. Foreshore facies and berm subfacies, Unit 1. A alternating openwork (light) and closedwork (dark) cross beds. Lowest openwork bed is graded; B pebble beds with a high percentage of fine grained matrix stand out as dark beds. Upper contact is sharper than the lower contact; C trowel for scale. Above trowel is the prominent pebble bed in the berm subfacies; D Unit 1 - Unit 2 contact.

Beds in the lower foreshore dip 5°-8°S, while those in the mid to upper foreshore dip 8°-14°S. Some of the beds flatten in the upper foreshore before passing into backshore beds. Bed thicknesses are generally 20-30 cm, with a maximum of 50 cm. The maximum length of a single bed is 17 m.

The poorly sorted gravel beds form an essentially conformable sequence. However, there are several erosional surfaces. At H and I on the photolog, scarp-like features are infilled with beds that are parallel to the surrounding foreshore beds. Coarse gravel occurs at the toe of the scarp at I. These features are similar to a buried scarp described by Thompson (1937, page 735, PL. 4, Fig. 1) in a sand beach.

2. Within the conformable sequence of poorly sorted gravel beds, there are cross beds consisting of alternating openwork and closedwork gravel dipping 20°-27°S (Figs. 13-16). Length and thickness of the beds vary, but most beds are approximately 1 m long and 15 cm thick. The cross beds are asymptotic, flattening at their lower contact to a dip which is conformable with the poorly sorted gravel beds. The openwork gravel is frequently graded from a coarse gravel at the base to a finer gravel at the top of the bed.

The contact between the cross beds and the poorly sorted gravel beds is erosional. The overall dip of the cross beds decreases in a seaward direction, until the cross beds pinch out within the poorly sorted gravel beds. An erosional contact occurs between two sets of cross beds in juxtaposition (Fig. 14).

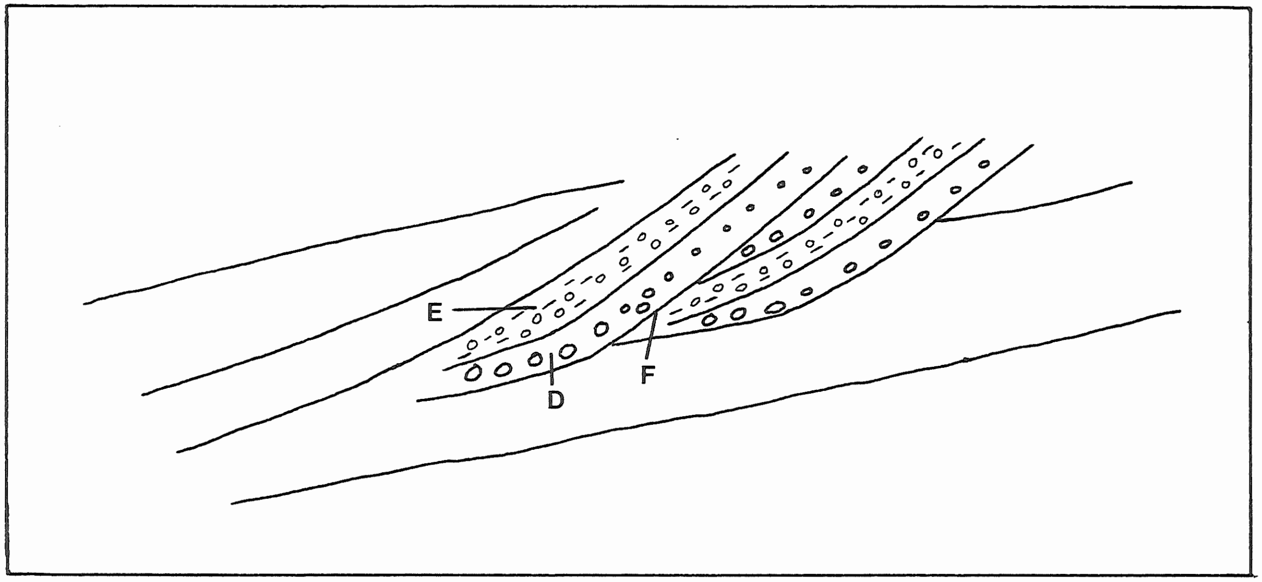


Fig. 14. Schematic diagram of the cross beds in the foreshore facies, Unit 1. D graded openwork cross bed; E closedwork cross bed; F erosional surface.

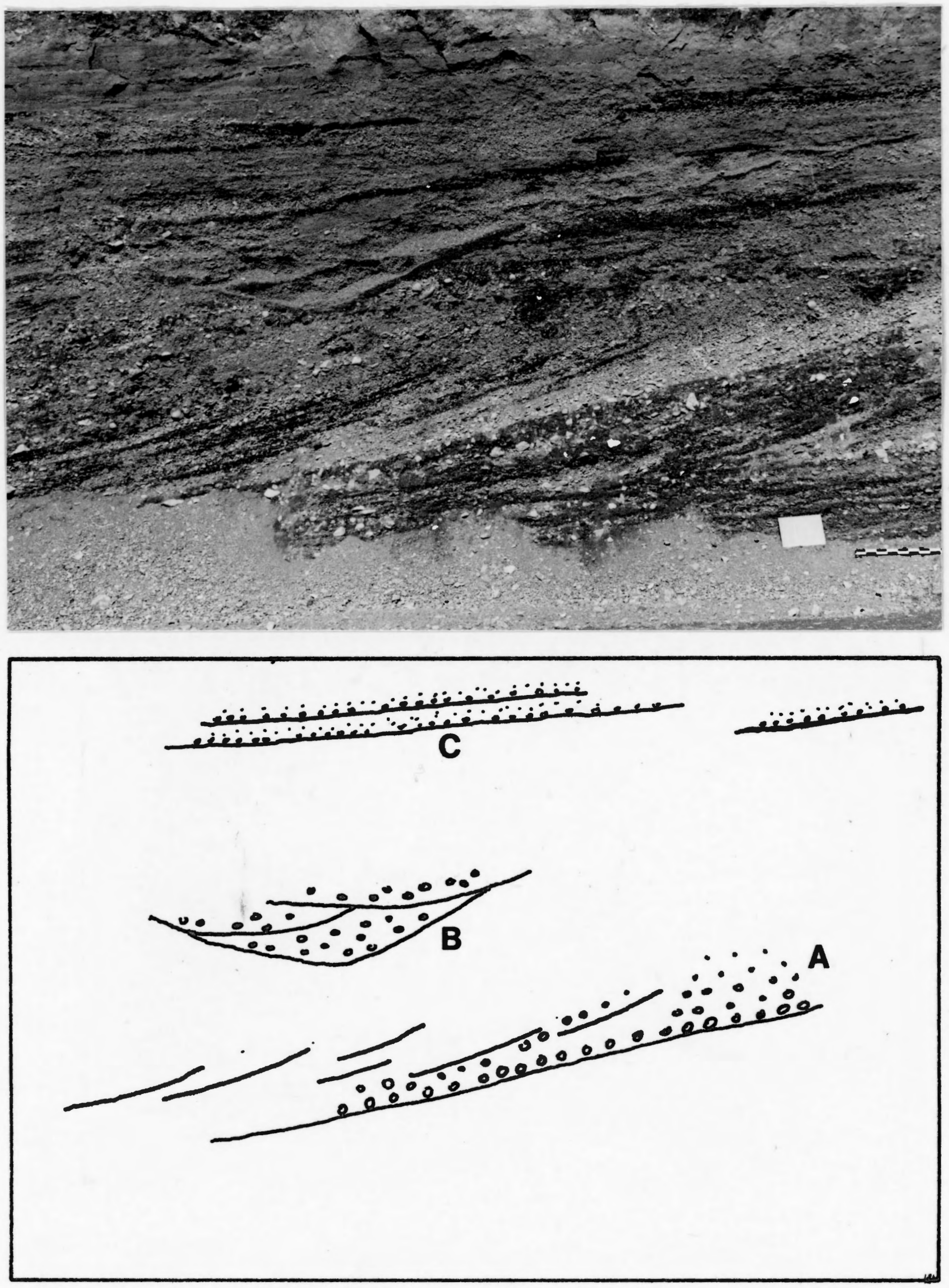


Fig. 15. Foreshore and backshore facies, Unit 1. A cross beds extending from the lower to upper foreshore. In the upper foreshore, the matrix-rich cross beds are absent; B channel deposits; C graded backshore beds.

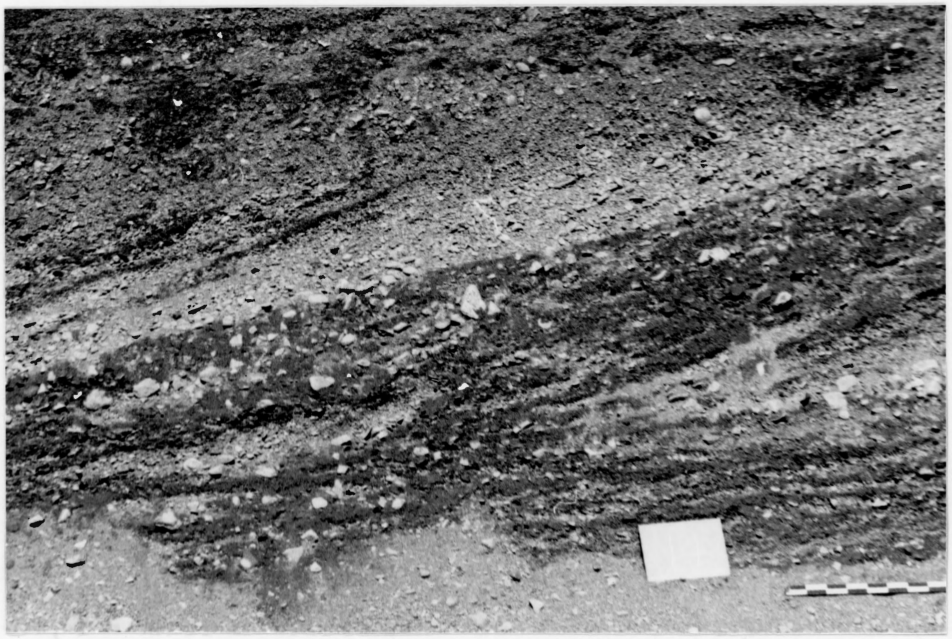


Fig. 16. Graded bed in Fig. 15 formed by amalgamation of graded openwork cross beds.

The cross beds occur anywhere from the upper to the lower foreshore, although they are larger in the lower foreshore (see photolog). A particularly long set of cross beds occurs at J on the photolog. This set extends from the upper to the lower foreshore (12.5 m horizontal distance). In the upper part of the bed, closedwork gravels are absent and the amalgamated openwork beds produce a graded bed with a sharp base (Fig. 15 & 16). The longest cross beds occur in the lower part of this bed (up to 3.3 m).

3. In the lower foreshore on the west wall, there are two lenses of well sorted sand with internal stratification having a strong northward component of dip (K and L, photolog). The sand lenses are the only occurrences of gravel-free sand in the foreshore facies of Unit 1.

The upper sand lens (L, photolog) consists entirely of thinly laminated sand dipping 13°-27°N (Fig. 17). The sand lens is 1.5 m long, with a maximum thickness of 20 cm. Foreshore beds above and below it dip 8°S and 5°S respectively. The laminae initially dip 13°N, but steepen to a maximum dip of 27°N in the central part of the lens. Stoss-side parallel lamination is absent, possibly due to the erosional upper surface of the sand lens.

The lower sand lens is more complex and was formed by several depositional events. At the down dip end, there is a parallel laminated sand that is conformable with the surrounding foreshore gravel beds. To the north of this, cross stratified sands dip both north and south. The northward dipping (15°-24°N) sands are similar to the sand in the upper sand lens. They are thinly laminated, and stoss side parallel lamination is absent.

Fig. 17. Upper sand lens in the lower foreshore, with cross stratification dipping landward (north). Note the dip of the foreshore bed below the sand lens is less than the dips of the foreshore beds above it.

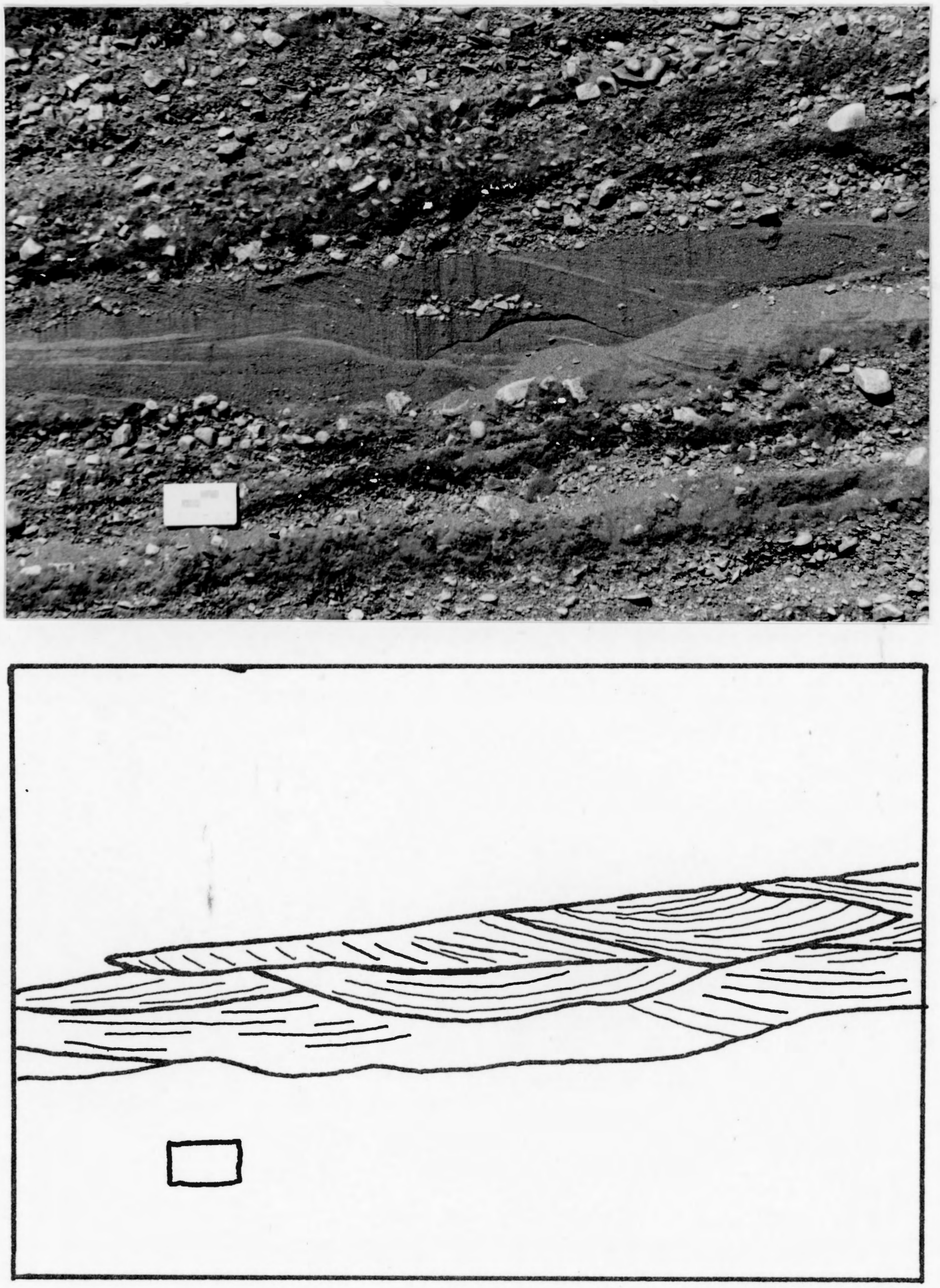


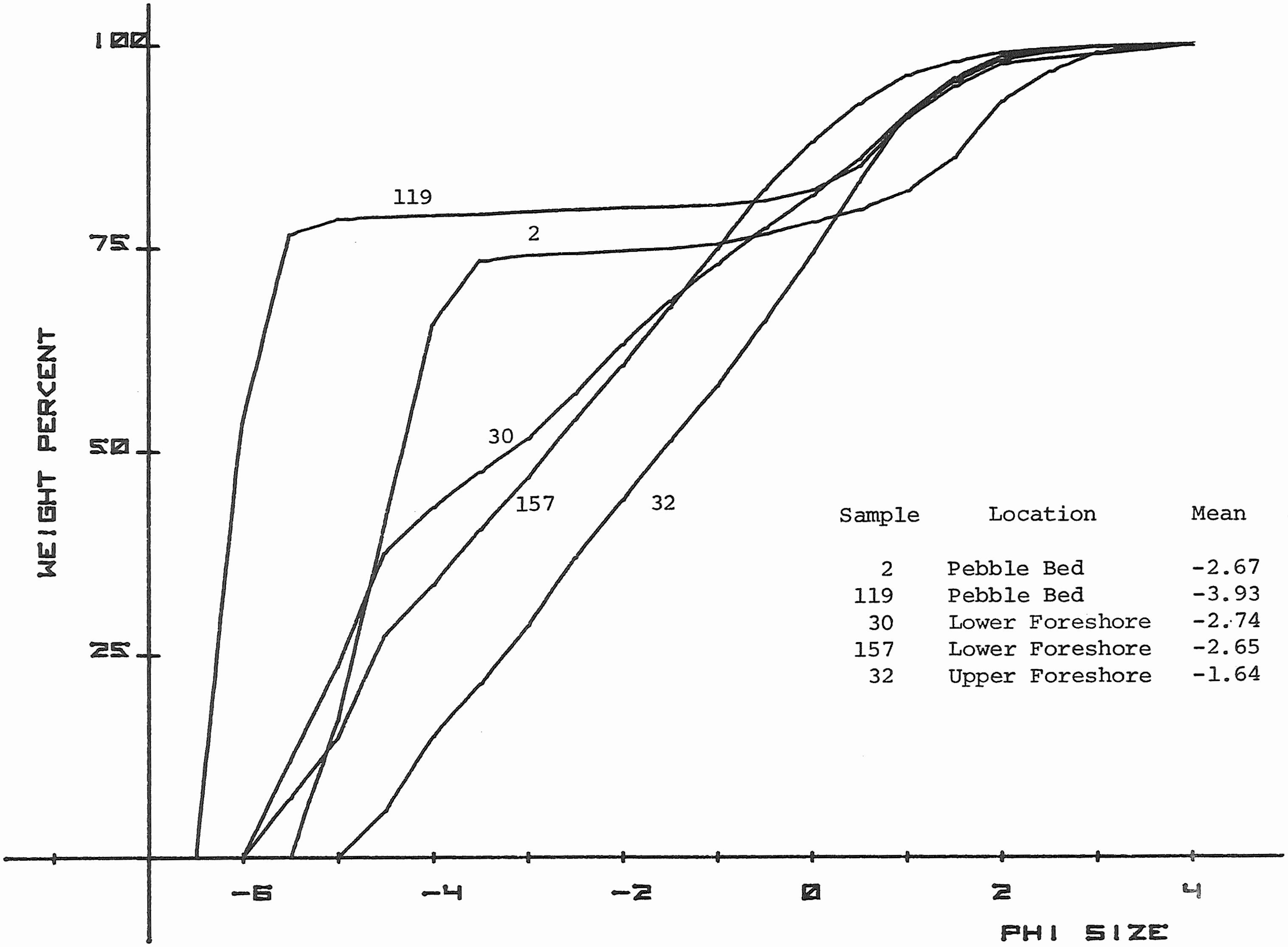
Fig. 18. Lower sand lens composed of ridges and runnels. Some runnels have cross stratification dipping predominantly to the south (left).

The predominantly southward dipping sands infill channel-like depressions up dip from the northward dipping sands. The sand dips 10°-12°S initially, but shallows as the channel is filled. Laminae may assume a symmetrical channel shape in the final stages of fill (Fig. 18).

Grain Size

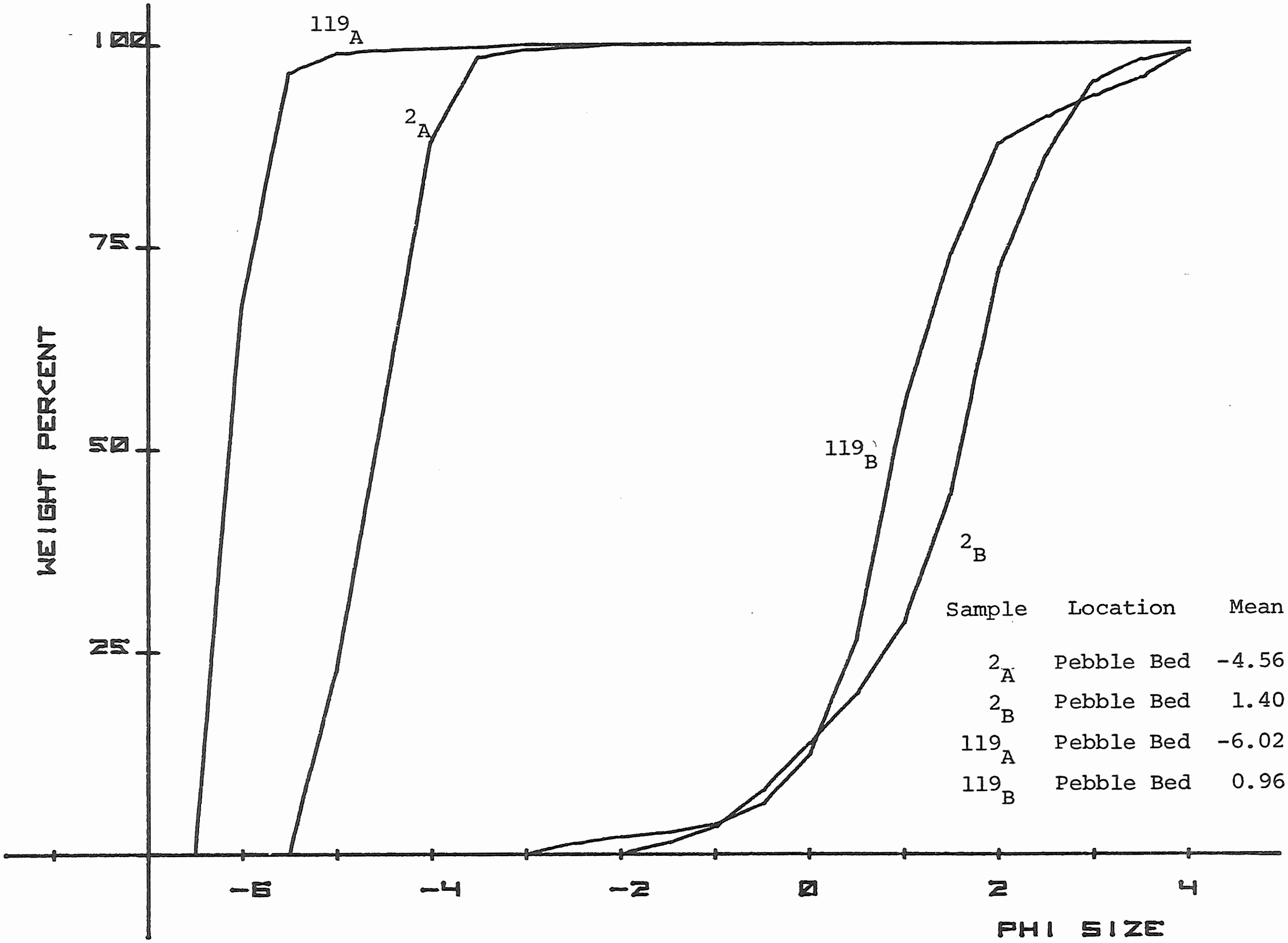
Changes in the matrix content and grain size of the poorly sorted foreshore beds are shown in Fig. 19. Samples 30, 32, and 157 are from massive beds, while samples 2 and 119 are from pebble beds. Samples 30, 32 and 157 show a decrease in grain size from the lower foreshore (30, 157) to the upper foreshore (32), which is the usual relationship. The samples are very poorly sorted, but sorting is better in the upper than in the lower foreshore. The marked concentration of pebbles and sand matrix in the pebble beds is evident in samples 2 and 119. The fine gravel and coarse sand components are almost entirely absent. Sorting is the worst for these two samples, but in fact, the samples are composed of two better sorted end members. This is shown in Fig. 20 where the end members have been replotted as separate samples. Samples 119 and 2 were split at -3ϕ and -2ϕ, respectively, for the replot. The pebbles are well sorted (2_A) and very well sorted (119_A), while the sands are both moderately poorly sorted. The sand is probably a post-depositional infiltrate. All of the samples are polymodal except for 2, which is bimodal.

Samples from the foreshore zone of the modern beach are shown in Fig. 21. They are polymodal and decrease in grain size from the lower (301) to the upper (308) foreshore, similar to samples 30, 32 and 157 in Fig. 19. The



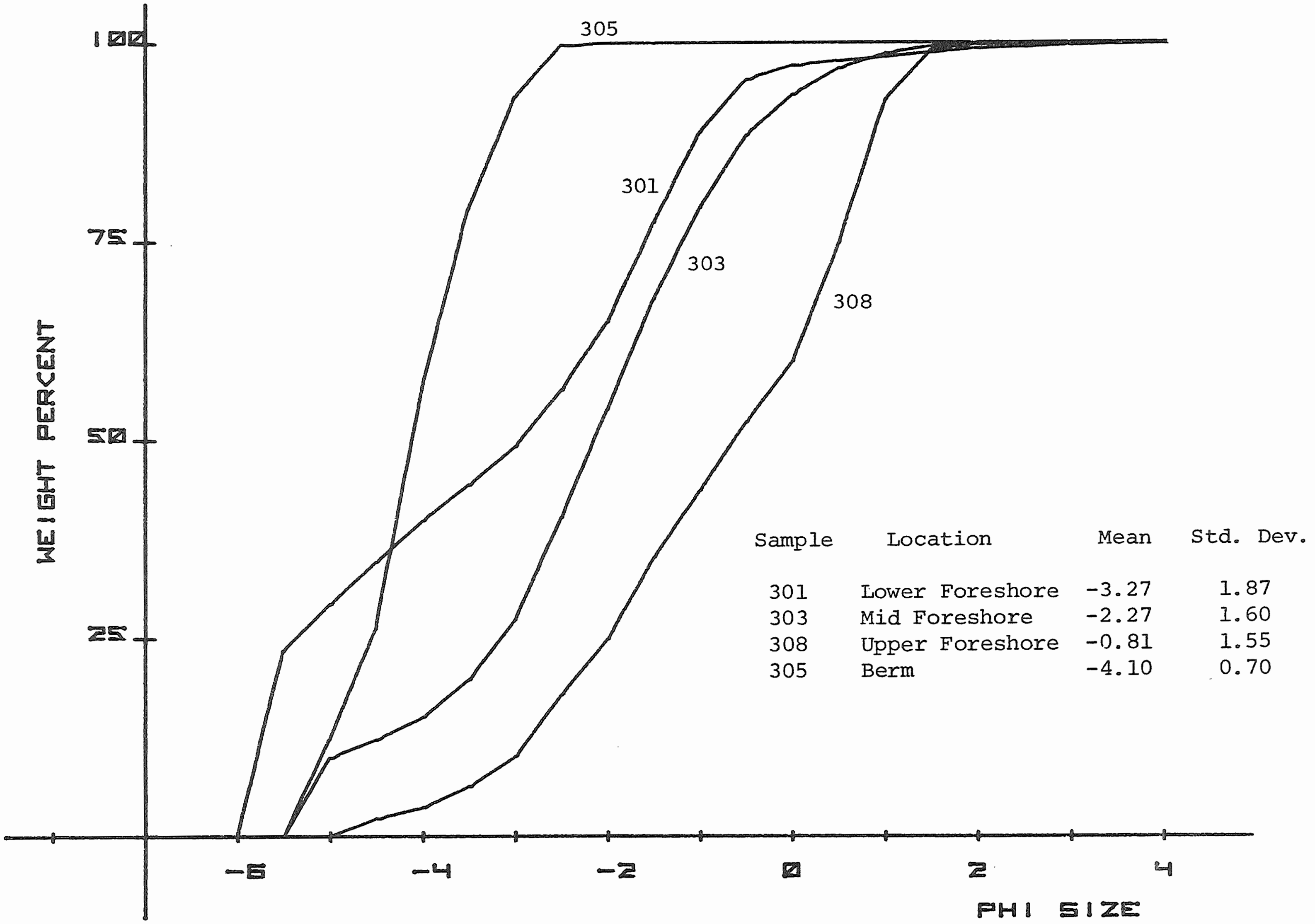
Sample	Location	Mean	Std. Dev.
2	Pebble Bed	-2.67	2.70
119	Pebble Bed	-3.93	2.82
30	Lower Foreshore	-2.74	2.46
157	Lower Foreshore	-2.65	2.13
32	Upper Foreshore	-1.64	2.02

Fig. 19. Grain size analyses, foreshore facies.



Sample	Location	Mean	Std. Dev.
2_A	Pebble Bed	-4.56	0.45
2_B	Pebble Bed	1.40	1.11
119_A	Pebble Bed	-6.02	0.19
119_B	Pebble Bed	0.96	1.03

Fig. 20. Replot of samples 2, 119, foreshore facies.



Sample	Location	Mean	Std. Dev.
301	Lower Foreshore	-3.27	1.87
303	Mid Foreshore	-2.27	1.60
308	Upper Foreshore	-0.81	1.55
305	Berm	-4.10	0.70

Fig. 21. Grain size analyses, foreshore and berm, modern beach.

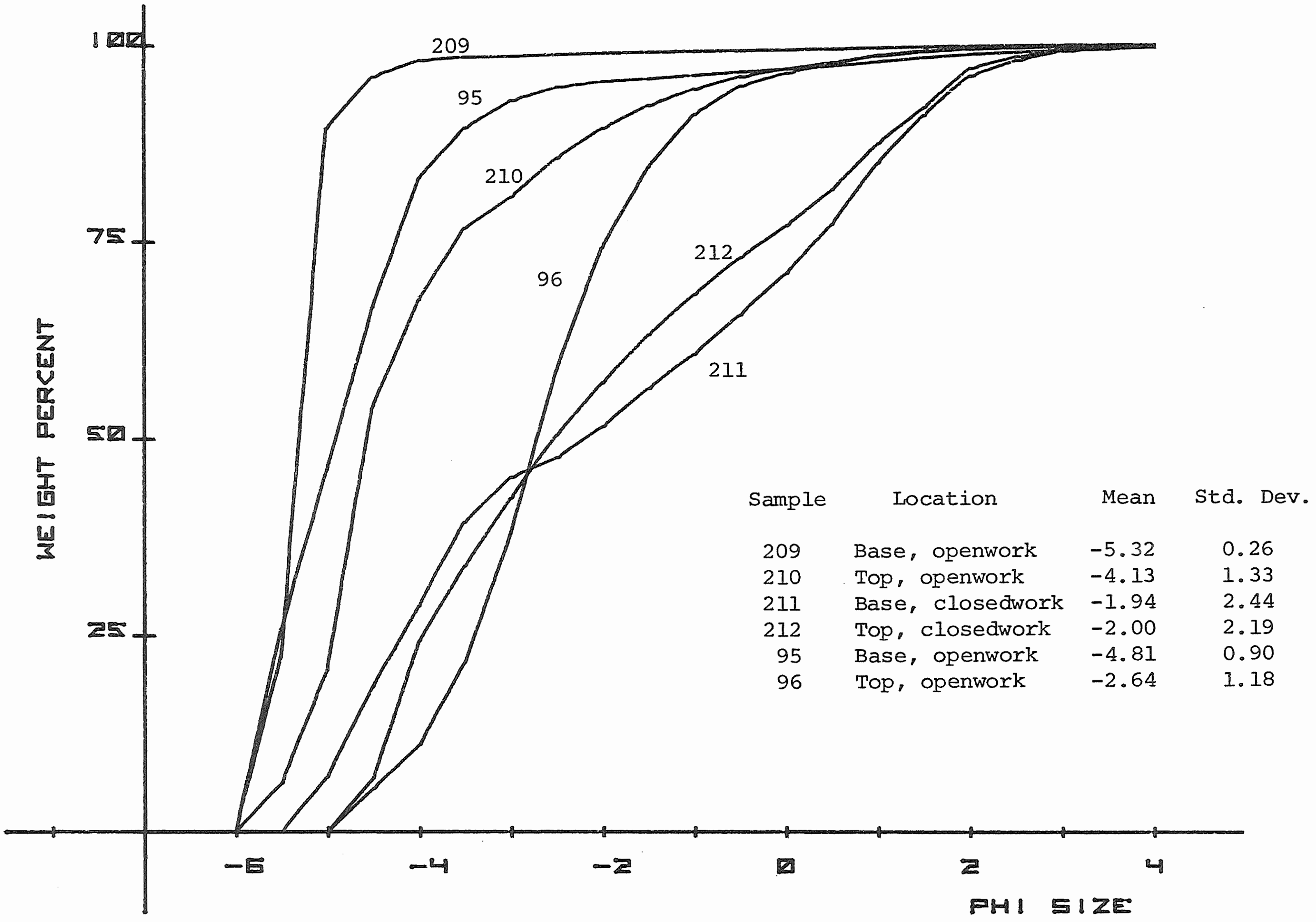
sediment is poorly sorted, with a minor increase in sorting from the lower to the upper foreshore. Foreshore samples from the raised beach have a greater percentage of sediment finer than 10, which causes them to be more poorly sorted. The fine material is probably a result of post-depositional infiltration.

The coarsest gravel in the beach occurred in the openwork cross beds (fig. 22). Sample 209 was taken at the bottom of an openwork cross bed, and has a mean grain size of -5.320. Gravel at the top of the same cross bed (210) is finer, with a mean grain size of -4.130. The closedwork cross beds are finer grained than the openwork, and are not graded (211, 212). Samples 95 and 96 show the graded nature of the amalgamated openwork cross beds in Fig. 16 .

The finest sediment in the foreshore facies occurs in the sand lenses in the lower foreshore. The upper sand lens is composed of moderately well sorted, medium grained sand (Fig. 23). Landward dipping sand in the lower sand lens is slightly coarser (152). The coarsest sediment occurred in the channel-like depressions of the lower sand lens, but unfortunately, they were not sampled.

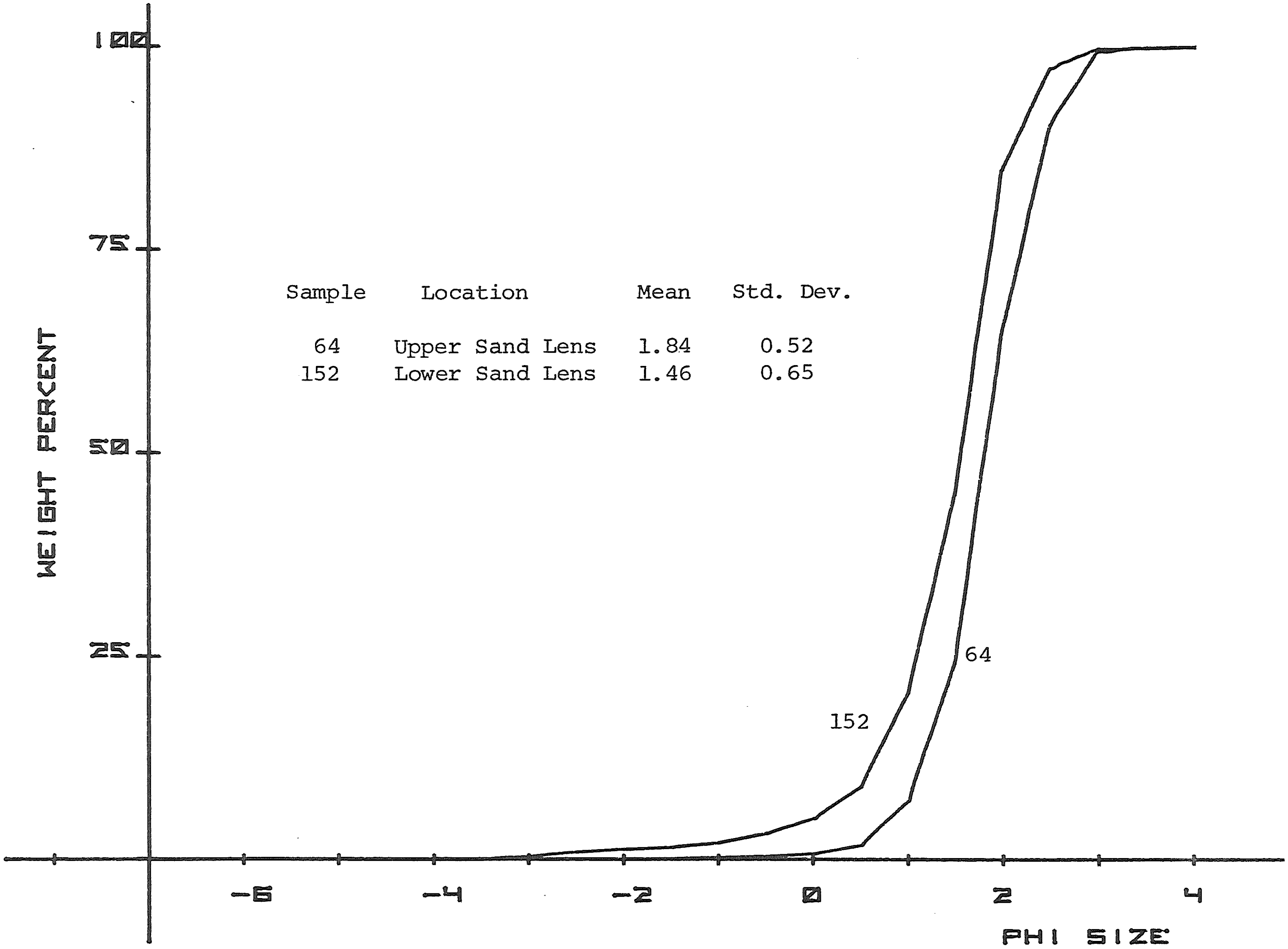
Fabric

Pebble imbrication is poorly developed in the foreshore facies. The orientation of flat pebbles appears to be determined mainly by packing. The equality in the strengths of the swash and bachwash probably precluded either a strong seaward or landward imbrication. However, there is a strong orientation of the long (a-) axis of roller-shaped pebbles (Fig. 24). The



Sample	Location	Mean	Std. Dev.
209	Base, openwork	-5.32	0.26
210	Top, openwork	-4.13	1.33
211	Base, closedwork	-1.94	2.44
212	Top, closedwork	-2.00	2.19
95	Base, openwork	-4.81	0.90
96	Top, openwork	-2.64	1.18

Fig. 22. Grain size analyses, cross beds, foreshore facies.



Sample	Location	Mean	Std. Dev.
64	Upper Sand Lens	1.84	0.52
152	Lower Sand Lens	1.46	0.65

Fig. 23. Grain size analyses, sand lenses, foreshore facies.

vector means of the orientations of all the pebbles in the lower and upper foreshore is 086° and 083° respectively. The vector mean strengths are 86% and 87%, respectively. Since the strike of the foreshore beds in Unit 1 is 111°, the orientation of the pebbles is oblique to the trend of the beach. Reineck and Singh (1973) state that the orientation of the long axis of pebbles is parallel to the beach, which is perpendicular to the direction of wave propagation. However, Hobday and Banks (1971) found that pebbles were oriented with their long axes at a marked angle to the shoreline. It is not known why the ofreshore pebbles are oriented at an oblique angle, but the orientation is well-developed.

Interpretation

The foreshore facies is interpreted as a deposit formed in the intertidal or foreshore zone of a beach. The criteria for an intertidal origin are:

1. a regular succession of seaward dipping beds
2. storm scarps
3. cross beds with erosional contacts
4. ridges and runnels

1. The succession of seaward dipping (5°-14°S) beds are characteristic of deposition in the foreshore zone of a beach (Thompson, 1937; McKee, 1957; Hey, 1967; Clifton, 1969). The depositional slope of the beach (and resultant dip of the foreshore beds) is directly related to grain size (Shepard, 1948; Bascom, 1951). With increasing grain size, and hence permeability, the loss of water on the swash is greater, and the backwash

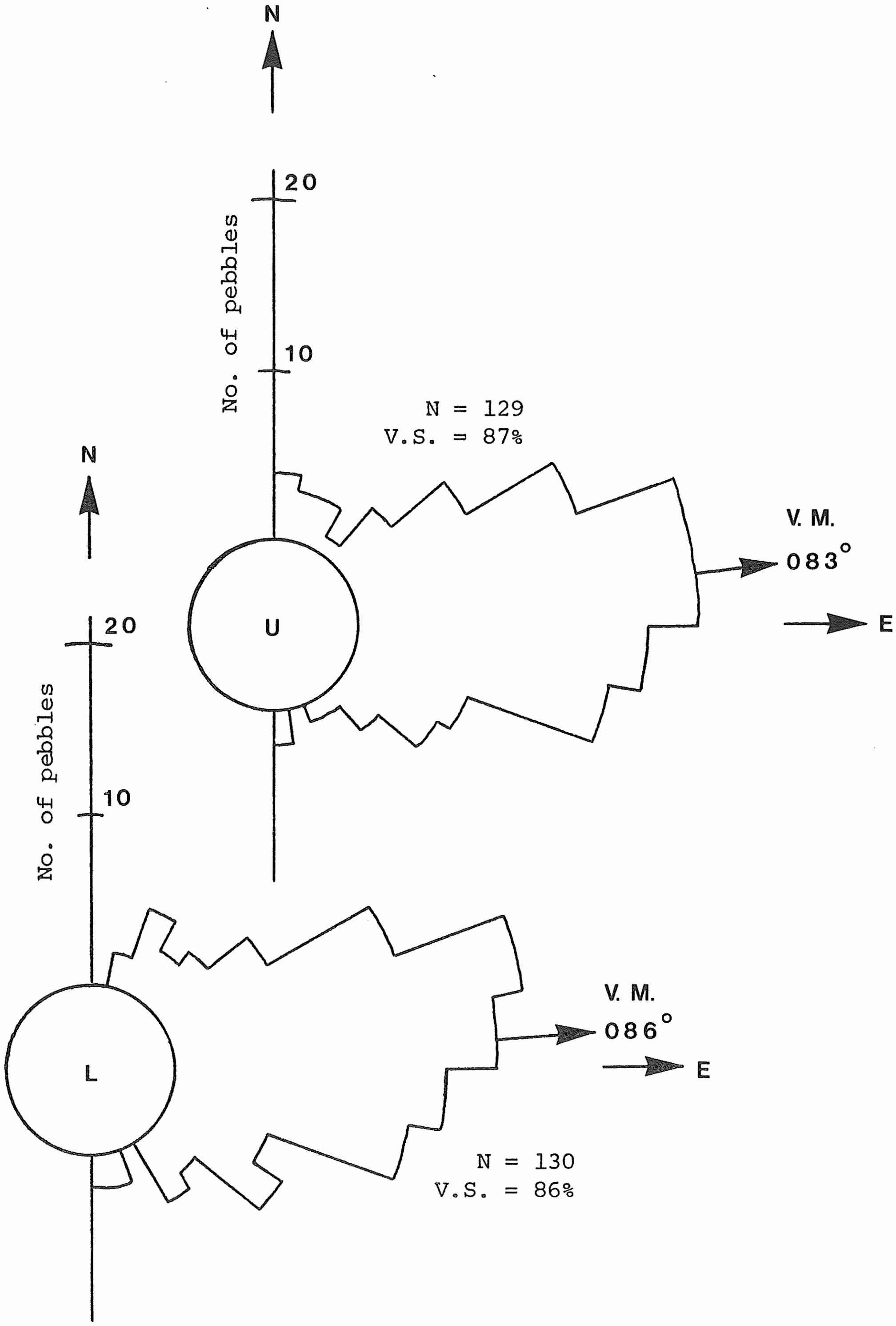


Fig. 24. Orientation of the A-axis of pebbles in the foreshore facies. U upper foreshore; L lower foreshore; N = total number of pebbles; V.M. = vector mean; V.S. = vector strength.

is reduced in strength and volume. The stronger swash tends to build-up or steepen the beach. In a fine grained beach (lower permeability), water loss is less and the backwash is stronger, creating a lower equilibrium slope.

The dip (5°-14°S) of the foreshore beds at Advocate is less than that which is predicted for its grain size (17° for pebbles, Shepard, 1973). This can be attributed to the high percentage of sand and granule matrix reducing permeability, and hence, the equilibrium slope.

Variations in matrix and pebble content in the foreshore beds must be related to varying wave conditions. Beds with a high percentage of coarse pebbles (M, photolog) are presumably produced by high energy wave conditions. The concentration of pebbles could be due to removal of the finer material (leaving a lag deposit of pebbles) and/or landward transport of coarse pebbles. Under high energy wave conditions, net sediment movement is seaward (King, 1972). Shepard (1973, p. 130) shows two photos (summer and winter) of a beach that is composed of sand in the summer and gravel in the winter. The sand is removed from the beach by the large winter waves, exposing the underlying gravel, and is returned to the beach by small summer waves. However, large pebbles and blocks of debris are also transported on to beaches during storms (Hayes, 1967). Bluck (1967) attributes the formation of coarse beach ridges to the landward movement of gravel during storms. Thus, although net sediment movement may be seaward, large particles can be transported landward in a storm.

Field evidence suggests that it is a combination of lag deposit and landward transport of pebbles that produces the pebble beds. The lower contact of the beds is gradational and irregular, compatible with a lag deposit because if all the pebbles were transported on to the beach, the lower contact would be sharp and planar. If the beds were solely the result of a lag deposit, they would be concave up due to the loss of winnowed material.

Neither mechanism explains why the pebble beds have a high percentage of sand matrix (Fig. 19). In fact, both mechanisms explain why there should be no sand matrix. Sand deposition is incompatible with pebble deposition, especially since the granule fraction is missing. If the pebbles acted as baffles to cause sand deposition, granule gravel would also be deposited. Grain size analyses indicate that the sand is a later infiltrate. Possibly, sand is more mobile and returns to the beach sooner after the storm than gravel, infilling the porosity of the openwork pebbles. The mobility of fine material was observed by Rector (1954), who found that in wave tank experiments, the finest sand was most mobile and sensitive to varying wave conditions.

Thus, the pebble beds are interpreted as the result of storms. The beds are frequently discontinuous, suggesting that the storm occurred during a neap tide, or did not last a semi-diurnal tidal cycle. More massive beds with all grain sizes present are the result of normal wave conditions.

2. The two scarps at H and I on the photolog are erosional features, similar to that described by Thompson (1937). Comparable erosional features are not described from the subtidal environment, where relief is more subdued (Clifton, 1971).

The storms that produce scarps are probably more severe than the storms that produce variations in matrix content in the foreshore beds. As the intensity of a storm increases, the frequency decreases, and there are only two scarps present in the pit. The storms may also occur when the foreshore zone has a partial cover of ice. Erosional and depositional features have been observed at the lower edge of an ice sheet covering part of the foreshore (Dionne and Laverdiere, 1972). Considerable erosion over a short period of time is required to produce the scarps. The erosion occurs at the beach/sea interface and a storm lasting the semi-dirunal tidal cycle would flatten the scarp. The very coarse pebble gravel at the toe of the scarp at I on the photolog is probably an erosional lag deposit created during the formation of the scarp.

3. The cross beds of the foreshore facies are the major difference between the gravel beach at Advocate and gravel beaches described in the literature. Hey (1967) described an essentially conformable sequence of gravel foreshore beds with rare low angle unconformities. The cross beds produce high angle discordances within the conformable poorly sorted foreshore beds.

The erosion of a hollow in the foreshore beds preceeds deposition of the cross beds. The cross beds are deposited in a seaward direction. Erosional contacts between cross beds suggest that initiation of deposition can reoccur. During deposition of the cross beds there is considerable relief on the beach; this contrasts with the smooth profile that exists when the poorly sorted gravel is deposited.

It is not known how the cross beds are deposited, but one possible mechanism is the development of beach cusps. The cross beds may represent the internal stratification of the horn or the infill of the bowl of a cusp. Cusps are common on shingle beaches (King, 1972; Shepard, 1973) and develop in the mature stage of a beach profile (Thompson, 1937; Hayes, et al. 1969); that is, they are removed by storms and reform under low wave activity. Thompson (1937) studied small cusps on a sand beach and described cross lamination produced when the bowl of a cusp was filled. Krumbein (1944) noted that beach cusps can migrate along a beach after they form, but did not study the internal structure of the cusps. Any proposed mechanism for the deposition of the cross beds must meet two requirements; 1. it must be able to operate in both the lower and upper foreshore and 2. since sets of cross beds can extend from the upper to the lower foreshore, the process must be able to exist for a considerable length of time (in terms of days).

The erosional cross beds are the best evidence for an intertidal origin for the foreshore facies. Because cross beds extend from the upper to the lower foreshore in the same bed (Fig. 15), short term fluctuations in sea level (i.e. tides) are necessary to effect the erosion and deposition at different levels.

4. The lower sand lens is composed of a number of ridges and runnels, or swash bars. The northward dipping sands are the ridge or megaripple, and the concave-up depression that occurs landward of the ridge is the runnel. The upper sand lens is a ridge that doesn't have a well developed runnel.

The ridges and runnels in the lower sand lens are unusual in that the runnels have no ripple cross stratification. The runnel is a catchment channel for water draining off the beach as the tide falls or for swash which overtops the ridge as the tide rises. Water flows in the runnel, parallel to the beach, until a break in the ridge allows the water to flow seaward. Linguoid ripples in the runnel produce trough cross stratification, with dips parallel to the trend of the beach (Hayes _et_ _al._, 1969). However, ripples will not form in sand coarser than 0.6 mm (Allen, 1970). The amount of sand coarser than this in the runnels (page 47) must preclude the formation of ripples. Some runnels were filled by sand moving seaward on the ebb tide, as the stratification dips south. Others were filled by accretion on the channel sides and bottom as water flowed parallel to the beach in the runnel, producing channel-shaped laminae.

The upper sand lens is a ridge with no visible runnel. This is not unusual: swash bars on a gravel beach in Norway have no runnel (Hobday and Banks, 1971). The term welded ridge is appropriated in this case, as it has probably migrated to an equilibrium position on the beach.

The ridges and runnels occur just above the low tide terrace on shallow dipping (5°S) foreshore beds. They do not occur on the more steeply dipping beds in the mid to upper foreshore. Their occurrence in the lower foreshore is controlled by the dip of the beds, as explained by ridge and runnel theory.

Ridges and runnels are characteristic of the intertidal or foreshore zone of a beach. They are a response to waves which attempt to establish an equilibrium gradient on a beach with a gradient that is too low. Ridges and runnels may preferentially occur in the lower foreshore, or are larger in the lower foreshore, as the gradient is frequently less in the lower foreshore than in the upper foreshore, i.e. the upper foreshore may have an equilibrium gradient. They will not form where the gradient is equal to, or steeper than, the equilibirum gradient (King, 1972). Thus, the dip of the beds in the mid to upper foreshore must be close to the equilibrium gradient of the beach.

The location of the ridges and runnels also agrees with the interpretation of the poorly sorted gravel beds. Below the ridges and runnels is a prominent pebble bed (M, photolog) that is interpreted as the result of a storm. Hayes et al. (1969) studied sand beaches and showed that a storm can remove beach material from the foreshore and deposit it subtidally, thereby lowering the beach gradient. After the storm, ridges and runnels form in the subtidal zone and migrate up the beach face, returning the material removed during the storm. This process is a wave-induced attempt to re-establish an equilibrium profile. Thus, the ridges and runnels are returning sediment that was removed during the storm to the beach.

Backshore Facies

Occurrence

The backshore facies occurs on all but the south wall of the pit. It is divided into backshore facies proper and a berm subfacies. The berm subfacies occurs only on the west wall.

On the north wall, the backshore facies overlies the foreshore facies and extends to the top of the wall. It is thickest, ranging from 2.0 to 2.7 m thick, and best exposed on this wall. The contact with the foreshore facies is erosional and distinct in the west corner (B, photolog) but is less obvious on the rest of the wall. At C on the photolog, a series of channel deposits with erosional lower contacts obscure the foreshore/backshore boundary. Farther to the east, a massive bed up to 0.82 m thick (N, photolog) is the lateral equivalent to the channel deposits and foreshore facies at C. It is questionable whether this bed belongs in the foreshore or backshore facies. The upper contact of the bed is higher, and the lower contact is lower, than the foreshore facies at B. It is fine grained and has scattered low angle bedding planes dipping either south or north. Beds above and below this bed belong to the backshore and foreshore facies respectively. A thin (10 cm thick), parallel laminated sand bed marks the lower erosional contact with the foreshore facies. The foreshore facies is cross stratified, with cross beds similar to those on the west wall. Because of the erosional lower contact, fine grain size and occasional low dip bedding planes, the massive bed is included in the backshore facies.

On the west wall, the backshore facies pinches out from north to south. In the north corner, the backshore facies overlies foreshore and channel deposits and extends to the top of the pit face, where it is obscured by the modern soil (see photolog). To the south, it lies between Unit 2 and the foreshore facies of Unit 1. The contact between Unit 2 and the backshore facies is erosional. Unit 2 gradually cuts down into the backshore facies, eliminating it entirely in the southwest corner. Here, Unit 2 rests directly on the foreshore facies of Unit 1 (F, photolog).

The backshore beds on the north wall can be traced on to the west wall and into time-equivalent foreshore beds (see photolog). Channel deposits in the north corner of the west wall obscure parts of the foreshore/backshore beds. Along the west wall, except for the south end, foreshore beds can be traced into backshore beds that rest on previously deposited foreshore and backshore beds. Unit 1 is thus progradational. The contact between the foreshore and backshore facies is often difficult to define sharply, except where the berm subfacies occurs.

Stratification

There are two types of stratified deposits within the backshore facies: 1. low angle beds dipping 3° to 7°S and 2. high angle beds dipping 24° to 32°N. They are found only in the backshore facies of the beach.

1. Beds dipping 3° to 7°S form the predominant stratification within the backshore facies. The beds are usually graded, fining from an openwork pebble gravel at the base to a medium sand at the top (Fig. 25 and 26). The basal contact is erosional. Graded beds range from 10 to 60 cm thick, and are stacked in an overlapping pattern. This is apparent on the north wall (see photolog), where the strike of the pit face is approximately 090°. Strike of the backshore beds over most of the north wall varies from 090° to 100°, giving apparent dips from horizontal to 2°W. However, several

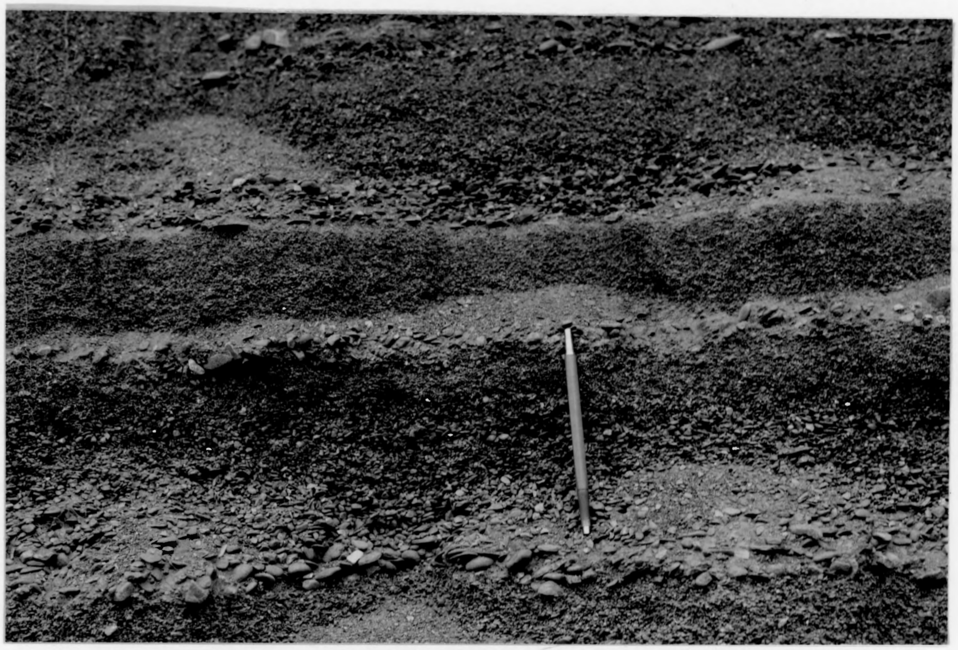


Fig. 25. Graded beds in the backshore facies of Unit 1. Beds thicken to the right (landward). Note the abrupt grain size change from pebbles to granules in the bed at the top of the pencil.

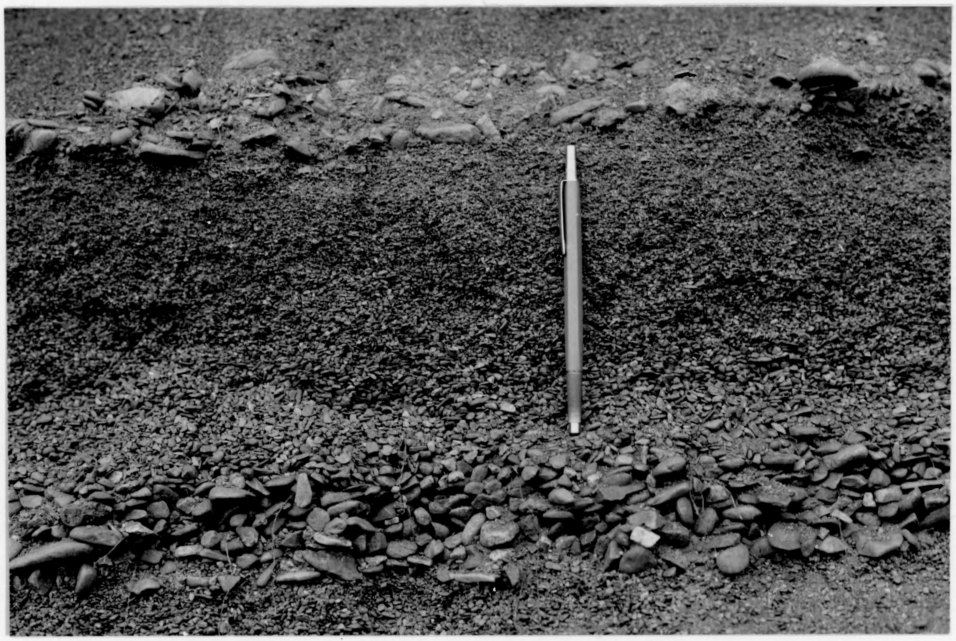


Fig. 26. Graded bed in the backshore facies of Unit 1. Pebble imbrication is predominantly low angle seaward (to the left).

beds on the west side of the north wall have a strike of 140° and truncate the backshore beds immediately below them (O, photolog). On the west wall, the graded beds appear as a conformable succession and thicken from the lower to the upper backshore. This is not a depositional thickening but an erosional thinning. Each succeeding bed erodes more of the previous bed in the lower than in the upper backshore (Fig. 27).

The texture of the graded beds is summarized in Fig. 27. The beds grade from an openwork pebble gravel at the base to a sand at the top. In some beds, the grading is characterized by abrupt changes in grain size, especially from the pebble gravel to the overlying granule gravel or sand. The thickening of the beds in the upper backshore is accompanied by an overall fining in the grain size, although the grading remains. Erosional basal contacts are frequently marked by a silt matrix.

2. The second type of stratified deposit in the backshore is composed of openwork pebble beds dipping 24°-32°N (landward). These beds occur within the graded beds, but are easily distinguished by their texture and stratification.

An openwork pebble deposit is usually composed of several sets of cross beds. The sets are similar and can be summarized as follows (Fig. 28). Initially, the openwork beds are graded from 2-4 cm pebbles at the base to 1 cm pebbles at the top. The cross beds decrease in both grain size and dip in a landward direction, and change in shape from planar to asymptotic. A fine grained "bottomset" bed completes the set. The sand is conformable with the underlying beds, and pinches out landward (N). Each succeeding

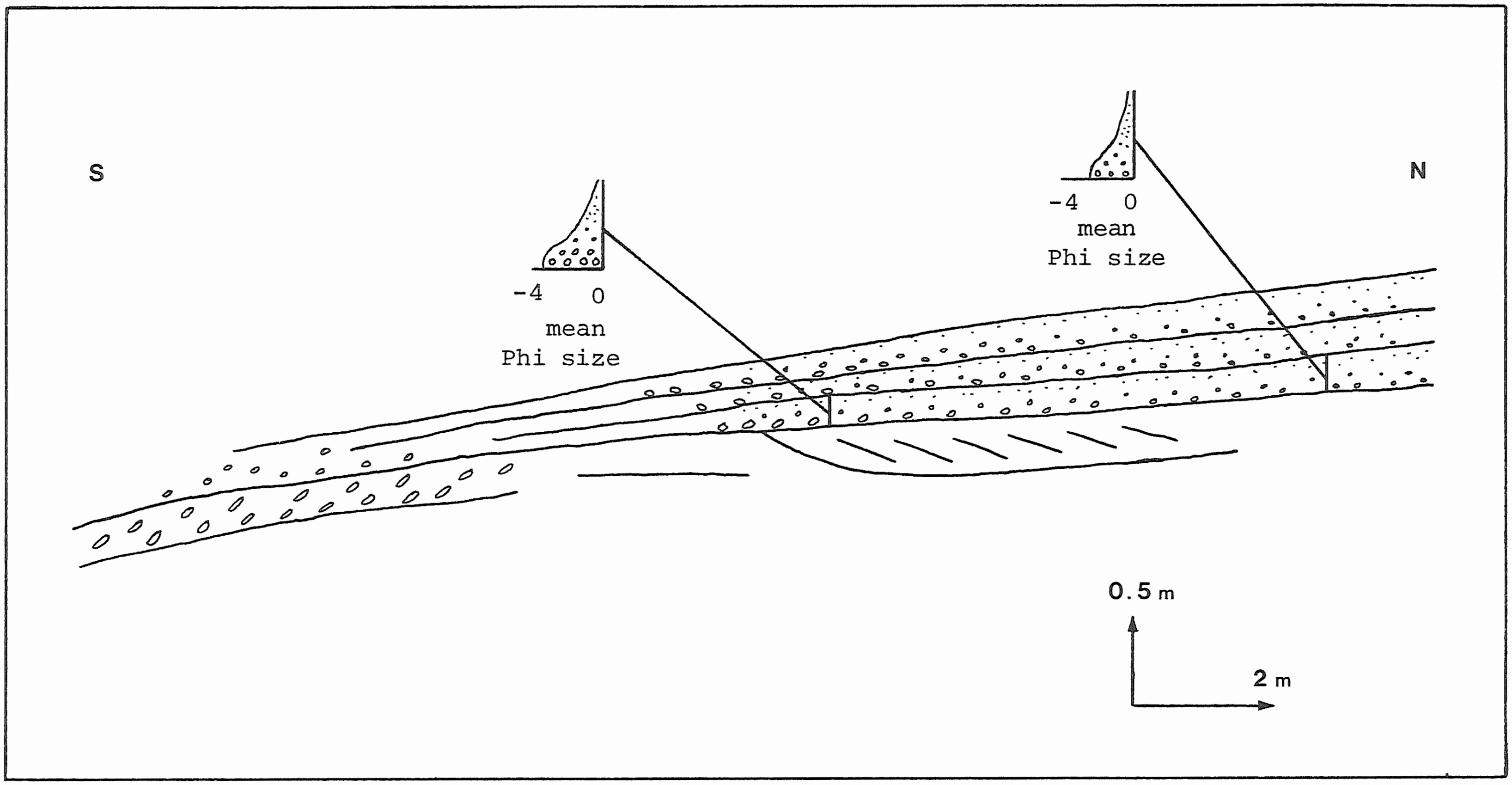


Fig. 27. Graded beds in the backshore facies. Note the landward (N) thickening and decrease in grain size.

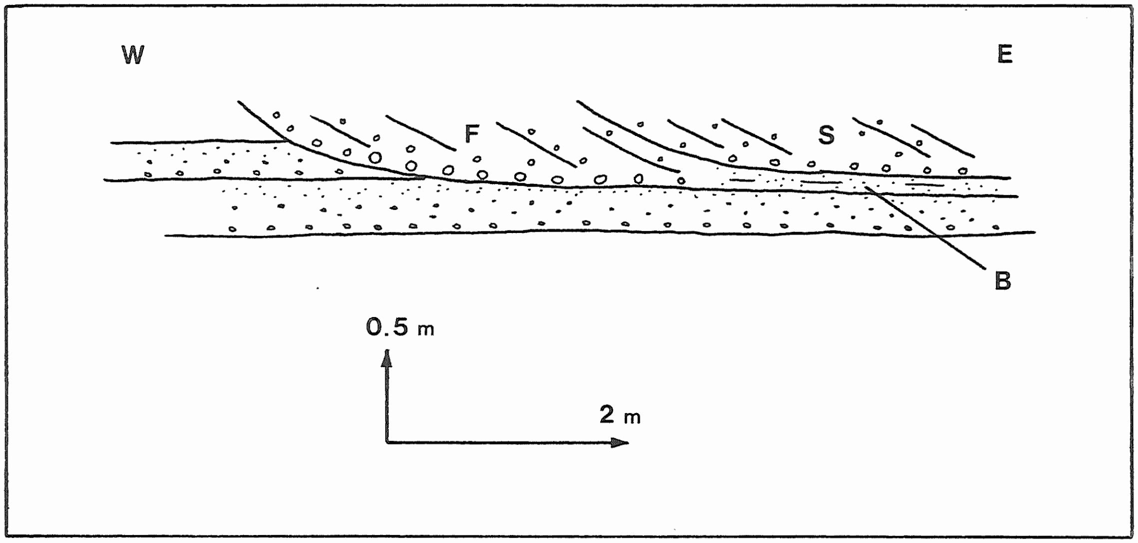


Fig. 28. Washover beds in the backshore facies, Unit 1. The second set of cross beds (S) is finer grained than the first set (F). B bottomset sand bed.

set of cross beds becomes finer grained and progrades across the "bottomset" bed of the previous set. Erosional contacts, usually at the base of the deposit or between sets are marked by a silt matrix.

Amalgamation of the cross beds both within and between sets produces a graded openwork deposit, lenticular in shape. Because the gravel is openwork and well sorted, the deposit weathers out to form recessive pockets on the pit walls (P, photolog). These deposits do not occur near the top of the backshore facies (north wall, photolog).

The west wall shows the relationship between the low angle graded beds and the openwork pebble beds more clearly than the north wall. The berm deposit at E on the photolog passes landward into an openwork pebble deposit, which in turn thins and passes into graded beds. The openwork pebble beds are sandier than equivalent deposits on the north wall, but have similar openwork gravels dipping 24°-32°N. Graded beds occur above and below the pebble beds, and when they occur above, the contact is erosional.

Thus, the openwork pebble beds occur within the graded beds in the lower backshore. A set of cross beds ranges from 25-40 cm thick and from 1.0-4.0 m long. Deposits composed of several sets range from 25-55 cm thick and from 3-10 m long. Although a definite strike for the beds was not obtained, the strike is similar to that of the graded beds, but can vary for sets in the same deposit.

Grain Size

The low angle graded beds, which make up the bulk of the backshore facies sediment in Unit 1, are finer grained and better sorted than the foreshore facies beds (Figs. 29, 30). The average of the means of all foreshore gravel samples is -3.1320, while the average of the means of the graded backshore beds is -1.4860. Sorting follows a similar pattern, averaging 1.857 (poorly sorted) for the foreshore gravels and .724 (moderately sorted) for the graded backshore beds. The grading and landward fining of the backshore beds is shown in Fig. 30.

Figure 31 shows the grain size difference between the openwork cross beds and finer grained "bottomset" beds of the backshore facies. More complete grain size analyses of this type of deposit are given on page 98.

Interpretation

The backshore facies is interpreted as a deposit formed in the backshore zone of the beach. The two types of stratified deposits are interpreted as: 1. storm graded beds and 2. washover fan deposits.

1. The low angle (3°-7°) beds are interpreted as storm graded deposits. Storm waves, driven over the berm of the beach, erode previously deposited backshore beds and deposit gravel of decreasing grain size as the storm subsides and/or the tide falls. Erosion is greatest near the berm, where the turbulence and energy of the waves are highest. This results in the landward thickening of the beds (Fig. 27). A low percentage of the beds are inversely graded, indicating increasing storm activity or a rising tide. However, most beds are normally graded, implying that deposition occurred during the waning of the storm. Landward fining of the beds is a result of the waves losing velocity as they are driven inland.

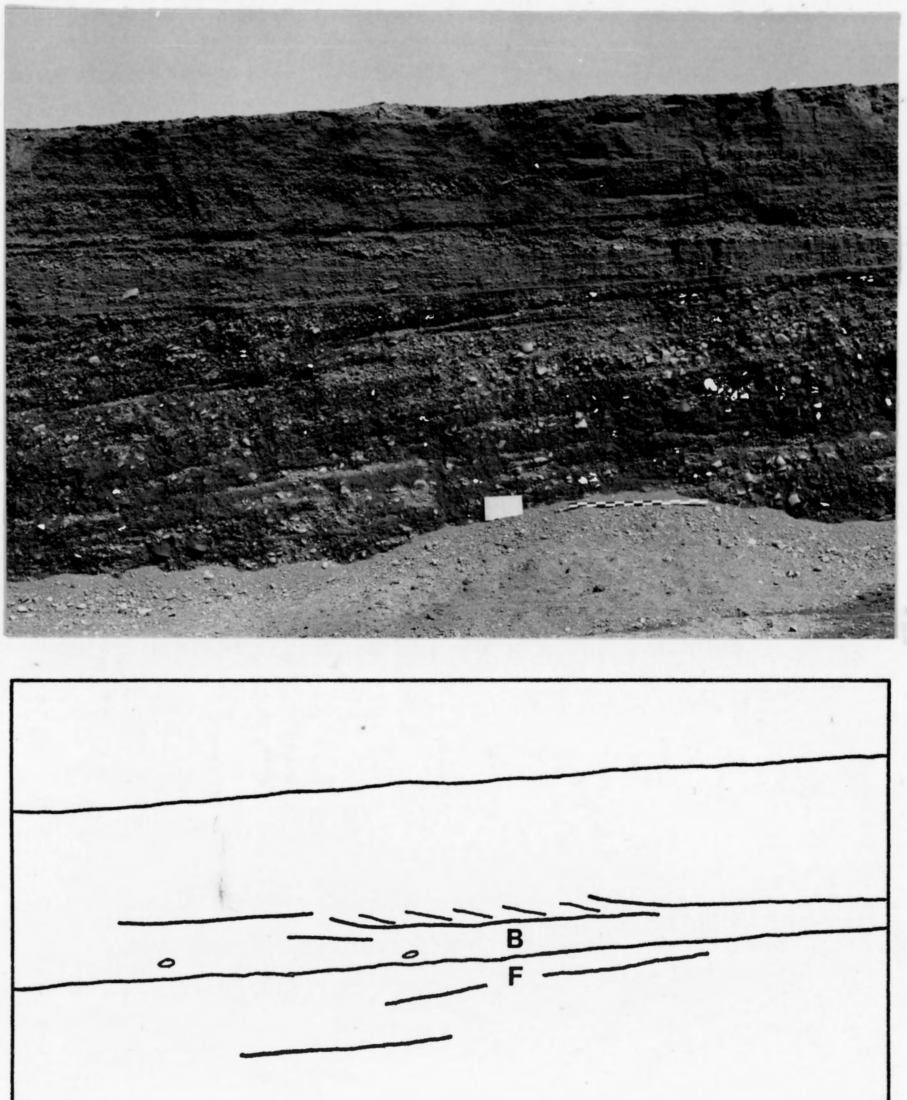
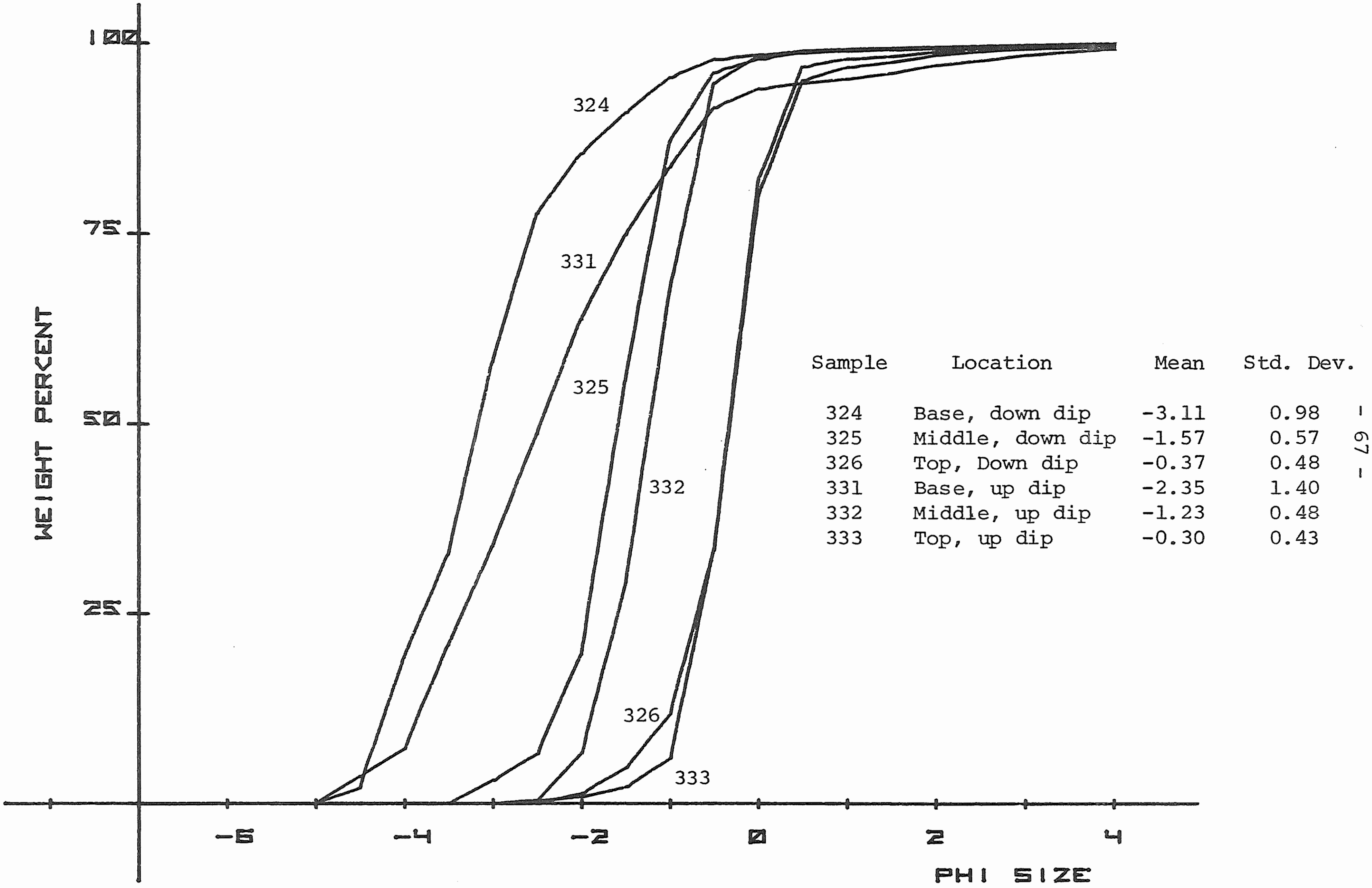
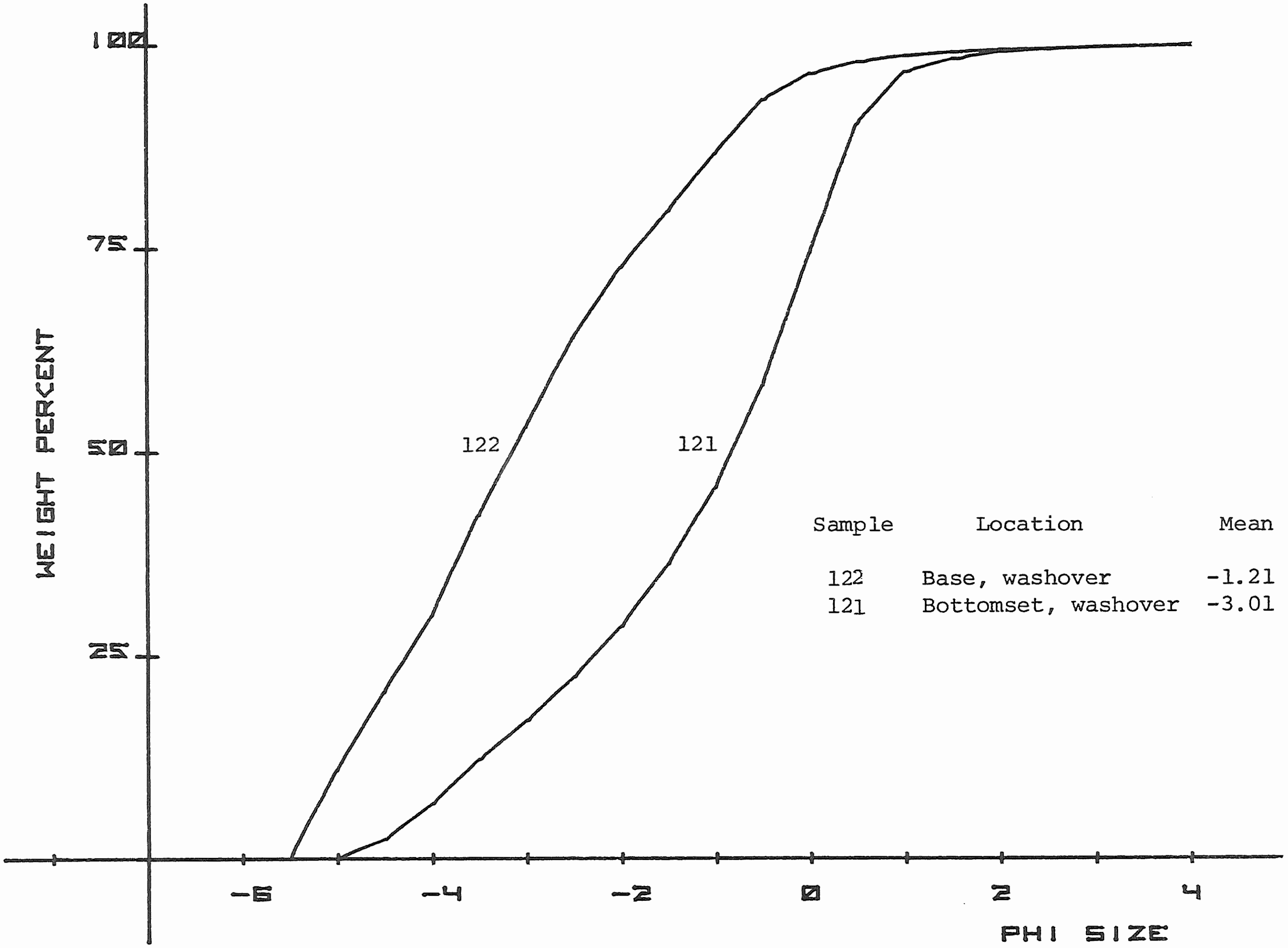


Fig. 29. Unit 1 on north wall. Fine grained backshore facies (B) overlying coarse grained foreshore facies (F) with an erosional contact.



Sample	Location	Mean	Std. Dev.
324	Base, down dip	-3.11	0.98
325	Middle, down dip	-1.57	0.57
326	Top, Down dip	-0.37	0.48
331	Base, up dip	-2.35	1.40
332	Middle, up dip	-1.23	0.48
333	Top, up dip	-0.30	0.43

Fig. 30. Grain size analyses of a graded bed sampled at a down dip (seaward) and an up dip (landward) location.



Sample	Location	Mean	Std. Dev.
122	Base, washover	-1.21	1.61
121	Bottomset, washover	-3.01	1.61

Fig. 31. Grain size analyses, washover beds, Unit 1.

The first sediment deposited by the waves is an openwork pebble gravel. At the base of the pebbles is a silt matrix. Erosional surfaces in the channel facies are also marked by a silt matrix. It appears that the silt matrix is deposited penecontemporaneously with the pebbles as it does not occur in the finer gravel and sand above. The reason for pebbles and silt to be deposited together is not known, but the pebbles may act as baffles to sediment in suspension, allowing deposition of the fines. An alternative explanation is that silt is deposited in the backshore zone by wind during periods of normal wave activity, and is then reworked by incoming storm waves.

Sand beds occurring in a graded bed have sharp contacts, indicating a distinct pulse within the event. Variations in storm intensity may cause waves to re-breach the berm after a relatively quiet period, bringing an influx of different-sized sediment. Sand in the graded beds is parallel laminated, suggesting that upper flow regime conditions existed in the storm waves. This is compatible with evidence that the swash zone of a beach is in the upper flow regime (Clifton, 1971).

Graded beds in the backshore zone of a beach have been described by Hayes (1967). He studied the effects of hurricanes on sand beaches in the Gulf of Mexico. During Hurricane Carla, the foreshore zone of the beach extended inland into what was previously the backshore zone of the beach. The storm deposit in the "hurricane" zone was graded from coarse shell material at the base to laminated sand at the top. The sand was not cross stratified at any position within the deposit, suggesting that deposition occurred in the upper flow regime. The "hurricane" deposits are analagous to the storm graded beds.

Imbrication of the pebbles in the storm beds is more poorly developed than in other backshore beds (pages 74, 105), but the predominant imbrication is low angle seaward. The landward and seaward movements of the waves probably preclude a well developed imbrication, but the landward surge is predominant. This is probably due to water loss through the underlying sand and gravel.

2. The high angle beds dipping 24° to 32°N are interpreted as washover fan deposits. These are also a result of high energy events, but the mode of deposition is different from the storm graded beds. This type of deposit is better exposed and more fully explained in the storm ridge subfacies of Unit 2 (page 95).

Sand and gravel is washed over the berm, by a high energy event. The gravel is deposited at or near the angle of repose on the slip face of the fan, with the coarsest gravel concentrated at the base of each cross bed. This size separation, due to the effect of gravity, is similar to that on the lee face of a ripple (Reineck and Singh, 1973, p. 19). The sand and fine gravel is deposited farther landward, parallel to the underlying beds. The gravel progrades over the sand as the fan builds landward, producing a graded, openwork pebble deposit. The abrupt change in grain size with the underlying sand is frequently marked by an irregular, erosional contact. As the fans prograde landward from the berm, the overall grain size decreases.

The relationship between the washover fans and the storm graded beds can be seen at E on the photolog. The washover beds occur landward of the well developed berm deposit. The berm deposit acts as an obstruction to water moving into the backshore, and initiates deposition on a landward-facing slip face. The deposition of washover fans instead of graded beds is probably dependent upon the presence of a well developed berm deposit. As the washover fan progrades landward, it thins and is replaced by storm graded beds. In most cases, the thinning of the fan is associated with a decrease in grain size from gravel to sand. The sand lowers the dip of the slip face and the washover-type deposition changes into graded bed deposition. Thus, washover fans are limited in their progradation away from, and above, the berm because of the gradual loss of the slip face.

Berm Subfacies

Occurrence

The berm subfacies occurs on the west and east walls of the pit, and only in Unit 1 (see photolog). The deposit is of limited extent, being 11 m long and 1 m thick.

The berm deposit occurs as a terrace at the foreshore/backshore junction. High angle (8°-14°S) foreshore beds flatten to approximately horizontal at the berm, with a concomitant coarsening in grain size (Fig. 32). The berm deposit passes landward (northward) into the backshore facies proper. The upper contact occurs where the berm beds lose their coarse, imbricated texture (page 76) and pass into deposits with typical backshore facies textures and stratification. A slight steepening of dip accompanies this change (see photolog).

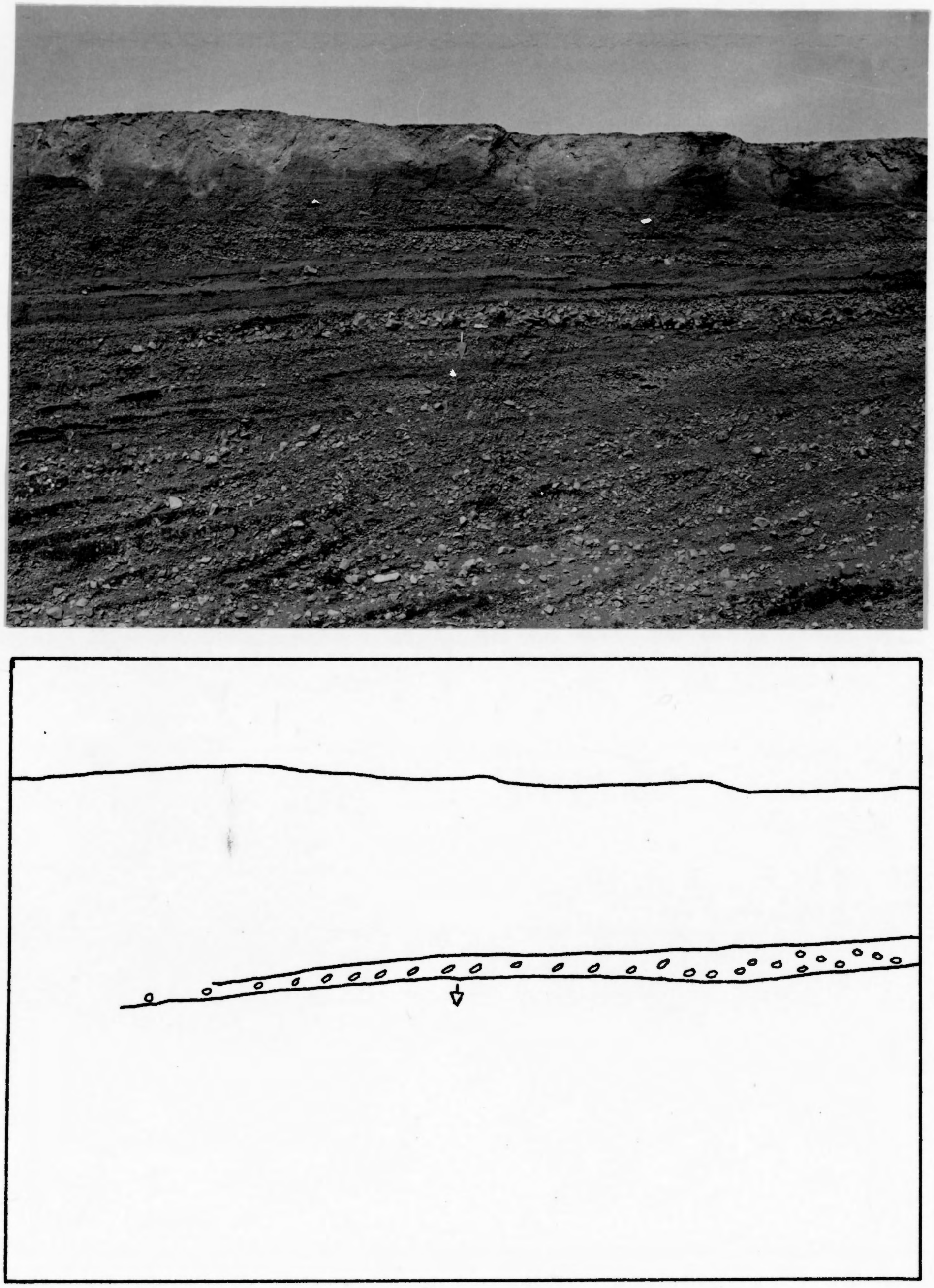


Fig. 32. Prominent pebble bed in the berm subfacies. Fabric analysis of this bed is shown in Fig. 34. Note the reversal in dip of the bottom of the bed. Trowel for scale.

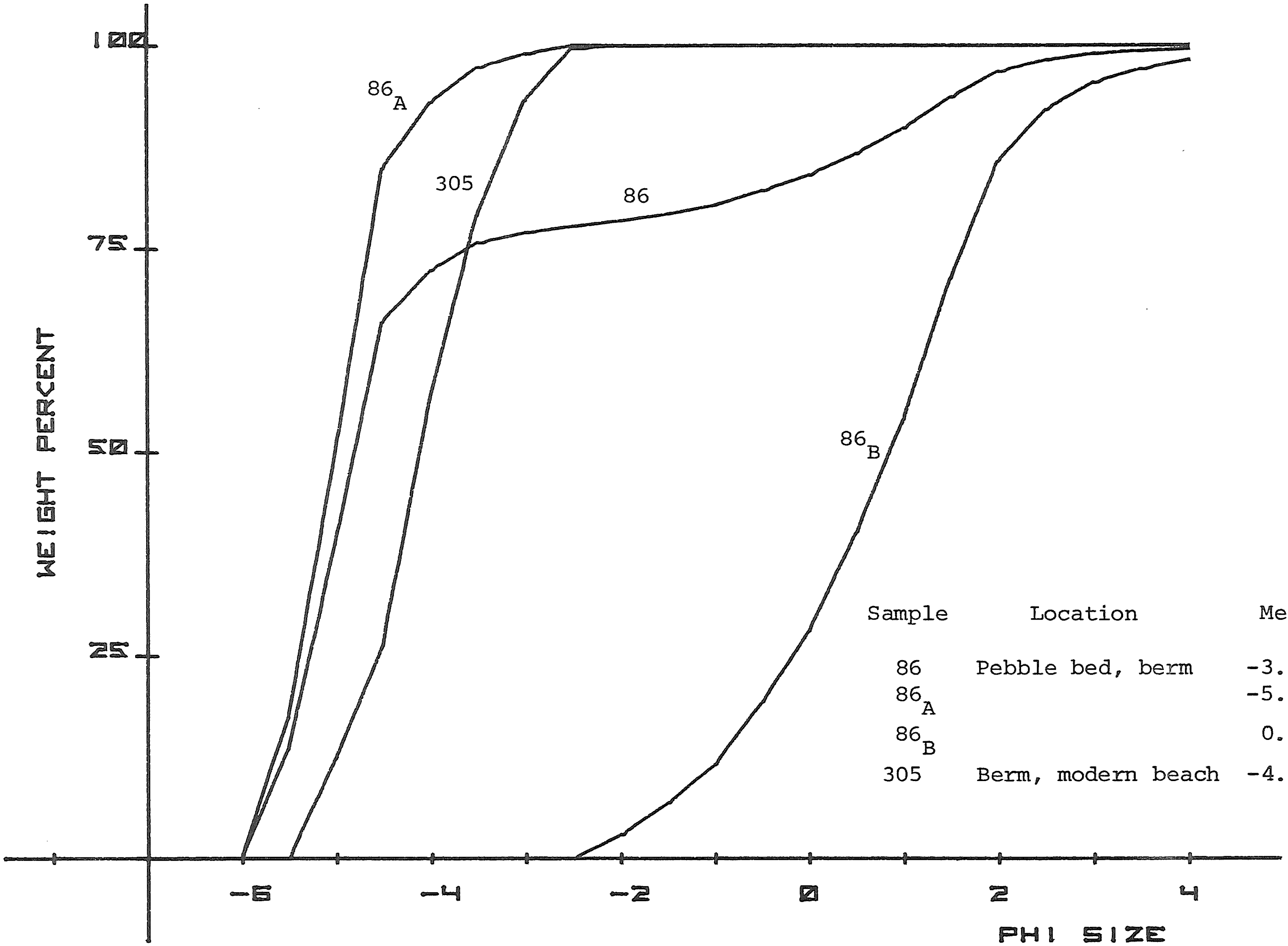
Stratification

The berm deposit is characterized by low angle beds (1°-5°) that dip north and/or south. The prominent pebble bed at E on the photolog and in Fig. 32 dips 5°S in the southern part and 3°N in the northern part. Such reversals in dip occur only in ther berm subfacies.

Bed thicknesses range from 10-30 cm, while bed lengths are determined by the length of the facies, 11 m. Bedding contacts tend to be erosional, causing some beds to thin or pinch out landwards. There is no cross stratification within berm beds, but pebbles are strongly imbricated.

Grain Size

The berm subfacies is marked by an accumulation of coarse pebbles, similar to that of the modern beach. Berm samples from the raised and modern beach are plotted in Fig. 33, and appear to be quite different. Sample 86 from the berm subfacies is strongly bimodal, while sample 305 from the modern beach is unimodal. However, the replot of sample 86 shows that it consists of two better sorted end members. The pebble component, 86_A, is very similar to sample 305, with mean grain sizes of -5.00Ø and -4.10Ø respectively and standard deviations in the moderately well sorted class. The sand, component, 86_B, is coarse grained and moderately poorly sorted. It is probably the result of post-depositional infiltration. The size of the pore spaces limits the maximum size of the infiltrating sediment, causing the bimodality. The mean grain size of the pebble component, 86_A, is much larger than the mean grain size of the foreshore samples in Fig. 19.



Sample	Location	Mean	Std. Dev.
86	Pebble bed, berm	-3.42	2.46
86_A		-5.00	0.53
86_B		0.70	1.35
305	Berm, modern beach	-4.10	0.70

Fig. 33. Grain size analyses, berm subfacies. Sample 86 is split at -2.5ϕ and replotted.

Fabric

Disc-shaped pebbles in the berm subfacies show a marked seaward imbrication (Fig. 34). Krumbein (1939) noted that the c-axis, which is the pole to the maximum projection plane, was more definitive of pebble imbrication than the orientation of the long axis. Apparently, the largest surface area of the pebble is oriented perpendicular to swash moving over the berm. The mean orientation of the maximum projection plane is 097°, while the strike of the berm beds is 111°. Either storm waves were refracted slightly more than the normal waves, or swash entered the backshore zone at slight angles to the wave crests. The pebble imbrication is high angle; the average dip of seaward imbricated pebbles (72% of the pebbles) is 50°, while the average dip of landward imbricated pebbles (28% of the pebbles) is 47°.

Interpretation

The berm subfacies is interpreted as a terrace-like deposit at the junction between the foreshore and backshore facies. It is important, and therefore distinguished as a subfacies, because it provides an upper limit to the foreshore zone. The lower limit of the berm subfacies occurs at the high spring tide position.

The coarse grain size of the sediments is characteristic of the berm on a gravel beach (Carr, 1969; Hobday and Banks, 1971). The modern beach at Advocate also has a marked coarsening in grain size at the berm (Figs. 21, 35).

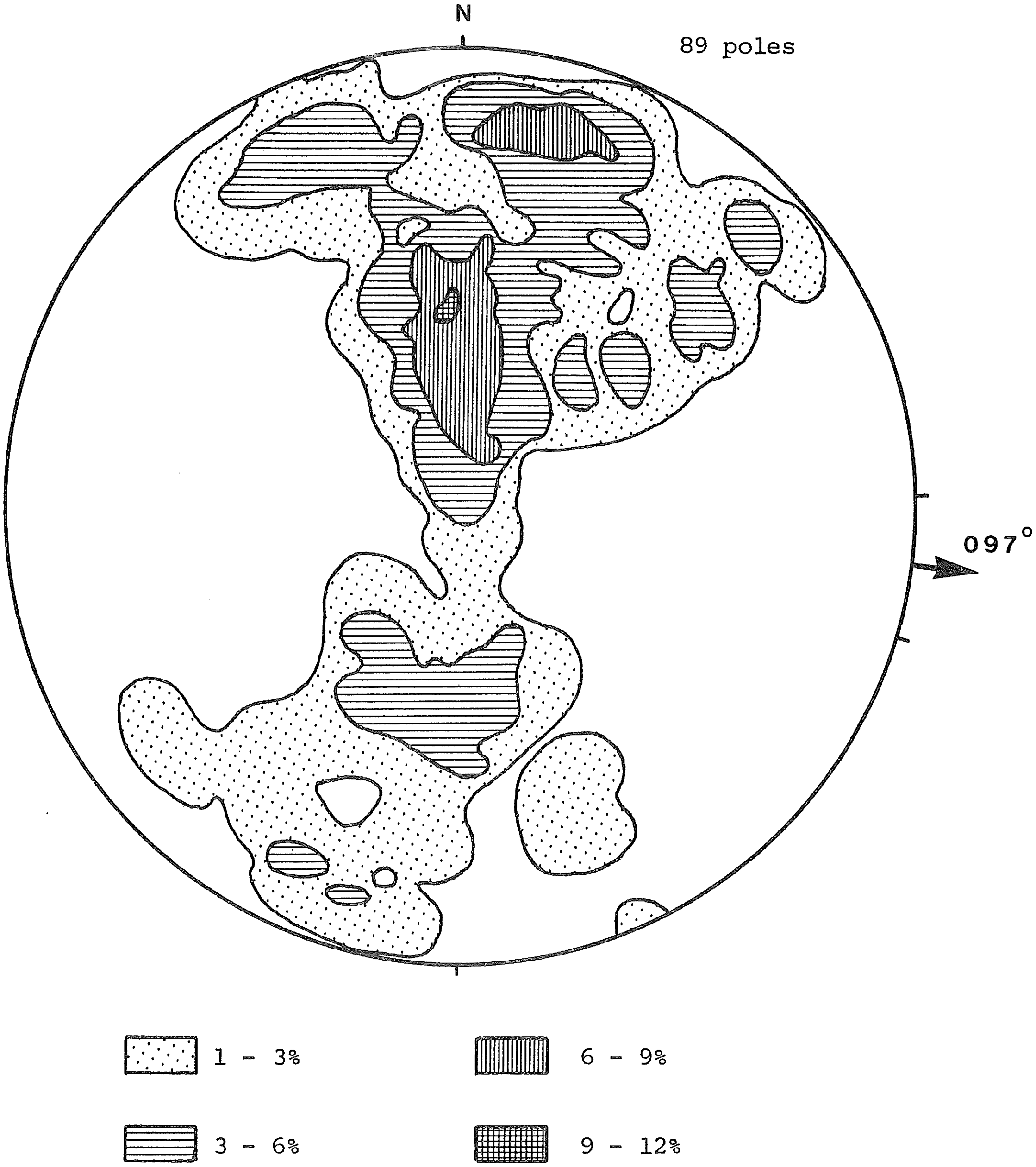


Fig. 34. Contoured stereoplot of the C-axis (pole to max. prj. ple) of imbricated pebbles in the berm subfacies. Mean orientation of the strike of the maximum projection plane = 097°. 95% cone of confidence = ±9°

Fig. 35. Berm on modern beach at Advocate. Note the abrupt coarsening in grain size from granule gravel in the upper foreshore to pebbles in the berm. The photo in Fig. 49 was taken from on top of the ridge in the background. Notebook for scale.

The coarse grain size can be explained by observing the modern beach at Advocate. During neap tides, the last high tide position is defined by a line of coarse pebbles (Fig. 36). The swash is stronger than the backwash and, as the tide rises, the waves continually throw the coarse pebbles in front of them. When high tide is reached and the tide begins to fall, the coarse pebbles are stranded because the backwash is below the critical velocity. As tides move from neap to spring, the coarse pebbles are gradually moved up the beach until they reach the high spring tide position, where a coarse berm is formed. Large waves during spring tides form a well developed coarse berm.

The strong imbrication of the berm deposit is the result of a predominance of disc-shaped pebbles and the domination of the swash. Bluck (1967) noted that disc-shaped pebbles were most abundant at or behind the berm crest. He attributed this to the varying hydrodynamic properties of different shapes. Disc-shaped pebbles have a lower settling velocity and a proportionally larger surface area than spherical pebbles. This causes them to get caught up in waves and thrown farther landward than spherical pebbles of the same weight. Also, they are not rolled down the beach by the backwash as easily as spherical pebbles. Thus, the pebbles that get concentrated at the berm are predominantly disc-shaped.

The disc-shaped pebbles are strongly imbricated seaward because of the powerful swash and weak backwash. The coarseness of the gravel at the berm causes a significant water loss to the swash and the resultant backwash is very weak.

Fig. 36. Coarse, disc-shaped pebbles marking the last high neap tide on the modern beach at Advocate. Dark patches are seaweed. Berm is to the upper left.

Channel Facies

Occurrence

All deposits of the channel facies have the shape of a channel, with an erosional lower contact. The channel facies does not occur in the lower foreshore or upper backshore and is more abundant in the upper foreshore than elsewhere. Many of the larger deposits were seen to have a meandering form, as they disappeared or appeared during excavation of the pit.

The channel deposits tend to occur in clusters (see photolog). The lowest deposit is usually the largest, with several smaller deposits above it. This can be seen on the north wall at R on the photolog. The main deposit, 5.0 m x 1.0 m, occurs in the upper foreshore and extends into the lower backshore. Two smaller channel deposits, approximately 2.0 m x 0.3 m each, occur in the upper part of the main deposit. A second large deposit occurs just to the east of this.

In the north corner of the west wall, there are several channel deposits in the upper foreshore/lower backshore (see photolog). The largest, 3.6 m x 0.75 m is a composite of three channel deposits (S, photolog). The erosional lower contact of the deposits is clearly visible. In the south corner of the west wall, two channel deposits of similar size, approximately 1.8 m x 0.3 m each occur in the upper foreshore, immediately below Unit 2 (T, photolog).

The largest deposit, 5.5 m x 0.9 m (Fig. 37), and the second largest deposit, 4.8 m x 11. m (Fig. 38), occurred on the west wall. They are not visible on the photolog as both disappeared during excavation. The deposit

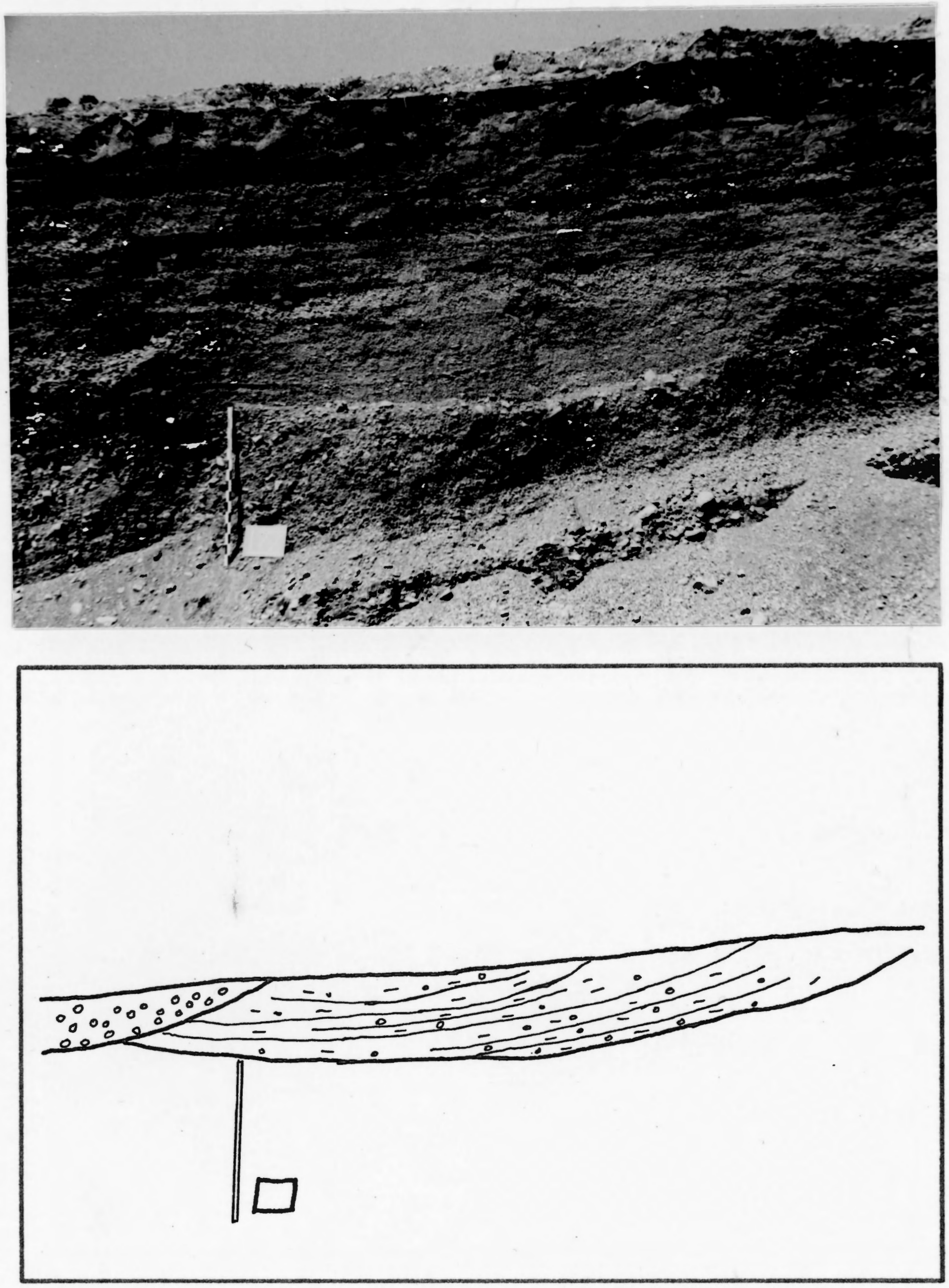


Fig. 37. Large channel deposit composed of fine grained gravel beds dipping to the south. It is not present on the photolog or in Fig. 15. as excavation removed this deposit (note graded cross beds at J on photolog below the channel deposit).

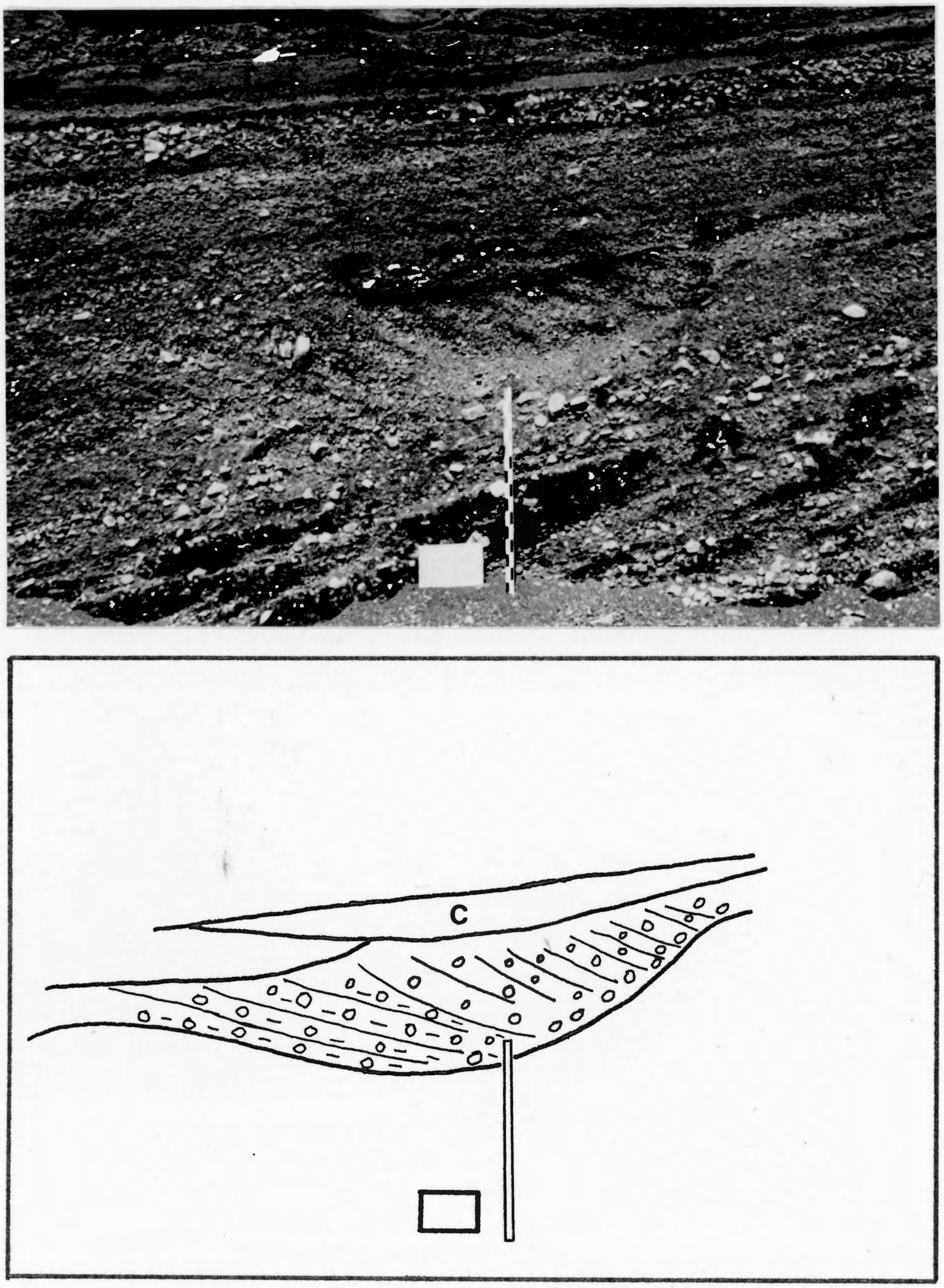


Fig. 38. Large channel deposit composed of landward dipping cross beds. Beds on the left side are closedwork while those on the right side are openwork. A small channel (C) occurs above the cross beds.

in Fig. 38 is the lowest channel deposit, being 23.7 m above sea level at its lowest point.

Stratification

There are three types of stratified deposits in the channel facies: 1. massive, poorly bedded, 2. low angle beds dipping in a direction dependent upon the channel trend, and 3. high angle beds dipping 18°-34°N.

1. Massive, poorly bedded gravel is typical of small channel deposits less than 2.0 m wide and 0.40 m deep. The gravel is of pebble size, and openwork except for the lower 3-10 cm which has a silt matrix. Some deposits are coarser at the top, some are coarser at the base and others have a constant grain size. Deposits in the foreshore tend to be finer grained than the surrounding gravel, while deposits in the backshore tend to be coarser. Channel deposits in the north corner of the west wall have this type of fill.

2. Low angle beds of variable dip are typical of the larger channel deposits in the foreshore facies. The gravel is finer grained and has less silt matrix (1-4 cm) at the basal contact than the massive gravels. The largest channel deposit (Fig. 37) is of this type. Beds 5-15 cm thick dip from 14°-20°S on the north side of the deposit and shallow to 0°-5°S on the south side, producing an asymmetric channel fill. The channel deposit at R on the photolog is also of this type. Stratification is poorly developed, but appears to be more symmetrical than in the aforementioned channel.

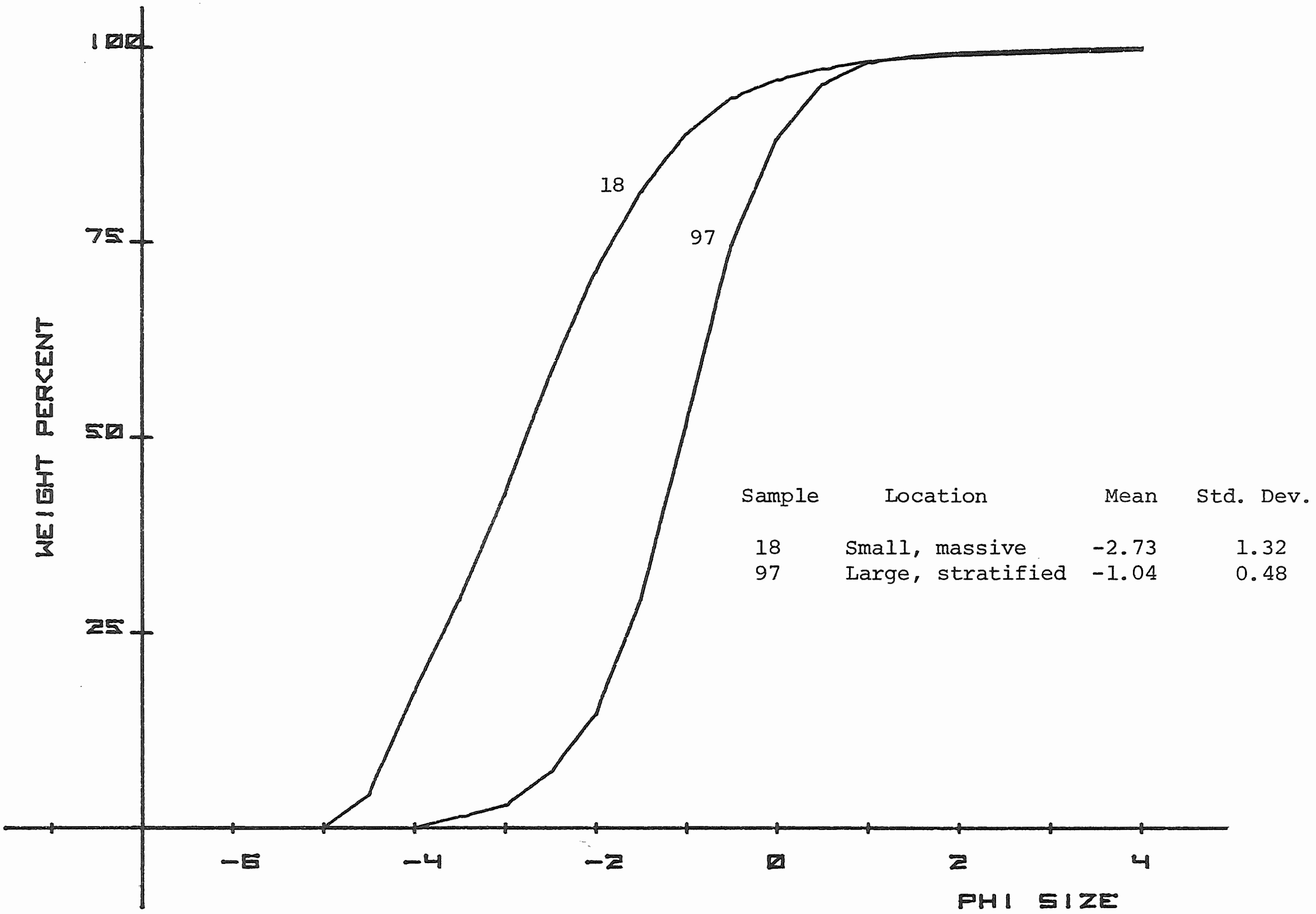
3. Channel fill consisting of high angle beds dipping 18°-34°N occurs

in both small and large channel deposits. The large deposit in Fig. 38 is a composite of low angle and high angle fill. High angle fill occurs in the lower part of the deposit. The initial fill (on the south side) is closedwrok and poorly sorted, while the later fill is openwork, graded and better sorted. The openwork gravel is graded from 2-4 cm pebbles at the base to 1-2 cm pebbles at the top. Dip of the beds increases from 18°N in the closedwork to a maximum of 34°N in the openwork gravel. Low angle fill overlies the high angle beds with an erosional contact.

On the south end of the west wall, at T on the photolog, the lowest channel deposit is composed of massive gravel and the upper channel deposit has high angle stratification. The high angle beds are finer grained (1-2 cm pebbles) than in the previous large deposit, and are not graded. However, two large pebbles, 8 cm and 10 cm long (a-axis), occur at the base of the beds.

Grain Size

Massive, poorly bedded channel deposits are composed of coarse, moderately poorly sorted gravel (sample 18, Fig. 39) with a small amount of fine grained matrix. The infiltration of fine material appears to be less than in foreshore pebble beds or berm beds, and may be due to the location of the channels. Most of the pebble channel deposits occur in the lower backshore, above the limit of the swash-backwash. Fine material occurs in definite beds in the backshore facies, and has less opportunity to infiltrate porous gravel below. Channel fill composed of low angle beds is the finest grained (sample 97, Fig. 39) and best sorted of the three types



Sample	Location	Mean	Std. Dev.
18	Small, massive	-2.73	1.32
97	Large, stratified	-1.04	0.48

Fig. 39. Grain size analyses, channel facies.

of fill. The mean grain size of sample 97 is barely coarse enough to be granule gravel, and it is well sorted. Unfortunately, the high angle channel fill was not sampled.

Interpretation

The channel facies is composed of channel deposits that formed in the foreshore and backshore zones of the beach. The deposits occurring in the foreshore and lower backshore are interpreted as tidal channel deposits, evidence of a lagoon landward of the beach. Channel deposits higher in the backshore are the result of storm wave runoff.

The largest channel deposits occur in the mid to upper foreshore (Figs. 37, 38), and are genetically similar to channels that meander across the modern beach at Advocate. These channels are used by the tides to fill and drain the lagoon twice each day. The channel deposits in the foreshore facies also have a meandering form, as revealed by excavation (Fig. 40). The three types of deposits are interpreted as follows:

1. Smaller channel deposits composed of an openwork gravel are probably the result of storm wave runoff, as some occur above high tide. Sedimentary structures are absent due to the coarse grain size, but the a-axis of the pebbles is generally parallel to the channel trend, indicating upper flow regime conditions (Kelling and Williams, 1967). Channel trends are sinuous.

2. Larger, finer grained channel deposits with low angle stratification are more typically fluvial. The large channel in Fig. 37 appears to be

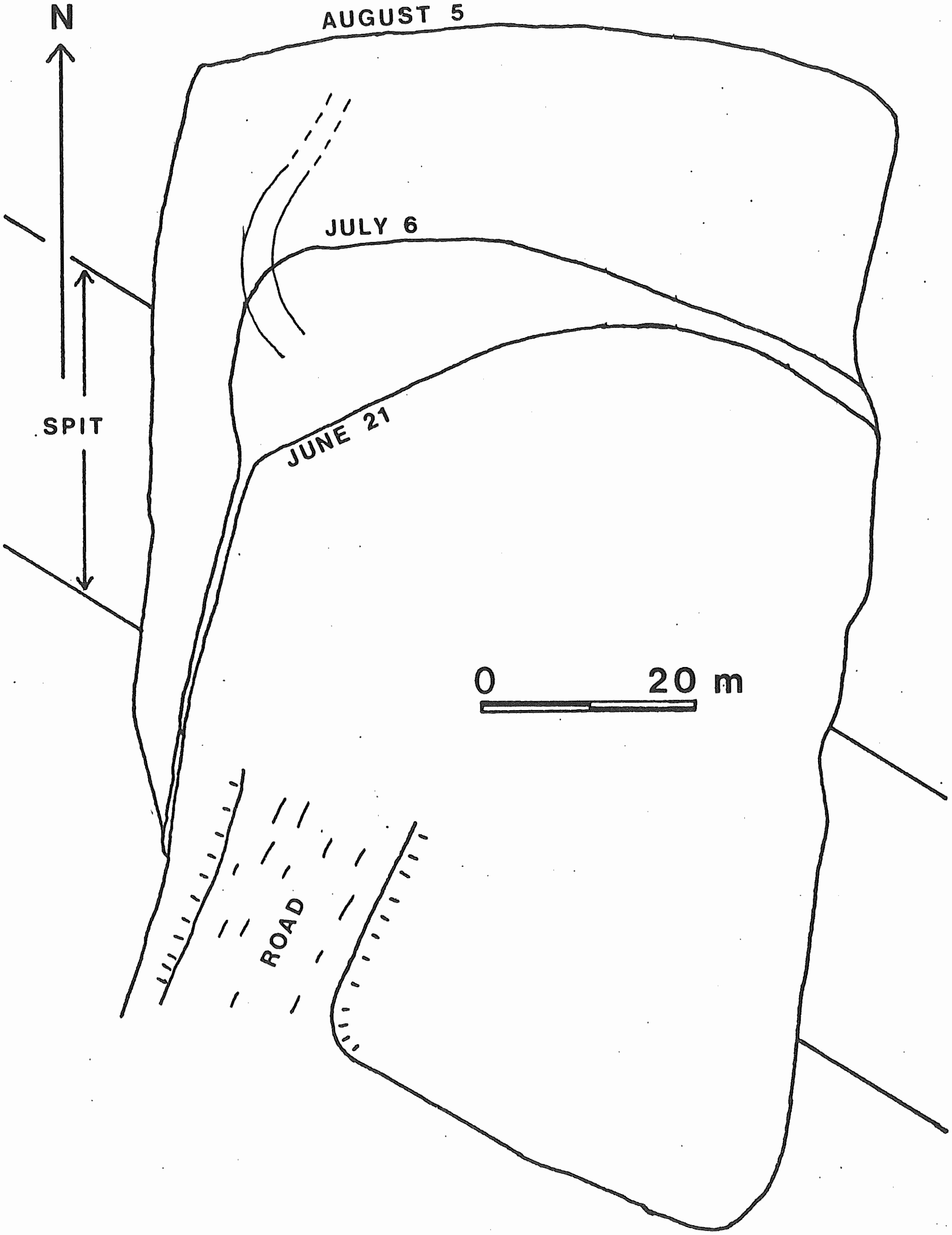


Fig. 40. The location of the channel deposit shown in Fig. 37 during excavation. The exact location was lost (shown by dashed lines) during a break from field work.

filled by a point bar deposit (Fig. 40). Ripple cross stratification is absent because the sediment is coarser than 0.6 mm (Fig. 39). The channel deposit is finer grained than the surrounding foreshore facies, probably because the channel fill is derived from the lagoon.

3. Channel deposits with a washover stratification (landward dipping cross beds) are probably the result of channel abandonment. Abandoned channels are filled from a seaward direction as the flood tide deposits sediment on the down dip channel bank. The coarsest gravel rolls to the bottom of each cross bed. The inactivity of the channel precludes effective removal of this sediment.

Channels of all types tend to occur in or above previous channel deposits, as seen by the channel clusters. Why channels would be used several times is not known. Breaks in the backshore zone would cause channels to occur in specific parts of the beach, but this does not explain why they occur one above the other. Possibly the finer grain size and better sorting of the channel fill cause it to be eroded preferentially during later channel development.

CHAPTER III

FACIES OF UNIT 2

Introduction

The facies of Unit 2 have been given genetic names, as in Unit 1. The genetic difference between Units 1 and 2 is reflected by the facies, as Unit 1 is predominantly foreshore facies and Unit 2 is predominantly backshore facies (Fig. 41). The backshore facies has been divided into the backshore facies proper and a storm ridge subfacies. The facies found in Unit 2 are:

Foreshore Facies

This facies is a fine grained deposit that overlies the southern part of the storm ridge subfacies. Stratification is composed of low angle sand beds that dip south. It is interpreted as the seaward face of a spit.

Backshore Facies

This facies is a fine grained deposit that overlies the northern part of the storm ridge subfacies. The predominant stratification is low angle sand beds that dip north. It is interpreted as the landward face of a spit.

Storm Ridge Subfacies

Coarse, openwork pebble beds dipping 20°-34°N and seaward imbricated

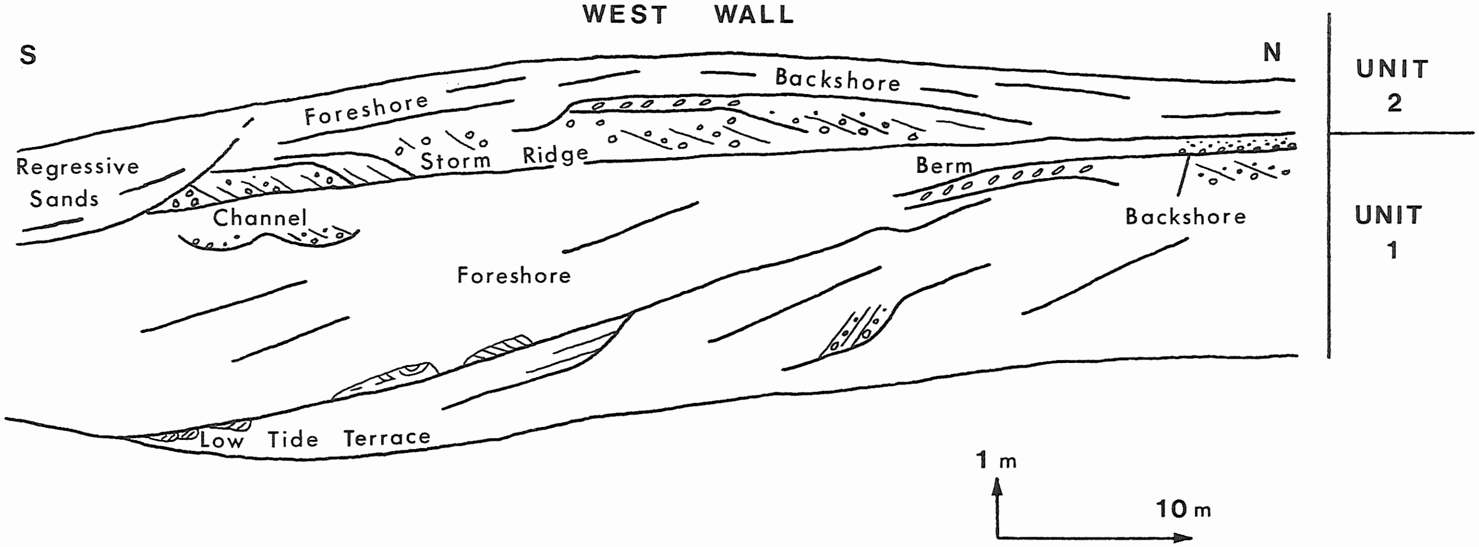


Fig. 41. Stratigraphy and facies of the main part of the west wall. Unit 2 is not present on the north wall.

gravel are predominant in this subfacies. The subfacies forms the core of Unit 2 and overlies Unit 1 with an erosional contact. The gravel was deposited in landward prograding washover fans that formed a ridge in the backshore zone of the beach.

Description and Interpretation

This section contains the description and interpretation of each of the facies in Unit 2. The facies will be described under the following headings:

a) Occurrence
b) Stratification
c) Grain Size
d) Fabric (only in Storm Ridge Subfacies)
e) Interpretation

The storm ridge subfacies will be described first, as it is at the base of Unit 2. The foreshore and backshore facies will be described together because of their similarity in genesis, stratification and texture. Unit 2 is exposed only on the west wall on the photolog.

Storm Ridge Subfacies

Occurrence

The storm ridge subfacies overlies the foreshore and backshore facies of Unit 1 with an erosional contact on the west wall. On the south end of the wall, the storm ridge facies ends against the regressive sands and is overlain by the foreshore facies. The storm ridge pinches out between the backshore facies of Units 1 and 2 on the north end of the wall. An irregular, gradational contact separates the storm ridge from the overlying foreshore and backshore facies, while the contact with the regressive sands is erosional.

The maximum thickness and length of the storm ridge are 1.1 m and 39 m respectively.

Stratification

There are two types of deposits in the storm ridge subfacies: 1. seaward imbricated openwork gravel and, 2. cross beds dipping 20° to 34°N. The two types of deposits are closely related.

1. The seaward imbricated pebbles occur in front of and/or above the cross beds. At V on the photolog (Fig. 42) a small pocket of imbricate pebbles occurs seaward of "washover" cross beds. Above the cross beds is a thin bed, 10 cm thick, of imbricate pebbles that pass into a set of cross beds contiguous with the first set. Above this, there is a bed of seaward imbricated pebbles 30 cm thick (Fig. 43) that pass into "washover" cross beds farther landward.

At W on the photolog, a bed of imbricated pebbles 40 cm thick show a similar relationship; imbricate pebbles sitting above and passing landward into "washover" beds.

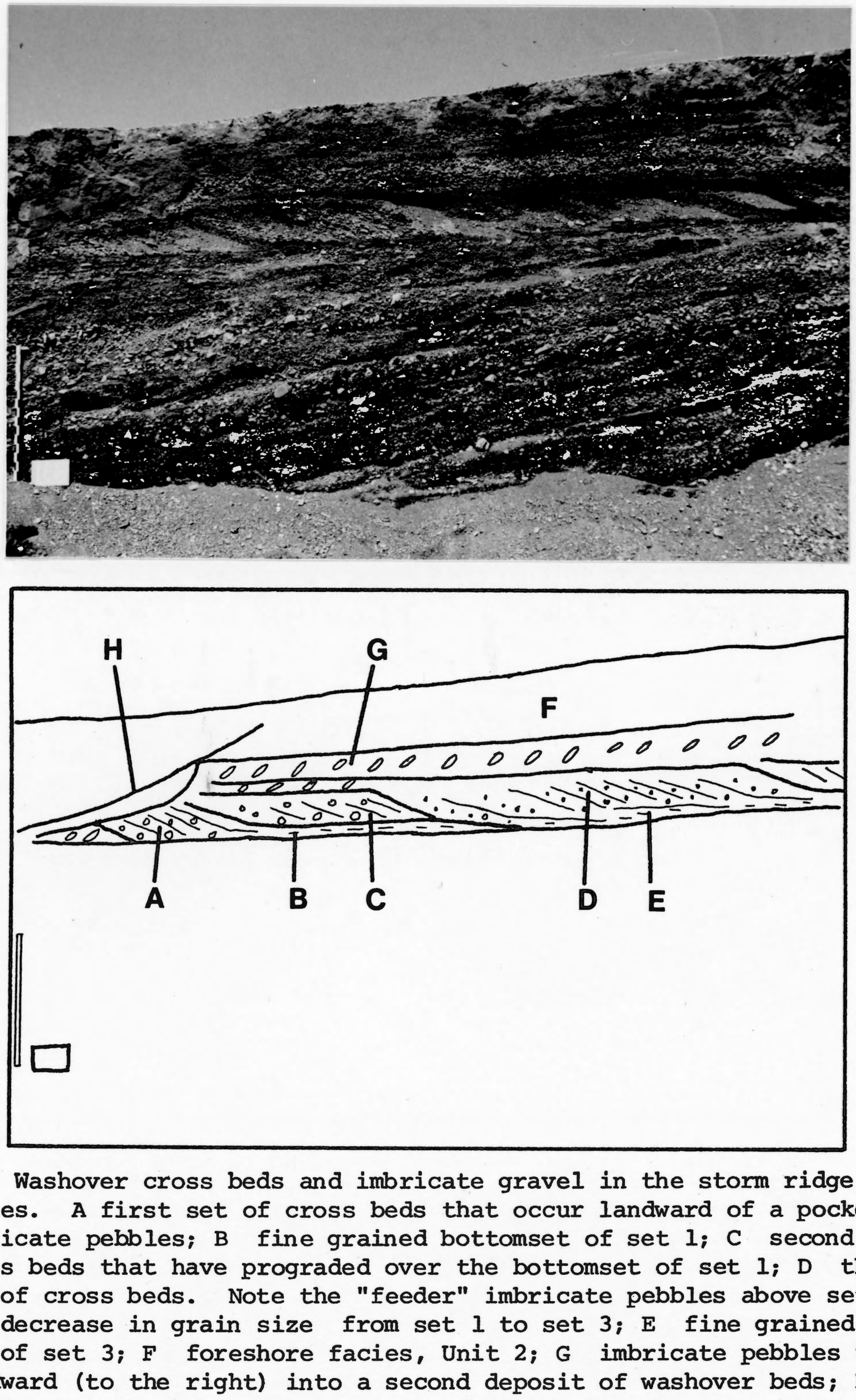


Fig. 42. Washover cross beds and imbricate gravel in the storm ridge subfacies. A first set of cross beds that occur landward of a pocket of imbricate pebbles; B fine grained bottomset of set 1; C second set of cross beds that have prograded over the bottomset of set 1; D third set of cross beds. Note the "feeder" imbricate pebbles above set 2, and the decrease in grain size from set 1 to set 3; E fine grained bottomset of set 3; F foreshore facies, Unit 2; G imbricate pebbles that pass landward (to the right) into a second deposit of washover beds; H erosional contact between regressive sands (above) and Unit 2 (below).

Fig. 43. Pebbles with a high angle seaward imbrication. The photo is of the bed marked G in Fig. 42.

The imbricate pebbles form a predominantly openwork gravel. The pebbles occur in subhorizontal to horizontal beds, with no internal stratification. A finer grained matrix may occur in the lower part of the beds.

2. The cross beds are similar both genetically and physically to the washover cross beds of the backshore facies in Unit 1 (page 61). However, these beds are better developed and exposed in Unit 2, which allows for a more detailed description. A set of cross beds is composed of two parts: 1. openwork pebble cross beds that dip 20°-34°N and 2. a finer grained bottomset bed that is subhorizontal to horizontal. A deposit of washover cross beds usually consists of several sets of cross beds. The cross beds of one set prograde landward over the bottomset bed of the previous set, with an accompanying decrease in grain size (Fig. 42).

The washover cross beds in the storm ridge subfacies can be divided into 3 deposits. The first deposit is shown in Fig. 42 (A-D). The second deposit (X, photolog) is finer grained than usual and is composed of pebbly sand passing upwards into a sandy gravel. Gravel in the upper parts of the cross beds is normally graded. Gravel in the upper parts of the cross beds is normally graded. The pebbly sand cross beds have a lower dip (12°-20°N) than the pebble cross beds (20°-34°N). The third deposit is very coarse grained and graded (W, photolog). The deposit thins landward with an accompanying decrease in grain size before pinching out between the backshore beds of Units 1 and 2. A channel deposit occurs seaward of the cross beds. An unlithified clast of sand occurs in this deposit of cross beds (Fig. 44). The sand is stratified similar to the overlying foreshore facies, and remains intact.

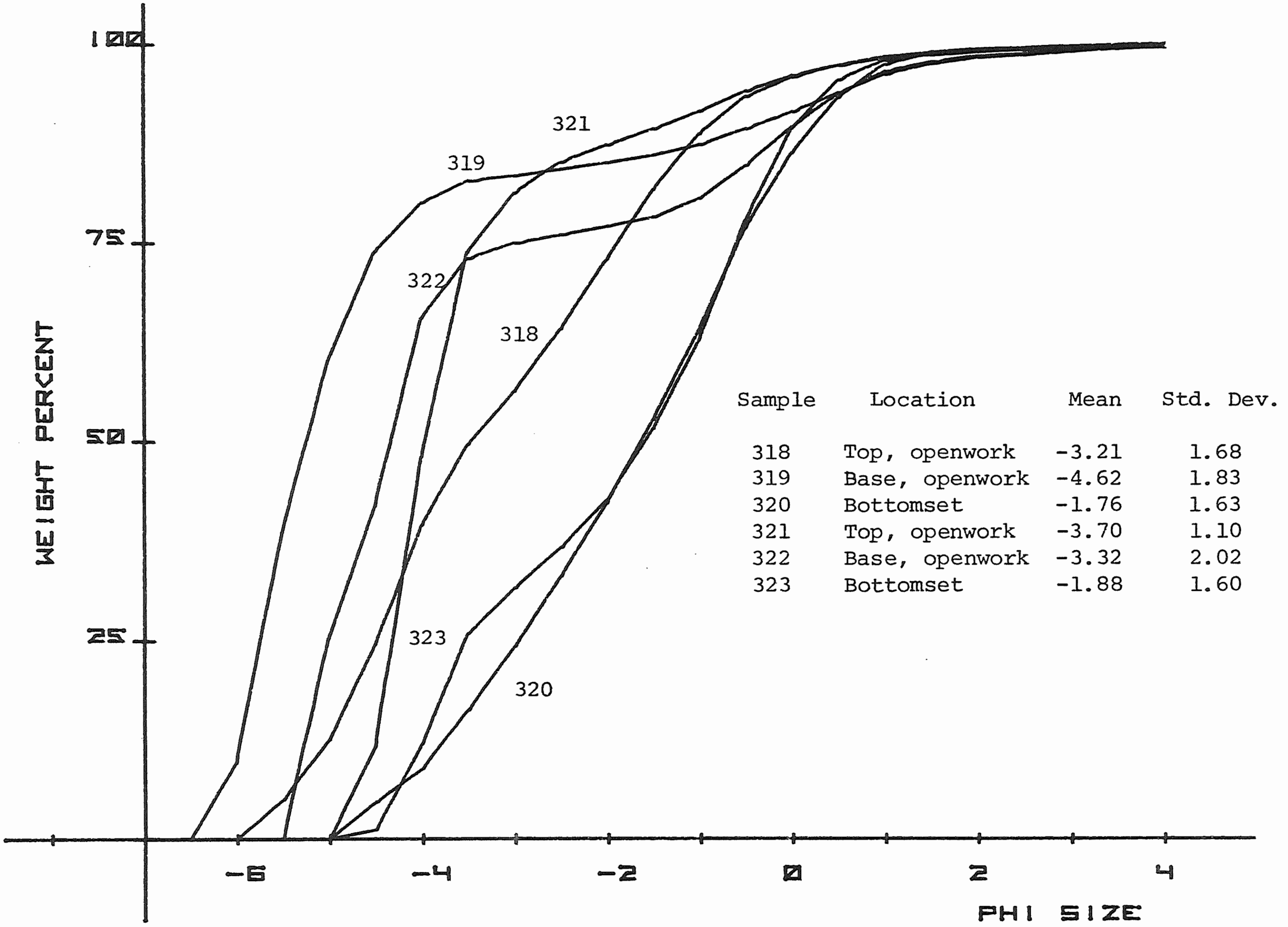
Fig. 44. Clast of unlithified sand in the coarse washover beds of Unit 2. Note landward dip of the clast. Stratification of the clast is similar to the stratification of the overlying foreshore facies.

Each deposit of cross beds, from one to three, is successively higher, and the third deposit of cross beds and imbricate gravel reaches an elevation of 26.8 m.

Grain Size

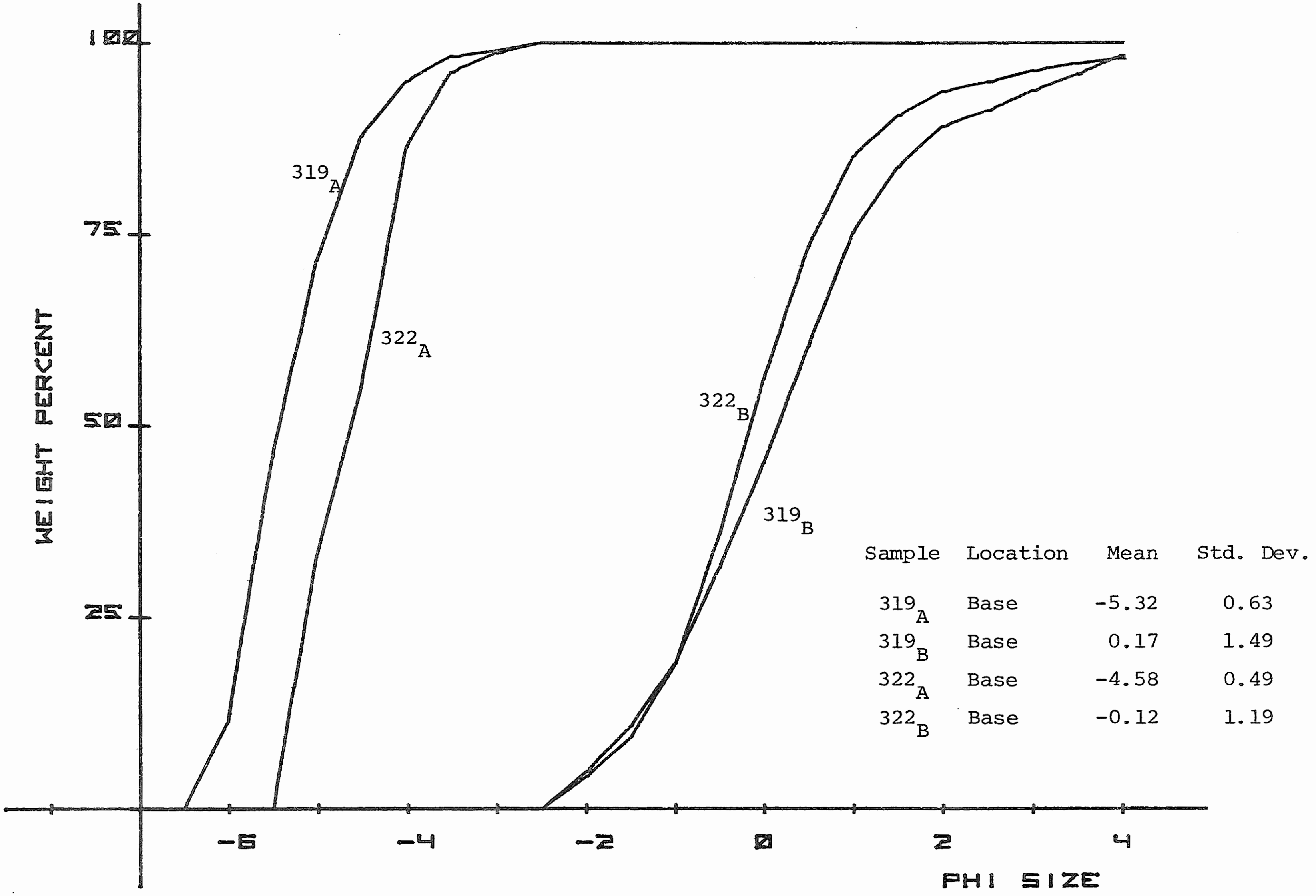
The coarse gravel in the storm ridge subfacies shows the same grain size relationships as the washover beds in the backshore facies of Unit 1 (Fig. 45). The coarsest gravel usually occurs at the bottom of each cross bed, with a finer grained bottomset bed landward of the cross beds. Samples 319 and 322 are similar to the pebble beds in the foreshore facies and berm subfacies, in that the intermediate grain sizes between coarse gravel and sand are deficient. The two samples have been split at -2.50 into two components and replotted in Fig. 46. The replot shows that the samples are composed of two better sorted end members, and implies that the sand is a later infiltrate. The top of the cross beds do not have this deficiency of fine gravel, although sample 321 has a tendency towards it. It appears that a continuum of grain sizes was deposited at the top of the cross beds. Samples 321 and 322 are anomalous in Fig. 45 in that the top of the cross bed (321) is coarser than the bottom of the cross bed (322). However, the removal of the post-depositional sand in the replot (Fig. 46) shows that sample 322 is indeed coarser. Sample 340, taken from the sand bed in the sand clast (Fig. 44), is plotted in Fig. 51, and is very similar to a sand bed in the foreshore facies of Unit 2.

Samples from storm ridges on the modern beach are similar to the replot of samples 319 and 322 and different from samples 318 and 321 from the



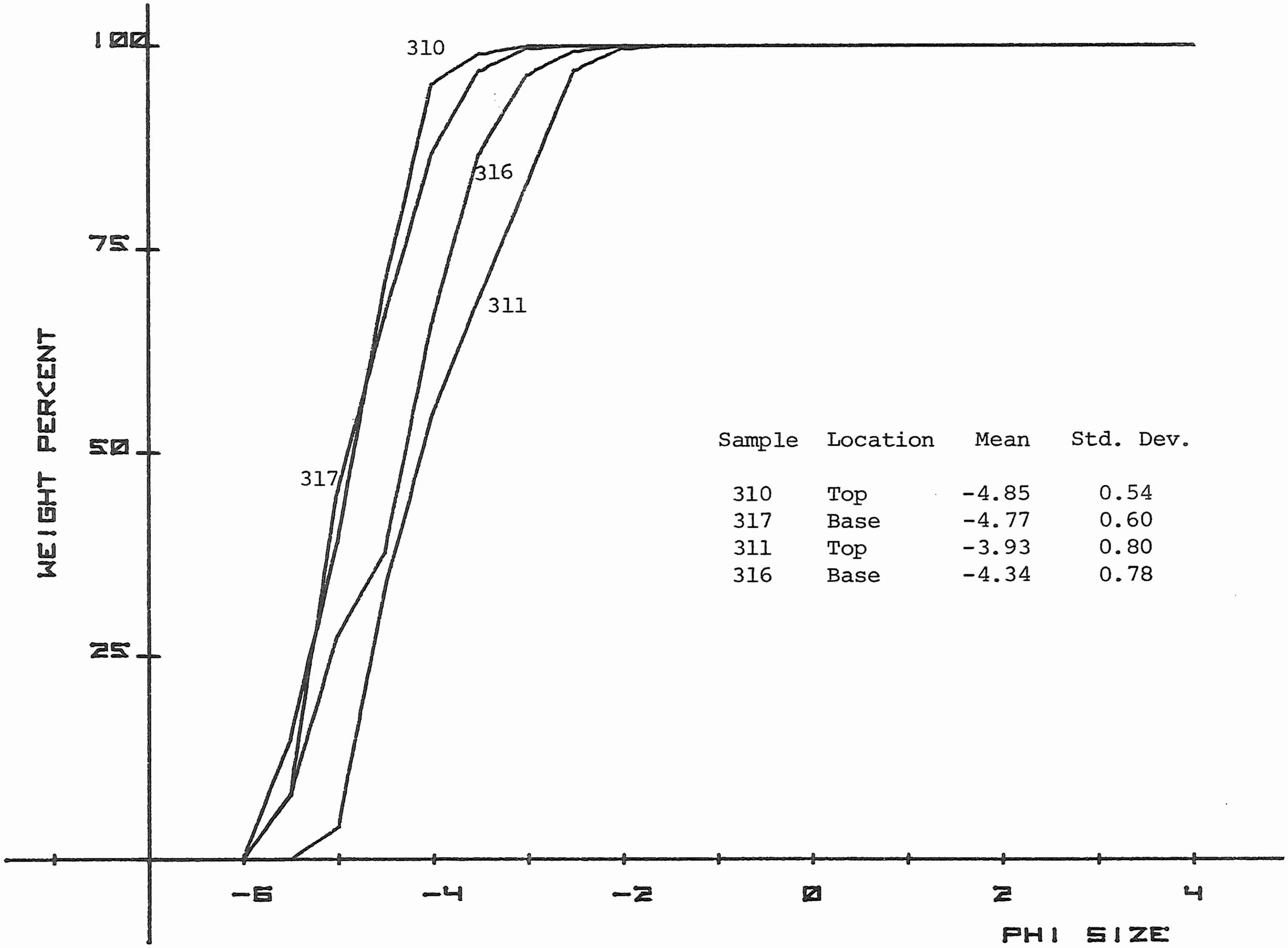
Sample	Location	Mean	Std. Dev.
318	Top, openwork	-3.21	1.68
319	Base, openwork	-4.62	1.83
320	Bottomset	-1.76	1.63
321	Top, openwork	-3.70	1.10
322	Base, openwork	-3.32	2.02
323	Bottomset	-1.88	1.60

Fig. 45. Grain size analyses of two washover beds, storm ridge subfacies.



Sample	Location	Mean	Std. Dev.
319$_A$	Base	-5.32	0.63
319$_B$	Base	0.17	1.49
322$_A$	Base	-4.58	0.49
322$_B$	Base	-0.12	1.19

Fig. 46. Replot of two samples, each from the base of a washover bed.



Sample	Location	Mean	Std. Dev.
310	Top	-4.85	0.54
317	Base	-4.77	0.60
311	Top	-3.93	0.80
316	Base	-4.34	0.78

Fig. 47. Grain size analyses of two washover beds, modern beach.

top of the cross beds (Fig. 47). Samples 318 and 321 are probably anomalous in that a continuum of grain sizes is not usually deposited in backshore gravels. On the modern beach, the coarsest gravel usually accumulates at the bottom of the slip face (Fig. 49), although samples 310 and 317 are approximately equal in mean grain size. The equivalent of the bottomset beds were not developed on the modern beach.

Fabric

The orientation of the maximum projection plane of the imbricate pebbles is shown in Fig. 48. The mean orientation is 094°, oblique to the strike of the trend of Unit 2, which is 122°. Since the washover beds in the storm ridge subfacies form washover fans and not straight crested ridges, orientations in the backshore zone should vary from the trend of the spit. The imbrication is fairly steep, but not as high as in the berm subfacies of Unit 1. Seventy-six percent of the pebbles dip seaward at a mean angle of 34°, while twenty-four percent dip landward at a mean angle of 33°.

Interpretation

The storm ridge subfacies is an accumulation of supratidal gravel that is built into the shape of a ridge. The ridge is a complex of washover fans deposited by storm waves. The washover fans are composed of imbricate gravel, openwork pebble cross beds and fine grained bottomset beds. Successive fans are built farther inland at higher elevations. This indicates a transgressive sequence of sediments.

The imbricate gravel is a supratidal gravel deposited by high energy

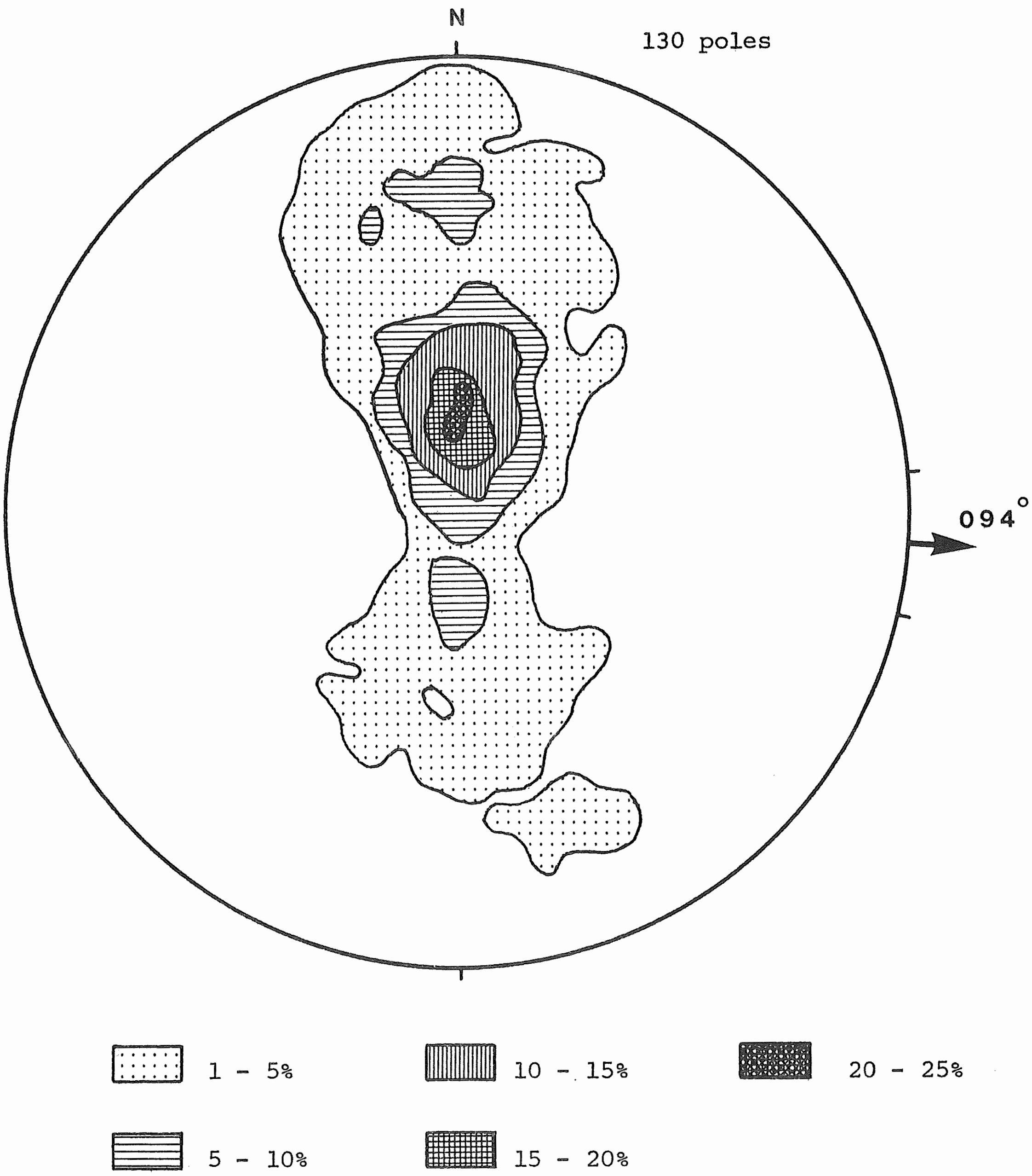


Fig. 48. Contoured stereoplot of the C-axis (pole to max. prj. ple) of imbricated pebbles in the storm ridge subfacies, mean orientation of the strike of the maximum projection plane = 094°. 95% cone of confidence = ±9°.

events. It is imbricated seaward because the water breaching the berm is moving landwards. The disc-shaped pebbles are imbricated with their maximum projection plane perpendicular to the direction of flow. The maximum projection plane is not synonymous with the long axis of a pebble.

The imbricate gravel has two possible relationships within a washover fan. In the first case, it can initiate deposition of the fan, and in the second, it feeds the fan. If the imbricate gravel is built into a significant topographic feature (berm deposit of Unit 1 or gravel landward of "A", Fig. 42), it will initiate deposition on a landward facing slip face. The converse of this is not true, that is, not all washover fans are built landward of imbricate gravels. Once a washover fan has been created, the sediment being supplied to the slip face of the fan forms an imbricate gravel on top of the fan. The imbricate gravel "feeds" the slip face of the fan as it progrades landward. This is similar to sediment movement on a ripple. Sand moves up the stoss side to be deposited on the slip face of the ripple. The imbricate gravel is similar to the sand on the stoss side, with the exception that it is more likely to be preserved as the fan does not move like a ripple. It grows by progradation without erosion on the stoss side. This concept of "feeder" imbricate gravels is shown in Fig. 42.

Deposition on the slip face produces graded openwork cross beds, as the larger pebbles roll to the bottom of the slip face. Finer grained sediment is deposited farther landward, and is the bottomset of the fan (Fig. 42). The graded nature of the washover beds is visible on the modern beach at Advocate (Fig. 49). Washover fans have coalesced to form ridges in the backshore zone that are in an early stage of development. The

Fig. 49. Looking seaward at a storm ridge in the backshore zone of the modern beach at Advocate. The crest of the ridge, which is parallel to the top of the photo, passes beneath the logs in the upper right. Note grading from large pebbles at the base of the ridge (lower part of photo) to smaller pebbles at top.

coarsest gravel is deposited at the bottom of the ridge slip face. The fine grained bottomset is not developed, partly due to man's interference (the backshore zone ends abruptly behind the gravel in Fig. 49 because of a man-made ridge).

The fans do not prograde ~~but~~ continually but rather in distinct depositional events, as storm waves or storm tides are needed to wash sediment into the backshore zone. Some of the gravel may be tossed over the berm crest by storm waves. Each event results in a rapid progradation over a short period of time. As the fans prograde away from the berm, the sediment supplied to the slip face becomes finer grained. Thus, pebble gravel is proximal to the berm and sand is more distal. The decrease in velocity as the storm waves move landward and the "toss-over" gravel are responsible for this "fining landward" sequence.

The sand clast in the third deposit of cross beds indicates that some of the gravel was tossed over the berm in the early spring or late fall, when ice existed on the beach. It must have been thrown over as a frozen lump as it would have been smashed in its present state. The sand is probably derived from the foreshore facies that existed during the formation of the storm ridge. The texture (Fig. 51) and stratification (Fig. 44) of the sand indicate that the foreshore facies was similar to the overlying foreshore facies and not the foreshore facies of Unit 1.

There are three washover fan deposits in Unit 2, and each one is higher and farther inland than the previous one. This stacking of sediments is the result of a transgression.

Foreshore and Backshore Facies

Occurrence

The foreshore facies overlies the storm ridge subfacies on the south end of the west wall. The contact is generally sharp but irregular. An erosional contact separates the foreshore facies from the regressive sands to the south. To the north, the foreshore facies meets the backshore facies and the contact is placed at the change in dip from beds dipping south (foreshore) to beds dipping north (backshore). The upper part of the foreshore facies is obscured by the soil and the contact between the foreshore and backshore facies is difficult to place because of this. The length and thickness of the foreshore facies are 23.2 m and 0.70 m respectively.

The backshore facies overlies the storm ridge subfacies of Unit 2 and the backshore facies of Unit 1 on the north end of the west wall. The contact with the storm ridge subfacies is sharp but irregular, and with the backshore facies of Unit 1, sharp and planar. The backshore facies of Units 1 and 2 are paraconformable, and the contact extends into the soil. To the south, the backshore facies is bounded by the foreshore facies. The upper part of the backshore facies is also obscured by the soil. The length and thickness of the backshore facies are 30.4 m and 1.1 m respectively.

Stratification

The foreshore and backshore facies consist of beds of pebble gravel, granule gravel and sand from 4 - 15 cm thick (Fig. 50). Bedding contacts are generally sharp and regular. In the foreshore facies, the beds dip

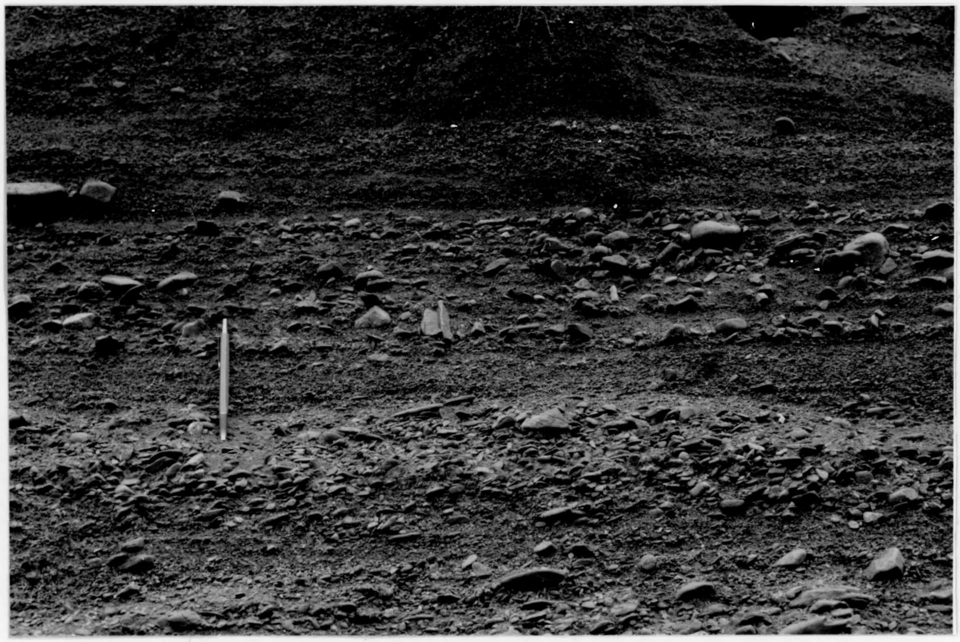


Fig. 50. Foreshore facies of unit two. The coarser grain size in the lower part of the photo is probably due to reworking of the underlying storm ridge subfacies.

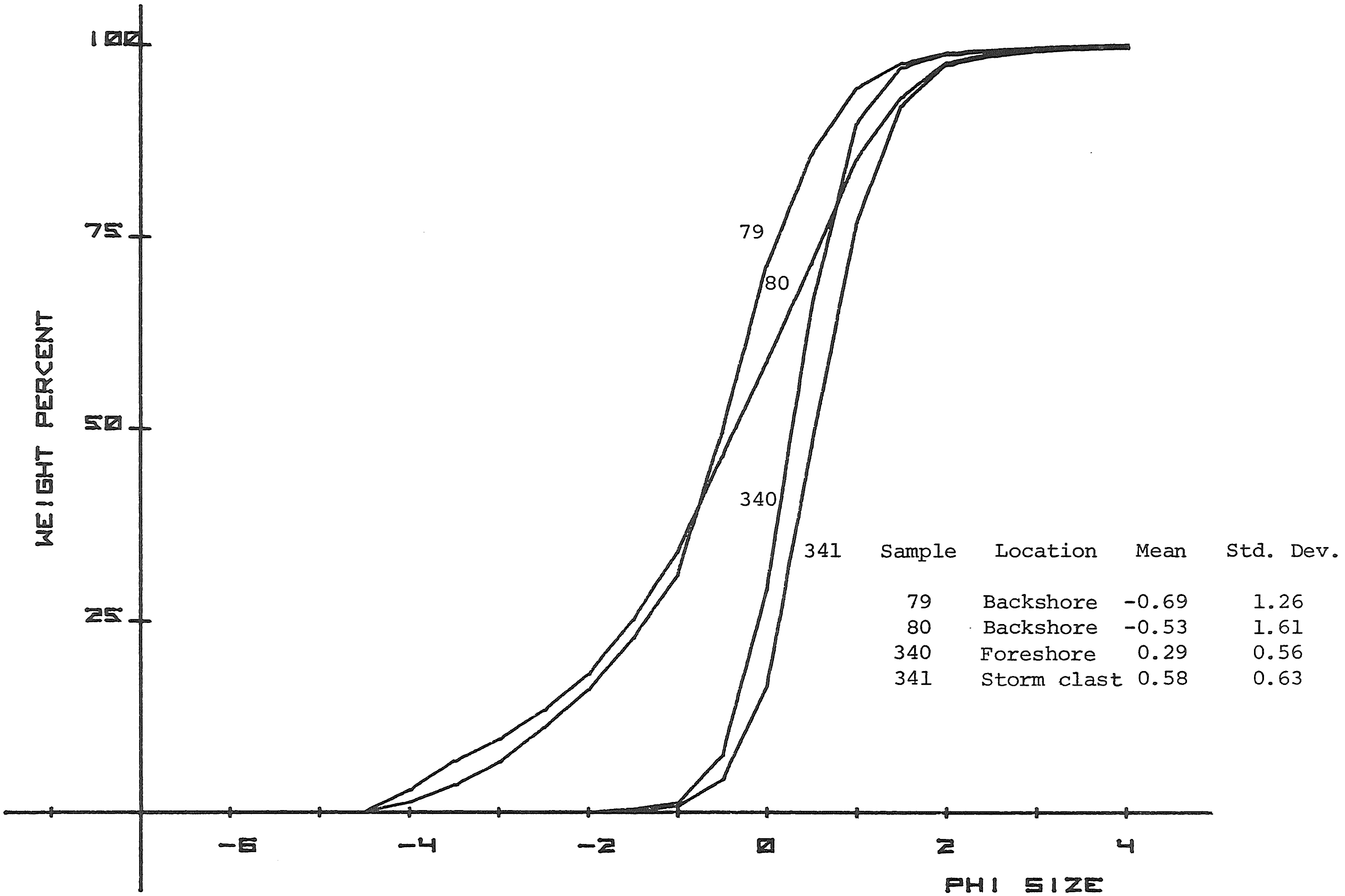
from 1°-4°S. In the backshore facies, the beds overlying the storm ridge dip from 1°-3°N, and the beds overlying the backshore facies of Unit 1 dip from 2°-4°S.

The pebble beds are thin, 3-6 cm thick, and usually discontinuous. Grain size changes occur along a bed and parts of the bed may be openwork, but most of the gravel is closedwork. Thicker pebble beds 10-20 cm thick, usually with a higher percentage of matrix, occur immediately above the storm ridge subfacies. These may be reworked sediments.

The granule gravel and sand beds are well sorted, with few pebbles. The sand beds are parallel laminated, while the granule gravel is massive. Bedding within the soil is difficult to distinguish. The predominant massive, pebbly sand is probably a mixture of pebble and sand beds, brought about by disruptive soil processes.

Grain Size

The foreshore and backshore facies of Unit 2 are much finer grained than the foreshore and backshore facies of Unit 1 (Fig. 51). Samples 79 and 80 are very coarse grained sands from the backshore facies that are moderately poorly sorted and poorly sorted, respectively. Sorting is poor because of the scattered pebbles in the sand, some of which probably came from the underlying storm ridge subfacies. Samples 340 and 341 show the similarity between a sand bed in the foreshore facies and the sand bed in the sand clast (Fig. 44).



Sample	Location	Mean	Std. Dev.
79	Backshore	-0.69	1.26
80	Backshore	-0.53	1.61
340	Foreshore	0.29	0.56
341	Storm clast	0.58	0.63

Fig. 51. Grain size analyses, foreshore and backshore facies, Unit 2 and "storm clast" (Fig. 44).

Interpretation

The foreshore and backshore facies are a fine grained cap of sediment that overlies the storm ridge subfacies. The stratification within the foreshore facies bears no resemblance to that of the foreshore facies of Unit 1. It is fine grained, has lower dips and the parallel lamination is typical foreshore zone stratification in a sand beach (Thompson, 1937; Clifton, 1969). The backshore facies is also different from the backshore facies in Unit 1. The beds are not graded, have no erosional contacts, and are parallel laminated. Stratification is similar to the foreshore beds with the exception of a change in dip.

There is no evidence of a supratidal origin for the foreshore and backshore facies. They exhibit none of the characteristics of the supratidal storm ridge that they overlie. The foreshore and backshore facies are comprised of sands washed over the storm ridge as a rise in sea level or increase in tidal range took place. The finer grain size indicates that the sediment being supplied to the beach was finer grained. As the sands were washed over the storm ridge, a spit was formed. The dip of the sands and thus the creation of foreshore and backshore facies, is a result of the topography on the underlying storm ridge subfacies. The crest of the spit (Y, photolog) overlies the highest point on the storm ridge. Landward of the crest, where the storm ridge slopes north and the sands dip north, is the backshore facies. Seaward of the crest, where the storm ridge slopes south and the sands dip south, is the foreshore facies. The elevation of the crest of the spit, 27.3 m above sea level, is a minimal estimate of the highest elevation that the sea reached during the formation of the raised beach at Advocate. It is a minimum because post-uplift erosion and soil formation may have removed some of the spit. Erosional flattening appears to be minor as the spit still retains a convex-up shape. But the soil obscures at least a metre of sand at the top of the spit. The upper part of the soil, approximately 0.5 m, was removed from the pit area, and the upper 0.5 m on the pit face is disturbed soil. However, the origin of the missing and disrupted sand is not known.

It must be noted that an elevation of the spit must not be taken as a marine limit where the sediments are not exposed. Elevations taken from a topographic map are meaningless as the underlying sediments may be supratidal. A marine limit can only be determined where the underlying sediments are exposed and the facies are known.

CHAPTER IV

DISCUSSION OF UNITS 1 AND 2 AND TIDAL AMPLIFICATION

Unit 1

Unit 1 is a progradational beach deposit composed of coarse gravel. The bulk of the sediment was deposited in the foreshore zone as poorly sorted, low angle gravel beds with interbedded high angle cross beds. Several ridges and runnels occur in the lower foreshore, indicating sediment movement landward. Sediment deposited in the subtidal zone is finer grained, and shows offshore sediment movement. High energy events are responsible for sedimentation in the backshore zone either as washover fans or storm graded beds. Sinuous channel deposits occur in the foreshore and lower backshore facies, as the result of a lagoon landward of the beach and storm wave runoff.

Unit 1 provides information on the thesis problem of determining the paleotidal range during the formation of the beach, and on the deposition of openwork versus closedwork beach gravel, a problem discussed by Hey (1967). Although the thesis attempts to define what the tidal range was and not why the tidal range was different, the problem of tidal amplification is discussed at the end of the chapter for completeness.

A. Openwork vs. Closedwork Beach Gravel

Pettijohn (1957, p. 248) states that most beach gravels are unimodal (openwork), although no specific beach zone is given. Hey (1967) found that gravel was bimodal (closedwork) in the foreshore zone and unimodal in the backshore zone in beach deposits at Dungeness. To explain the bimodal gravel, he suggests that either openwork beach gravels contain sand at depth or sand and gravel coexist on a beach. In contrast, Bluck (1967) describes unimodal (openwork) gravel in the foreshore and backshore zones of a beach.

Gravel in the foreshore facies in Unit 1 is closedwork. Sand and gravel were deposited together in the foreshore zone, which is the same as deposition in the foreshore zone of the modern beach at Advocate. So why do some beaches have openwork and some beaches have closedwork gravel in the foreshore zone? Ultimately, the matrix content of foreshore gravel is dependent upon sediment supply. Where sand and gravel are being supplied to a beach, the foreshore beds will be closedwork. Storms may remove the fine material only to have it return under low wave conditions and infiltrate the openwork gravel. If only gravel is supplied to a beach, the foreshore beds will be openwork.

In contrast, gravel in the backshore zone tends to be openwork. Storm waves wash both sand and gravel over the berm, but there is a size segregation during deposition. In washover fans, the coarse gravel is deposited close to the berm in landward dipping cross beds and the sand is carried farther inland. Gravel is proximal and sand is distal to the berm. In the storm graded beds, gravel is deposited at the base and sand is deposited in the upper part of the bed. Fine sediment may later infiltrate the gravels in the backshore zone, but frequently they are sealed off and remain openwork.

Thus, the matrix content of beach gravel is dependent upon the zone of the beach as well as sediment supply. Depositional processes in the foreshore zone tend to produce closedwork gravel, while processes in the backshore zone tend to produce openwork gravel.

B. Paleotidal Range

The paleotidal range of a beach is given by the thickness of the foreshore facies. As the tidal range increases, so does the vertical distance between the low tide terrace and the berm of the beach. The paleotidal range of the beach in Unit 1 can be determined on the west wall as both an upper and lower limit for several beds in the foreshore facies are present. The lower limit is the low tide terrace/foreshore boundary, which is 22.2 m above sea level. The upper limit is the foreshore/berm boundary at 25.6 m. This gives a paleotidal range of 3.4 m. Is this the neap, mean, spring, or equinoctial spring tidal range? Washover beds immediately landward of the berm deposit show no evidence of being in the swash zone at any time. The coarse berm deposit on the modern beach at Advocate occurs at the high spring tide position. Neap tides do not reach the berm. It seem probable that the foreshore/berm boundary is at the high spring tide position. Equinoctial spring tides may rise above this, but probably not higher than the berm deposit itself.

The position of the low tide terrace varies on different beaches and even within the same beach (Hey, 1967). Many beaches on the New England coast described by Hayes <u>et al.</u> (1969) have the low tide terrace/foreshore boundary above the mean low tide position. Low tide terraces occurring above the low spring tide position should show intertidal features because of the regularity of exposure. The low tide terrace facies at Advocate is composed of subtidal sedimentary structures only, and thus, the low tide terrace/foreshore boundary is probably at the low spring tide position. Thus, the tidal range of 3.4 m is probably a spring tidal range; neap tides would be less and large spring tides would be more.

The spring tidal range of 3.4 m can not be taken as an exact figure, but more a close estimate. The estimate is probably accurate to within ±0.5 m. The present tidal range at Advocate is a maximum of 12.6 m. Certainly, the raised beach shows that the tidal range was considerably less in the late Pleistocene, only about a quarter of what it is today. On the modern beach, the foreshore zone is much larger due to the extreme paleotidal range; the beaches are really on two different scales (Fig. 52).

A paleotidal range can not be determined for the older part of the beach on the north wall. The upper and lower limits do not exist (berm deposit and low tide terrace, respectively). However, the maximum height of the foreshore facies is 26.4 m (B, photolog), 0.8 m above the height of the foreshore facies on the west wall, and it occurs at an erosional contact (therefore a minimum elevation). Thus, the elevation of the foreshore facies drops at least 0.8 m from the north to the west wall. This can be

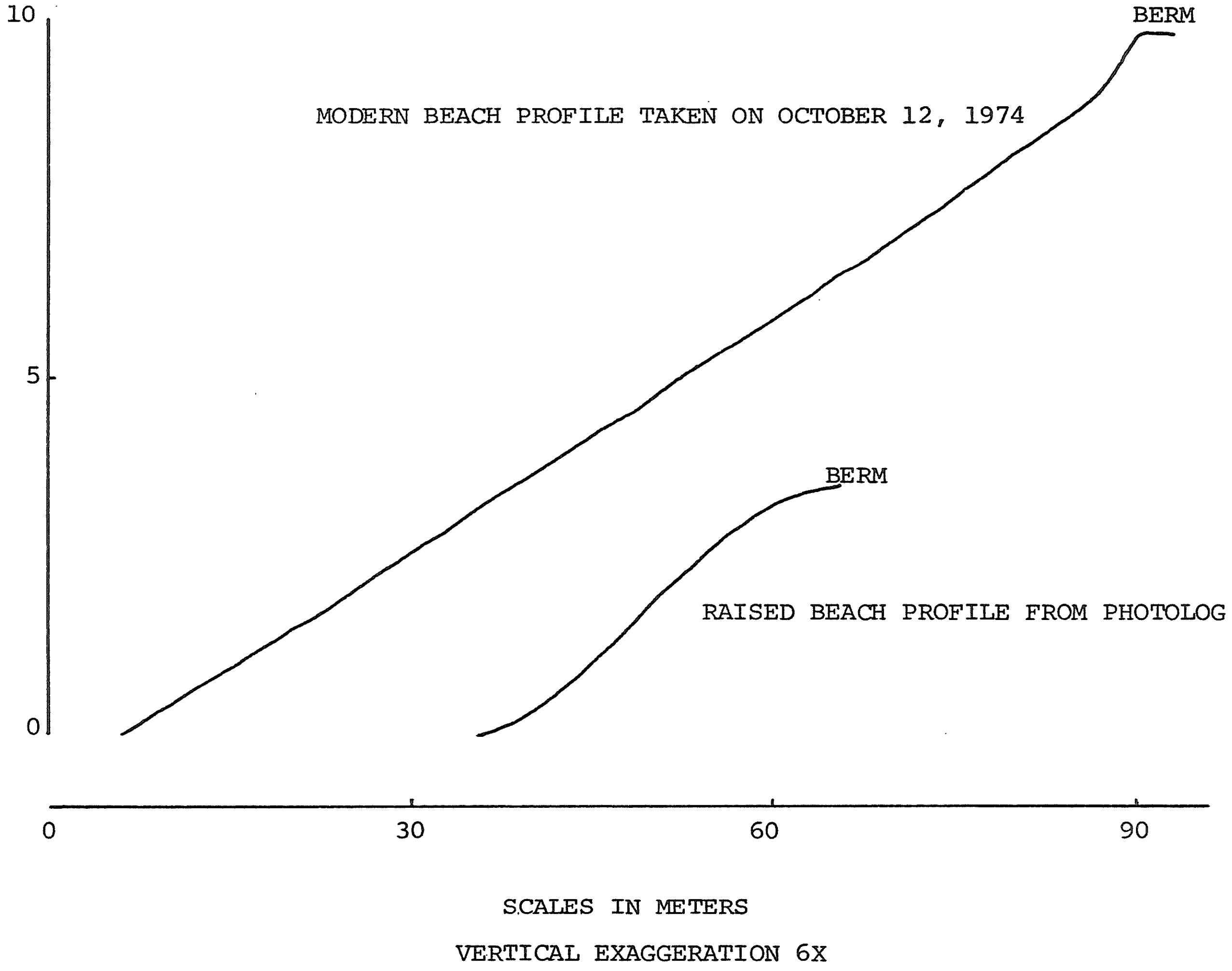


Fig. 52. Beach profiles for the modern and raised beached at Advocate. On October 12, the tidal range was approximately 9.2 m.

explained by a minimum lowering of 0.8 m in sea level or a minimum decrease in tidal range of 1.6 m (high and low tides are symmetrical about mean sea level) during progradation of the beach.

Although it cannot be proven, circumstantial evidence favours the lowering of sea level. In actual fact, it was not a drop in sea level but an uplift of the land, as glacial rebound exceeded the eustatic rise in sea level by approximately 30 m (elevation of the beach above sea level) in the Advocate area. The alternative explanation requires a decreasing tidal range in the late Pleistocene and an increasing tidal range in the Holocene. This complicates a problem that can be explained by an increasing tidal range in both the late Pleistocene and Holocene, although it was probably accelerated after 6000 B.P.

Unit 2

Unit 2 is a transgressive deposit that lies unconformably on Unit 1. Unit 2 is important in that it records a local reversal in the regression that formed the terrace. Reconnaissance work on the deltas in the terrace shows that the sea level fell during the formation of the deltas. Since the deltas represent the earliest sedimentation in the Bay of Fundy after deglaciation (Swift and Borns, 1967), the rate of uplift exceeded the eustatic rise in sea level in the Late Pleistocene as well as in the Holocene. Unit 2 represents a short period of time when either the eustatic rise in sea level exceeded the rate of rebound or there was a sudden increase in tidal range. The implications of Unit 2 on ice retreat and sea level changes are discussed below.

A. Ice Retreat

Sediments in Unit 1 are coarser grained than sediments in Unit 2. The supratidal sediments in Unit 2 are coarse gravel, but this is a function of facies. Coarse gravel accumulates in washover fans in the backshore zone of a beach. The equivalent foreshore facies of the storm ridge was probably finer grained than the foreshore facies of Unit 1, as indicated by the "storm clast" of sand (Fig. 44) and the foreshore facies of Unit 2. The regressive sands, which were deposited after Unit 2, are also predominantly sand.

The change in grain size from coarse gravel in Unit 1 to predominantly sand in Unit 2 reflects a change in grain size of the sediment being supplied to the beach. This change is probably related to the position of the melting ice on the Chignecto peninsula. Melting ice close to the shoreline would supply gravel to the beach. As the ice retreated, the coarser sediment would be deposited in the upper reaches of the drainage systems, and finer sediment would be supplied to the beach. Thus, Unit 1 represents a "proximal" ice position and Unit 2 represents a "distal" ice position.

B. Sea Level Changes

The vertical succession of sediments in Unit 2 (supratidal overlain by foreshore) indicates a transgression. The transgression may be a result of: 1. an increase in tidal range, 2. a rise in mean sea level or, 3. both.

1. The crest of the spit in Unit 2 is 1.7 m above the upper limit of foreshore deposition (27.3 m vs. 25.6 m) in Unit 1. Since tides are symmetrical about mean sea level, an increase in tidal range of 3.4 m is required to cause the transgression. This would be a doubling of the tidal range (the tidal range during the formation of Unit 1 was 3.4 m) over a short period of time.

Grant (1970) gives evidence that tidal amplification in the Bay of Fundy began approximately 6000 years B.P. Swift and Borns (1967) tentatively place the formation of the terrace, including the spit, between 13,000 and 11,500 B.P. It seems improbable that a sudden doubling of the tidal range would occur before tidal amplification in the Bay of Fundy. Grant's (1970) evidence suggests that large tides would not have existed until after 6000 years B.P.

2. and 3. The transgression was probably caused by a rise in sea level of 1.7 m. This may have been accompanied by a small increase in tidal range, in which case the rise in sea level would be less than 1.7 m. Glacial rebound is substantial in the Bay of Fundy (Gadd, 1973; Swift and Borns, 1967) but the rate of rebound must have been exceeded by the eustatic rise in sea level for a short period of time in the late Pleistocene. Regressive sands were deposited after Unit 2 when the rate of uplift was once again greater than the eustatic rise in sea level. The transgression implies that glacial rebound in the Advocate area was not a simple function and may have been composed of periods of rapid uplift followed by periods of relative stagnation.

Tidal Amplification

Tidal amplification of approximately seven times in the Bay of Fundy is caused primarily by resonance in the Bay of Fundy - Gulf of Main system (Garrett, 1972) and to a lesser extent, the funnel shape of the Bay of Fundy. The funneling effect due to the shape has remained approximately constant since the late Pleistocene, as the raised marine deposits occur along the present shoreline (Swift and Borns, 1967; Glass, 1972; Gadd, 1973). However, tidal resonance may not have been present in the late Pleistocene.

A first approximation of a basin's natural period is given by the formula:

$$\text{Period} = 4 \times \text{length} / \sqrt{g \times \text{depth}}$$

The natural period of the Bay of Fundy - Gulf of Maine system is 13.3 ± 0.4 hours (Garrett, 1972). The main tide-producing semi-diurnal component has a period of 12.42 hours. Thus, the natural period of the bay and the period of the semi-diurnal tides are nearly equal, which results in tidal resonance. In a simplified manner, this may be explained as follows. A high tide in the Atlantic forces water into the bay. The tide travels into and out of the bay and reaches the edge of the system at approximately the same time as another Atlantic high tide occurs. The gentle "push" from the Atlantic Ocean occurs at the right time to amplify the tides in the Bay of Fundy.

The natural period of the bay was probably different in the late Pleistocene because of the pre-rebound higher sea level, which changes depth in the formula above. Grant (1970) calculates that 14,000 years ago the natural period of the bay was about 7 hours and so out of phase with the semi-diurnal tides that there was no tidal resonance. Grant (1970) also suggests that the mouth of the Bay of Fundy was constricted by the emergent Georges Bank until about 6,000 years ago (Figs. 53, 54). The narrow threshold width at the mouth of the bay precluded tidal amplification by restricting the volume of water moving into and out of the bay.

Thus, the small tides in the late Pleistocene - early Holocene were probably a result of a lack of tidal resonance and a constriction at the mouth of the Bay of Fundy.

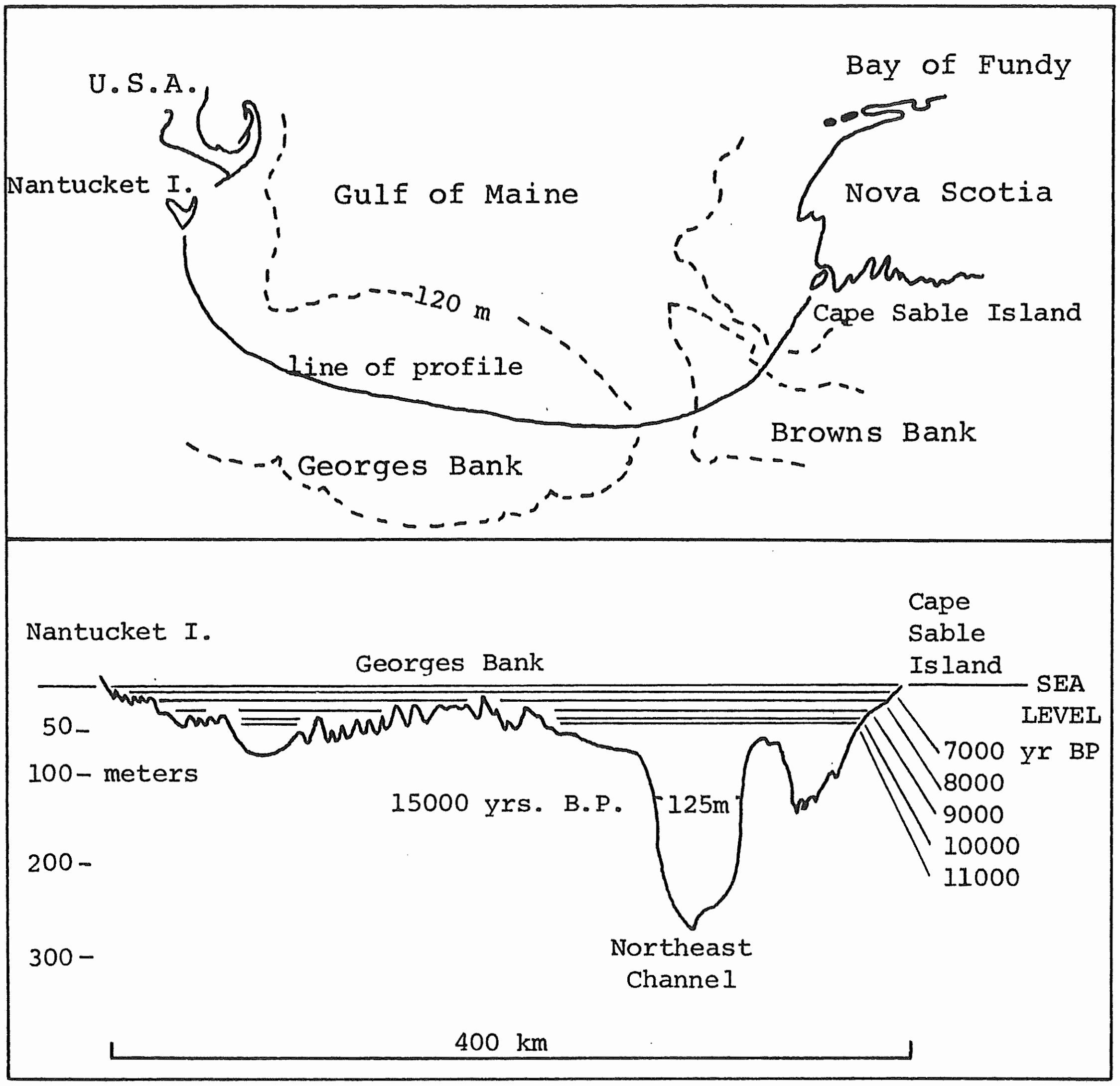


Fig. 53. Eustatic rise of sea level in relation to the longitudinal profile of the threshold of the Gulf of Maine. (after Grant, 1970).

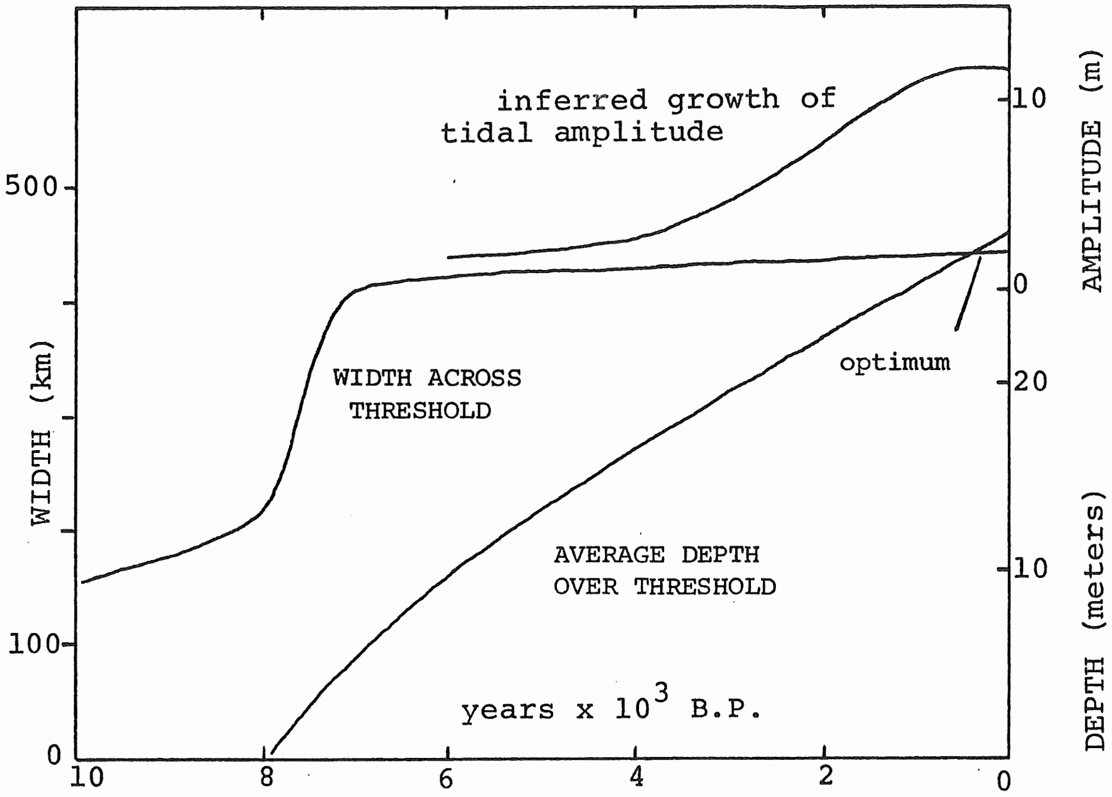


Fig. 54. Inferred tidal amplification (= rise of high tide Datum) in the Bay of Fundy as a function of increasing depth and width of the entrance to the Gulf of Maine due to eustatic rise of sea level. (after Grant, 1970).

CHAPTER V

MODEL FOR GRAVEL BEACHES

A model for gravel beaches is proposed based on a synthesis of data from the raised beach at Advocate and from the literature (Fig. 55). The model is divided into the low tide terrace, foreshore and backshore zones, each of which is described separately. The determination of tidal range and the distinction between tidal and non-tidal beaches are discussed at the end of the chapter.

Low Tide Terrace

If sufficient sand is supplied to the beach, the sand will concentrate in the subtidal zone and form a low tide terrace. The upper surface of the terrace is at a lower angle than the foreshore slope because the steepening action of the swash is absent below low tide. The break in slope creates a step at the base of the foreshore zone. The grain size change from foreshore gravel to low tide terrace sand will occur at the step.

The location of the step depends upon sediment supply and the level of the water table. If the water table intersects the beach face above the level of low spring tide, the step will occur at this intersection. The water table precludes water loss on the swash and the relatively powerful backwash reduces the beach face slope. This usually occurs when the gravel supply is insufficient and the gravel/sand contact is above the level of low

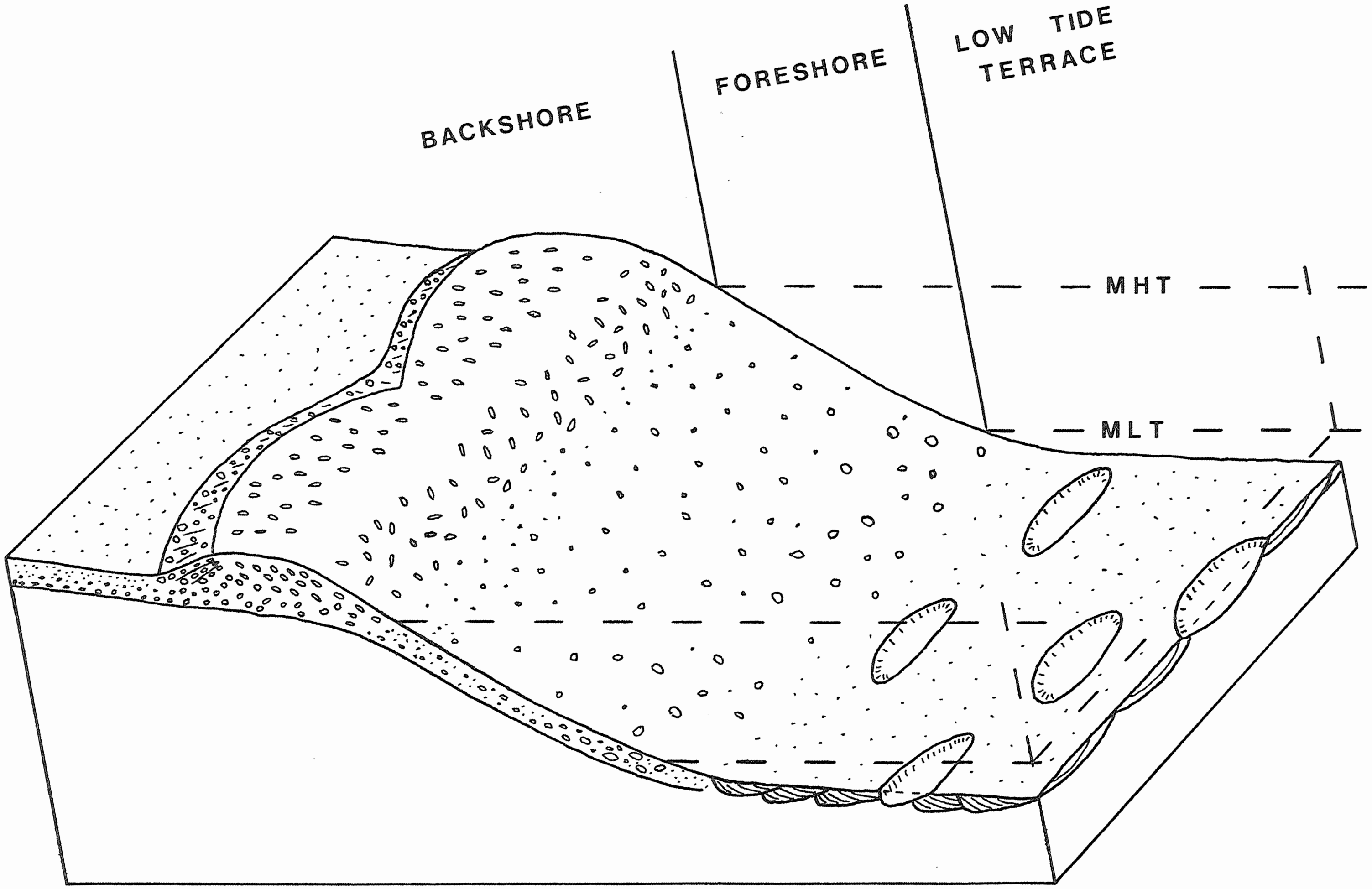


Fig. 55. Sedimentological model of a gravel beach. MHT = mean high spring tide, MLT = mean low spring tide.

spring tide. The relatively impermeable sand tends to retain the groundwater. When the water table intersects the beach face at the level of low spring tide, the step occurs at or slightly below the level of low spring tide. This is typical of a gravel foreshore zone.

Sediment movement in the subtidal zone is both onshore and offshore, depending upon the wave steepness. Onshore sediment movement occurs when wave steepness is below the critical value, and offshore movement occurs when wave steepness is greater than the critical value. The critical value increases directly with grain size and beach gradient. Sediment movement onshore is in the form of ripples or megaripples. Offshore movement produces asymmetrical troughs or depressions that are parallel to the shore, with the steep side facing seaward. The offshore sediment movement bedforms and structures have a greater preservation potential, so that seaward dipping trough cross stratification is predominant.

When low tide terraces are partly intertidal, the intertidal sand can be distinguished from the subtidal sand using sedimentary structures and bedforms. Intertidal sand consists predominantly of parallel laminated sand (swash-backwash). Landward dipping cross stratification (ridges and runnels) and emergence runoff features, such as rills or channels, may be present. These structures contrast with the offshore dipping cross stratification in the subtidal zone.

If little sand is supplied to the beach, the low tide terrace is composed of gravel. The dip of the gravel beds in the terrace is less than the dip of the beds in the foreshore zone, but the step at the base of the foreshore slope is replaced by a more gentle curvature. The low tide terrace gravel is thinner bedded, and may be finer grained, than the foreshore gravel. Sediment movement is both on and offshore as in the sand terrace, but due to the coarse grain size, cross stratification is not present.

Foreshore Zone

There are two types of seaward dipping gravel beds in the foreshore zone; beds that are conformable with the overall beach face slope and higher angle cross beds. The conformable beds extend from the lower to the upper foreshore. They are deposited as sediment is added to the beach face slope. Variations in texture are the result of different wave conditions. The size of the sediment that can be removed from the beach increases directly with the wave size. However, there should always be a particle size that can be moved landward by the swash, but is too large to be moved seaward by the backwash. The high angle cross beds form angular discordances within the conformable gravel beds. The cross beds are graded and asymptotic, and may consist of an alternation of openwork and closedwork gravel. It is not known how the cross beds are deposited.

Erosional scarps occur in the foreshore zone. The fill of the scarps is dependent upon the grain size of the available sediment. Ridge and runnel systems tend to infill the scarps if sand or fine gravel is abundant. If fine sediment is not available, the gravel fill is stratified parallel to the foreshore beds. Severe storms probably of short duration erode the scarps.

From a review of beach literature, it is apparent that ridge and runnel systems (swash bars) are more commonly developed on sand beaches than on gravel beaches. This phenomena is explained by the causative factors of ridge and runnel formation. Ridge and runnel systems form where the slope of the foreshore zone is below the equilibrium gradient. Waves move sediment onshore and build ridges in an attempt to steepen the foreshore slope. Large waves move sediment offshore and have a lower equilibrium gradient. The grain size and gradient of gravel beaches are not conducive to ridge and runnel formation. Most gravel beaches have a higher gradient than sand beaches, thereby requiring less steepening. Secondly, the low wave conditions necessary for ridge and runnel formation may be below the energy level required to form gravel ridges. At Advocate, the conditions necessary for ridge and runnel formation were present, but only the sand was formed into ridges and runnels. The gravel around the ridges and runnels is parallel bedded. It is possible that the large waves necessary to form gravel ridges are above the critical value for wave steepness and require a lower equilibrium gradient (i.e. ridge and runnel formation is not possible due to offshore sediment movement). Thus, wave energy and grain size of the sediment conflict in ridge and runnel formation on a gravel beach.

Gravel ridge and runnel systems do form on beaches, however. Hobday and Banks (1971) describe swash bars on a gravel beach in Norway. The swash bars consisted of the finest gravel on the beach (Banks, 1975, personal communication). The conditions necessary for gravel ridge and runnel formation are a beach gradient less than the equilibrium value and gravel fine enough to be formed into ridges by waves below the critical value for wave steepness. Since the lower foreshore of a gravel beach generally has the lowest gradient, ridge and runnel systems will preferentially form in the lower foreshore.

The grain size of the gravel decreases from the lower to the upper foreshore, and the largest pebbles and cobbles occur in the lower foreshore. The matrix content of the gravel is dependent upon sediment supply. If sand and gravel are supplied to the beach, the foreshore gravels will be closedwork, and if only gravel is supplied, it will be openwork. The grain size and matrix content of the gravel determine the foreshore slope. The slope increases as grain size increases, and decreases as the amount of fine sediment increases. Fine sediment reduces the amount of water loss on the swash, creating a stronger backwash, which reduces the slope. Thus, a closedwork beach gravel has a lower slope than an openwork beach gravel. Generally, the lowest gradient is in the lower foreshore.

Disc-shaped pebbles increase in abundance up the beach, and will be imbricated seaward in the upper foreshore zone if the gravel is openwork. Openwork gravel allows sufficient water loss on the swash to form an imbricated deposit. A strong backwash precludes the imbrication. The strike of the maximum projection plane is parallel to the trend of the beach. Spherically-shaped pebbles are more abundant in the lower foreshore.

Backshore Zone

Berm

The upper foreshore/berm boundary is marked by a conspicuous coarsening in grain size. The berm deposit consists of an openwork pebble gravel. Disc-shaped pebbles are most abundant, and are imbricated seaward. The strike of the maximum projection plane is perpendicular to the direction of the storms that washed the coarse gravel into the berm. Gravel beds in the berm are low angle that dip either landward or seaward.

The division between the berm and the backshore zone proper is arbitrary, and may not be possible in some cases. Washover fans or storm ridges may form immediately above the upper foreshore, eliminating the berm as such. The important distinction is recognizing the backshore fiaces from the foreshore facies.

Backshore Zone Proper

Deposition in the backshore zone is in the form of low angle storm beds dipping seaward or washover fans with high angle stratification dipping landward. Storm waves that wash into the backshore zone erode previously deposited strata and deposit beds that are usually graded from an openwork pebble gravel at the base to a finer grained sand at the top. A silt matrix frequently occurs at the bottom of the openwork gravel. The beds may be parallel laminated, but contain no cross stratification. The pebbles are predominantly disc-shaped and imbricated seaward. Erosion of the underlying beds, which is greatest near the foreshore/backshore boundary, produces a landward thickening sequence. A fining in grain size accompanies the thickening.

Where an obstruction to storm waves passing into the backshore zone has developed, sedimentation is initiated on a landward facing slip face. The obstruction is usually a build-up of seaward imbricated gravel in the berm. Deposition on the slip face produces a landward prograding washover fan. The cross beds in the fan consist of openwork pebble gravel, with the coarsest pebbles at the base of the bed. Finer sediment is deposited landward of the fan. As the fan builds landward, the gravel becomes finer grained and progrades over the finer sediment. Amalgamation of the cross beds produces a graded, openwork deposit. Gravel deposition is eventually replaced by sand deposition, which results in a lowering of the slip face slope. As the slope decreases, the fan loses its morphology and passes into storm-type beds. Thus, washover fans are limited in their progradation away from, and above, the berm because of the gradual loss of the slip face.

The slip face of the fan is fed by gravel which is washed over the top of the fan. The "feeder" gravel consists of seaward-imbricated pebbles that cap the cross beds. The strike of the maximum projection plane of the pebbles is perpendicular to the direction of the waves washed over the berm. Some of the gravel in the fan is tossed over the berm, and is more chaotic. Thus, imbricated pebbles are an integral part of the initiation and continued growth of a washover fan. Imbrication is common because storm waves preferentially transport disc-shaped pebbles into the backshore zone.

Both sand and gravel are washed into the backshore zone, but a size segregation occurs during deposition. This results in openwork backshore gravel. In washover fans, coarse gravel is deposited near the berm in the landward dipping cross beds and imbricated cap, while sand is deposited farther inland. Gravel is proximal and sand is distal to the berm. Gravel in the storm graded beds is deposited at the base, which finer sediment above. Sand infiltration may occur in the backshore gravel after deposition, but frequently they are sealed off and remain openwork. Processes in the backshore zone size segregate the sediment, while those in the foreshore zone do not.

Ridges in the backshore zone are formed by coalescing imbricated gravel build-ups or washover fans. The former usually leads to the latter. Where ridges, washover fans or berm deposits occur immediately above the upper foreshore, there is a pronounced and abrupt coarsening in grain size from the foreshore to the backshore. However, storm graded beds are finer grained than the foreshore beds. Thus, it is not a rule that the backshore zone is marked by a coarsening in grain size. Indeed, the bulk of the backshore sediment is finer grained than the foreshore sediment in Unit 1 (Fig. 29).

Channel Deposits

Large channels crossing the foreshore zone are the result of a lagoon landward of the beach. If channels are abandoned, they are filled by wave transported sediment. The channel fill consists of high angle beds dipping landward if sediment movement is onshore or dipping seaward if sediment movement is offshore. The grain size of the fill is similar to the grain size of the foreshore gravel. Channels filled by fluvial-type processes are finer grained and have lower dip beds. The direction and angle of dip is dependent upon the type of fill; point bar deposit or channel bank accretion.

Smaller channels in the upper foreshore and backshore zone are the result of storm runoff. The fill is a well sorted, openwork pebble gravel. It is coarser than the storm beds in the backshore zone but finer than the foreshore gravel.

All channels have an erosional lower contact that is frequently marked by a silty matrix. Channels tend to follow the paths of previous channels, creating composite channel deposits.

Tidal Range, and Tidal vs. Non-Tidal Beaches

The tidal range of a beach is given by the vertical distance between the low tide terrace and the backshore zone, or the thickness of the foreshore facies. As the tidal range increases, so does the vertical distance between the low tide terrace and the backshore zone. Delineating tidal range is contingent upon the recognition of the foreshore zone.

Distinguishing between tidal and non-tidal beaches is easier as the tidal range increases. Beaches formed in seas with a small tidal range are difficult, or even impossible, to tell apart from non-tidal beaches. However, beaches formed in seas with a large tidal range are on a larger scale than non-tidal beaches. Clifton (1975) points out that the step at the base of the foreshore zone is abrupt when the tidal range is less than 1 meter, and more transitional when the tidal range is large. The problem of tidal versus non-tidal beaches has been discussed by Davis et al. (1972), particularly with respect to ridge and runnel formation and migration. They studied sand beaches on Lake Michigan and on the New England coast, and noticed that the scale and rate of migration of ridges and runnels were different. Ridge and runnel systems in the tidal environment were larger and migrated more slowly. The other major difference was that the non-tidal beach had no low tide terrace. Fig. 56 is redrawn from Davis et al. (1972) and shows the difference in scale of the beaches and ridge and runnels and the absence of the low tide terrace in the non-tidal beach. The difference in scale is a result of the tides and the size of the waves operative on the beaches.

In summary, a close estimate of the tidal range of a beach can be made based on the characteristic textures and structures of the different beach zones. Tidal beaches can only be distinguished from non-tidal beaches where the tidal range is significant.

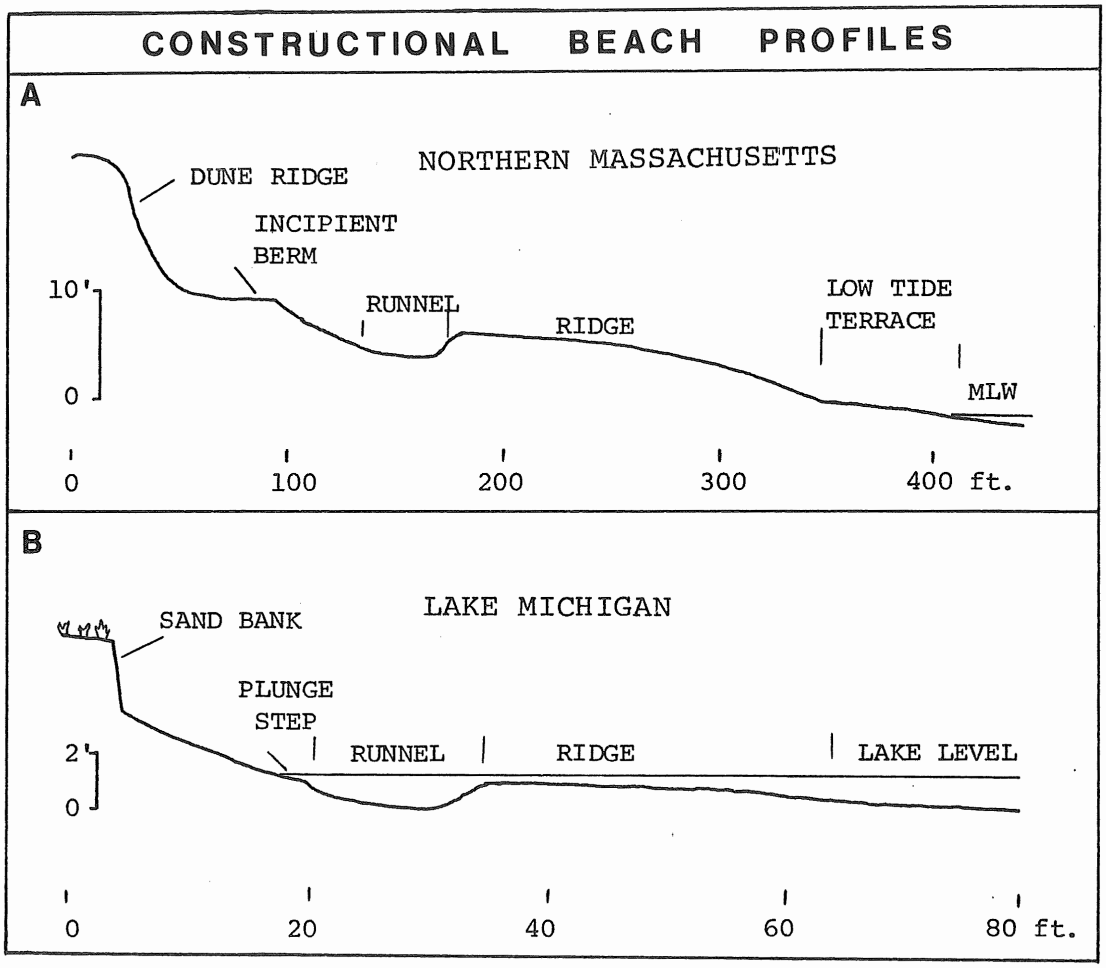


Fig. 56. (after Davis et al. 1972). Generalized ridge and runnel profile for A) Northern Massachusetts and B) Lake Michigan. Note that although the profile configuration is quite similar there is a considerable difference in scale, and there is no low tide terrace on the non-tidal beach.

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APPENDIX I

Grain Size Analysis

Grain size analysis was used for descriptive purposes within facies and not for subdividing or distinguishing facies. It is felt that cumulative curves are a useful means to the end but not an end in themselves.

Samples were dry sieved from -6.5ϕ to 4.0ϕ at 0.5ϕ intervals according to Folk (1974). A Hewlett-Packard 9100B calculator and 9125B plotter were used to plot the cumulative curves with an arithmetic ordinate and calculate Folk and Ward's (1957) graphic statistics. Kurtosis and Skewness were calculated for the samples but were not included because it was felt that they added little to the thesis. Wentworth's scale was used for classifying sand and gravel.

The verbal classification of sorting, based on standard deviation, is modified from Folk (1974). The 1.0-2.0ϕ class was subdivided into 1.0-1.5ϕ and 1.5-2.0ϕ. The classification is as follows:

σ	SORTING
<0.35	very well sorted
0.35 - 0.50	well sorted
0.50 - 0.71	moderately well sorted
0.71 - 1.0	moderately sorted
1.0 - 1.5	moderately poorly sorted
1.5 - 2.0	poorly sorted
2.0 - 4.0	very poorly sorted
>4.0	extremely poorly sorted

The following table lists the sample and sample weight for each sieve. All weights are in grams.

SAMPLE	-6.5	-6.0	-5.5	-5.0	-4.5	-4.0	-3.5	-3.0
147							3.214	16.741
155				178.452	104.448	68.147	96.632	142.552
156				126.912	149.418	140.337	185.872	167.944
157			172.686	173.892	302.428	145.387	160.315	149.221
30			233.466	232.702	278.898	110.357	86.273	81.451
32					85.265	137.133	96.485	107.291
119		1518.155	653.906	53.572	9.392	5.343	2.869	7.377
2				258.292	370.658	381.147	120.262	10.156
301			909.426	226.232	206.898	204.227	174.232	185.464
303				275.992	62.978	78.637	130.232	208.054
308					41.938	22.377	50.404	76.443
210			112.106	261.272	605.528	245.337	164.902	71.674
95			788.526	620.582	632.638	504.367	195.842	105.899
96					109.418	109.947	207.292	321.664
209			548.646	1658.852	163.478	51.656	11.297	3.443
211				120.862	199.558	177.937	185.120	99.241
212					97.688	247.347	134.692	122.244
64								
152								0.570

SAMPLE	-2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0
147	34.939	10.476	13.626	11.820	14.412	15.243	31.408	81.429
155	188.278	139.736	198.896	200.380	178.316	122.380	99.636	81.132
156	204.554	210.419	215.145	178.916	173.956	149.40	124.164	91.700
157	171.502	158.039	166.288	170.414	173.012	138.064	112.968	82.88
30	110.225	119.573	105.282	90.272	85.750	80.044	88.896	108.55
32	125.308	105.349	108.128	102.60	117.266	123.566	131.518	126.356
119	7.567	4.528	3.528	5.990	14.208	35.128	82.512	168.166
2	4.094	3.762	5.332	7.794	17.296	23.016	23.648	34.588
301	277.858	330.616	485.856	441.128	257.912	68.632	24.112	18.672
303	357.378	377.656	384.232	319.556	251.460	142.528	92.04	51.752
308	174.482	158.580	235.412	192.628	196.50	174.728	338.416	412.056
210	91.088	67.346	52.511	38.094	28.561	18.191	15.292	14.834
95	53.283	22.692	10.658	12.878	12.629	11.732	12.743	16.629
96	414.778	306.446	230.186	132.792	71.530	32.652	24.278	21.846
209	4.412	3.576	3.434	2.024	2.363	2.177	2.826	3.440
211	43.759	69.075	85.332	75.292	85.324	90.736	107.984	136.544
212	114.912	94.331	86.696	71.978	66.446	56.522	65.506	84.142
64			0.308	0.324	0.440	0.917	3.098	15.434
152	1.384	0.778	0.658	1.233	2.408	4.133	8.818	25.792

SAMPLE	1.5	2.0	2.5	3.0	3.5	4.0	PAN	TOTAL
147	130.019	58.207	6.366	1.084	0.297	0.158	0.312	429.751
155	42.184	25.120	9.216	7.372	5.360	4.212	7.068	1899.519
156	41.592	27.096	9.216	6.808	3.976	2.916	5.324	2215.665
157	39.80	27.176	10.224	7.30	3.504	2.34	3.896	2371.338
30	81.502	53.112	19.264	12.426	4.014	1.938	4.234	1988.229
32	66.848	40.642	11.134	5.962	2.290	1.362	3.242	1497.745
119	110.708	79.440	19.240	14.966	13.014	20.276	5.03	2835.409
2	62.42	107.284	56.61	35.994	10.732	4.128	4.008	1541.221
301	21.704	18.936	7.576	8.136	5.064	3.592	5.522	3881.795
303	24.708	10.60	1.704	0.844	0.264	0.392		2771.007
308	143.916	15.228	2.380	1.504	0.724	0.416	0.612	2238.744
210	9.310	6.695	2.576	2.013	1.077	0.833	2.129	1811.359
95	13.793	14.285	6.532	7.172	5.195	8.655	7.198	3063.928
96	10.546	6.272	2.458	2.322	1.570	1.280	0.542	1953.819
209	2.695	2.373	1.112	0.914	0.409	0.244		2469.371
211	104.776	88.456	34.144	20.552	6.592	2.948	4.420	1738.652
212	63.664	72.842	20.568	12.536	3.690	1.830	3.044	1420.689
64	48.445	116.189	73.469	25.887	1.338	0.280	0.466	286.59
152	54.832	89.443	28.421	5.142	0.365	0.163	0.441	224.389

SAMPLE	-6.5	-6.0	-5.5	-5.0	-4.5	-4.0	-3.5	-3.0
324					31.244	31.723	118.360	112.337
325								7.641
326								
331					15.608	130.077	101.509	191.694
332								
333								
121					43.528	83.447	102.762	90.33
122				221.392	198.528	190.117	253.082	223.994
86			316.564	590.948	638.227	148.653	79.758	29.931
305				412.042	467.178	1015.367	757.312	472.364
18					54.888	173.947	157.582	177.734
97							26.047	26.063
321					175.538	552.947	390.282	112.724
318			135.366	206.062	332.628	410.957	278.742	185.734
323					20.868	196.397	252.152	103.996
320					60.631	55.318	96.705	104.71
319		370.495	1124.536	838.182	527.638	240.057	106.402	25.081
322				683.792	446.728	643.147	200.454	53.234
316			211.196	531.972	275.418	773.047	556.882	260.364

SAMPLE	-2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0
324	129.089	130.466	97.034	77.280	67.696	21.306	6.930	4.778
325	8.722	32.565	89.471	78.067	22.789	4.421	2.212	0.829
326		1.722	4.258	8.827	26.913	61.006	19.130	1.251
331	147.552	59.798	40.623	34.854	17.992	4.637	2.084	1.584
332	1.534	21.475	76.569	132.401	94.504	12.492	2.208	0.819
333	0.786	1.50	3.383	9.643	69.860	117.479	38.440	4.406
121	101.668	115.33	143.28	178.312	237.168	305.104	299.20	122.20
122	224.178	175.869	141.776	145.508	134.932	66.744	30.132	14.984
86	18.622	14.930	20.451	24.728	40.327	45.625	62.320	73.201
305	218.068	10.186	1.314					
18	203.758	176.876	135.798	98.350	61.940	31.094	19.594	13.098
97	75.051	131.956	264.288	396.216	417.160	241.128	127.224	50.552
321	58.894	32.149	30.426	33.675	38.396	29.146	21.582	16.039
318	215.878	237.916	241.596	192.088	129.004	67.936	40.928	24.98
323	91.780	107.468	163.184	202.98	270.576	209.096	111.320	45.416
320	116.357	118.435	139.568	148.044	166.924	123.136	91.20	55.468
319	32.983	29.789	36.092	50.404	75.964	83.056	92.884	90.816
322	26.866	27.652	33.258	61.928	110.238	131.722	112.462	75.758
316	80.112	16.579	2.438	0.238				

SAMPLE	1.5	2.0	2.5	3.0	3.5	4.0	PAN	TOTAL
324	6.260	9.524	5.310	5.724	3.75	3.046	7.236	869.093
325	0.533	0.419	0.291	0.316	0.192	0.143	0.311	248.926
326	0.420	0.750	0.509	0.319	0.184	0.155	0.268	125.712
331	1.251	1.487	0.891	1.086	0.792	0.595	1.820	755.934
332	0.492	0.459	0.319	0.357	0.277	0.220	0.581	344.707
333	1.696	2.313	1.168	0.723	0.441	0.401	1.263	253.512
121	28.832	16.448	5.952	4.264	2.128	1.672	4.24	1885.865
122	7.916	6.164	3.04	3.584	3.16	2.74	2.356	2050.196
86	89.742	74.997	33.093	17.451	8.882	5.812	9.239	2343.501
305								3353.831
18	6.516	4.80	2.128	2.324	1.57	3.06	2.75	1327.807
97	16.16	8.152	3.024	3.08	2.12	1.896	0.12	1790.237
321	8.702	6.034	2.039	2.008	1.539	1.386	2.940	1516.446
318	12.792	10.532	5.976	6.20	4.228	3.324	8.256	2751.123
323	13.788	7.016	3.088	3.748	2.576	2.292	6.132	1813.873
320	18.328	7.220	2.40	2.488	2.028	1.828	0.348	1311.136
319	51.568	32.508	12.496	15.72	13.40	15.38	10.184	3875.635
322	34.102	20.858	8.154	9.528	6.486	4.63	13.020	2704.017
316								2708.246

SAMPLE	-6.5	-6.0	-5.5	-5.0	-4.5	-4.0	-3.5	-3.0
310			506.126	836.922	1085.398	866.737	127.312	34.101
317			272.126	1245.692	719.808	679.857	338.662	92.541
311				109.592	809.978	605.847	400.872	388.544
79						17.070	29.077	38.918
80						47.578	60.544	45.892
340								
341								
146								

SAMPLE	-2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0
310	1.577	0.510						
317	11.614	0.362	0.399	0.034				
311	388.978	73.881	10.323	0.759	0.086	0.026		
79	59.038	65.038	87.624	107.452	240.724	284.692	189.90	112.364
80	62.347	76.346	115.325	142.498	200.384	201.848	207.628	222.308
340			0.678	1.750	12.201	42.583	71.888	47.712
341				0.717	3.002	10.744	27.236	25.602
146		1.483	0.459	0.386	0.736	1.554	5.938	32.958

SAMPLE	1.5	2.0	2.5	3.0	3.5	4.0	PAN	TOTAL
310							0.502	3459.185
317								3361.095
311						0.360		2789.246
79	42.128	18.180	4.820	4.024	2.220	1.456	2.116	1306.841
80	129.636	74.252	19.856	11.812	3.956	1.80	1.932	1625.942
340	14.376	3.427	0.800	0.426	0.181	0.169	1.043	197.234
341	13.350	4.718	1.016	0.508	0.339	0.213	0.317	87.762
146	156.338	144.509	32.128	6.571	1.352	0.473	0.592	385.477

APPENDIX II

Fabric Analysis

The azimuth of the a-axis and strike and dip of the maximum projection plane of pebbles were taken with a Brunton and Silva Ranger compass. A-axis measurements were taken on pebbles with an a:b:c ratio (Pettijohn, 1957) of at least 3:1:1. The strike and dip of the maximum projection plane was used to define imbrication on pebbles with an a:b:c ratio of at least 3:3:1. Rose diagrams showing the orientation of the a-axis were hand drawn with class intervals of 10°. A computer program was used to to plot and contour poles to the maximum projection planes on Schmidt equal area nets using a lower hemisphere projection. Statistics for the fabric data were calculated using a computer program given by Andrews and Shimizu (1966).

The following tables list the fabric data.

A-Axis, Lower Foreshore

ORIENTATION	DIP	ORIENTATION	DIP	ORIENTATION	DIP
117.	0.	78.	0.	126.	0.
80.	0.	94.	0.	64.	0.
66.	0.	92.	0.	76.	0.
93.	0.	61.	0.	132.	0.
82.	0.	68.	0.	89.	0.
110.	0.	73.	0.	85.	0.
75.	0.	31.	0.	71.	0.
71.	0.	85.	0.	136.	0.
56.	0.	94.	0.	128.	0.
56.	0.	52.	0.	88.	0.
22.	0.	52.	0.	93.	0.
64.	0.	90.	0.	84.	0.
96.	0.	67.	0.	68.	0.
34.	0.	100.	0.	100.	0.
63.	0.	41.	0.	12.	0.
126.	0.	126.	0.	138.	0.
108.	0.	26.	0.	68.	0.
62.	0.	56.	0.	107.	0.
86.	0.	85.	0.	121.	0.
79.	0.	109.	0.	87.	0.
83.	0.	119.	0.	83.	0.
148.	0.	109.	0.	104.	0.
79.	0.	125.	0.	96.	0.
80.	0.	126.	0.	129.	0.
78.	0.	76.	0.	80.	0.
79.	0.	146.	0.	52.	0.
50.	0.	46.	0.	141.	0.
171.	0.	105.	0.	117.	0.
148.	0.	70.	0.	86.	0.
87.	0.	82.	0.	63.	0.
24.	0.	107.	0.	90.	0.
94.	0.	120.	0.	93.	0.
74.	0.	26.	0.	110.	0.
166.	0.	75.	0.	89.	0.
51.	0.	110.	0.	101.	0.
77.	0.	48.	0.	91.	0.
172.	0.	69.	0.	106.	0.
107.	0.	14.	0.	72.	0.
94.	0.	90.	0.		
24.	0.	74.	0.		
166.	0.	83.	0.		
33.	0.	91.	0.		
79.	0.	106.	0.		
91.	0.	103.	0.		
91.	0.	77.	0.		
112.	0.	69.	0.		

A-Axis, Upper Foreshore

ORIEN-TATION	DIP	ORIEN-TATION	DIP	ORIEN-TATION	DIP
79.	0.	97.	0.	88.	0.
18.	0.	104.	0.	73.	0.
83.	0.	94.	0.	78.	0.
102.	0.	78.	0.	64.	0.
108.	0.	54.	0.	55.	0.
51.	0.	81.	0.	98.	0.
86.	0.	94.	0.	111.	0.
86.	0.	100.	0.	124.	0.
12.	0.	78.	0.	98.	0.
92.	0.	107.	0.	110.	0.
81.	0.	112.	0.	48.	0.
121.	0.	83.	0.	59.	0.
23.	0.	91.	0.	141.	0.
30.	0.	106.	0.	74.	0.
152.	0.	93.	0.	44.	0.
72.	0.	92.	0.	71.	0.
97.	0.	96.	0.	39.	0.
77.	0.	75.	0.	64.	0.
88.	0.	89.	0.	68.	0.
14.	0.	90.	0.	68.	0.
65.	0.	102.	0.	46.	0.
99.	0.	68.	0.	71.	0.
78.	0.	72.	0.	70.	0.
92.	0.	1.	0.	45.	0.
99.	0.	75.	0.	122.	0.
102.	0.	89.	0.	56.	0.
108.	0.	107.	0.	52.	0.
52.	0.	90.	0.	68.	0.
7.	0.	108.	0.	75.	0.
81.	0.	112.	0.	65.	0.
112.	0.	35.	0.	35.	0.
81.	0.	78.	0.	68.	0.
83.	0.	76.	0.	57.	0.
10.	0.	132.	0.	58.	0.
131.	0.	177.	0.	77.	0.
129.	0.	101.	0.	112.	0.
6.	0.	94.	0.	80.	0.
70.	0.	68.	0.		
112.	0.	174.	0.		
97.	0.	86.	0.		
103.	0.	109.	0.		
130.	0.	89.	0.		
121.	0.	109.	0.		
74.	0.	134.	0.		
112.	0.	65.	0.		
88.	0.	28.	0.		

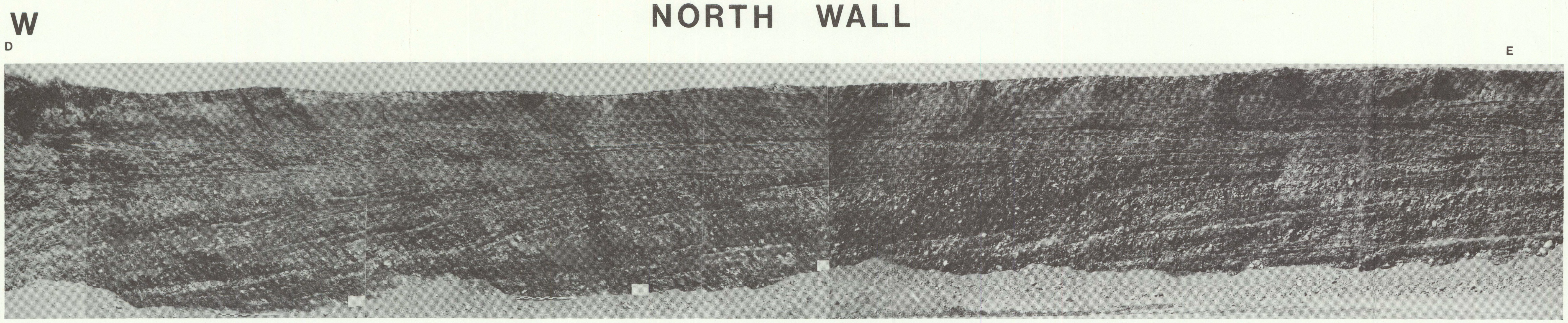
Maximum Projection Plane, Berm Subfacies, Unit 1

ORIEN-TATION	DIP	ORIEN-TATION	DIP
96.	75.	99.	54.
101.	72.	107.	77.
99.	66.	73.	72.
92.	76.	90.	42.
98.	76.	121.	57.
142.	44.	82.	56.
140.	80.	265.	41.
114.	46.	299.	34.
117.	20.	276.	50.
86.	30.	256.	30.
105.	50.	269.	35.
76.	40.	277.	38.
113.	36.	287.	35.
89.	44.	292.	38.
101.	17.	298.	47.
90.	44.	303.	24.
74.	28.	269.	39.
120.	68.	291.	81.
74.	72.	248.	55.
70.	86.	277.	64.
58.	78.	292.	72.
71.	20.	299.	70.
85.	48.	250.	66.
110.	74.	307.	56.
93.	34.	265.	22.
134.	73.	88.	24.
140.	54.	281.	82.
82.	38.	140.	35.
114.	74.	53.	76.
112.	80.	103.	36.
94.	12.	322.	72.
77.	20.	107.	68.
115.	57.	318.	72.
131.	24.	140.	62.
68.	57.	134.	36.
91.	26.	68.	75.
54.	68.	248.	6.
136.	78.	142.	58.
64.	74.	90.	74.
84.	6.	106.	6.
74.	10.	311.	24.
107.	62.	246.	33.
75.	41.	95.	32.
79.	62.		
66.	38.		
109.	18.		

Maximum Projection Plane, Storm Ridge Subfacies, Unit 2

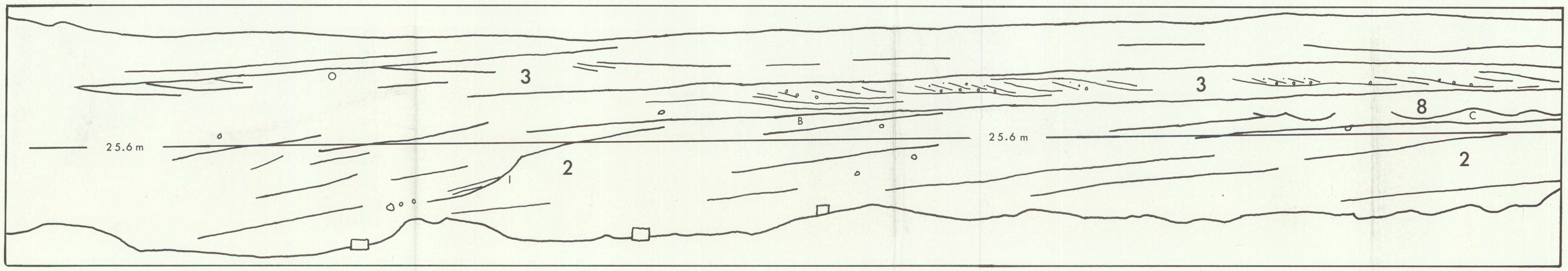
ORIENTATION	DIP	ORIENTATION	DIP	ORIENTATION	DIP
257.	53.	119.	54.	71.	20.
84.	30.	94.	26.	116.	13.
289.	42.	88.	81.	279.	20.
46.	40.	94.	18.	104.	36.
82.	23.	66.	59.	113.	31.
91.	36.	95.	60.	92.	52.
45.	61.	70.	80.	86.	54.
249.	66.	281.	10.	124.	25.
235.	37.	84.	21.	151.	12.
68.	60.	247.	61.	110.	12.
269.	46.	247.	33.	126.	22.
66.	39.	230.	29.	93.	28.
66.	37.	257.	29.	80.	8.
144.	18.	262.	28.	114.	12.
82.	59.	82.	22.	85.	15.
66.	20.	108.	18.	78.	14.
70.	37.	286.	15.	94.	6.
79.	25.	254.	20.	269.	15.
94.	30.	110.	77.	105.	40.
110.	34.	106.	65.	68.	29.
85.	7.	89.	64.	104.	36.
62.	30.	299.	34.	87.	4.
115.	4.	80.	34.	280.	24.
112.	18.	72.	21.	79.	17.
72.	16.	245.	12.	310.	88.
74.	70.	102.	16.	297.	42.
85.	67.	92.	8.	88.	36.
66.	33.	85.	58.	143.	40.
67.	50.	103.	61.	290.	3.
72.	20.	96.	27.	136.	14.
262.	65.	107.	26.	255.	14.
128.	19.	114.	50.	85.	46.
69.	58.	96.	32.	100.	52.
148.	10.	68.	16.	312.	25.
254.	37.	82.	56.	261.	44.
94.	82.	81.	25.	82.	14.
100.	32.	82.	76.	71.	20.
258.	34.	70.	63.	107.	18.
104.	30.	89.	64.		
68.	12.	276.	45.		
55.	10.	254.	10.		
58.	4.	89.	15.		
64.	51.	92.	72.		
289.	18.	96.	58.		
125.	38.	99.	23.		
102.	21.	276.	38.		

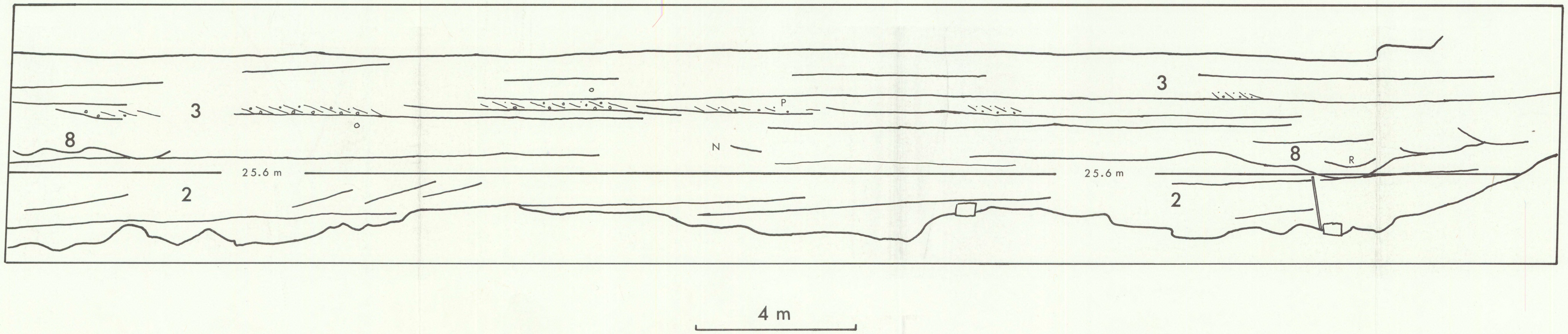
NORTH WALL



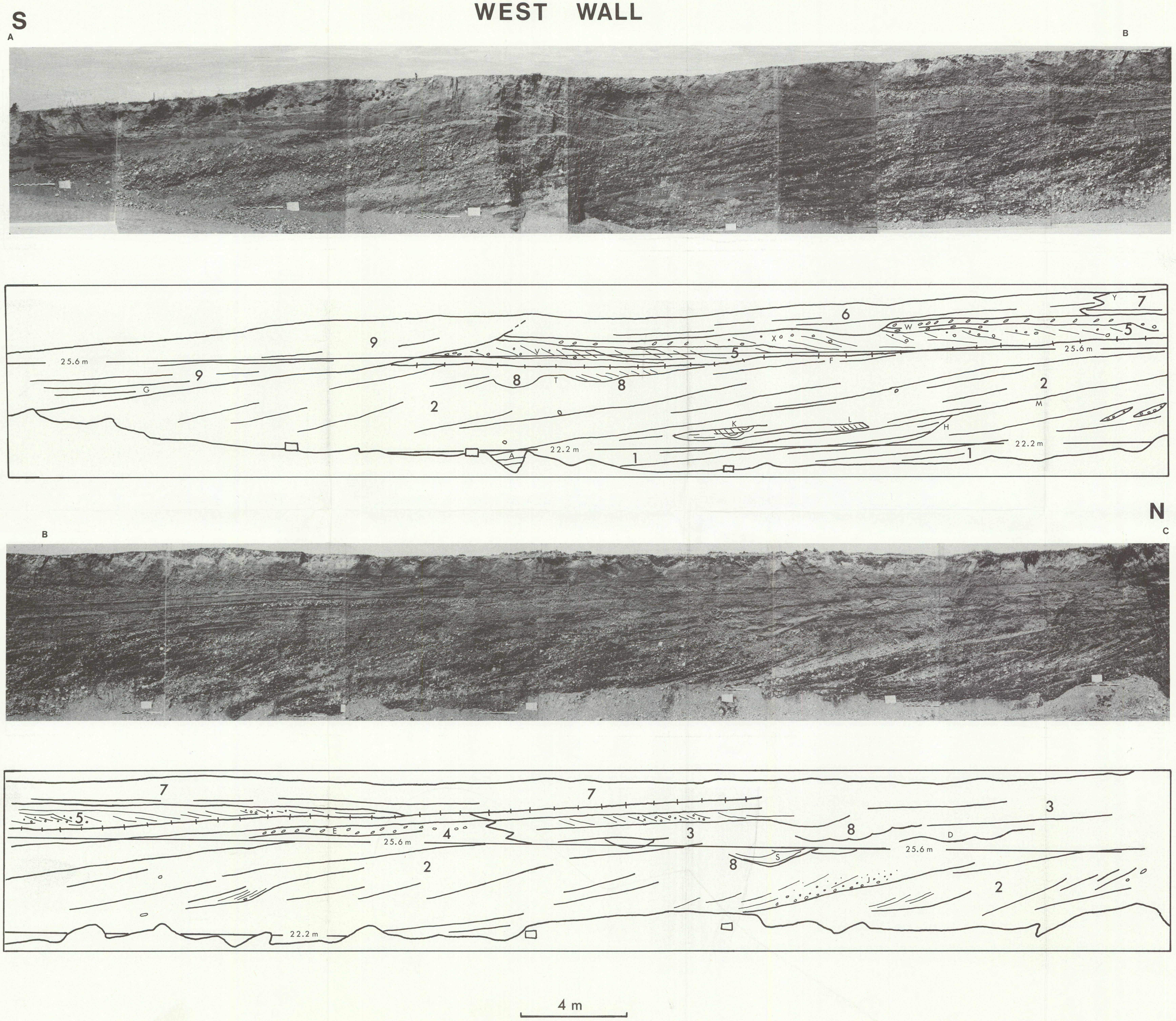
FACIES UNIT 1

2	FORESHORE
3	BACKSHORE
8	CHANNEL





WEST WALL



FACIES UNIT 2

5	STORM RIDGE
6	FORESHORE
7	BACKSHORE

FACIES UNIT 1

1	LOW TIDE TERRACE
2	FORESHORE
3	BACKSHORE
4	BERM
8	CHANNEL
9	REGRESSIVE SANDS
┼	UNIT 1 - UNIT 2 CONTACT