THE SEDIMENT SOURCES OF ATLANTIC SHORE BEACHES BETWEEN MONTAUK POINT AND DEMOCRAT POINT, LONG ISLAND, NEW YORK, U.S.A..

BY

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CERTIFICATION OF RESEARCH

This is to certify that except where specific reference is made, the work described in this thesis is the result of the candidate. Neither this thesis nor any part of it has been presented or is currently submitted in candidature for any degree at any other university or polytechnic.

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This thesis is presented in two volumes. Volume 1 contains the main text of the work along with accompanying figures and tables. Volume 2 presents plates of photographic examples and appendices.

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ABSTRACT

Speculation has arisen regarding the possibility of an additional offshore sediment source on the Atlantic inner shelf south of Long Island, New York, as a result of deficits in recent south shore budgetary estimates. In view of the importance of Long Island's inner shelf as a possible sediment source for other conflicting commercial uses in the future, the present study attempts to compare the known source at Montauk Point with sediments from buried palaeodrainage channels and nearby offshore and to examine the degree to which they may be linked to south shore beaches.

Samples from each of these three environments were subjected to S.E.M. analysis using a checklist approach. Qualitative results comparing individual quartz grain surface feature variability with transport distance west of Montauk Point divided the south shore into three sections largely on the basis of mechanically derived and source textures: the distinctive glacial deposits formed in Ronkonkoma moraine at Montauk Point; Headlands section beaches, and Fire Island beaches. Surface feature variability plots and between-sample variability plots revealed a more complex pattern of surface feature development than may be expected from what appears to be generally a single alongshore-trending wave dominated regime, which suggests an additional control such as an offshore source.

Canonical variate analysis, as well as cluster and factor analyses confirmed qualitative findings and tentatively link off-shore lobe deposits with onshore Fire island beaches, and distinguish them from Headlands beaches and Montauk Point. Strong supporting and complementary links between qualitative results, photographic

evidence and subsequent statistical analysis suggest that the technique employed is a useful and valid sedimentological tool.

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I N T R O D U C T I O N

INTRODUCTION

The problem of balancing Long Island's south shore, sediment budgets has occupied the attentions of many workers (Taney, 1961a, 1961b; Williams, 1976; Panuzio, 1968; R.P.I., 1983). In essence more sediment has been found to be moving westward in littoral drift, than has been thought to be supplied by wave erosion of glacial, Ronkonkoma moraine at Montauk Point (Taney, 1961a; Leatherman, 1985b).

A major conceptual stumbling block has been a reluctance to accept the possibility of an offshore source, because no known mechanisms for effecting onshore sediment transport in large quantities have been established beyond doubt (Allen, 1988). Acceptance of onshore transport as an important sediment supply mechanism would contradict the 'Bruun Rule' (Bruun, 1962), but many have called for a revision of ideas in this area (Wolff, 1982; Pizzuto, 1985; Leatherman and Allen, 1985; Williams and Meisburger, 1987).

Leatherman (1985b), has related a southward bulge in central Fire Island to the need for an additional onshore source on the shelf to the south, in the form of buried glacial, or fluvioglacial meltwater deposits in a deep channel (Channel H, Fig. 2.3) in pre-Holocene times.

Williams and Meisburger (1987), showed a direct onshore link between glauconitic sands on the shelf south of Fire Island and glauconitic sand grains on south shore beaches. Work has been undertaken to establish a link between wave eroded sand sized sediments from glacial bluffs at Montauk Point and westward littoral drift, using T.E.M. analysis (Krinsley and Takahashi, 1962d; Krinsley et al, 1964). Other workers have used S.E.M. analysis of Long Island's south shore sands in order to determine whether such a technique may be able to discriminate accurately between sand grains from different shore environments (Evans, 1983; Williams et al, 1985; Williams and Thomas, 1989; Williams and Morgan, 1988).

This study attempts to break new ground in S.E.M. analysis studies of sediments found alongshore and offshore, between Montauk Point in eastern Long Island and Democrat Point in western Fire Island. It attempts to examine the validity of S.E.M. analytical techniques and subsequent multivariate analysis as important tools, which may be used to discriminate between multiple cycle sands from glacial, glacial-beach, beach and offshore shelf environments.

Scanning electron microscope analysis evolved from pioneering work carried out by Porter (1962), Biederman (1962), Krinsley and Takahashi (1962d), and Krinsley et al (1964), using transmission electron microscopes. Subsequent development of S.E.M. analytical techniques and procedures established them as a major tool in interpreting palaeoenvironments by means of quartz grain, surface texture recognition. Fundamentally, there are a number of environments within which characteristic energy conditions work to modify sediments passing through them. The uniqueness of environmental energy regimes means that such modifications (mechanical abrasion, chemical solution and precipitation), produce characteristic grain surface textural assemblages indicative of each environment. If a previous environment's textures are not completely erased by the superimposition of a new textural suite in the ensuing environment, grain history may be deduced.

Many claims have been made for the accuracy and validity of the technique: palaeoenvironmental reconstruction (Krinsley et al, 1964); interpretations of ancient sedimentary environments (Krinsley and Donahue, 1968a);depictions of modern surface textures through laboratory simulations and their use as a predictive tool (Margolis and Krinsley, 1971).

This study has used a multi-texture checklist approach (Margolis and Krinsley, 1974; Bull, 1978a; 1981a; 1984; Goudie and Bull, 1984), supported by an integral edge study. The advantages and limitations of such an approach have been outlined by Culver et al (1983), and the validity and consistency of its results have been established, providing rigorous precautions are taken. The author has been involved in S.E.M. analysis using other techniques such as those outlined by Setlow and Karpovich (1972), (Williams et al,1985), as well as having used the checklist approach (Williams and Morgan, 1988).

The geomorphology of Long Island's south shore is presented in the light of Recent and Pleistocene geology and sedimentology. Several parallel themes run through the project, linked by south shore barrier behaviour after the Ice Age. Arguments for differing modes of barrier retreat (continuous shoreward migration versus in place drowning and surf skipping), are outlined, as well as their relevance to the preservation of palimpsest sediments offshore.

Criticisms of the 'Bruun Rule' by workers who have called for an additional offshore source on Long Island's south shore, and who have established sediment links between the offshore shelf and onshore beaches are presented. Wind and wave regimes which may be responsible for onshore and alongshore sediment transport in the study area are described.

An attempt has been made to extend the use of the checklist approach and to outline problems associated with the use of as many as forty textures to discriminate between sand grain samples that are closely related genetically. Reinforcement of checklist methodology and an explanation of modifications needed to accomodate this project's design and aims are discussed. In particular, the use of new textures specific to Long Island's south shore grains and the finer detail involved in scanning procedures and texture interpretation, so rarely found in print, have been described.

An attempt was made to develop a photographic representation of checklist textures, so that textural examples which have been quoted and illustrated in previous work may be compared with their counterparts on grains from Long Island's south shore. Operator variance can be a major problem and pinpoint specifications of textural features by the incorporation of many photographs into published work has not always been forthcoming with some notable exceptions (Krinsley and Doornkamp, 1973). This may be the result of the relative newness of S.E.M. analysis and its rapid, sometimes hasty development. The viewpoint adopted here is that even if alternative interpretations of grain surface textures and their histories may be made, the photographic checklist will still provide a valuable record of grain characteristics in the study area.

Visual results and their analysis and interpretation are presented in terms of detailed notes made during scanning, supported by a variety of diagrammatic, tabular and photographic evidence. Surface feature variability plots for each sample have been drawn as a graphic record of 'all feature' variations at each sample site. In order to refine such records, percentage differences of surface feature variability have been plotted to show more clearly the magnitude of any trend in environmentally modified grain textures as sediments proceed from glacial terminal moraine to beach, or possibly from offshore to onshore locations.

The possible impact of distance as a variable influencing surface texture modifications has been portrayed graphically by means of simple and multiple line plots of feature variations with distance transported westward from Montauk Point. Both surface feature variability plots and distance-feature variation plots have been brought together in a grain surface feature variability chart (Bull, 1984).

Problems of grain history interpretation were expected for several reasons.

(i) The environmental significance of some individual textures and their validity as discriminatory tools are still a matter of debate. Workers are continuously trying to establish precise quantitative links between individual texture form, size and distribution, and the energy conditions which have created them (Whalley, pers comm).

(ii) There is the problem of equifinality of form (Bull, 1981a). Several textures may be produced in different environments, as long as there is a gradational overlap of energy levels and duplication of feature-modifying processes.

(iii) The study area has more than one buried offshore channel containing fluvioglacial sediments (Williams, 1976), which may be supplying grains onshore. These would cloud any possible picture of a straightforward glacial-beach transition westward from Montauk Point as far as microtextural modifications are concerned.

Despite such problems, it is hoped to show that visual results manage to discriminate between samples and illustrate the complexities of grain surface feature modifications alongshore. Such complexities may be related to offshore locations of fluvio-glacial sediments preserved in buried palaeodrainage channels, as well as to the nature of a possible strained quartz source of metamorphic origin in New England to the north (Grant, pers comm).

It may also be necessary to revise estimates regarding the ability of violent extra tropical (northeaster) storms to inflict high energy breakages on grains along Long Island's south shore. Consistent patterns of two tier-scale breakages were found throughout beach grains, with larger breakages often crosscutting smaller edge abrasions.

Statistical analysis and interpretation on the scale envisaged in this project pose several problems. A checklist of 40 textures scanned for each of 25 grains per sample, in a total of 22 samples, produces a maximum of 22,000 observations. Together with the fact that many samples are from the same environment (south shore beaches), it was difficult to discriminate between grain groups, the differences between which were represented by only subtle increases in surf induced modification.

Initial hierarchical cluster analyses produced a very fuzzy picture. The main problem is that discernible groupings may be found only if grains from adjacent samples are accepted as substitutes. The need to be able to substitute adjacent samples for each other was evident throughout statistical analysis and interpretation, but to have arbitrarily grouped adjacent samples to obtain representative examples of fewer points along the shore would be inappropriate given the checklist design and project's aims.

In order to simplify the task, the number of discriminatory textures needed to be reduced by removing those that contributed least to discrimination of grain groups. Hierarchical cluster analysis was used to distinguish surface texture groups on the basis of their discriminatory powers. This was combined with surface feature weightings of amounts of variance within the grain population attributable to each texture feature.

As a result, ten surface textures were chosen as major discriminants and were crosstabulated for non-independence of each other. Final analyses (factor analysis and multiple stepwise discriminant analysis) were carried out. Quantitative analysis is essential for accurate comparisons to be made of the results of different projects. It is hoped to show that this project's aims created special difficulties in applying appropriate statistical techniques and interpreting their results. Nevertheless, a degree of success was achieved, vindicating the calls by workers such as

Bull (1981a), for an increase in the use of quantitative analysis. Given the limitations imposed by the data, there may be a tenuous but noticeable statistical link between offshore lobe samples and beaches on Fire Island shown by S.E.M. checklist data.

CHAPTER 2

THE STUDY AREA:

ITS GEOGRAPHICAL SETTING

AND PHYSICAL BACKGROUND

THE STUDY AREA: ITS GEOGRAPHICAL SETTING AND PHYSICAL BACKGROUND

2I LONG ISLAND: ITS LOCATION AND EXTENT.

Long Island lies on the coastal plain of north east U.S.A. between latitudes, $40^{\circ}33'$N. and $41^{\circ}10'$N., and between longitudes $71^{\circ}51'$W. and $74^{\circ}33'$W (Fig. 2.1). The Study Area is located along the south shore of Long Island, between Montauk Point on the easternmost promontory and Democrat Point on the western extremity of Fire Island (Fig. 2.2). The island has an elongate, narrow shape stretching for about 193 km. from Brooklyn in the west to Montauk Point. It does not exceed 40 km. in width.

Its north shore faces long Island Sound and the Connecticut coast, while to the south, New York Bight opens out into the vast expanse of the North Atlantic Ocean (Fig. 2.1). Western Long Island is dominated by the urban skyline of New York City, which faces Manhattan and Staten Islands across the East River and Hudson River. East of Montauk Point lies Block Island Sound which extends toward the offshore zone south of New England and Martha's Vineyard (Fig. 2.2).

2II PHYSICAL BACKGROUND

2IIA Relief and Drainage

Long Island's relief is characteristically low lying and subdued, with a maximum elevation of 105 m.MSL along the Harbour Hill moraine in the north (Fig. 2.2). The topography is a product of depositional processes during the Pleistocene epoch, when standstills occurred along the position of two major moraine

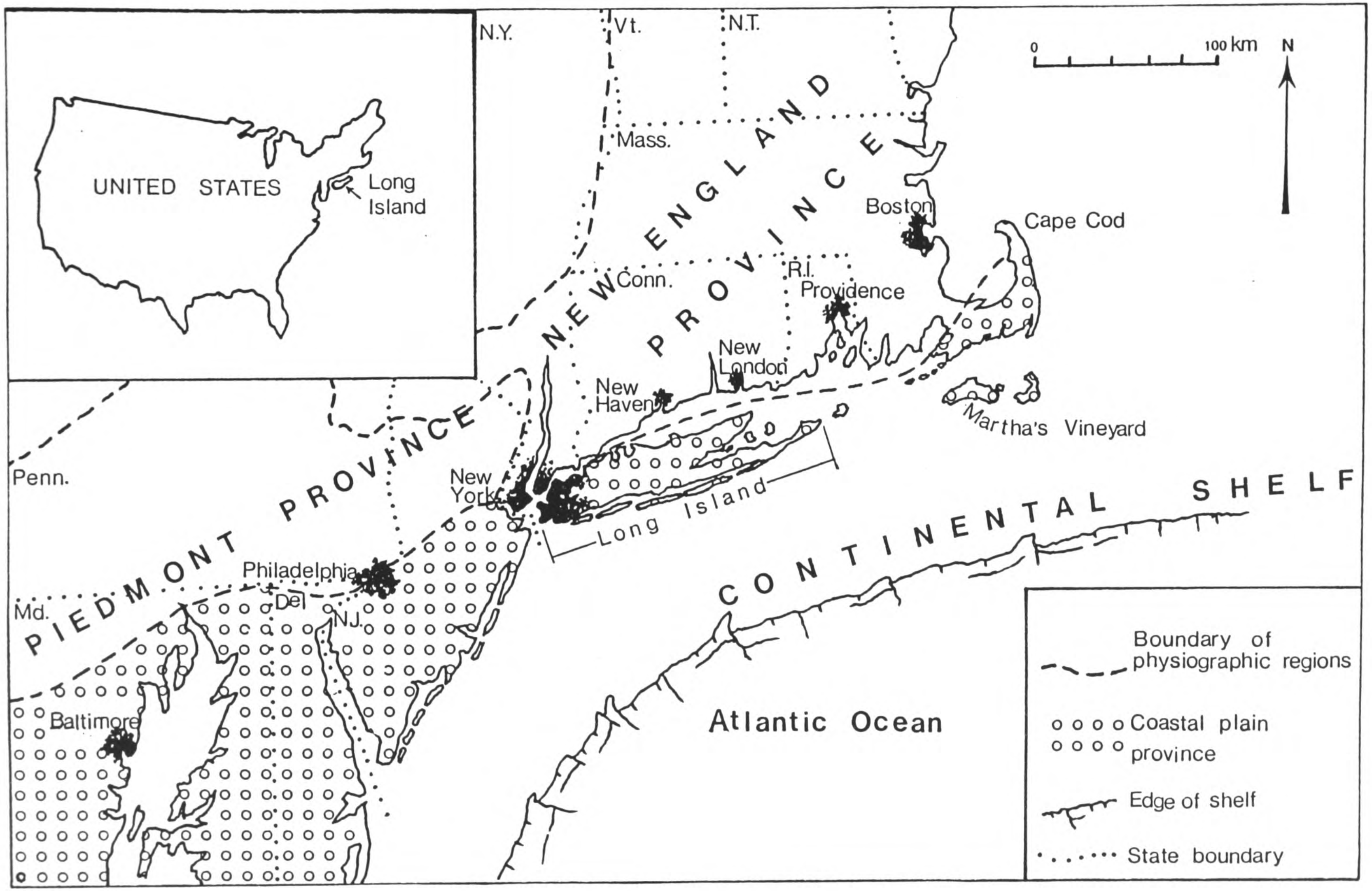


Fig 2.1. Location of Long Island

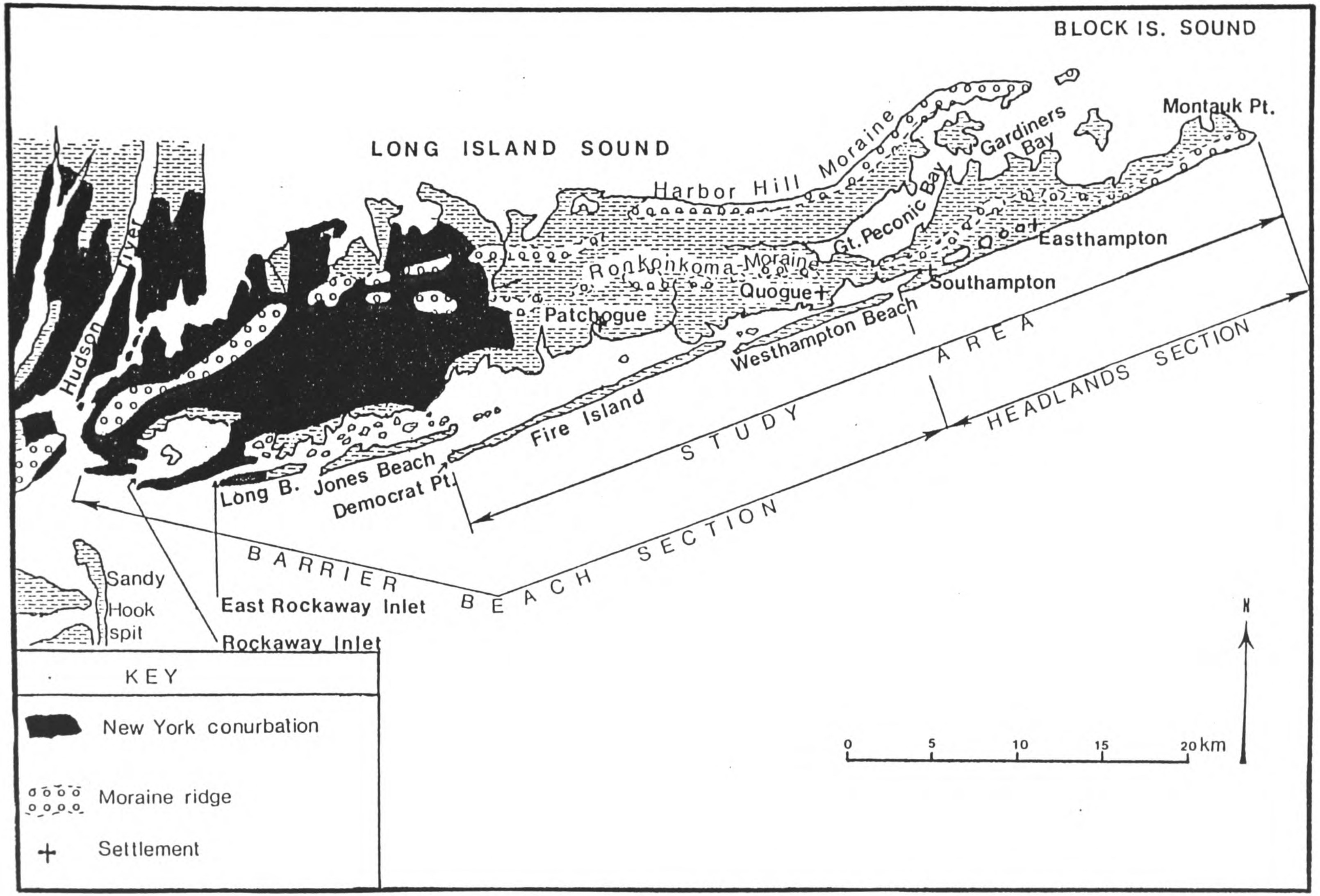


Fig. 2.2. The Study Area and Physiographic sections of Long Island's south shore.

ridges and subsequent recession (Fuller, 1914). Morainic ridges, outwash fans and plains, and marshy depressions typify the varied nature of the drift veneer.

Rising above this hummocky landscape are the Harbor Hill and Ronkonkoma Moraine ridges (Fig 2.2). They converge in the west to form a single ridge, but farther east they bifurcate to form northern and southern forks. The Harbour Hill moraine forms the northern fork and is the younger of the two (Rampino, 1978). It is erosion of the southern Ronkonkoma moraine at Montauk Point, forming cliffs on the eastern headland, that has been thought to be responsible for the supply of beach material to the south shore farther west (Taney, 1961a). Between the forks in eastern Long Island lie shallow flat bottomed, brackish water bays such as Great and Little Peconic Bay, Gardiners Bay and Block Island Sound (Fig 2.2).

The western half of Long Island's north shore is indented with many small bays such as Flushing Bay, Hempstead Harbor, Cold Spring Harbour, and Smithtown and Huntington Bays (Fig 2.3). Williams (1976) has linked the positions of such north shore bays to the courses of buried palaeodrainage channels eroded in underlying Cretaceous strata. He has measured their thalwegs southward over Long Island, and on into the offshore zone south of Fire Island (Fig 2.3). Sediment sample sites 20 and 21 (Fig 2.3) were taken from the lobe of glacial infill in one of the buried channels, south of Fire Island (Fig 2.3). The eastern half of Long Island's north shore contrasts markedly with the western half, in that the line of the Harbor Hill moraine has been eroded to form steep

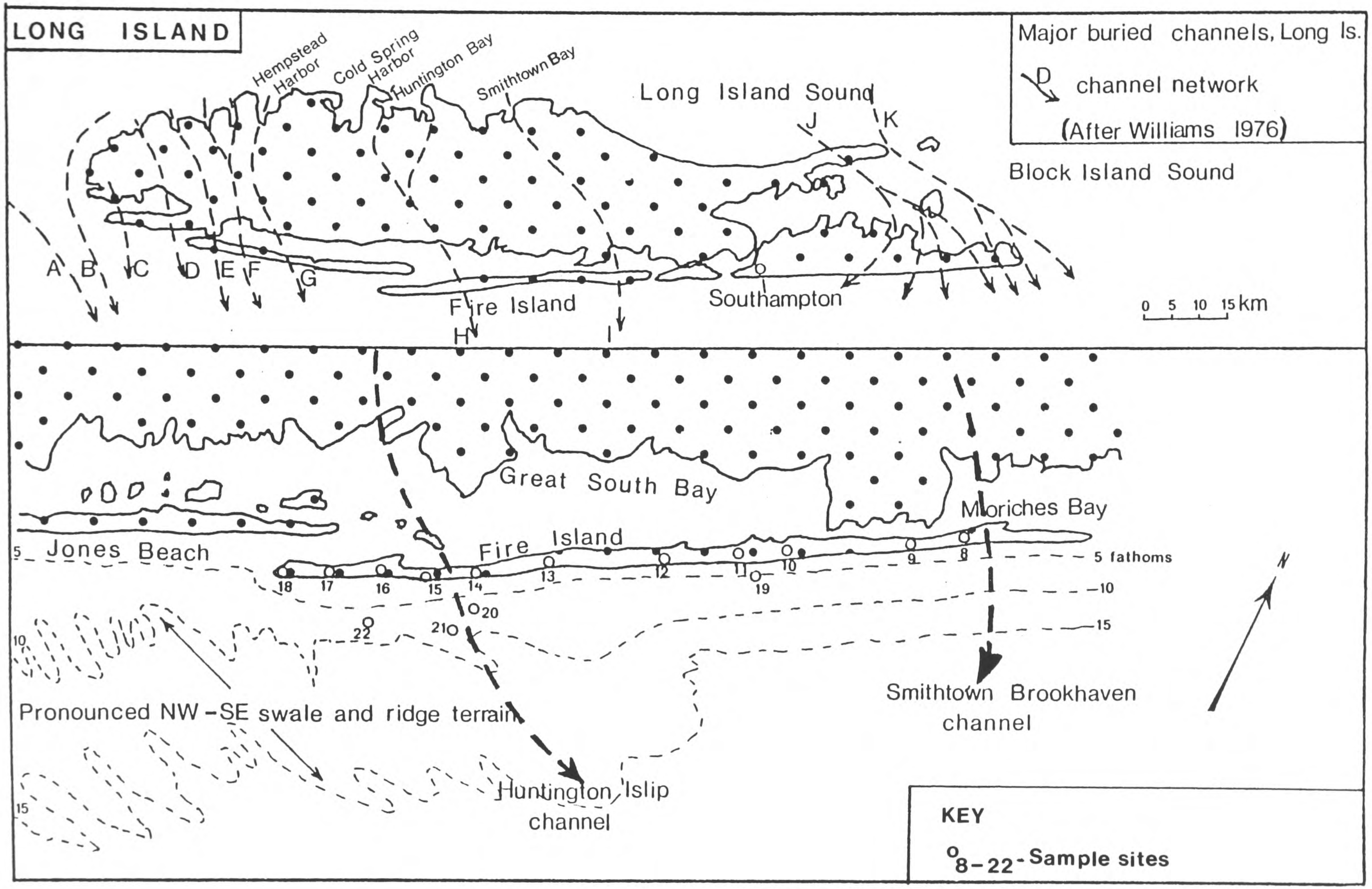


Fig. 2.3. Location of buried palaeodrainage channels and Sample Sites (After Williams, 1976).

cliffs, producing a smooth, linear coastline (Fig 2.2).

Long Island's south shore is also a smooth straight coastline for much of its length. It consists of dune-backed sandy beaches, spits, islands and shallow, brackish water lagoons and fringing marshes. Taney (1961a), divided the south shore into two major physiographic sections on the basis of their dominantly glacial or non-glacial characteristics:- (a) Headlands Section

(b) Barrier Beach Section

(a) Headlands Section:-

This section extends for about 53 km. west from Montauk Point to Southampton (Fig 2.4). It is thought that formerly, the Headlands may have extended eastwards as far as Montauk Shoals, but has been eroded and has receded 3,000m. to 4,500m. during the last 5,000 years (Taney, 1961a). The Headlands Section may be further subdivided into three smaller units (Fig. 2.4):-

(i) Bluff's Unit

(ii) Connecting Beach

(iii) Beach Fronting Headlands

(i) Bluff's Unit:-

For 16 km. west of Montauk Point to Hither Hills State Park, the shoreline is formed from 18m. high bluffs eroded in Ronkonkoma moraine. Fronting these are narrow beaches of coarse sand and gravel eroded from moraine. The Bluff's unit has long been considered to be the primary source of beach sediment transported westward in littoral drift, nourishing beaches, spits and islands in the Headlands section (Colony, 1932; Taney, 1961a; Krinsley et al,

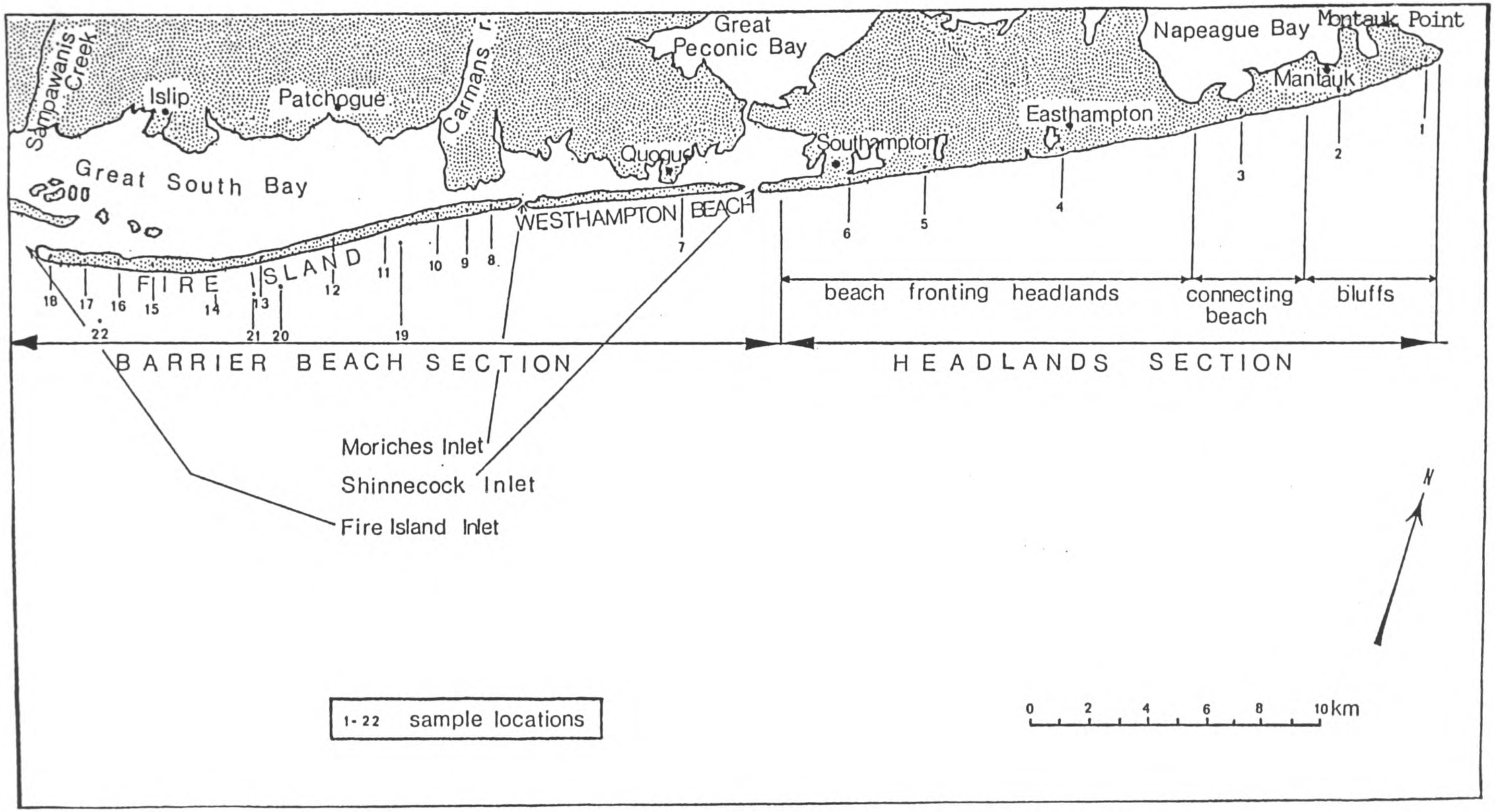


Fig. 2.4. Location of Sample Sites and Physiographic Sections on Long Island's South Shore.

1964; Williams, 1976).

(ii) Connecting Beach:-

West of the Bluff's Unit extend low sandy beaches backed by sand dunes leading inland to marshes (Fig. 2.4). This unit forms a weak link in the Headlands Section and has been inundated by storm water during the onset of large hurricane-induced tides and storm waves (Taney, 1961a).

(iii) Beach Fronting Headlands:-

For about the next 30km. westward, sandy beaches are backed by continuous sand dunes reaching 61m in height. Former stream channels draining southward have been blocked off by the growth of baymouth bars, formed by westward littoral drift (Fig. 2.4). Now seen as small ponds, occasionally they have been reconnected to the open sea when severe storms have breached the bars (Taney, 1961a). Proceeding westward, the Ronkonkoma moraine ridge swings northward away from the shore. South of the terminal moraine, a low hummocky - relief outwash plain slopes gently south eastwards below the coastal dunes and offshore for at least 4km. (Williams, 1976; Rampino, 1978).

(b) Barrier Beach Section:-

The study area extends only part way along this section for about 80km. west of the Beach Fronting Headlands (Fig. 2.4). The shore consists of a spit and two barrier islands, including Fire Island. Its smooth linear outline is broken only twice by Shinnecock Inlet, which leads into Shinnecock Bay, and by Moriches

Inlet which leads into Moriches Bay. At Democrat Point, the western tip of Fire Island overlaps the seaward face of Oak Beach and is separated from it by the east-west trending Fire Island Inlet.

West of the study area, the beach continues in the same barrier beach style in the form of Jones Beach, Long Beach, Rockaway Beach and Coney Island. These are separated from each other by Jones Inlet, East Rockaway Inlet and Rockaway Inlet (Fig. 2.2).

Long Island's south shore barriers are made up of straight, long, shoestring islands and spits, varying in width from 0.4 km. to 1.5 km. The barrier-front beaches vary from 150m. in width in the west to almost nothing in the eastern part, the average width being about 30m. to 60m. (Taney, 1961a).

Barrier dunes along this stretch of coast reach 3m. to 9m. MSL. From their steep, ocean-facing ramparts they slope northwards gently toward backbarrier lagoons and fringing marshes. Many lagoons are interconnected by narrow channels, as at Quogue-Westhampton and Mastic Beaches. Here, low promotories extend southward almost to the barriers. Lagoons vary in width from about 8 km. to about 100 km.

Barrier islands on Long Island's south shore form a dynamic unstable zone, where there is a delicate balance between beach sediment supply from westward littoral drift and the erosive actions of wind and waves. In historic times, inlets like Moriches Inlet have been breached and then blocked off several times (Leatherman, 1988). The present inlet is a product of man's dredging activities in addition to marine processes (Taney, 1961a).

As a result of its veneer of glacial and fluvio-glacial sands gravels and clays, much precipitation percolates downward rapidly into the subsurface zone. The water table cuts the ground surface near the coast, surface runoff reaching the sea in the form of fresh to saltwater marshes and backbarrier lagoons. Many streams emerge from the lower flanks of the Harbor Hill and Ronkonkoma moraine ridges. They flow over the hummocky surface in a vague dendritic pattern. Some streams like East Meadows Brook, Massatayou Creek, Carlls River, Sampawanis Creek and Carmans River flow southward along old, surface glacial outwash channels from the Harbor Hill Ridge through gaps in the older Ronkonkoma ridge. Williams (1976) has related these to buried palaeodrainage channels (Fig. 2.3). Long Island's rivers have not been considered to be an important sediment source for south shore beaches (Taney, 1961a).

IIB Continental Shelf Topography south of Long Island.

South of Long Island, the sea bed which forms a part of the coastal plain of northeastern U.S.A. dips gently toward the Atlantic Ocean in the southeast for about 130 km. before it meets the shelf edge (Fig. 2.5). South of the barrier beach section, the water reaches 20 fathoms within 32 km. to 48 km. offshore. The gradient is steeper south of the Headlands section, where similar depths occur within 16 km. of the shore (Williams, 1976).

The continental shelf is bounded clearly in the west by the Hudson Channel (a submarine extension of the Hudson River), and in the east by Block Island Channel (Williams, 1976) as shown in Fig. 2.5 . Bathymetric contours south of the Barrier beach section

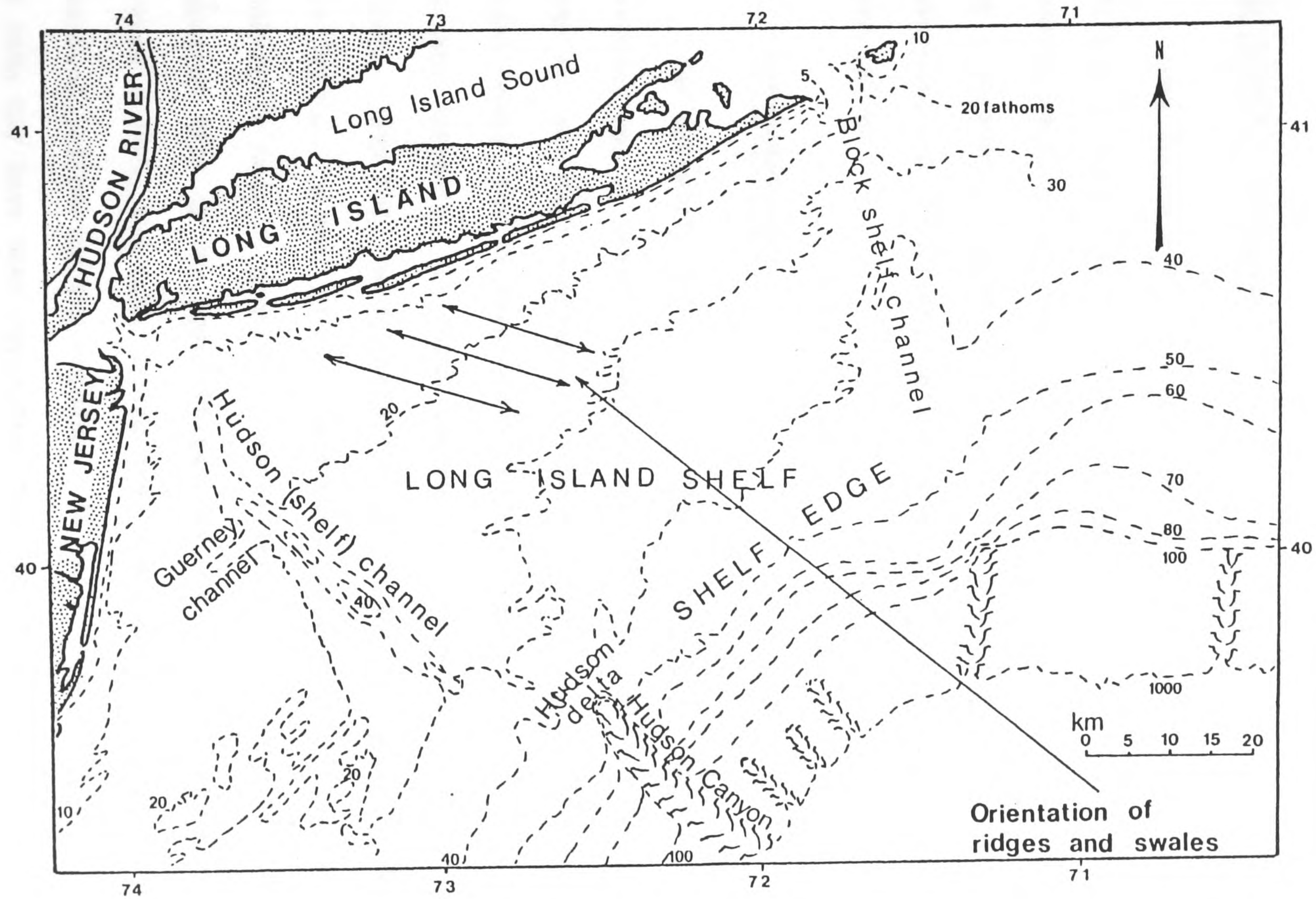


Fig. 2.5. Long Island Shelf Topography (After Williams, 1976).

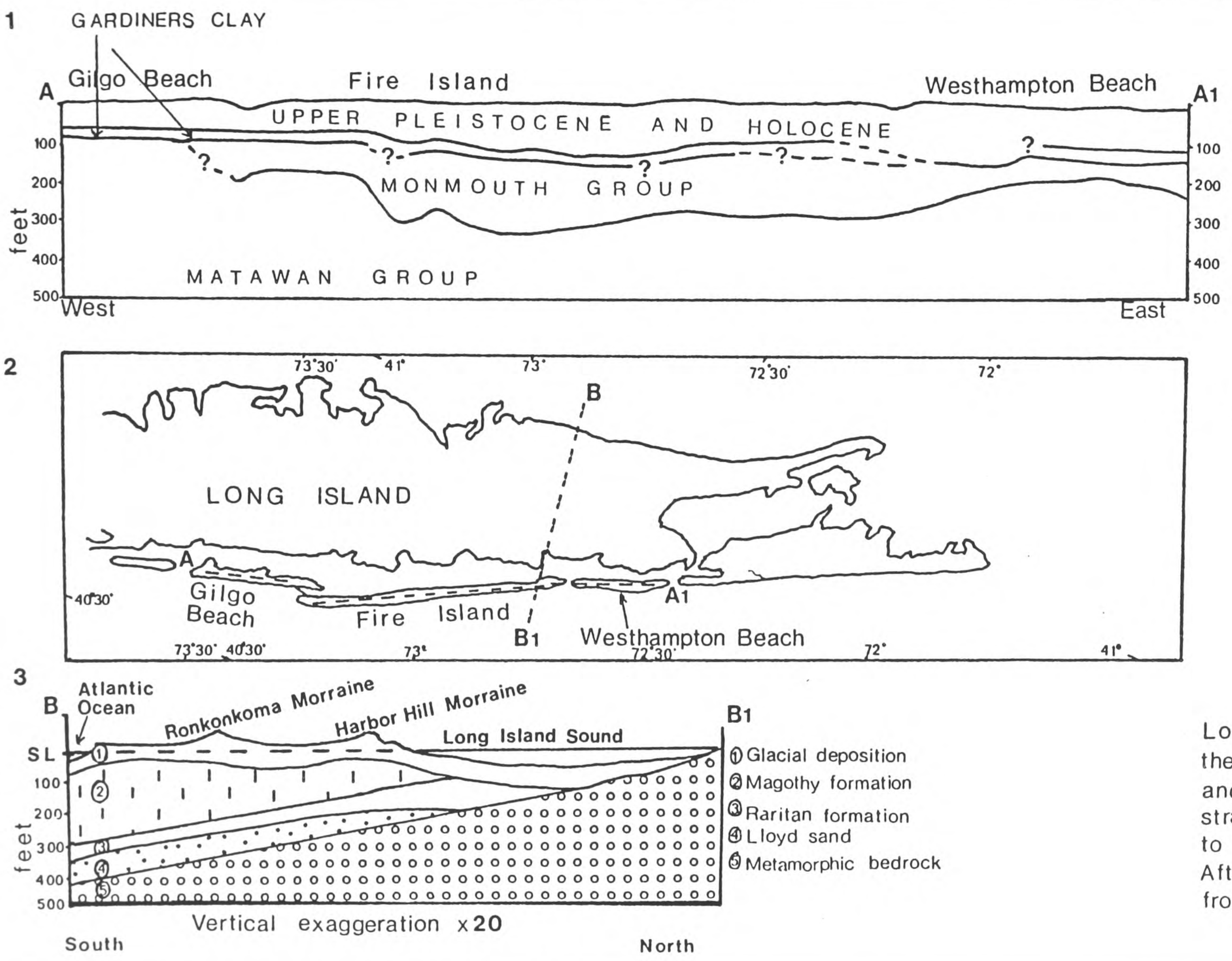
are sharply crenulated, revealing a pronounced ridge and swale topography on the sea bed. The crest and trough orientations trend northwest to southeast. Farther east, the ridges and swales are not so well developed and have been modified by modern sea floor currents (Williams, 1976).

IIC Long Island: Geological background

Long Island's Pleistocene drift covered surface has been modified by subaerial processes during the Holocene. Pleistocene deposits rest unconformably on Cretaceous sediments, beneath which lies a basement complex (Fig 2.6). The salient points of Pre-Quaternary and Quaternary geology are discussed in chronological order below.

(a) Pre-Quaternary:-

The basement complex forms the bedrock and is possibly of Pre-Cambrian, or Lower Palaeozoic age (Fuller, 1914). Its eroded upper surface dips southeast at about 1 in 55. In northern Long Island Sound the basement complex underlies Pleistocene and Holocene deposits, its depth increasing to-61m MSL. in Queens County, - 335m MSL. below eastern Rockaway Beach, and-610m. MSL below Fire Island (Fuller, 1914). Basement complex rock is a crystalline metamorphic mass of granitic composition and Fuller (1914) has suggested that in the upper Palaeozoic era (Siluro - Devonian to Permian times), the Long Island area was probably subjected to subaerial weathering and erosion. In early Mesozoic times Triassic Red Beds may have been deposited, but Taney (1961a), has stated that no evidence had been found below Long Island for these deposits



Geological section from west to east. A – A1

After Williams (1976) modified from Perlmutter and Todd (1965)

Location of geological sections

Long Island section, showing the low relief bedrock surface and offlapping Cretaceous strata which dip and thicken to the south east.
After Williams (1976) modified from de Laguna (1963)

Fig. 2.6. Idealised geological sections of Long Island's South Shore (After Williams, 1976).

(Fig 2.6).

The Cretaceous period was marked by successive episodes of tectonic instability, warping the basement complex gently to the southeast. This formed the surface on which Cretaceous strata were deposited by successive marine transgressions and regressions. The sequence consists of strata overlapping each other to the northwest, thickening southeastward. The basal member of the oldest Cretaceous beds (Raritan Formation), is known as the Lloyd Sand and it rests unconformably upon the eroded basement complex. Renewed subsidence resulted in deposition of the younger Magothy Formation, a dominantly non-marine unit of clayey sands and gravels, especially in its upper horizons (Williams, 1976). The ensuing transgression led to deposition of the overlying Matawan and Monmouth Groups. The Monmouth Group consists of marine, glauconitic sands and silty clays and is restricted to the south coast and offshore.

Of the rocks mentioned above, the only deposits which outcrop in areas close enough to the study area to be considered a possible sediment source are those of the Matawan - Monmouth Group. Williams (1976) described bottom sediments extending south from Fire Island Inlet, which, on the basis of the presence of glauconitic grains may have been derived from underlying Monmouth Beds by erosion during upper Cretaceous, or Tertiary times. Bottom sediments may also have been derived from erosion of Pleistocene deposits which themselves may have been eroded from underlying Coast Plain strata (Williams, 1976).

No known Tertiary deposits have been discovered in Long Island, therefore, from Palaeocene to Pleistocene sedimentary environments were either erosional, or non-depositional in character. Another possibility is the deposition and subsequent erosion of deposits, as may have been the case with the Chalk cover in Wales. Quaternary deposits rest unconformably upon upper Cretaceous deposits along Long Island's south shore (Fig 2.6), and in the off-shore zone (Williams, 1976).

(b) Quaternary:-

Worldwide climatic pulses in the Pleistocene affected some 4 million square miles of the North American continent. During glacial phases, ice centres to the north of Long Island thickened and advanced, feeding glaciers which followed pre-Pleistocene river valleys. Both the Harbor Hill and Ronkonkoma Moraine ridges mark the limits of southerly advances of the Hudson - Champlain lobe in central Long Island and the Naragansett lobe in eastern Long Island (Rampino, 1978). The Ronkonkoma moraine is located south of the Harbor Hill moraine and has been considered to be the older of the two. However, the contribution, chronology and extent of possible glacial modifications at a later date are not certain (Rampino, 1978).

During the Pleistocene epoch, the hydrological cycle would have been altered greatly, as large volumes of water became land-locked in glacial stores causing sea level to fall worldwide. Pre-glacial shorelines advanced many kilometres seaward, reaching much lower levels than at present. South of ice fronts in the Long Island region periglacial conditions would have prevailed (Rampino, 1978). Glacial meltwater streams issuing from ice fronts would have deposited and reworked their glacially derived loads as coalescing fans of sand and gravel forming a proglacial outwash plain (Taney, 1961 b).

When glacial phases gave way to milder interglacial stages, the worldwide amelioration in temperatures would have reversed those changes in the hydrological cycle brought on during the preceding cold stage. Glacial budgets would have had higher ablation to accumulation ratios. Glacial lobes thinned and ice fronts receded northward. Terminal moraine ridges marking previous standstills became separated from their sediment supplies by a broadening band of hummocky recessional moraine. South flowing meltwater streams would have reworked proglacial sediments between and north of the Harbor Hill and Ronkonkoma moraines, in the same way that they had to the south of these earlier on.

As surface runoff increased and meltwater returned to the sea, a worldwide rise in relative sea level would have followed. In reverse to the sequence of events that operated in the preceding cold stage, interglacial shorelines contracted and migrated landwards. Outwash plains south of the Ronkonkoma and Harbor Hill moraines would have been progressively engulfed and subjected to a regime of wave action and sea currents (Williams, 1976).

Fuller (1914), envisaged a scenario on Long Island with four glacial advances separated by three interglacial retreats preceding the Holocene epoch and deposition of Recent sediments (Table 2.1). Interpretation of Pleistocene stratigraphy and chronology by Fuller (1914), has been revised largely by later workers like Fleming (1935), MacLintock and Richards (1936),

STAGE		SUBSTAGE		ORIGIN		EQUIVALENT STAGE IN MID-CONTINENT AREA
Wisconsin	-	Harbor Hill Ronkonkoma	-	Glacial (terminal Morained)	-	Early Wisconsin
Vineyard	-		-	Interglacial	-	Sangamon
Manhasset	-	Hempstead Montauk Herod	-	Glacial	-	Illinoian
Jacob	-	None	-	Transitional	-	Yarmouth
Gardiners	-	None	-	Interglacial	-	
Jameco	-	None	-	Glacial	-	Kansan
Post-Mannetto	-	None	-	Interglacial	-	Aftonian
Mannetto	-	None	-	Glacial	-	Nebraska

Pleistocene Events of Long Island (Taney (1961a) After Fuller (1914)).

STAGE		SUBSTAGE		ORIGIN
Wisconsin	-	Harbor Hill Ronkonkoma Manhasset	-	Glacial
Sangamon	-	Jacob Gardiners	-	Transitional Interglacial
Pre Sangamon	-	Jameco Mannetto	-	Glacial

Later interpretation of Pleistocene events on Long Island. Taney (1961a).

TABLE 2.1

Suter, de Laguna and Perlmutter (1949) and others (Table 2.1). The precise details of Pleistocene chronology and stratigraphic nomenclature are still not completely certain (Rampino, 1978). Fuller's (1914), separate Manhasset 'glacial' has been included by Rampino (1978), within the mid-Wisconsin and late Wisconsin glacial advances. Taney (1961a), interpreted the oldest Pleistocene deposits (Mannetto and Jameco Gravels), as being pre-Sangamon Age. Jameco Gravels vary from 0m. to 45m. in thickness in northern Long Island, but their 'outwash' origin and importance as an index of a separate and widespread Pleistocene event has been questioned (Rampino, 1978).

Williams (1976), described the overlying Gardiners Clay as a greyish-green, marine silty clay. Rampino (1978), considered the fossil assemblages found in Gardiners Clay in the 'type area' to be of too discontinuous and patchy a nature to be correlated accurately with sediments outside.

The Jacob deposits have been described by Taney (1961a), as overlying Gardiners Clay, and assigned both deposits to the Sangamon Interglacial. Rampino and Sanders (1981), devised a threefold division for Long Island Pleistocene deposits along the south shore (Fig. 2.7). From core evidence they recognised a possible mid-Wisconsin barrier, rising perhaps 10m. above the lower mid-Wisconsin landscape below the present Jones Island. They named this deposit as the sandy facies of the Wantaugh Formation, now buried beneath younger sediments (Fig. 2.7).

Rampino (1978), has stated that both major tills and terminal moraine ridges may, or may not be correlated on a one to one basis,

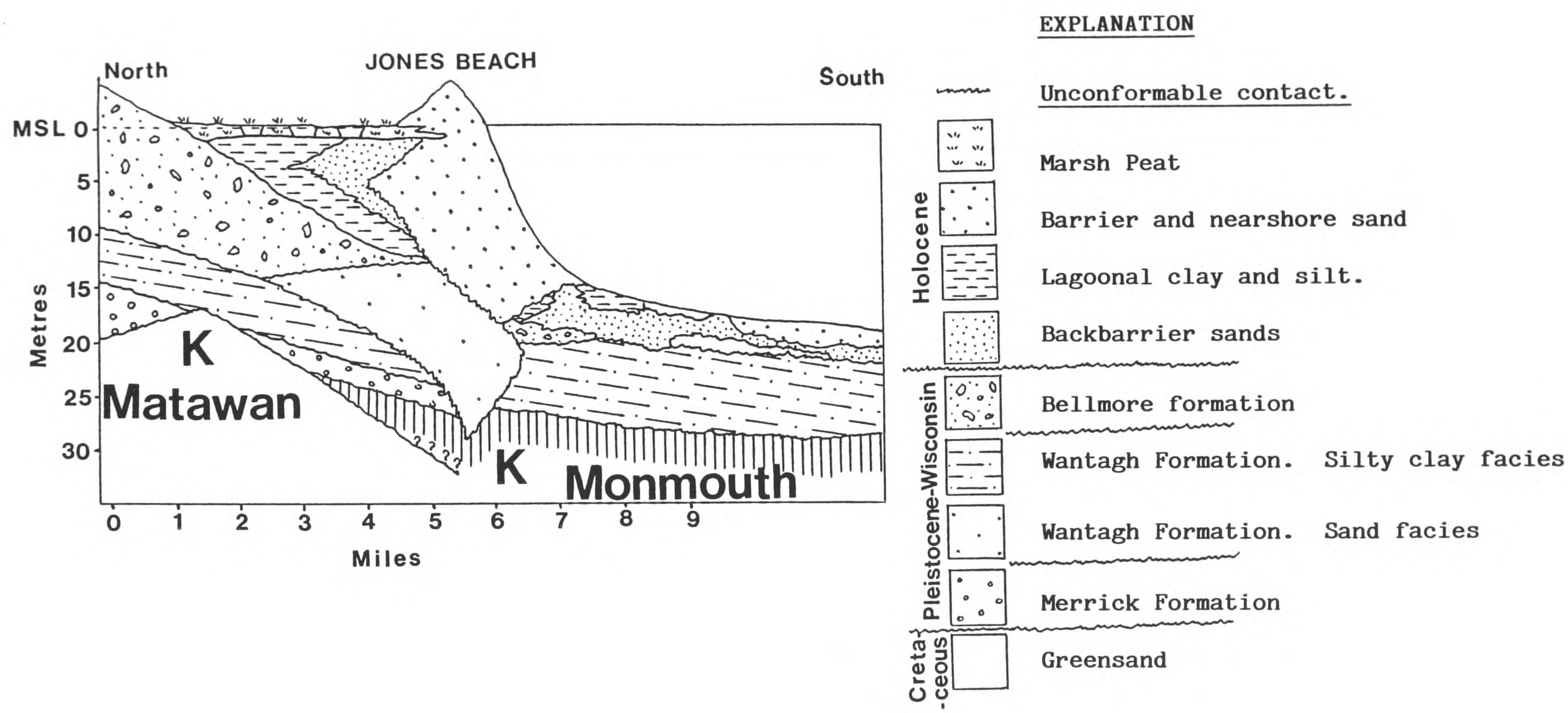


Fig. 2.7 Schematic Section through Jones Beach barrier island (After Rampino and Sanders, 1981).

however, the older Montauk Till has been equated with the Ronkonkoma moraine ridge and the Merrick outwash sands and gravels. There is an overlying surficial till which has been associated with the younger Harbor Hill moraine ridge and the Bellmore outwash deposits (Rampino, 1978).

The Holocene-Pleistocene contact ranges from less than -1m. MSL to -26m. MSL on the inner continental shelf, thickening as a wedge seaward to 10m. (Fig. 2.7). Williams (1976), found that reworked Pleistocene sediments have been redistributed southward over the shallow shelf zone as outwash fans for at least 4 km. This process must have occurred during deglaciation in the 10,000 years, when Pleistocene shorelines migrated 50km. landward over the continental shelf with the Flandrian transgression. Table 2.2 shows the vertical and horizontal transgressive sequence which may be expected from the successive shoreward displacement and replacement of depositional environments during this period.

Rampino and Saunders (1980, 1981), have described rates of sea level rise in the Flandrian and have related these to the theory of 'barrier overstepping' as a mechanism for barrier island migration with a rising sea level. From 9,000 years B.P. on Long Island, sea level rise may have been rapid (about 5mm per year). At the onset of such a period when sea level was about -24m MSL (Sanders and Kumar, 1975), Rampino and Sanders (1980), postulated the existence of an ancient Pleistocene barrier island, 7km offshore and roughly parallel to the existing shoreline. By 7,500 years B.P., sea level had risen to -16m MSL and the top of the -24m MSL barrier, thus drowning it 'in situ'. They suggested that the barrier was over-stepped and that the surf zone skipped 5km

1. Submerged Pleistocene Highland (outwash sands).

2. Fringe of brackish to salt marsh (peat with organic silty clay and grey silty sand).

3. Open lagoonal silty clays.

4. Backbarrier tidal delta and washover sand lobes (grey, very fine to medium sand grading upwards toward medium to coarse sands and gravel of inlet infill).

5. Backbarrier fringe salt marshes (grey organic silty peat and sands).

6. Barrier island sands of beach ridge, dune, beach berm and inlet fill origin (fine to coarse sands).

7. Shore face sands.

8. Shallow inner shelf sands.

Table 2.2 Transgressive sequence from land to sea (after Rampino and Sanders 1980).

landward to form a new shoreline at -16m. MSL., where another barrier island had formed. This mechanism, known as surf skipping, is highly contentious (Leatherman and Williams, 1982), and will be described in more detail in the section on Sediment Sources.

Between 7,000 years B.P. and about 3,000 years B.P., sea level had risen by a rate of approximately 2.5mm each year relative to the Long Island coast. According to Rampino and Sanders (1981), the -16m. MSL barrier coast 2km. offshore had migrated continuously toward its present position. The rate of sea level rise possibly slowed down to about 1mm each year after 3,000 years B.P..

IID Shore Processes

The nature of landforms plays an important role in coastal Geomorphology, but the present study is concerned less with form than with the processes and mechanisms of transport, erosion and deposition of quartz sand grains and subsequent textures imprinted on their surfaces. In this context such processes have a two-fold significance:-

(i) Whether sand has experienced previous episodes during which it suffered transport in turbulent surf zones, or, has been lying passively in a sediment sink, textural variations produced on each sand grain surface as a direct consequence can be determined with the aid of S.E.M. analysis (Bull, 1981a). The 'forms' with which this study is concerned are those on a 'micro' scale. They include the microscopic cracks, impact pits, scratches and etchings on quartz, sand grain surfaces.

(ii) The energy regimes through which sand grains pass, vary from those of extremely violent storms to which beaches are subjected relatively infrequently, to quiet low energy conditions which are the 'norm' for long periods. Different energy regimes produce different varieties of quartz grain surface textures.

Barrier beaches of Long Island's south shore are but one part of a much larger, complex interactive coastal system operating along the shores of eastern and north-eastern U.S.A.. A strong interdependence exists between beaches, spits, islands, lagoons and the offshore zone. Fluctuations in energy flows and regimes are reflected in concomitant changes in sediment flows through such sediment stores as beaches, dunes and nearshore sinks (Williams and Scott, 1985).

The study area falls within a dominantly wave controlled energy regime (microtidal, with moderate wave energy). On many coastlines the tidal range is between 2m and 4m, but Long Island experiences short range, semi-diurnal tides of about 1.3m. Storm tidal ranges of 2m. and 3m. have occurred. In sheltered lagoons such as Great South Bay the tidal range is even less at about 0.3m. to 0.6m. (Reister et al, 1982).

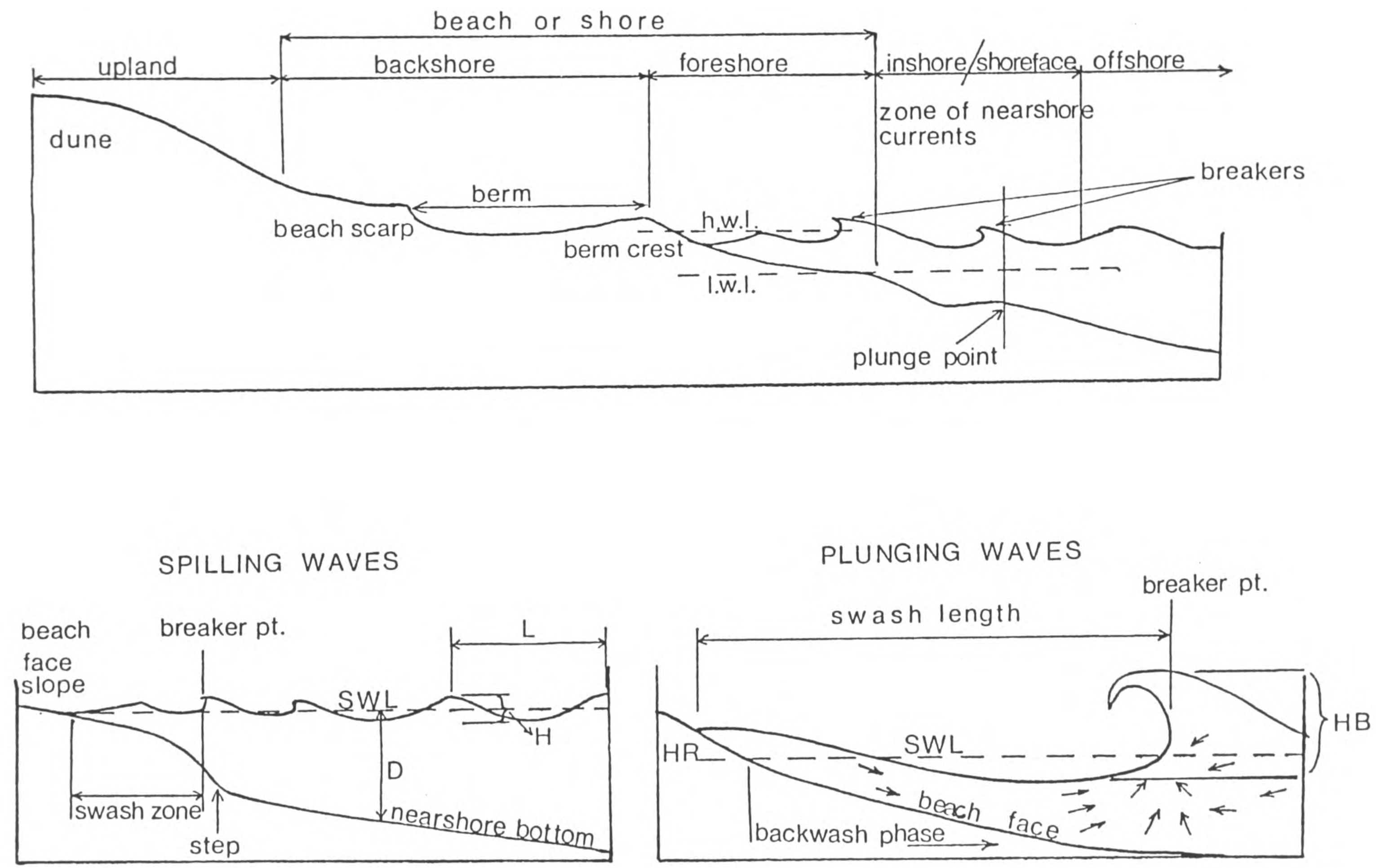
The following account of shore processes in general, as they apply to Long Island, attempts to set the scene for discussions and analysis in the section on results. It also attempts to pave the way for the following chapter which examines the important subject of sediment sources.

Beaches experience a variety of wave energy regimes, responding quickly to changes on a daily basis and over shorter time periods. They may be defined as accumulations of wave-washed, loose sediments extending between the outermost breakers and the landward limit of wave and swash action. Leatherman (1988 , Fig 2.8), shows a characteristic beach profile in the study area. The landward part of the beach ends in barrier dunes, or, in the case of the Headlands section (Fig. 2.8), in both dunes and moraine bluffs. Fronting this is the backshore, a gently sloping zone with berms only affected by wave action during storms. Seaward of the berm crest lies an intertidal zone known as the foreshore.

Berms are beach terraces produced by sediment accretion as incoming wave energy is translated into swash. There may be several berms, each marking a change from the seaward face of the foreshore to the gently landward sloping backshore. Berms generally build upwards in the summer when lower energy conditions prevail, the swash of low, longer period waves moving sand up-beach from near-shore bars. During winter , when weather conditions generate high, steep, short period waves locally, the profile is degraded. Powerful backwash may erode the beach face, removing sand stored in berms seaward to nourish offshore bars.

Generally a summer profile has a wide backshore separated from a steep foreshore by a well developed berm. In winter, the foreshore is flattened and extended landward, eating into the narrower backshore and supplying beach sand to a growing offshore bar.

Beaches adjust their profiles in order to maintain equilibrium



D	water depth	L	wave length
H	wave height	↓↘	velocity vectors
HR	run-up height		
HB	breaker height		
SWL	still water level		

Fig. 2.8 Beach and Wave terminology (Modified from U.S.A. C.E.R.C. after Leatherman, 1988).

with seasonal fluctuations in wave energy regimes. Such adjustments may be dramatic during a storm when powerful, short high waves may flatten a berm in a few hours. Clearly, berms and bars are inextricably linked as parts of an 'onshore-offshore' movement of sediments. Changes in one are reflected in changes in the other. Bars act as mechanisms which filter wave energy inputs to a beach system, causing larger waves to break offshore, allowing only smaller waves to run on toward the water's edge (Leatherman, 1988).

Bars exposed at low tide are termed ridges and are separated by broad troughs called runnels. The development of a bar into a ridge and its onshore migration is an important mechanism by which berms recover after severe storms.

Probably the most important agent shaping Long Island's south shore beaches is 'waves'. They originate in the Atlantic Ocean south and east of Long Island. Steep, irregular sea waves are actively blown shoreward by wind and have periods up to 9 seconds. On the basis that the diameter of most Northeaster storms is no more than 1,000km, the maximum fetch for such waves is about one quarter of the storm's diameter (250km). Such 'sea' waves are responsible for flattening and eroding beaches.

During the rest of the time, waves arriving on beaches constitute swell. These are long, low, regular waves which originate as 'sea' but have been propogated beyond the limits of the storm. Normal swell ranges from periods of 6 seconds to 14 seconds and may achieve 20 seconds or more (Leatherman, 1988).

The waves described are deep water oscillatory waves. The energy of such a low sinusoidal, rounded swell wave is proportional to the product of wave length (L), and the square of wave height(H).

$$E \propto L.H^2$$

Even a small increase in wave height results in a proportionately much larger increase in wave energy. The total amount of energy originally acquired would depend upon the duration and velocity of the storm and the fetch. The dominant direction of water particle movement in a deep water wave is an open, circular, oscillatory pattern decreasing in scale vertically down the orbital path as far as one wavelength.

Oscillatory waves change to translatory, or shoaling waves on entering shallow water (where the water depth is about half the wavelength). The circular water particle orbit changes to an elliptical path with a greater forward and backward component. Potential energy stored in a wave form is translated into kinetic and potential energy shorewards. Whereas wavelength was the major factor controlling wave energy, in shallow water it is wave height (H), and water depth (D), which are dominant.

$$C = \sqrt{g.(D + H)}$$

Where C - wave energy

g - acceleration due to gravity

D - mean depth of water (m)

H - wave height (m)

Solitary wave theory is based on the assumption that water particles in troughs are motionless. Friction with the sea bed slows down the wave form, but as wave period remains constant the elliptical motion increases in speed. Wave length shortens causing there to be insufficient water to sustain wave form.

Plunging breakers are those where the faster, rolling orbit of water particles outruns the supply of water needed to maintain wave form. At a critical point 'where water depth to wave length' ratio increases to 0.05 (Friedman and Sanders, 1978), and where wave steepness (the ratio of wave height to wave length-H/L), reaches 1/7, or, 0.143, the wave form is maintaining the steepest crestal angle that it possibly can (120^{o}). At this juncture, breakpoint occurs where $D = 1\ ^{1}/_{3}\ H$. Much of the wave energy is dissipated on the beach face from this point on, part of it being used to entrain and transport sediment up and down the beach face.

Leatherman (1981), has stated that there were five major sand moving processes perpetuating east coast U.S.A. barrier islands.

(a) Littoral drift
(b) Onshore bottom currents
(c) Wind
(d) Overwash
(e) Inlet formation

(a) Littoral drift:-

In the study area, waves approaching from east to south-easterly directions will break obliquely on beaches. Shoreward of the breaker zone, longshore currents are significant in transporting sediment, but only rarely so in the zone of shoaling waves

(Friedman and Sanders, 1978; C.E.R.C. Shore Protection Manual, 1986). Prevailing winds from the northwest to southwest sector, although more persistent are not as strong as easterly winds associated with 'northeasters' (McCormick and Associates Inc., 1975). This is a product of the orientation of Long Island from east-northeast to west-southwest and the diagonal tracks across the area followed by extra-tropical storms. Such storms are known as 'northeasters' in Atlantic Ocean areas east of the U.S.A.. In the northern hemisphere, winds are drawn into the low pressure centre of the storm in an anticlockwise direction. This produces winds from the south-east and north-east sectors which have a greater fetch.

The sawtooth action of swash and backwash on a beach face, combined with longshore currents moving parallel to the shore in the surf zone, have been responsible for the formation of barrier islands and beaches along Long Island's south shore (Leatherman, 1988; Taney, 1961a; Krinsley et al, 1964). The sediment budget has been quantified by Taney (1961b), by estimating rates of sediment accretion on the updrift sides of groynes. The main sediment source nourishing littoral drift has been generally accepted as being cliffs formed in Ronkonkoma moraine in the Headlands section (Colony, 1932; Taney, 1961a; Krinsley et al, 1964; Williams, 1976). The drift-smoothed and straightened shore is breached only by tidal inlets at Fire Island, Moriches Inlet and Shinnecock Inlet (Fig. 2.4). Schwartz and Musialowski (1978), found that sediment dumped in the nearshore zone (-2m to -4m MSL.), near New River Inlet in North Carolina, moved rapidly onshore as a migrating ridge and runnel, destroying the existing runnel. Just before it reached the beach, much of the sediment was transported alongshore in the breaker zone.

Littoral drift from Montauk Point west-southwest along the south shore is not the only drift direction. Southwesterly prevailing winds reverse this dominant trend on occasions, creating a more complicated 'set up' than the uni-directional model described so far (Taney, 1961a; Williams, 1976). The smooth, westward flow of beach sediment is punctuated also by the actions of rip currents and tidal inlets. The former occur when excess water builds up in the surf zone and then punches its way seaward, removing sediment to the nearshore and offshore zones. The latter form gaps in barrier beaches, through which flood tidal currents are channelled. At such locations, littoral drift is breached and sand is removed into the relatively quiet waters of lagoons like Great South Bay (Fig. 2.3) forming flood tidal deltas. The latter may eventually develop into platforms and later become colonised by saltmarsh once an inlet closes, or, migrates downdrift (Leatherman, 1988). There is a reverse flow of sediment toward the seaward shore of a barrier beach, but the net result is positive in favour of lagoons.

(b) Onshore Bottom Currents

In the nearshore zone of shoaling waves (Fig. 2.9), water undergoes not only orbital, oscillatory and elliptical motions, but also experiences mass movements or currents flowing along the bottom toward the breaker line. In breaker zones, shoreward bottom currents may flow upward and return seaward at the surface. Such wave-generated, outward surface currents may entrain fine sediment, stirred into suspension by turbulent breakers and remove it seaward

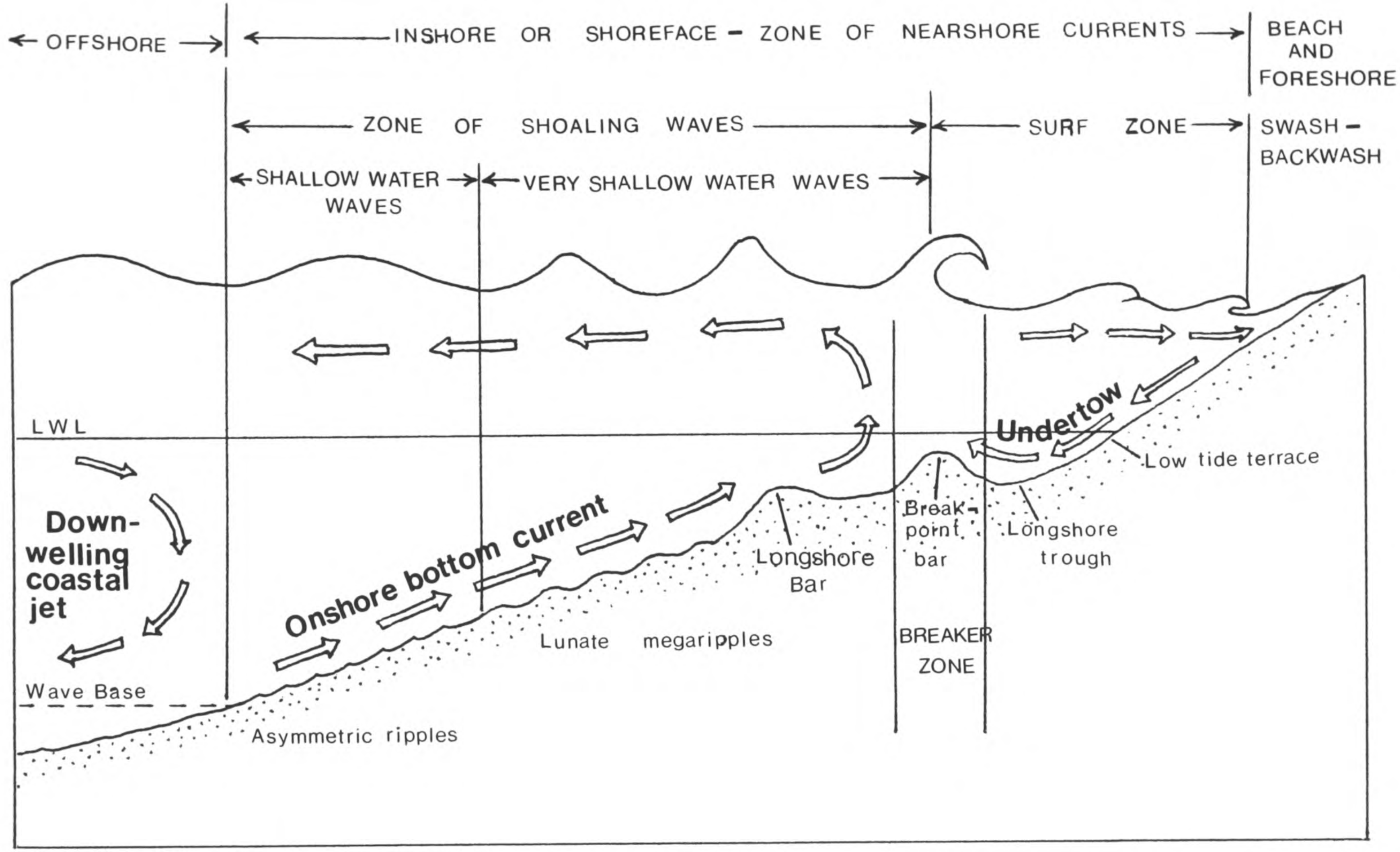


Fig. 2.9 Nearshore and Offshore Zones (Modified from Friedman and Sanders, 1978).

(Friedman and Sanders, 1978). Associated with such currents are submerged, linear ridges of cohesionless sediment with long axes parallel to the shore and normal to wave approach. Such features are known as longshore bars, already described above in the section on beaches. They are separated by linear depressions known as longshore troughs. They may remain stable for long periods, or, may migrate onshore or offshore (Leatherman, 1988). Fig. 2.9 shows locations of bars and troughs in relation to the positions of shore zones. In adition to onshore, wave-generated bottom currents the nearshore zone is characterised by return, seaward bottom currents induced by tides, an excess of water piled up against the coast, and the down-welling coastal jet.

As a shoaling wave approaches a shore, oscillatory-elliptical water particle motions cause discrete movements of cohesionless sediments such as sand. The bottom of an orbital motion becomes the interstitial water at the top of a sandy bed. Particles describe flattened ellipses that do not quite close, causing upward lift, shearing toward the shore, downward push, and shearing away from the shore (Friedman and Sanders, 1978).

Generally, in the outer part of the shoaling zone the seaward edge is characterised by a belt of symmetrical ripples with an inner belt of asymmetrical ripples. In the inner shoaling zone of very shallow water waves (where water depth to wave length ratio is 1 to 20), asymmetrical ripples give rise to more diverse forms, with megaripples and sand waves as much as 0.3m to 1.0m high and with wavelengths of 1m to 4m (Friedman and Sanders, 1978).

Processes operating in nearshore and offshore zones are of considerable interest to the present study as samples 19 to 22 were taken from these zones south of Fire Island (Fig 2.4). Surface textures on sample sand grains will have been modified by such processes and S.E.M. analysis has been used to qualify and quantify the results. There is some question of definition as regards the limits of nearshore and offshore zones. The scheme adopted here, is based on U.S.A., C.E.R.C. parameters where the nearshore is considered to end at about a water depth of -10m MSL. (Leatherman, 1988).

Large waves may stir bottom sediments well out on the continental shelf. They include long period swells (ranging from 14 seconds to 22 seconds), which may immediately precede a storm and which nearly always generate a landward flowing bottom current (Friedman and Sanders, 1978). Because of their enormous wavelengths (300m to 900m), such swells usually undergo complete refraction, meeting the coast almost parallel. In contrast, storm waves generate offshore currents and if they do not experience complete refraction may meet the coast obliquely, causing powerful littoral drift and rip currents (Friedman and Sanders, 1978). The frequency of 'Northeaster' storms is very high in the Long Island region (Leatherman, 1988). A very severe storm in March 1962, combining strong northeasterly winds with high Spring tides, drove 30 foot waves shoreward, breaching dunes, flooding bays and causing massive overwashing and inlet breaching along much of Fire Island.

Less frequent but more violent forms of storm include hurricanes which originate in the Atlantic ocean west of Africa and move northwards, occasionally near the eastern seaboard of the U.S.A.. About a dozen have affected Long Island since 1875 (Williams, 1976), and have caused storm surges which sweep across a low lying coast such as Long Island's south shore. Clearly, a vast amount of work is achieved in short periods of storms. One aim of the present study is to find out whether sand grain surface textures produced by such high energy episodes, with long return periods, may be distinguished from textures produced by more quiescent, low energy conditions that prevail for most of the time.

(c) Wind:-

The presence and extent of dunes in the barrier beach section of the study area are testaments to the importance of aeolian transport inland from beaches. Overwash is also an important mechanism which introduces sand into a barrier beach complex (Leatherman and Williams, 1982; Evans, 1983). Sand grains deposited on the beach from offshore and updrift sources are transported in littoral drift westward and after drying out at low tide may be blown inland by winds achieving a threshold velocity of 8.9 m.p.h. or more (Olsen, 1958).

The presence of vegetation has a baffling effect on wind which encourages deposition of sand particles, creating small dunelets. Further colonisation by perennial, dune plants such as Ammophila Brevigulata stabilise the system, promoting more sand accumulation. Higher backshore areas, inundated infrequently by high Spring tides, gather beachgrass colonies. A foredune develops, providing an obstacle to further sand movement, marking the coastal dune line.

The most common Fire Island dunes are crescent shaped, secondary dunes commonly found as low ridges a few feet high (Evans, 1983). Some areas, however, have well developed primary dunes (foredunes), in excess of 25 feet although most are 15 feet MSL (Williams et al, 1985). Fig. 2.10 shows two profiles across Fire Island illustrating the character of barrier dunes and the beach.

During the passage of a storm, stronger northeasterly and easterly winds are onshore, eroding the beach and transporting sand grains inland. Storm waves may erode the frontal dune scarp and remove sand to the nearshore, or may form overwash deposits in the lee of dunes. Offshore prevailing winds from the northwest however, would redistribute sand from the backdune zone and inter-dune swale to the back of the dune crest where it may be trapped by dune vegetation. Some sand may be transported through throats in dunes from washover platforms back onto the beach (Evans, 1983).

It is difficult to quantify the magnitude of beach-dune interaction in terms of quartz sand sediment exchange (Williams and Morgan, 1988). Onshore transport by strong easterly winds during the passage of Northeasters and by winds from the south and west, which dominate in Autumn in the study area, move sand across the beach-dune divide. The dominance of prevailing offshore, north westerly winds in winter reverses this trend. Some grains may cross the divide in opposite directions several times. (Williams et al, 1985).

Studies of quartz sand grain, surface textures on Long Island's south shore have shown that percentages of well rounded

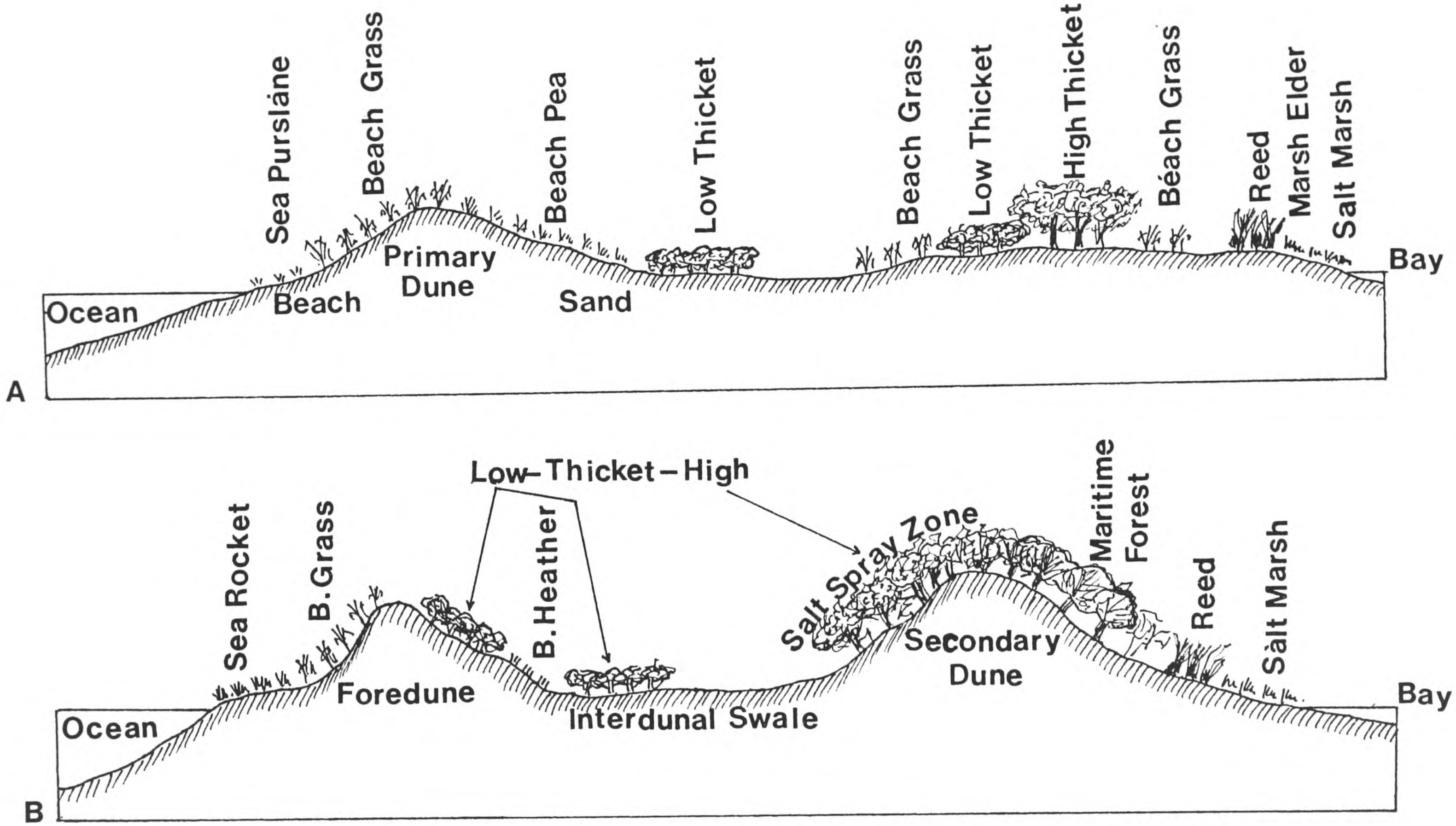


Fig. 210 Generalised transects across Fire Island (After Snyder, 1963).

A. Possible profile in a recently disturbed area.

B . Possible profile in an area of stable topography.

grains revealing dish shaped concavities and parallel and radiating straight steps, with considerable masking by chemical solution and precipitation textures are low (Williams et al, 1985). Surf abraded grains are most abundant. This S.E.M. study tends to support the fact that, unlike true desert dune grains, the trapping effect of vegetation combined with dominant onshore winds on Long Island's south shore, dune textures inherited from inland are relatively unimportant on beach sand grains. (Williams and Morgan, 1988).

(d) Overwash:-

Apart from the relatively, unimportant redistribution of sand grains from barrier flats through gaps in the dunes by prevailing northeasterly winds, overwash is also not considered to be an important mechanism influencing quartz beach sand grain, surface textures in mid-tide locations. Overwash is an important landward transporting mechanism of beach sand, building up barrier complexes in south U.S.A., but not in the north (Godfrey, 1976).
They are associated with storm surges which allow waves to overtop the beach and push sand across a barrier island. Overwash is the means by which barrier flats are created and sand is deposited above normal high tide mark (Leatherman, 1981). Over hundreds of years this causes barrier beaches to be displaced landwards.

(e) Inlet Dynamics:-

The fifth and final sand moving mechanism, mentioned by Leatherman (1988), is an important means by which the continuity of littoral drift is interrupted along Long Island's south shore. The more complex details involved in the role of inlet dynamics in the formation of migrating barriers is not of direct concern to the present study as far as quartz grain surface textures are concerned. However, the sediment budget in the study area is affected by sediment removals from beach systems into lagoons, some of which re-enters the system during the formation of ebb tide deltas and therefore has some relevance.

Flood tidal currents sweep through inlets into lagoons behind, where it is deposited as a flood tidal delta. On the ebb tide, some sand is returned but the net effect is one of bayside accretion. Inlets may have been caused initially by overwash, followed by a flow of super-elevated water in a bay after a storm surge (Leatherman, 1988). Normal tidal currents maintain the inlet, building a prominent flood tidal delta in the bay with a less prominent ebb tide delta because of disturbances by ocean currents. Gradually, longshore drift builds a spit which grows westward across an inlet sheltering water in the lagoon on the updrift bayside. Eventually, the inlet migrates downdrift and is closed as the spit becomes a bay bar, protecting the flood tidal delta which may be colonised by salt marsh vegetation (Godfrey, 1976). It is thought (Leatherman, 1988), that inlet formation and the growth of flood deltas are the main ways by which barriers can migrate landward along an eroding shoreline if the island exceeds 400 feet to 700 feet in width.

(f) Summary:-

Long Island's south shore beaches are a product of the reworking of glacial deposits by agents of weathering and erosion in the Headlands section (Fig. 2.4), where Ronkonkoma moraine forms bluffs at Montauk Point. Sediments produced in this area are transported westward as littoral drift, nourishing barrier beaches. A veneer of reworked glacial and fluvioglacial sediments occurs on the continental shelf south of Long Island. Some of these are preserved in buried palaeodrainage channels which can be traced onshore across Long Island (Williams, 1976).

Waves and wave-generated currents, along with tidal and other currents, are the most significant sand transporting mechanisms. Barrier island complexes are inextricably linked with flows of energy and sediment along their sea beaches and in the nearshore and offshore zones to the south.

C H A P T E R 3

S E D I M E N T S O U R C E S

SEDIMENT SOURCES

3.I INTRODUCTION

The juxtaposition of a dynamic fragile system such as Long Island's south shore barrier beaches and a densely populated urban-industrial region such as New York and its environs, has led to great demands being placed on the former by the latter. The consequences of human interference in the delicate balance which exists between the system's elements, through the development of recreational, residential, transportational and other land uses may have serious repercussions for the system's long term and shorter term stability (Leatherman and Allen, 1985). It is therefore of no great surprise that the area has focussed the attention of many coastal studies workers.

The areas which are of particular relevance to this study include those which are related to the nature of sediments stored and transported in Barrier islands and the associated nearshore sand prism, as well as relict sediments.

Colony (1932), Taney (1961a; 1961b), Kumar (1976), Williams (1976), Riester et al (1982), Leatherman and Allen (1985), and Williams and Morgan (1988), are but a small number of those workers who have studied surficial sediments and their possible sources on Long Island's south shore. In the last decade several studies have focussed attention on modes of barrier migration during the Holocene transgression (Rampino, 1978; Rampino and Sanders, 1982; Leatherman, 1983a; 1983b; Leatherman and Allen, 1985).

Sediment budgets have been estimated by Taney (1961a), Panuzio (1968), Czerniak (1976), and R.P.I. (1983), as shown in Fig. 3.1. Without exception, such studies found that sediment volumes transported westward in littoral drift increase in size. Estimates vary slightly, but all point to the problem of a sediment budget deficit in the volume of beach-size sand eroded by waves from glacial moraine bluffs at Montauk Point in the Headlands section (Fig. 2.4). The question arises as to the nature of another source which may supplement the glacial source at Montauk Point. Recent opinion has focussed on the possibility of an offshore source, particularly in the region east of the 'ridge and swale' topography south of Fire Island and in the vicinity of Williams' (1976), ancient, buried palaeodrainage Channel H (Fig 2.3), south of the bulge in central Fire Island (Leatherman and Allen, 1985; McCormick and Associates, 1975; McCormick and Toscano, 1981).

This study is interested in four areas relating to sediments and coastal processes along Long Island's south shore and the inner shelf.

(a) It is important to know precisely the values of recent south shore sediment budget estimates and to be aware of the ways in which they vary along different stretches of coast. There may be specific locations where budgetary estimates increase or decrease, and may thus be related to the need for an additional possible offshore source.

(b) The distinctiveness of palimpsest sediments preserved offshore in the buried palaeodrainage channels (Fig 2.3), described by Williams (1976), is important as far as methodology is concerned.

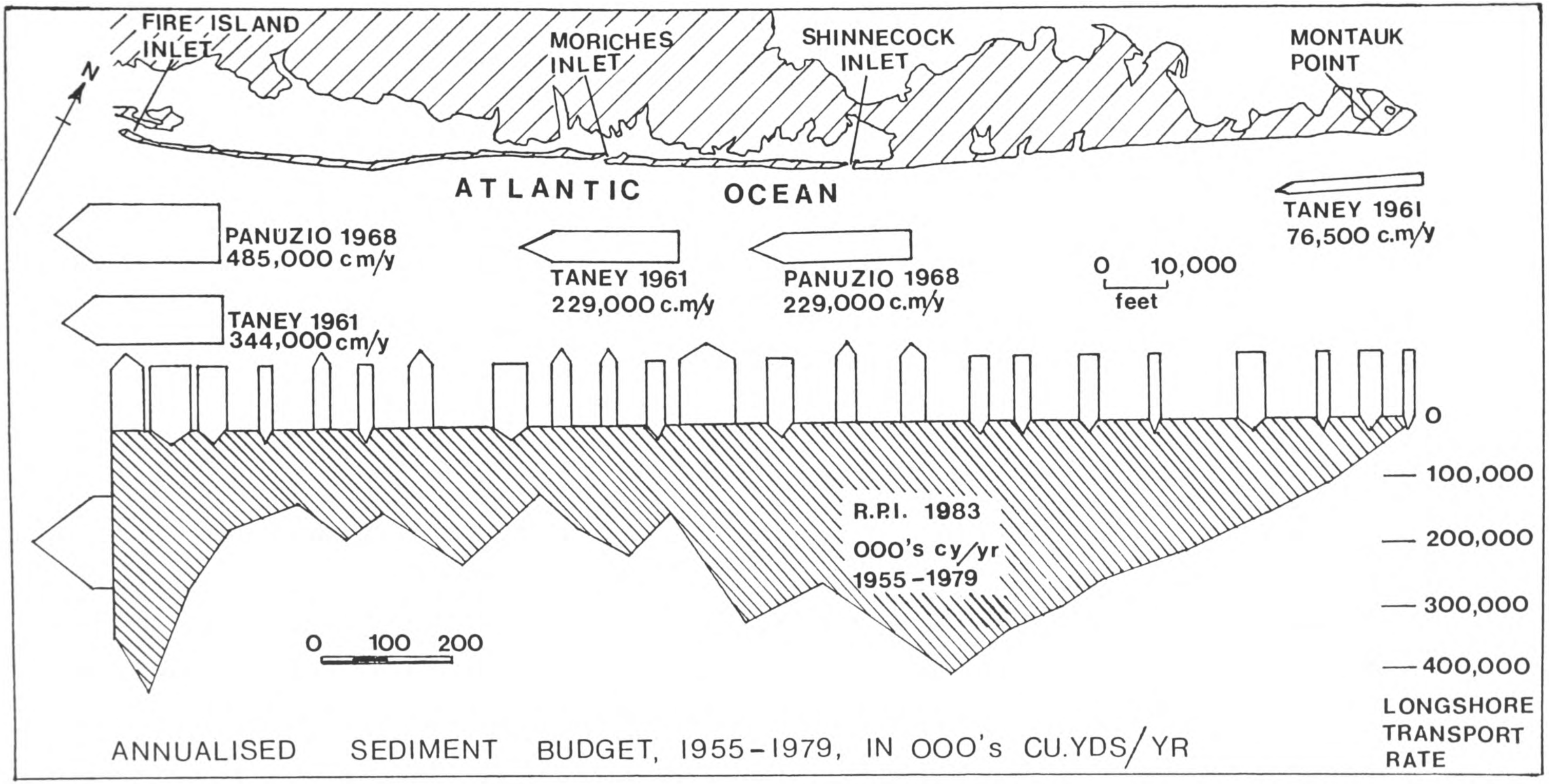


Fig 3.1. Annualized sediment budgets for Long Island's south shore. (After Taney, (1961); Panuzio, (1968); R.P.I. (1983). Figs. in cubic metres and cubic yards per year.

They may contain glacial/fluvioglacial sediments which were remnants of ancient river deltas or glacial lobes, formed at the mouth of Williams's (1976), ancient Huntington Channel (H), (Fig 2.3). Such deposits have been claimed to represent a possible offshore sediment source for central Fire Island (Leatherman, 1985b; Wolff, 1982).

(c) Equally as important is the possibility of the extent to which such sediments have been protected from the wave beveller as shorelines migrated landward during the Flandrian transgression. The nature of mechanisms which may have operated to prevent the destruction of relict grain surface textures inherited from a glacial/fluvioglacial past will be examined.

(d) Finally, mechanisms which may be responsible for transporting relict sediments onshore from the inner shelf will be outlined.

3.II LONG ISLAND SOUTH SHORE SEDIMENT BUDGETS

Taney (1961a), used two methods to compute littoral transport rates:-

(a) Periodic surveys were made of the accretion rate updrift from a substantially complete littoral barrier such as a long jetty. Surveys continued until the impoundment capacity of the jetty had fallen enough to allow an appreciable portion of drift to bypass it naturally.

(b) When a barrier structure such as a jetty was not present, the area of growth of the end of the updrift shore of an inlet was calculated on an average annual basis and multiplied by the average depth of the inlet. It was less accurate than the former method and gave no estimate of the volume of sediment bypassing the inlet in littoral drift, nor of the amounts transferred to the lagoon through inlets to form an inner shoal or bar (Taney, 1961a).

Estimates of Long Island's south shore, sediment budgets vary to a greater or lesser degree (Fig 3.1). Taney (1961a), estimated that approximately 76,500 cu.m/yr of beach-size sand was produced by erosion of Ronkonkoma terminal moraine and Montauk Till forming the bluffs unit in the Headlands section of eastern Long Island (Fig 3.1), at Montauk Point. By Moriches Inlet (Fig 3.1), longshore drift volume had increased to about 229,000 cu.m/yr; a rise of just less than 200%. Further downdrift at Fire Island Inlet (Fig 3.1), if we take Taney's (1961a), average estimate for that site, littoral drift volume had increased to 344,000 cu.m/yr, an increase of 50% on Moriches Inlet. Taney (1961a), estimated a minimum of 122,000 cu.m/yr for littoral drift at Fire Island Inlet and a maximum of 458,000 cu.m/yr.

Further west outside the study area at Rockaway Inlet (Fig 2.2), littoral drift volume was estimated at 344,000 cu.m/yr if we accept the higher of Taney's (1961a), estimates. A similar picture is presented by Panuzio (1968). By Shinnecock Inlet, further updrift east of Moriches Inlet, Panuzio (1968), estimated an increase of just under 200% to 229,000 cu.m/yr in drift volumes if we use Taney's (1961a) estimate for Montauk Point as a base (Fig 3.1). By Fire Island Inlet (Fig 3.1), Panuzio estimated a greater increase than Taney (1961a), to 485,000 cu.m/yr, falling to 306,000 cu.m/yr, further west at Rockaway Inlet (Fig 2.2).

Annual sediment budget and longshore transport rate estimates by R.P.I. (1983), are shown in Fig 3.1. The diagram shows longshore transport rates in 000's of cubic yards p.a. below the horizontal base line and fluctuations in the budget above the base line. If we change values from cu. yards/yr to cu.m/yr, R.P.I.'s estimates are generally lower than Taney (1961a), and Panuzio (1968), but allow a more detailed pattern to be analysed along the south shore.

R.P.I.'s (1983), estimates follow the same trend as Taney, (1961), and Panuzio (1968), longshore transport rates increasing to just less than 400,000 cu.y/yr (Fig 3.1), by the end of the Headlands section (Fig 2.2). Estimates decrease to just over 100,000 cu.y/yr west of Moriches Inlet and until west-central Fire Island (Fig 3.1), fluctuate without increasing or decreasing. From west-central Fire Island to Fire Island Inlet, budget deficits increase sharply as longshore transport rates rise to approximately 400,000 cu.y/yr (R.P.I., 1983). It is evident from Fig 3.1 that between Fire Island and Moriches and Shinnecock Inlets, estimated sediment budgets do not follow a smoothly increasing trend especially between Southampton in the western Headlands section (Fig 2.2), and western Fire Island (Fig 3.1).

Estimates of sediment budgets and longshore transport rates have been dealt with at some length because this project's design was developed in order to identify a possible offshore source south of Fire Island using S.E.M. analysis of quartz sand grain surface textures. Estimates of longshore transport rates (Taney, 1961a; Panuzio, 1968; R.P.I., 1983), point to the need for additional supplies of sediment from a hitherto unspecified source of about

152,000 cu.m/yr at Shinnecock Inlet (Panuzio, 1968), and 152,000 cu.m/yr at Moriches Inlet (Taney, 1961a). At Fire Island Inlet, additional supplies needed to balance the shore sediment budget vary from a minimum of 45,500 cu.m/yr (Taney, 1961a), to a maximum of 408,500 cu.m/yr (Panuzio, 1968).

3.III THE NATURE AND EXTENT OF DISTINCTIVE OFFSHORE GLACIALLY DERIVED SEDIMENTS

Johnson (1919), was one of the earliest workers to develop theoretical concepts relating continental shelves to adjacent shore systems. His (Johnson, 1919), notion of the size-graded shelf and a coarse to fine continuum of sediments across the shelf was universally accepted and incorporated in major textbooks dealing with coastal studies. However, Shephard (1932), pointed to an inherent flaw in Johnson's (1919), model when he revealed the existence of a mantle of relict Pleistocene sediments on continental shelves.

Classifications of shelf sediments have become progressively more detailed and elaborate. Emery (1968), distinguished between modern and relict shelf sediments and Swift (1969), adopted a three fold division:-

(a) A nearshore modern sand prism which included mainland beach, barrier island or spit, and a seaward thinning (and fining) wedge of nearshore sand.

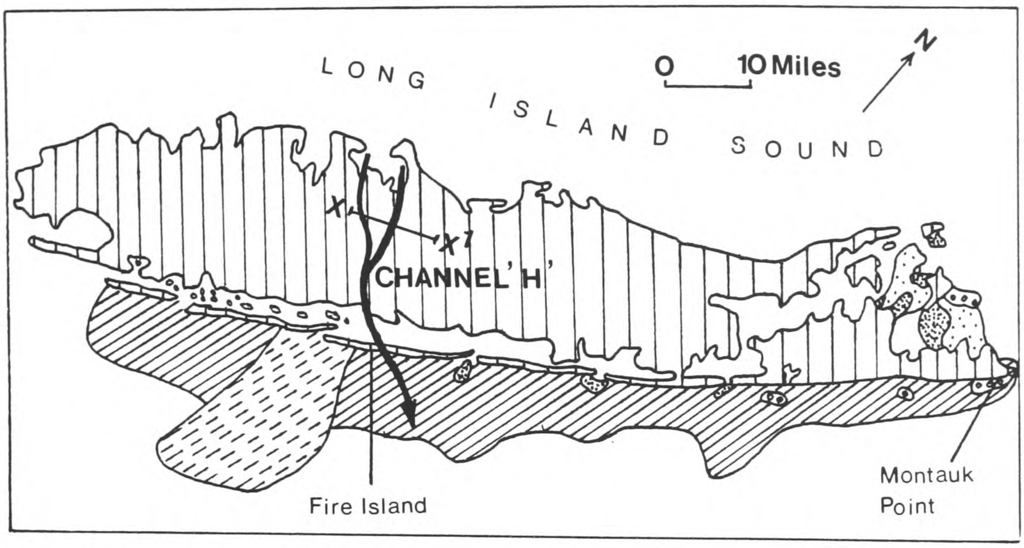
(b) A modern shelf mud blanket.

(c) A shelf relict sand blanket which was a discontinuous veneer overlying Tertiary or older bedrock.

Williams (1976), studied shore and offshore sediments comprehensively on the Atlantic inner continental shelf off Long Island. He found that Holocene sediments were difficult to identify because they closely resembled and were often derived from, underlying Pleistocene or Cretaceous strata. Holocene sediments were most abundant between Fire Island Inlet and Shinnecock Inlet (Fig 3.2), and consisted of typical back-barrier beach sequences, where modern marine sands overlay compact organic-rich muds.

The predominant sediment extending southward offshore from the study area (Fig 2.2), was a fine to medium sand (0.50mm to 0.125mm), composed mainly of quartz. Mean grain-size diameter decreased westward from Montauk Point, with a predominance of coarse sand and gravel, or pebbles (>1mm), on the shelf south of eastern Long Island (Williams, 1976). Such blanket sands appeared to be relict or palimpsest sediments winnowed and modified by modern marine processes. In western Fire Island and offshore to the south west Williams (1976), found clean, fine to coarse white quartz sand (1mm-0.125mm), and rounded pea gravel with silt sized glauconite (Fig 3.2). This was interpreted (Williams, 1976), as being derived from an admixture of outwash sand and residual detritus from marine erosion of underlying Coastal Plain glauconitic strata (possibly Monmouth Group (Fig 2.6)).

Pleistocene sediments varied considerably in thickness and lithology in the Long Island region (Williams, 1976). They were difficult to distinguish owing to the fact that they strongly resembled underlying Cretaceous strata and overlying Holocene sediments derived from them by reworking (Williams, 1976). Generally consisting of oxidised medium to coarse sand and gravel, with some



SEDIMENT FACIES

- Residual sediment from Coastal Plain outcrop (fine to medium glauconitic sand)
- Coarse sand and pea gravel (>0.50 mm)
- Fine to medium sand (0.50 to 0.125 mm)
- Very fine sand to silt (0.125 to 0.625 mm)
- Silt and Clay (<0.625 mm)

Fig. 3.2(a) Surface sediment distribution for five primary sediment facies on the Long Island Inner Shelf. (After Williams (1976)).

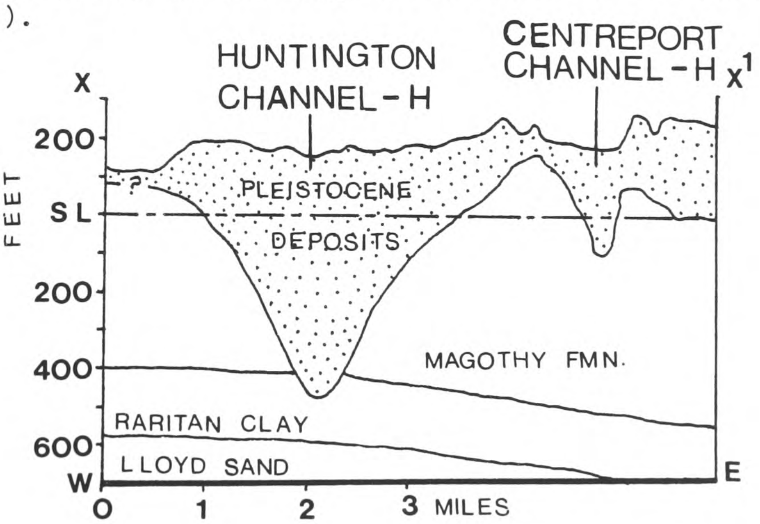


Fig 3.2(b) Sub-bottom profile of major buried channels (Huntington - Centreport) on northern Long Island. (After Williams (1976)).

degree of compaction, Pleistocene units were either flat lying or dipping gently seaward, showing some degree of stratification (Williams, 1976). They have been interpreted (Williams, 1976), as outwash plains and river deltas deposited by southward flowing melt-water streams during the Pleistocene, when sea level was depressed several hundred feet. Subsequent sea level rises caused fluvio-glacial and glacial sediments to be modified in ways which are still evident at Montauk Point in the Bluff's unit (Fig. 2.4).

Maximum thicknesses of sediment occur in buried ancestral river channels which, at least in northern Long Island, have been occupied and scoured directly by glaciers (Williams, 1976). Seismic records show that the south shore and eastern shelf of Long Island are traversed by an intricate system of such channels (Williams, 1976), which trend northwest-southeast (Fig. 2.3). The most westerly channels (A to G in Fig. 2.3), lie outside the study area and were probably eroded by meltwater streams, glacial lobe scour, ancient courses of the Hudson River, or combinations of these (Williams,1976).

The Huntington Channel (Fig. 2.3; Fig. 3.2), is one of the largest, with a maximum width of 3.3 miles and a thalweg extending to a depth of -475 feet MSL. (Williams 1976). The smaller Centre-port channel (Fig. 3.2), was a minimum of 1.5 miles wide and extended to -100 feet MSL. Both channels converged to form a single major channel extending 10 miles offshore south of central Fire Island (Williams, 1976).

Eastern Long Island was traversed by two channels (J and K in Fig. 2.3), which bifurcate southward into seven smaller distributary channels, breaching Long Island's south fork and continuing offshore

(Williams, 1976).

The origins of Channels H and I are speculative (Williams, 1976), but may be related to ancestral Housatonic and Quinnipiac rivers in central Connecticut (Grim et al, 1970), to the north. The large gap in eastern Long Island between Channel I and Channels J and K (Fig. 2.3), has been related to the existence of deep east-west channels in southern Long Island Sound (-800 feet MSL), which may have intercepted southward flowing pre-Pleistocene streams, diverting discharge eastwards toward Block Island Sound (Fig. 2.2). This channel and the ancient Connecticut river may explain the courses of Channels J (Three Mile), and K (Orient Point), in eastern Long Island (Williams, 1976).

It is the distinctiveness of Pleistocene sediments in Channel H (Huntington-Centreport Channel in Fig. 2.3 and Fig. 3.2), that is important as far as the present study is concerned. This is where the greatest volume of Pleistocene sediments is preserved (Williams, 1976), offshore south of Fire Island. The nature of such buried channel deposits was largely unknown (Williams, 1976), but core evidence of the Orient Point Channel (Channel K in Fig. 2.3), showed three sediment groupings. The top 41 feet consisted of poorly sorted sandy gravel with a yellowish tan, which Williams (1976), interpreted as either outwash detritus from the Harbour Hill moraine (Fig. 2.2), or actual parent moraine. Below this unit, a downward fining, micaceous silty sand extends to -146 feet MSL, thereafter giving way to glacial lake varved sediments underlain by largely unknown sediments.

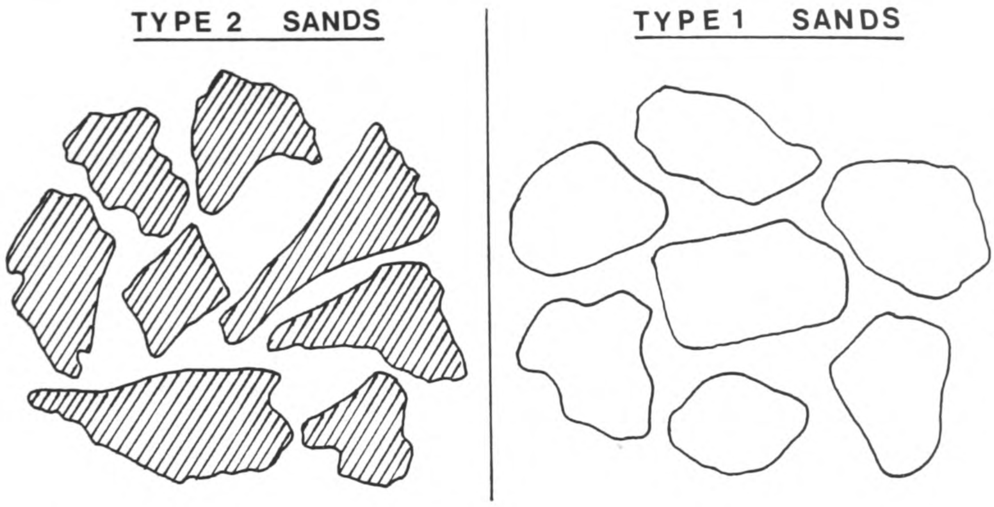
Wolff (1982), referred specifically to the emergent Pleistocene outwash lobes filling pre-glacial (pre-Wisconsin), channels cut into underlying Cretaceous sediments. He (Wolff, 1982), interpreted the present offshore 'ridge and swale' topography as modified products of the lobes which provided an offshore source (Fig 2.3) Wolff (1982), used a mainland slope of 5 m/Km to postulate a former lobe offshore extent of 10 to 12 Km during sea level minimum. Near-shore bathymetry revealed a series of oblique linear sand bars described by Swift (1972), as a dynamic 'ridge and swale' topography (Fig 2.3). In fact they are located offshore between Long Beach and Western Fire Island at depths of 10m to 15m, and with spacings of 2 Km to 3 Km and heights of 5m to 8m (Swift, 1972). Wolff (1982), refers to Williams' (1976), Huntington - Centreport Channel (H) as the Huntington-Islip Channel and Williams' (1976), Channel I as the Smithtown-Brookhaven Channel (Fig 2.3).

Riester et al (1982), used Fourier analysis of quartz grain shapes to determine how much of a record of shelf sedimentation history remained after the passage of a major transgressive event such as the Flandrian transgression in the last 10,000 to 12,000 years.

Analyses revealed the presence of two major sand types:-

Type 1 - These were more abraded mature grains showing a greater degree of rounding (Fig 3.3). Riester et al (1982), interpreted TYPE 1 sand as having been subjected to several cycles of abrasion when they were involved in the beach/dune environment during two or more transgressive/regressive cycles in the Pleistocene.

Type 2 - These grains were more angular and less abraded (Fig 3.3). They may have had high percentages of first generation



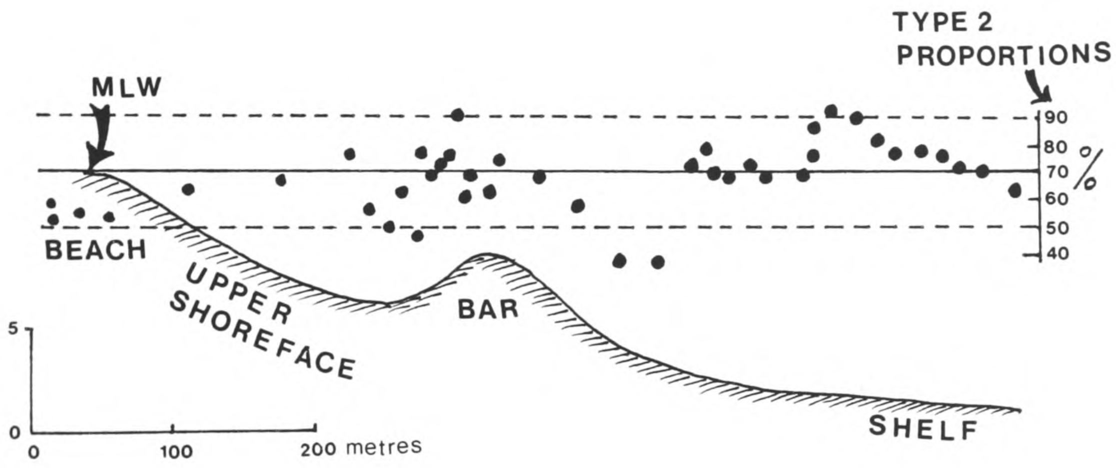


Fig. 3.3. Distribution of immature 'Type 2' sands of glacial origin on Long Island's inner shelf (After Riester et al (1982)).

sands originating from metamorphic and igneous rocks and in this way may resemble fluvial and glacial sands (Riester et al, 1982).

On the basis of these two end members Riester et al (1982), distinguished three zones on the Long Island Shelf.

(a) Nearshore Zone - from the beach to a depth of -10m to -15m MSL, which includes the nearshore bar (Fig 3.3), there were higher percentages of Type 1 (abraded) sands, Type 2 (irregular) sands averaging about 55%. However, proportions did not follow a constant trend and samples varied from 35% to 90% Type 2 (irregular) sand content. The bar crest samples had very high Type 2 (irregular) sand proportions (70% to 90%), and a second peak in Type 2 sand proportions occurred about 80m seaward of the bar crest (Fig 3.3).

(b) Inner Shelf Zone - from -10m to -15m MSL out to depths of -40m MSL to -50m MSL, proportions of Type 2 (irregular) sand averaged 15%.

Riester et al (1982), also took samples of the glacial substrata from Long Island sand and gravel quarries and boreholes and found that they had 70% or more Type 2 (irregular) sand. They contrasted strongly with the higher percentages of abraded Type 1 sand found on beaches. Bottom observations showed that at water depths of -10m MSL to - 16m MSL throughout the area, patches of coarse sand and abundant granules and pebbles occurred (Riester et al, 1982). Unlike the grey-brown, fine to medium blanket sands described by Williams (1976), such patches were yellow-tan and may represent a Pleistocene fluvioglacial deposit, only thinly veneered by Recent sands which may be exposed during the passage of storms (Riester et al, 1982).

From descriptions of nearshore and offshore sands presented above, it is reasonable to argue that distinctive beach-size sediments with inherited glacially, or fluvioglacially modified textures are preserved offshore. Williams (1976), has drawn attention to the existence of a large volume of outwash detritus or parent moraine in buried palaeodraingage channels (Fig. 2.3). The largest of these is the Huntington-Centreport Channel (H) south of central Fire Island (Fig. 3.2). Wolff (1982), referring to Channel H as the Huntington-Islip lobe, traced it offshore from the mainland for 10Km to 12Km, and related it to the 'ridge and swale' topography (Fig. 3.2) located immediately to the west. Riester et al (1982), reported a sharp boundary on the Long Island shelf at approximately -40 MSL to -50 MSL, which divided an inner zone with an average of 15% Type 2 (irregular) sand from the outer zone. Throughout the shelf area landward of this boundary, in depths of -10m MSL to -16m MSL, patches of coarse, gravelly sand could be found representing a mosaic of Pleistocene palimpsest sediments exposed during storms.

.IV POSSIBLE MECHANISMS RESPONSIBLE FOR THE PRESERVATION OF OFFSHORE PLEISTOCENE SEDIMENTS

A detailed analysis of the nature and origin of barrier islands would not be appropriate, nor entirely relevant to the present study. However, barrier island behaviour on Long Island shelf during the Flandrian transgression, the effects such behaviour had upon pre-existing Pleistocene shelf deposits and the impact of Holocene history on modern processes is of considerable importance. The following description outlines briefly various models for barrier migration and discusses ways in which palimpsest sediments may have been preserved offshore.

Three major theories which have been advanced in order to account for the initial formation of barriers are:-

(a) The upward growth of marine bars.

(b) Segmentation of long coastwide-prograding spits by tidal inlets.

(c) Submergence of coastal beach ridges by a rising sea.

Fig 3.4 illustrates the main features of these three theories. Perhaps Johnson (1919), was the first worker to produce serious comprehensive studies of continental shelves. He accepted the hypothesis of submarine bar upgrowth first proposed by de Beaumont (1845). Four processes were outlined for barrier island formation on emergent shorelines:-

(a) Large waves break out at sea.

(b) Smaller waves reach the land and erode the coast. Landward erosion proceeds by the action of smaller waves and a wave cut terrace forms.

(c) Large waves continue to erode and a wave cut terrace migrates landward.

(d) When large waves reach the small wave cut terrace, some of the eroded material is carried out to sea and a proportion is thrown upward onto the terrace forming a bar.

These processes coincided with Johnson's (1919), concept of equilibrium, whereby shelf slope was adjusted to the rates of

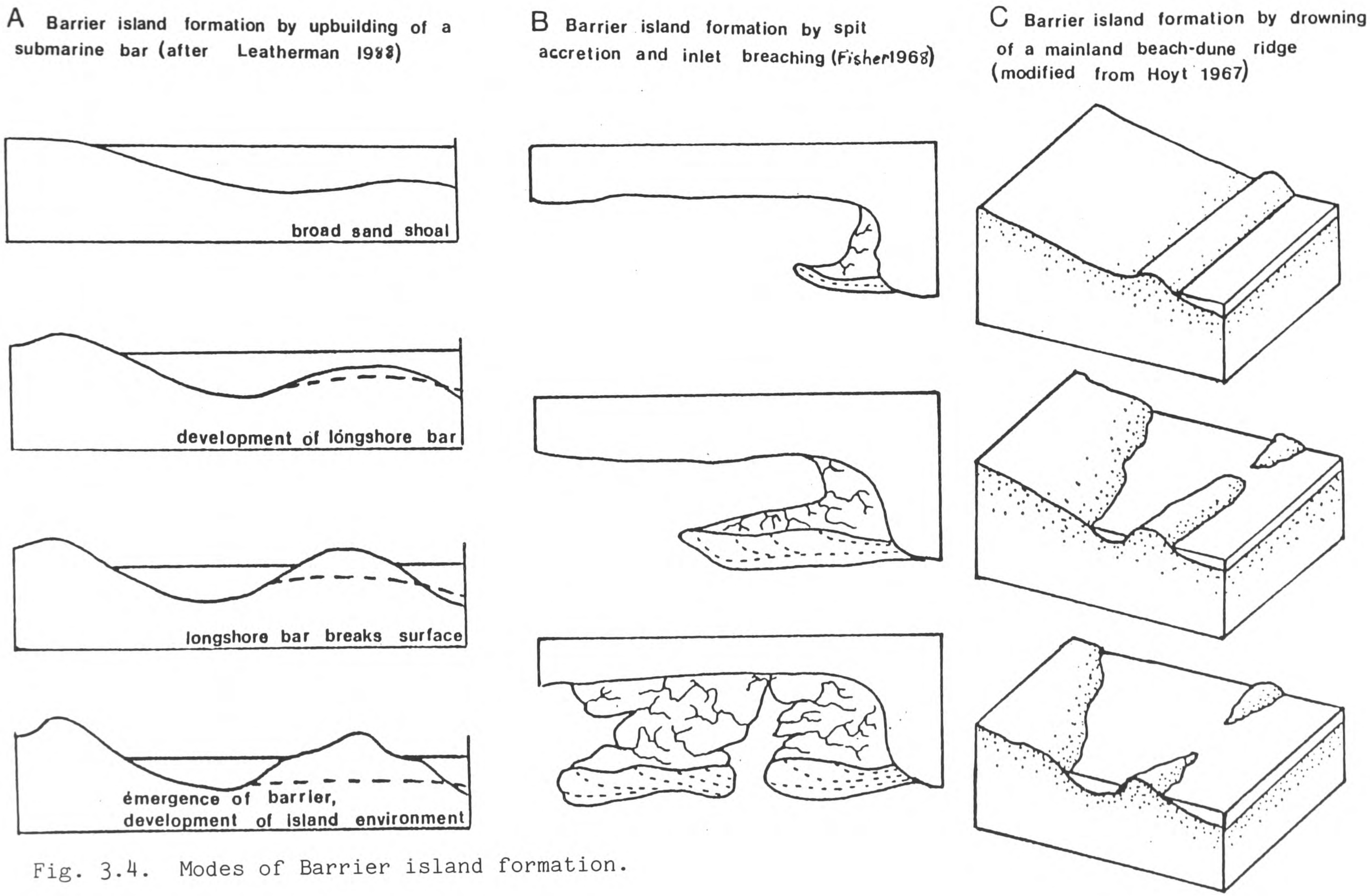


Fig. 3.4. Modes of Barrier island formation.

erosion of his inner wave-cut platform and outer wave-built terrace. Shelf slope would be precisely the steepness required to allow wave energy amounts developed there to dispose of the volume and grade of debris in transit.

Gilbert (1885), investigated longshore drift as a barrier island forming process. He suggested that the resultant spit may be breached later by tidal inlets. Fisher (1968), proposed spit accretion and inlet breaching as mechanisms which could be responsible for northern U.S.A. barriers.

Submergence of a coastal ridge by a rising sea level, which led to the formation of a barrier island was favoured by Hoyt (1967), and substantiated by field evidence (Pierce and Colquhoun, 1970; Schwartz, 1975), indicating that modern barriers could have been formed by each of the above mechanisms either in isolation, or in combination.

A major problem has been the nature of barier behaviour during coastal retreat and marine transgression. Arguments have arisen as to the precise nature of barrier migration mechanisms with continuous submergence, wave bevelling and longshore drift (Swift, 1975). Panageotou et al (1985), stated that the origin of south shore barriers on Long Island was still largely unknown. There are two main theories regarding barrier migration and shoreline retreat during the post-glacial marine transgression on the continental shelf south of Long Island.

(a) Continuous migration.

(b) In-place drowning and stepwise shoreface retreat.

Leatherman and Allen and co-workers (1985), have comprehensively examined the problem of Long Island south shore barrier behaviour over the past 500 years. Their report (Leatherman and Allen, 1985), outlined six characteristics of barrier island behaviour and their relevance to barriers from Fire Island Inlet to Montauk Point.

(i) Transgressive Barrier Behaviour - Panageotou et al (1985), have defined such behaviour as when the barrier island centroid moved landward. Continuously transgressive migration involved time-averaged movement of a barrier centroid over hundreds or thousands of years, interruptions to migration being limited to less than a few centuries. Such behaviour typified an overwash dominated barrier which was not wholly applicable to south shore barriers (Leatherman and Allen, 1985).

Punctuated transgressive migration is similar to continuous migration, but composed of long stable periods interrupted by sudden changes in response to inlet formation (Leatherman and Allen, 1985). Such behaviour has characterized the eastern south shore barrier islands for the past few thousand years. During storms, low thin barrier island sections have been breached, forming a new inlet (Fig 3.5). Sediments moving onshore, or alongshore are directed into shallow backbarrier lagoons forming flood-tidal deltas. Some sediment returns seaward to form ebb-tidal deltas, but net movement is toward the lagoon (Fig 3.5). Near inlets, island recurves and flood-tidal deltas provide basal sediments and platforms over which the barrier island can migrate. The presence of several inlets closing up at the same time as new ones form will dominate barrier deposits as old inlet fill (Leatherman and Allen, 1985).

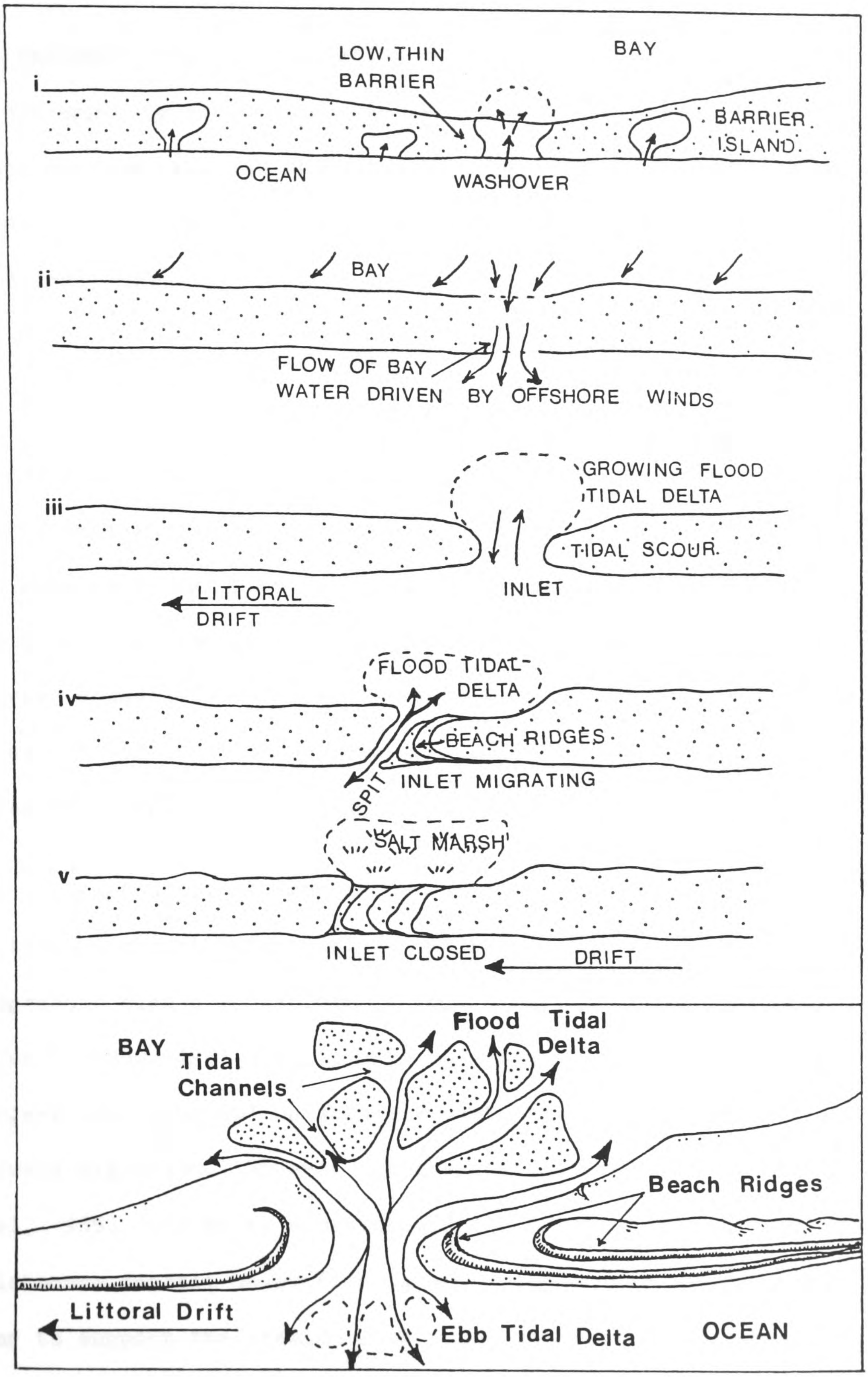


Fig. 3.5. Inlet dynamics and sequential stages in the development of a large flood tidal delta (After Leatherman (1988)).

(ii) Regressive Barrier Behaviour - This was defined (Panageotou et al, 1985), as where barrier islands experience seaward accretion over time scales of hundreds to thousands of years, when there may be a sediment surplus or relative sea level fall. Such behaviour did not apply to south shore barrier islands on a large scale, unless the special case of spit extension occurred, where seaward accretion is a necessary component of alongshore growth (Leatherman and Allen, 1985).

(iii) Erosional Barrier Behaviour - This is a condition whereby both oceanside and bayside beaches recede on either side of a stable island axis. Despite the masking effects of human activities and interference in the natural coastal system, it is probable that no long term erosional trends have been witnessed over the centuries. Localised site-specific erosional behaviour over shorter periods has occurred downdrift of inlets where longshore drift has been diverted, as well as updrift of a prograding spit where localised shortfalls in sediment supply relationships occurred.

(iv) Constructional Barrier Behaviour - This involves the superposition of recent sediments upon a pre-existing (pre-Holocene), topographic high over periods of 1000's of years. Rampino and Sanders, (1980, 1981, 1982), have suggested that present south-shore barriers are 'hung up' on such a Pleistocene 'high', which prevents landward migration. However, geophysical investigation (Panageotou et al, 1985), failed to substantiate the presence of a sub-surface Pleistocene deposit below Fire Island, neither was solid evidence found to support the premise that south shore barriers exhibited constructional behaviour. As sea level rises, barriers will migrate landward and any short term constructional storage will only be temporary (Leatherman and Allen, 1985).

(v) Oscillatory Stasis - In this case, shorelines move both seaward (accretion), and landward (recession), over decades or centuries. Such a condition has been observed along south shore barriers but may have been a feature of the shoreline rather than the entire barrier centroid location (Leatherman and Allen, 1985), and may have been partly produced, at least, by beach and dune nourishment projects.

(vi) In Situ Drowning - As sea level rises, the barrier remains as a stable island with receding shorelines, the rate of sea level rise exceeding the rate of upward growth of the island. Eventually however, in order to maintain a shoreface profile of equilibrium the growing island must extend itself into deeper water and migrate landwards (Leatherman, 1983b).

Rampino and Sanders (1980, 1981, 1982), favoured a model of in situ drowning followed by barrier overstepping, causing the surf zone to 'skip' landwards if sea level rise was rapid and sand supply low. They maintained (Rampino and Sanders, 1980, 1981, 1982), that such conditions were met 7,000 years ago when an ancestral Fire Island (-16m MSL) was drowned and the surf zone 'skipped' 5Km landward. Leatherman and Allen (1985), suggested that all the evidence pointed toward continuous, if intermittent, landward migration from a position 2Km offshore over the last 7,000 years. However, if sea level continued to rise, Fire Island may theoretically drown 'in situ' if coastal engineering projects interfere with the natural processes of inlet dynamics and overwash associated with the narrowing trend of western Fire Island and its transgression (Leatherman and Allen, 1985).

It is worthwhile examining the models of south shore behavioural patterns in a little greater depth at this point, especially Fire Island, because they may be linked to sediment supply sources offshore to the south. On the basis of estimated shoreline changes between the 1870's and 1979, Fire Island has been divided into three sections by Crowell and Leatherman (1985).

The western section suffered both oceanshore and bayshore erosion of (a maximum) 245 metres and 61 metres respectively. The eastern section was characterized by net erosion of the ocean shore and a mixed picture of westerly bayshore erosion and easterly bay-shore accretion. The central section seemed to be more stable, with only moderate bayshore erosion (Crowell and Leatherman, 1985).

In fact, marked east-west differences have been reported on Fire Island, hinged about a central oceanward bulge (Leatherman, 1985b). Western Fire Island appears to be migrating landward only very slowly and sporadically at inlet sites, but is also becoming narrower as a result of shoreface and bayshore erosion during the last 1,000 years (Leatherman, 1985b). The more rapid landward migration of eastern Long Island may be a result of its locational setting which takes the brunt of strong easterly winds circulating anticlockwise around storms (Leatherman, 1985b). In fact, Leatherman (1985b), implied a link between the more stable oceanward bulge in central Fire Island and the offshore lobes of glacial sediments preserved in buried channels to the south (Fig 2.3).

In order to conclude this section on barrier behaviour on Long Island's south shore, it is appropriate to examine the conflicting opinions which surround the two opposing schools of thought, viz:- the 'In Place Drowning Hypothesis', and 'Continuous Shoreface Retreat Hypothesis'.

Supporters of the 'In Place Drowning Hypothesis' have argued that an ancestral barrier island existed 7Km offshore to the south, when sea level was -24m MSL, parallel to the present system (Sanders and Kumar, 1975). Fellow supporters (Rampino, 1978; Rampino and Sanders, 1980, 1981, 1982), argued further that about 7,500 years B.P., as a result of a rapid sea level rise, the ancestral barrier drowned in situ and the shoreline 'skipped' 5Km landward in the following 1,500 to 2,500 years, to form a new chain 2Km seaward of the present shoreline. Rampino (1978), suggested that this new location was controlled by the presence of a (mid-Wisconsin), Pleistocene barrier ridge. Such a superconstructed barrier has migrated continuously landward to its present position forming Long Island's south shore in the last 6,000 years.

Sanders and Kumar (1975), based their hypotheses on interpretations of cores taken at -21m to -24m MSL on the shelf parallel to Fire Island and at -25m to -27m MSL. The former revealed relict backbarrier deposits and the latter relict shoreface deposits (Sanders and Kumar, 1975). Backbarrier sediments with a typical transgressive sequence of lagoonal silty clays and marsh sediments overlying upper Pleistocene deposits were recovered from vibracores at depths of -5m to -23m MSL (Rampino, 1978; Rampino and Sanders, 1980, 1981).

The 'raison d'etre' for the 'In Place Drowning Hypothesis' is based on the two planks of the preservation of relict backbarrier deposits dated at 8,500 to 9,000 years B.P. in depths of -25m to -27m MSL, and the absence of tidal, inlet filled channels in the zone 2Km to 7Km offshore (Sanders and Kumar, 1975; Rampino and Sanders, 1980, 1981, 1982, 1983).

It was postulated that in order for such relict backbarrier sediments to be preserved they must have escaped surf erosion and excavation. This would be possible only if 'in place drowning' occurred followed by barrier overtopping and surf zone skipping from 7Km to 2Km out. In addition, this zone would then contain the preserved transgressive sequences discovered by Rampino (1978). If a continuous shoreline migration had occurred, backbarrier sediments would have suffered complete, or near complete destruction and reworking (Rampino and Sanders, 1981, 1982).

However, continuous shoreline retreat may allow tidal inlet filled channels to be preserved because they are often deposited at depths below the wave beveller (Hoyt and Henry, 1967). Absence of such inlet sands from the inner shelf would suggest that continuous shoreline retreat did not occur assuming that inlets migrate at a constant rate , (Hoyt and Henry, 1967). Conversely, the existence of linear bands or ribbons of inlet sands on the inner shelf would imply a standstill of the ancient shoreline and would have marked the positions of in place drowning (Kumar and Sanders, 1974). Of crucial importance to the arguments is the exact nature of sediments preserved on the inner shelf. Williams (1976), stated that barrier spit complexes existed offshore in the past and had migrated landwards as sea level rose. Williams (1976), based his evidence upon core samples which displayed preserved compact, organic rich muds below Holocene backbarrier-beach sediment sequences with modern marine sands.

The complex geological history of Long Island's south shore inner shelf has been revealed by the presence of a seaward sloping wedge of Holocene backbarrier silts, clays and peat underlying modern marine sands thinning seaward and eastward from central Fire Island to Moriches Inlet (Fig 2.4) (Williams, 1976). Holocene sediments were resting unconformably upon a flat, or low angle seaward dipping erosion surface cut in Pleistocene sediments (Williams, 1976). Further east, Pleistocene sediments occurred at or near the surface (Panageotou et al, 1985).

Other workers have strongly criticised the 'In Place Drowning Hypothesis' and have attempted to explain sedimentological, stratigraphic and geophysical evidence in terms of a model of continuously migrating shoreline behaviour (Williams, 1976; Swift and Moslow , 1982; Leatherman and Williams, 1982; Leatherman and Allen, 1985). Post Pleistocene sea level rise would provoke a barrier response which maintained a dynamic equilibrium between the rate of rise and the rate of sediment supply. This would involve either a continuous, or discontinuous shoreface retreat during the Holocene transgression rather than stepwise retreat (Swift and Moslow, 1982).

Panageotou et al (1985), reanalysed the original seismic profiles used by Sanders and Kumar (1975), Rampino (1978), and Rampino and Sanders (1980, 1981, 1982, 1983), and found no evidence for the inferred drowned barrier island. What Rampino and Sanders (1981), recognised as an emergent mid-Wisconsin barrier 2Km south of the present shore, on which the new barrier was 'hung up' and superconstructed (after the shoreline skipped 5Km 7,500 years ago), Panageotou et al (1985),have interpreted as a topographic high in the form of a linear shoal and adjacent swale.

National Ocean Survey Bathymetric charts showed many N.W. - S.E. trending finger shoals south of Fire Island, making up a 'ridge and swale' topography as defined by the -60, -90 and -120 feet MSL contours discussed by Williams (1976) and shown in Fig. 2.5. Rampino and Sanders (1981), referred to remnants of such a mid-Wisconsin barrier as the sandy facies of the Wantaugh Formation lying below the present Jones Beach (Fig. 2.7), but it would be unlikely that such a barrier, lying between a 9,500 year B.P. shoreline 7Km to the south and a rapidly deglaciating landscape behind, would survive the attack from glacial front meltwater (Panageotou et al, 1985). Such linear shoals may represent detached remnants of former barrier systems, preserved as landward transgression proceeded (Panageotou et al, 1985).

Many inlet filled channels have been found at various depths (-12m MSL to -20m MSL), on the inner shelf south of Fire Island 1 to 5Km out (Leatherman, 1983a). These suggested a continuous shoreline retreat from the ancient 7Km (-25m MSL to -27m MSL) shoreline to the 2Km shoreline at 7,500 years B.P. rather than barrier overstepping and 'surf skipping' (Leatherman, 1983b).

The preservation of backbarrier sediments may not need 'in place drowning' and 'surf skipping' as mechanisms to ensure their existence (Leatherman, 1983b). During a long term eustatic sea level tillstands may have occurred (Swift, 1975). If there was an adequate sand supply an equilibrium response would allow a stable barrier upper shoreface to prograde, building up the barrier (Leatherman, 1983b). With each unit rise in sea level the wave beveller rides upward rather than landward, reducing the rate of barrier retreat (Leatherman, 1983b). This would clearly allow the preservation of a large convex lens of backbarrier sediments at that position on the inner shelf (Leatherman and Allen, 1985). A diminution in sand supply, or an increase in the rate of sea level rise would reestablish normal continuous shoreface retreat. The barrier has retreated more or less continuously in the long term from the -30m MSL shore , 7Km to the south to the present shore (Panageotou et al, 1985).

3.V ONSHORE SEDIMENT TRANSPORT

"For most of the coast on the globe, data about quantities of sand input , output and transport are incomplete and the relative contributions of longshore and shore-normal transport beach morphology are unknown for many beaches" (Allen, 1988, p.148). It is not the aim of this project to attempt to explain the nature of possible onshore sediment-transporting mechanisms in detail, but an examination of past and current thinking on this problem is appropriate at this point.

Many workers have provided convincing evidence for the importance of onshore sediment transport in supplying sand to coasts (McMaster, 1954; Shepard, 1963; Guilcher, 1963; Swift, 1969; Pizzuto, 1985; Williams and Meisburger, 1987). However, universal acceptance of its existence has often faltered on the stumbling block presented by the 'Bruun Rule' (Williams and Meisburger, 1987).

Per Bruun (1962), tried to relate past and modern sea level rise to erosion with special reference to the Florida coast. In order for an equilibrium profile to be maintained during a marine transgression and concomitant sea level rise, the volume of sand eroded from a mainland beach would have to equal the volume of sand deposited on the inner shelf (Bruun, 1962). As long as an adequate supply of sand was available, each vertical unit rise in sea level would be compensated by an equal unit increase in the thickness of sediment on the shelf bottom.

Bruun (1962), was following in the footsteps of workers who hail back to the days of classical Victorian geomorphologists such as Penck, Davis and D.L. Johnson. In the absence of advanced technology and computer data processing techniques, which are the hallmarks of modern research, their philosophic stances and inductive theoretical methodology produced subjective, qualitative solutions to the problems they studied. They placed great emphasis upon a geochronological approach, devising neat conceptual solutions to grand problems, but produced few illustrations and no corroborative equations (Swift and Palmer, 1978).

Bruun (1962), assumed the shoreline to be in longshore quantitative equilibrium so that the same quantity of material being delivered from the updrift side was also lost on the downdrift side. This in turn assumed that the only source of sediment needed to reestablish offshore bottom profiles was erosion of the shore and its corresponding landward displacement. Bruun (1962, p.49) stated, "The material needed to raise the bottom is assumed to come from the corresponding shore area by movement of material by transversal (rip) currents and by diffusion currents". His assumption of the existence of, or need for, an equilibrium condition was never explained and Bruun (1962), gave few details regarding the nature of the nearshore sediment-transporting mechanisms involved.

Pizzuto (1985), has criticised the Bruun rule and called for a more realistic approach whereby models and general rules should be verified and modified in the light of site specific criteria. The 'Bruun rule' did not allow for offshore exposures of coarse and fine sediment mixtures, nor did an assumption of longshore quantitative equilibrium apply in all cases, since longshore transport rates varied along coasts (Pizzuto, 1985).

Sediment budget estimates show a complex picture (Fig 3.1), along Long Island's south shore and Bruun (1983), has admitted that some of his earlier assumptions needed to be qualified in the light of new research. In fact, the necessity of balancing south shore budgets has led several workers to call the Bruun rule into question to allow for an offshore source (Leatherman, 1985b; Panageotou et al, 1985; Williams and Meisburger, 1987).

Actual onshore transport mechanisms have not been identified with any certainty. Lavelle et al (1978), used radio-isotope tracers and bottom current meters to study sand transport in depths of -20m MSL to -22m MSL south of Long Island. Their results pointed to a contrast between eastward sediment transport during fair weather conditions which was more frequent but less intense than westward shore parallel transport during less frequent high energy extra-tropical storms (Lavelle et al, 1978). The ridge and swale system south of Fire Island (Fig 2.3), may influence sediment movement, possibly along troughs which were aligned in a west-north west to east-southeasterly direction (Lavelle et al, 1978).

Pizzuto (1985), admitted that onshore sediment transporting mechanisms which he claimed were nourishing beaches in southwest Delaware Bay were unclear. He suggested that residual onshore shear stress associated with second order Stokes waves alone, and the existence of the combined stresses of assymetrical Stokes waves generated by frequent northeasterly winds and dominant ebb tidal currents, may be involved (Pizzuto, 1985).

Allen (1988), reviewed some of the problems and possibilities of nearshore sediment transport, in which he grouped approaches to this problem into two schools.

(i) The development of bulk transport models that evaluate total amounts of sediment flux in a surf zone, based on either wave power, or momentum transfer.

(ii) Instantaneous estimates of dispersal by a bottom shear-stress model that evaluates the fluid force balance at a specific site in a surf zone.

Wave induced water motions are the principal cause of near-shore sediment transport, although tidal and other influences may be substantial (Kumar, 1976). In simple terms, waves may stir sand into suspension and longshore currents may move sediment in a particular direction (Fig. 3.6 A). Sediment flux associated with the direct displacement of sand by the orbital motion of waves incident on a beach, in addition to superimposed currents would be more probable (Fig. 3.6 B , Allen, 1988).

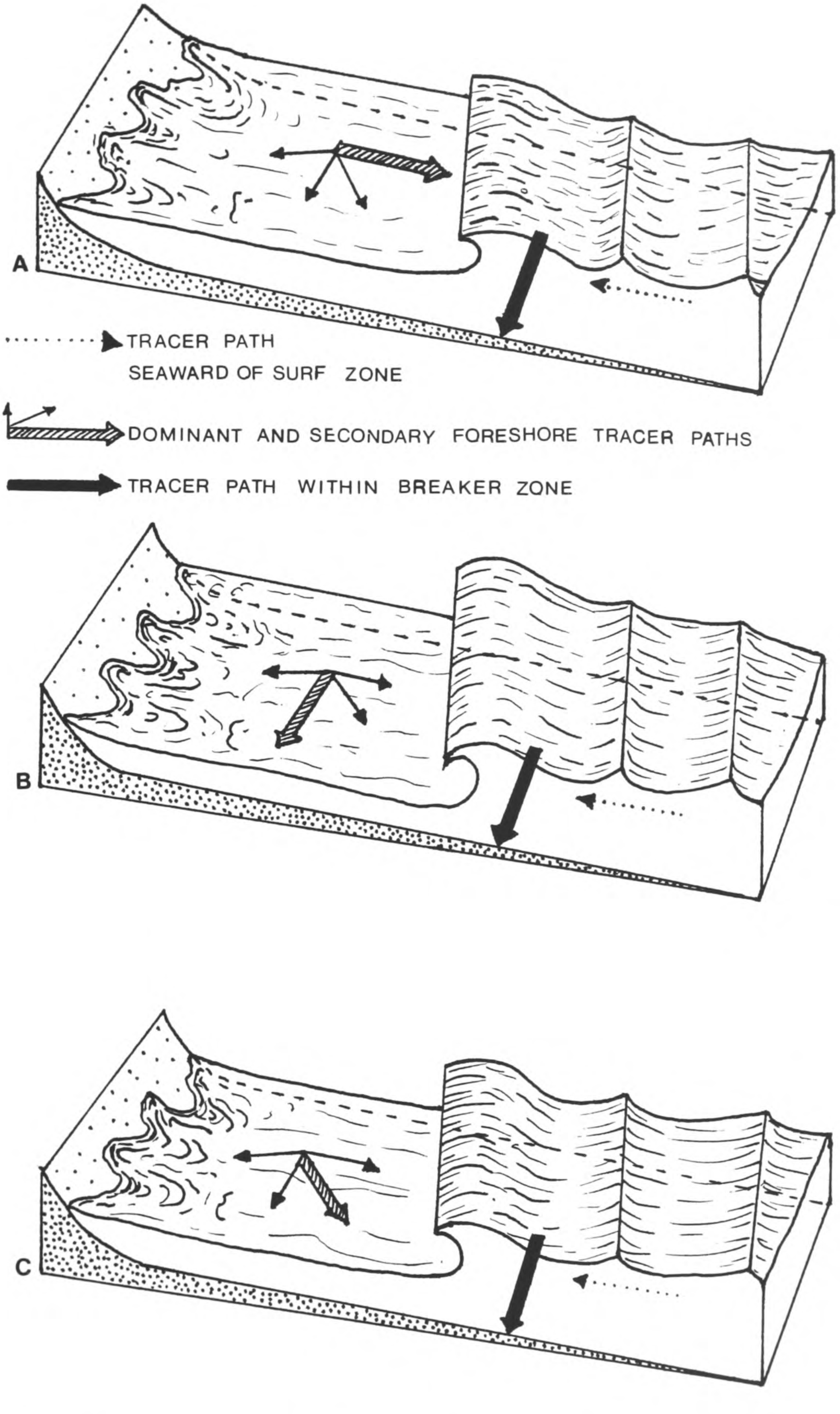


Fig. 3.6 Generalised sediment dispersion at inshore, breaker and offshore locations: A - wave-forcing dominant; B - longshore current-forcing dominant; C - forcing equal for wave and longshore currents (After Allen (1988), adapted from Ingle (1966)).

The null point hypothesis of Cornaglia (1888), which distinguished between gravity (offshore), movement forces and wave (onshore), movement forces has not been substantiated by laboratory testing (Allen, 1988), and an empirically substantiated theory has been elusive. As far as onshore sediment transport was concerned Bailard and Inman (1981), and Richmond and Sallenger (1984), found that different sized sediments moved in opposite directions, coarse materials moving landward because of larger orbital velocities under wave crests, while fine grains moved offshore.

A transport-direction mechanism based upon sediment size as an underlying control has also been favoured by Pizzuto (1985). He suggested that shore normal movements in southwest Delaware Bay varied with offshore exposures of coarse and fine sizes. His findings are directly related to the question of onshore sediment transfer in the study area (Fig 2.2), in that Pizzuto's (1985), coarse sized grains were derived from Pre-Holocene Columbia formations sub-cropping offshore, which he claimed were nourishing small onshore washover barriers. Could the distribution of coarse glacial, or fluvioglacial sediments preserved in buried lobes such as Channel H (Fig 2.3), offshore represent a site-specific control of onshore transport south of Long Island?

In a study of mid-Atlantic Bight barriers, Swift (1969), claimed that seaward diversions of longshore drift by cuspate capes or other discontinuities, necessitated appreciable onshore movements in order to balance the onshore sediment budget. Pierce (1968), estimated that approximately one third of sediment supplies must be derived from offshore as far as Cape Hatteras coast beaches are concerned. McCormick and Toscano (1981), supported the theory of continuous, onshore barrier migration and the preservation of a lens of backbarrier shelf sediments by citing the necessity for onshore sediment supplies. During temporary upward barrier building, upper shoreface progradation would demand a sufficient input of sand from eroding offshore fluvioglacial material with specific reference to Long Island's south shore barriers (McCormick and Toscano, 1981).

Leatherman (1985b), has worked extensively in the Fire Island region (Fig 2.2), and has found contrasting barrier island behaviour on Fire Island, east and west of a central southward bulging hinge point which may be, "correlated with a lobe of sediment formed at the mouth of the ancient Huntington Channel" (Leatherman, 1985b, p.181). Although not aware of the precise mechanisms, Leatherman (1985b, p.181), stated that, "the shelf sediment lobe is speculated to contribute sediment to the bulging section of Fire Island, because of the large increase in longshore sediment transport westward along the barrier chains."

Finally, in a follow up study to work on the geomorphology and shallow sub-bottom structures of the Atlantic inner continental shelf, Williams and Meisburger (1987), used glauconite-rich sediments as a natural tracer to establish the existence of onshore sediment transport. Marine Monmouth sediments of Cretaceous-early Tertiary age sub-cropping on the continental shelf south of Fire Island(Fig 2.2; Fig 2.6; Fig 2.7), could be identified by their glauconite rich sands which had been traced onshore (Williams and Meisburger, 1987). Clearly, sediments may be seen to be moving onshore in the study area and these may explain the imbalance in estimates of annualized, onshore sediment budgets (Fig. 3.1).

3.IV SUMMARY

Discrepancies have been found to occur in annualized sediment budgets on Long Island's south shore (Fig. 3.1), which demand the existence of an additional source to balance the deficit in sand sized material being supplied at Montauk Point (Taney, 1961a; Leatherman and Allen, 1985). The existence of suitable materials on the shelf south of Long Island has been established (Williams, 1976; Reister et al, 1982; Leatherman and Allen, 1985a), in the form of fluvioglacial sediments preserved as lobes in buried palaeo-drainage channels (Fig. 2.3).

Palimpsest sediments such as those preserved on the shelf in Channel H (Fig. 2.3), may not be destroyed by reworking in the surf zone during onshore barrier migration and Holocene marine transgression (Leatherman, 1985b). Increasing attention has been devoted to the possible nature of onshore sediment-transporting mechanisms (Allen, 1988), and several workers have called for the need to recognise their existence (Williams and Meisburger, 1987).

Leatherman (1985b), has related the unusual east-west differences in behaviour of the Fire Island barrier to a lobe of glacial-fluvioglacial deposits to the south. Williams and Meisburger (1987), have positively linked offshore glauconitic sands to onshore beaches. The problems of establishing precise theories which explain the nature of onshore sediment-transporting mechanisms have been outlined (Allen, 1988). The directions in which nearshore sediment flux studies should move must pay attention to the complex inter-relationships between secondary waves and edge waves as well as reflected, subharmonic and infragravity waves in the effects they have on spatial and temporal sediment transport variations (Allen, 1988).

The role of rip currents in nearshore transport and complex feedback loops which relate sediment and fluid patterns on barred beaches need to be examined in greater detail, as do the relationships between shore-normal and shore-parallel forces (Allen, 1988). Only with improved instrumentation and increased focus on the problems, mechanisms and their underlying theory can advances be made (Allen, 1988).

CHAPTER 4

LITERATURE SURVEY

LITERATURE SURVEY

4.I INTRODUCTION

It is interesting to compare statements made in the last three decades by SEM workers, which reflect the state of the art at different stages in its development. In 1962 Porter stated that the use of TEM analysis had provided evidence to demonstrate differences in the surface textures of sand grains. Biederman (1962, p.183), could say little more when he stated that, "The fundamental idea is that the depositional history (of grains) is reflected in their surface features. The assumption is that a water film protects the water deposited grain, whereas the windblown equivalent is allowed to collide freely with its neighbours".

Ten years later in the early 1970's when SEM analysis' popularity reached a peak in terms of major publications (Bull, 1981a), workers made far greater claims for the technique, as the statement made by Krinsley and Smalley (1972), in their treatise on sand showed. They claimed to be able to deduce from a single sand grain's surface that, "during its life of about 200,000 years, it was picked up by a glacier and abraded, then released from glacial ice when the glacier melted, carried by a glacial stream to a beach and beyond where it was rolled about by waves, cast up on a beach, picked up by the wind, transported and abraded over a period of time, carried out across the continental shelf, perhaps by turbidity currents, and finally deposited in the deep sea" (Krinsley and Smalley, 1972, p.291).

Such claims may seem to give the impression that the problems of grain surface microtexture analysis had been cut and dried as far as SEM analysis was concerned. However, it will be shown below that such problems are far from being solved, especially when more rigorous quantitative techniques and statistical analysis are applied.

At the close of the 1980's Mazzullo and Magenheimer (1987, p.479), made more circumspect claims when they stated that, "the shapes of quartz grains from a given source reflect the genesis or lithology of that source and are distinct from the shapes of quartz grains from other sources. These quartz grains were subjected to varied mechanical and chemical processes during the genesis of these, and these processes have imprinted these grains with unique source indicative shapes".

Bull (1981a), provided a useful and informative review of develolpments in electron microscopy in the 1960's and 1970's in which he illustrated the growing popularity of SEM studies between 1962 and 1979 on the basis of the frequency of cited and other major publications. The technique enjoyed what may be described as its golden age in the early 1970's, apart from an anomalous peak in 1978 which was partly accentuated by the publication edited by Whalley (1978a). A survey of SEM publications in the 1980's reveals no resurgence of the popularity gained in the early 1970's, although the publication edited by Marshall (1987), followed in the same footsteps as that edited by Whalley (1978a).

In the account of SEM studies which follows, developments have been arbitrarily subdivided into four sections.

A. EARLY SAND GRAIN SURFACE TEXTURE STUDIES.

B. TRANSMISSION ELECTRON MICROSCOPY.

C. SCANNING ELECTRON MICROSCOPY - PRE 1981.

D. SCANNING ELECTRON MICROSCOPY - POST 1981.

The choice of 1981 as a watershed in the evolution of SEM studies between the early 1960's and 1990, is not intended to represent a real break in the ideological development of the technique. Rather, it provides an appropriate breathing space in the narrative, hinging upon Bull's (1981a) apt review of the previous two decades and his thoughts on possible trends in the 1980's.

4.II EARLY SAND GRAIN SURFACE TEXTURE STUDIES.

Sorby (1880), was one of the earliest workers to draw attention to the nature of sand grain textures, classifying grains on the basis of their frosted appearance. Much later, Cailleux (1943), used a binocular microscope and oblique incident illumination to devise a fourfold division of sand grains:

(i) Not abraded grains

(ii) Well rounded shiny grains

(iii) Well rounded frosted grains

(iv) Rounded dirty grains

Grain frosting was attributed to collisions during wind transport, whereas waterborne grains became shiny as a reult of the polishing action of suspended silt and clay in the water cushion between colliding grains.

The nature and causes of frosting were taken up by later workers (Bond, 1954; Kuenen and Perdok, 1962). Bond (1954), attributed fluvially derived frosting to freshwater chemical action.

These findings were later supported by the work of Kuenen and Perdok (1962), who found that frosting on desert sand grains was caused by chemical action. Ten years later during the early stages of SEM studies in the early 1970's, the problem of grain frosting led to the study of upturned plate textures and their relationships to quartz cleavage (Margolis and Krinsley, 1971).

4.III TRANSMISSION ELECTRON MICROSCOPY

Early TEM workers were the first to pioneer the new technique, laying down ground rules for grain preparation methods, grain surface microtexture recognition and interpretation. Biederman (1962), Porter (1962) and Krinsley and Takahashi (1962a, 1962b, 1962c, 1962d), broke new ground in sedimentological studies as they organised the exploration and realisation of possible new fields of application.

Such early efforts led to the publication of important publications in the field in the late 1960's such as those of Margolis (1968), and Krinsley and Donahue (1968 a), Margolis and Kellner (1969), and Krinsley and Margolis (1969).

Biederman (1962), used T.E.M. analysis in order to distinguish between beach, dune, lagoon and marsh environments in an attempt to unravel the history of ancient sediments. He observed triangular and rhombohedral etch pits on water-deposited grains (Biederman, 1962), which he related to crystallographic control.

One of the earliest grain classifications on the basis of surface textures determined by T.E.M. analysis was devised by Porter (1962).

(i) Abraded texture - a surface with a chipped or ground appearance.

(ii) Lobate texture - a surface with a distinct cobbled appearance.

(iii) Corroded texture - a surface which appears to result from the removal of material by solutions in contact with the sand or silt.

(iv) Smooth texture - smooth surface.

(v) Faceted texture - evidence of planes or facets associated with crystallinity.

Grain size was also incorporated into the analysis (Porter, 1962).

A major problem for T.E.M. workers was that of the complicated procedures necessary for grain preparation and surface replication, often with limited efficiency (Krinsley and Takahashi, 1962a, 1962b, 1962c, 1962d). Although the quality of resolution was about twenty times that of the S.E.M., it was difficult to relate textures to an entire grain surface (Steiglitz, 1969). It should be appreciated that work produced in the 1960's was based upon photographs of grain surface replicas, a technique which contrasts strongly with that of Bull (1978a, 1984), and Goudie and Bull (1984), using a checklist approach.

A great deal of the work relating to glacial and beach sediments carried out by Krinsley and Takahashi (1962b, 1962c), and Krinsley et al (1964), was based on sediments derived from Montauk till and beaches from the Headlands section in eastern Long Island (Fig. 2.4).

They adopted an approach which was necessary in order to establish T.E.M. analysis as a valid tool in geological research, viz:- identification of modern sand grain surface textures and their casual mechanisms and, via the principle of uniformitarianism, the application of results to ancient sediments (Krinsley et al, 1964).

Characteristic textural assemblages diagnostic of known aeolian, littoral and glacial environments were described and supported by laboratory simulations (Krinsley and Takahashi, 1962a, 1962b, 1962c, 1962d). The textures observed included meandering ridges (aeolian), small pyramidal V shaped indentations (littoral), blocky textures (littoral), arc shaped steps-conchoidal fractures (glacial grinding), semi parallel steps (shear stress), and very high relief (glacial). Such textures were amongst the earliest to be described on Long Island's south shore sand grains within the study area, highlighting the dominance of glacial and glacial-beach environmental modifications (Krinsley et al, 1964: Krinsley, pers. comm.).

One of the earliest serious attempts at relating a grain surface texture (MV pits), to energy conditions was made by Krinsley et al (1964). They observed that MV pit densities were very low or absent on grains from Montauk till and increased from approximately 0.5 per μm^2 near Montauk Point (Fig. 2.4), to approximately 3 per μm^2 at a distance of 20 miles to the west (Krinsley et al, 1964). This phenomenon was found to correlate with distance of transport, turbulence being considered to be uniform along the easternmost 20 miles of Long Island's south shore beaches, with the exception of highly localised intense turbulence near Montauk Point. Krinsley et al (1964), stated that glacial textures had been almost entirely obliterated and replaced by beach textures, although the former were still recognizable on certain grains.

Possible coastal dune sediment input to the beach system was found to be insignificant on the basis that none, or few, aeolian textures were observed on beach grains (Krinsley et al, 1964). Considerable attention has been paid to this particular work because along with Krinsley and Takahashi (1962b, 1962c), they produced the earliest electron microscope analysis of quartz sand surface textures in the study area (Fig. 2.4).

Such pioneering efforts prepared the way for T.E.M. analysis to expand into the field of ancient sediment studies (Krinsley and Schneck, 1964; Krinsley and Hamilton, 1965; Waugh, 1965).

Waugh (1965), devised a three-stage model for secondary silica overgrowths in order to categorise sand grains which had been diagenetically altered in the Penrith sandstone:

(i) Formation of rhombohedral projections.
(ii) Overlapping of rhombohedra to give planar faces.
(iii) Formation of euhedral crystals.

The smooth progress of T.E.M. analysis development was occasionally halted by workers who questioned the validity of the diagnostic importance of certain textures (Soutendam, 1967). A cautionary note was issued regarding the extension of a textural assemblage considered to be diagnostic of coastal dunes and aeolian transport in general, to tropical desert grains (Soutendam, 1967). His findings suggested that chemical pitting on tropical desert grains was produced by desert dew chemical action and that this removed the ultimate event (a wind transporting episode) thus supporting the findings of Kuenen and Perdok (1962).

Throughout its development electron microscopy experienced relatively quiescent periods when progress was slow, punctuated by episodes of rapid progress and consolidation following the publication of an important paper. The work of Krinsley and Donahue (1968a),and later Margolis (1968), Margolis and Kellner (1969), and Krinsley and Margolis (1969), fall into the latter category.

Based on an analysis of over 4,000 grain surfaces Krinsley and Donahue (1968a), updated and catalogued the results of work through the 1960's. Many of their grain surface textures are still in use today (Table 4.1). They recognised the complexities of multicycle textures and stated that although many textural patterns may still not be related to mechanical or chemical events, the textures presented (Table 4.1), were widespread and consistently present on grain surfaces from specific environments and could be considered to be reliable qualitative environmental indices. "It is possible to work out a time sequence by determining which textures replace previous ones. Early surface textures are commonly preserved in low areas where they are protected from abrasion." (Krinsley and Donahue, 1968a, p.747).

Margolis (1968), extended studies in the complexities of multi-cycle textures and using Tanner's (1960), classification of coasts based on wave energy he used a semi-quantitative approach to mechanical, chemical and mechanical-chemical combination textures.

LITTORAL

High Energy (Surf)		Low-Medium Energy Beach	
I	V shaped patterns (irregular orientation). a. 0.1 m wave depth. b. 2 V's per μm^2 density.	I	En-echelon V shaped indentations at low energy. As energy increases, randomly orientated V's replace the en-echelon features.
II	Straight or slightly curved grooves .		
III	blocky conchoidal breakage patterns .		

AEOLIAN

Tropical Desert		Coastal	
I	Meandering ridges.	I	Meandering ridges.
II	Graded arcs.	II	Graded arcs.
III	Chemical or mechanical action - regular pitted surface replacing the above features.		

GLACIAL

Normal

I	Large variation in size of conchoidal breakage patterns.
II	Very high relief (compared with littoral and aeolian grains).
III	Semiparallel steps.
IV	Arc shaped steps.
V	Parallel striations of varying length.
VI	Imbricated breakage blocks (like a series of steeply dipping hogsback ridges.
VII	Irregular small-scale indentations (associated with conchoidal breakages).
VIII	Prismatic patterns consisting of a series of elongated prisms and a very fine grained background.

Glacio-fluvial.

Rounding of glacial patterns I to VIII.

DIAGENETIC

Wavy patterns - curved branching irregular lines.

Relatively flat featureless surfaces.

Table 4.1 Summary of Surface Texture Characteristics (after Krinsley and Donahue, 1968a).

The numbers of grains possessing such textures were counted and related to wave height (and thus energy). Chemical textures were equated with low energy beaches, while a mechanical-chemical texture combination may have represented greater silica removal by abrasion than by solution in higher energy beaches (Margolis, 1968).

4.IV SCANNING ELECTRON MICROSCOPY - PRE 1981.

In the late 1960's S.E.M. analysis superceded T.E.M. analysis largely because the former possessed several advantages for sediment analysis which were absent in the T.E.M.. Many grains could be viewed quickly at the same time, allowing irregularly shaped particles to be viewed at a range of magnifications (Oatley, 1966). The deep field of focus and additional contrast allowed individual textures to be placed within their correct positions as far as cross cutting relationships and the whole-grain textural mosaic were concerned (Steiglitz, 1969).

Such versatility allowed new analytical techniques to involve a more rapid scan of a greater multiplicity of textures. Margolis and Kellner (1969), were amongst the first to use a checklist approach, developing and extending the work of Margolis (1968). They used the presence-absence of thirty sand grain surface textures.

The introduction of such a semiquantitative approach depended a great deal on the validity of the diagnostic capabilities of surface textures used in the checklist. To this end, Krinsley and Margolis (1969), attempted to update and consolidate existing S.E.M. analytical procedures and to validate environmentally diagnostic textures cited in the literature. They introduced several new textures and ascribed existing textures to causal mechanisms or their environments:

(i) Straight and slightly curved grooves-scratches.

(ii) Chattermarks - littoral environments where grains skipping across each other produced a series of sub-parallel indentations about 0.5 μm long.

(iii) Oriented fractures - indicative of aeolian transport. (In later papers this texture was related to the formation of upturned plates).

(iv) A previously cited texture known as prismatic patterns no longer appeared in descriptions of glacial textures.

(v) Relatively flat featureless surfaces were replaced by low relief solution surfaces as features of chemical origin.

(vi) Wavy diagenetic patterns - diagenesis. (Interestingly the electron micrograph presented to illustrate this texture (Krinsley and Margolis, 1969, p.474, Fig. 15), appears to be identical to textures which have been later interpreted as chattermarks by other workers e.g. Bull et al (1980)).

Such texture assemblages were adopted by many workers and used to interpret other sediments and their histories e.g. Krinsley and Donahue (1968a), Margolis and Kellner (1969), Coch and Krinsley (1971), Hey et al (1971), and Nordstrom and Margolis (1972). There was a feeling that the acceptance of such textural assemblages and their diagnostic importance in discriminating between the wide variety of environments which occur at the earth's surface, should be qualified by returning to studies of source grain textures. Schneider (1970), Scholle and Hoyte (1973), and Brown (1973), concentrated upon original first cycle textures produced in granitic source rocks in order to produce a known texture framework within which subsequent environmental modifications could be correctly assessed.

Krinsley and Hyde (1971), used S.E.M. analysis in the cathodoluminescent mode to determine grain subsurface textures and found that glacial grinding may produce a great deal of grain cracking as evidenced by lattice strain.

Margolis and Krinsley (1971), produced a detailed study of the nature of submicroscopic frosting upon aeolian and subaqueous sand grains. About this time, upturned plates were introduced as a texture indicative of aeolian transport and described previously (Krinsley and Margolis, 1969) as oriented fractures. Upturned plates were an expression of quartz cleavage and may be recognised on grain surfaces ranging from crushed quartz to glacial, subaqueous, desert and ancient origins (Margolis and Krinsley, 1971).

Margolis and Krinsley (1971), also confirmed the presence of other textures such as spalling and adhering particles. The former may be caused by abrasion of plates exposing fresh oriented cracks below, the latter representing comminution debris. Subaqueous MV pits were interpreted as defrosting agents along with chemical action and diagenesis, frosted subaqueous grains being the products of abrasion solution and subaqueous chemical sea solution. "This concept (abrasion solution), possibly can account for the balance between chemical solution and mechanical abrasion features on beach sands, and explains why many of the grains from turbulent subaqueous environments show high densities of etch modified impact pits" (Margolis and Krinsley, 1971, p.3404).

There was considerable debate in the early 1970's on the existence of quartz cleavage and microfracturing by such authorities as Berry (1974), Hoffer (1974), Smalley and Krinsley (1973), Krinsley and Smalley (1973). An attempt was made to link the production of clay sized quartz particles to a hitherto unsuspected cleavage mechanism and the spalling of upturned plates on larger quartz grains with a breakage sequence of: sand (500 μm to 200 μm), silt (50 μm to 20 μm), clay size (5 μm to 2 μm), being postulated by Krinsley and Smalley (1973).

The problem of the possibility of cleavage in quartz sand grains was difficult to resolve, mineralogists differing in opinion with S.E.M. workers. Berry (1974), and Hoffer (1974), argued that the production of small blade and flake shaped particles and their crystallographic orientation was controlled by the manner in which pressure was applied and not by atomic structural factors. It was pointed out that poor quartz cleavage (a statistical preference for rupture in a certain direction of atomic structure), which has been attributed to $r(10\bar{1}1)$, and $z(01\bar{1}1)$ planes (Krinsley and Smalley, 1973), has erroneously been interpreted (Hoffer, 1974). It was agreed that this direction ($51^{\circ}46'$ from the C axis) by coincidence happened to be one of several directions of weakness in quartz bonding, but the azimuthal position of this particular bonding weakness lay at

30° from the normals to r and z and cannot give rise to good cleavage (Hoffer, 1974).

It is worth examining discussions on the degree of crystallographic control of sand grain surface textures, because it may influence interpretations of the amount of energy required to initiate curved as opposed to flat (possibly) cleavage controlled fractures (Grant, pers. comm). Moss et al (1973), offered an alternative viewpoint in that ordinary quartz sand grains are normally derived from imperfect quartz in granitic rocks which contain some characteristic defects. Apparently, rock forming processes exert a great deal of stress, deforming crystals by 'slip-type' mechanisms found in metals, rather than cleavage (Moss et al, 1973).

Such arguments provided useful information for work which focussed upon loess production (Krinsley and Smalley, 1973; Smalley et al, 1978; Vita-Finzi et al, 1973). Work on the nature of quartz sand grain microfracturing and cleavage continued into the late 1970's (Bull, 1978b; Smalley et al, 1978; McKee et al, 1979), forming the basis for studies investigating lunar martian aeolian processes (Krinsley et al, 1979a, 1979b).

The importance of the Pleistocene epoch and its possible quartz grain modifications were reflected in papers in the early 1970's (Margolis and Kennett, 1971; Hey et al, 1971; Nordstrom and Margolis, 1972; Coch and Krinsley, 1971). Many sediments found in modern terrestrial and subaqueous environments would clearly have been involved in glacial and fluvioglacial transportation episodes with the probable inheritance of such glacially derived environmental modifications.

SURFACE FEATURE CATEGORIES

1. Small scale (<1 μm) imbricate breakage blocks.
2. Small scale (<1 μm) conchoidal fractures.
3. Large scale (>1 μm) breakage blocks.
4. Large (>1 μm) conchoidal fractures.
5. Straight grooves or scratches.
6. Curved grooves.
7. Randomly oriented striations.
8. Semi-parallel step like fractures.
9. Arc shaped steps.
10. Meandering ridges (>5 μm in length).
11. 'V' shaped irregularly oriented impact pits.
12. Small fractures caused by crack propagation.
13. Sharp angular outline.
14. Rounded outline.
15. Low relief (<0.5 μm).
16. Medium relief (between 0.5 μm and 1 μm).
17. High relief (>1 μm).
18. Crystallographically oriented etch pits.
19. Irregular finely pitted surfaces.
20. Anastomising patterns and diagenetic etching.
21. Smooth featureless surface (fracture planes).
22. Crystallographic overgrowths.

Table 4.2. Checklist of surface feature categories (After Margolis and Kennett, 1971).

In an attempt to unravel the Caenozoic palaeoglacial history of Antarctica, Margolis and Kennett (1971), used a variety of techniques, including micropalaeontology, to analyse deep sea cores. Their work was exceptional at the time for its application of a quantitative approach using a 22 surface feature checklist (Table 4.2). Each texture's presence was noted when they occurred on more than 10% of each grain's surface. Using this criterion, percentages of total sample grains exhibiting such textures were calculated and presented diagrammatically as surface feature variability plots (Margolis and Kennett, 1971).

In addition, percentages of sand grains with V shaped impact pits (on more than 10% of grain surfaces), were graphed against V pit densities per μm^2, supporting earlier work (Krinsley and Margolis, 1969), which linked small subaqueous breakages to energy conditions (Margolis and Kennett, 1971). Nordstrom and Margolis (1972), used a similar approach, but increased the area on which each texture was observed to a qualifying minimum of 50%.

In a similar vein, Krinsley (1972), and Krinsley et al (1973), examined quartz grain surface textures from glacial environments and their inheritance impact on later textural modifications. A growing number of size and shape limitations were being developed for various textures and a more rigorous definition of the applicability of textural assemblages. Krinsley et al (1973), stated that no single feature was enough in its own right as a valid diagnostic implement, but that a minimum of four on a number of areas, would be satisfactory as far as glacial environments were concerned.

An attempt to develop a novel quantitative approach was made by Setlow and Karpovich (1972). They encountered the same problem as earlier workers in S.E.M. studies (Margolis and Kennett, 1971; Nordstrom and Margolis, 1972), in that the subjective element could not be avoided when trying to reduce surface textures to representative numerical values (Setlow and Karpovich, 1972). The degree of development (dominance), and area of development (density), of surface textures were assigned values (Table 4.3).

Developed from previous work by Karpovich (1971), the method is difficult to apply (Williams et al, 1985), and would suffer from a great deal of operator variance in estimations of grain surface area over which textures may be observed.

An attempt to focus upon the origin of chemical textures was made by Mackenzie and Gees (1971). They claimed to have produced authigenic quartz crystals directly from seawater at room temperatures. Quartz-cemented sandstones, secondary quartz rimming of recent lacustrine quartz sands and quartz crystals found in weathering profiles could be interpreted as precipitates of quartz from aqueous solutions at earth surface conditions in relatively short periods of time (Mackenzie and Gees, 1971). This suggested that many chemical precipitation textures which may have been interpreted as inherited from source or weathering cycles could be revised using a much shorter time scale.

Surface textures of quartz sand grains were studied along the Atlantic shelf off North America by Blackwelder and Pilkey (1972), two of their samples coming from the shelf immediately south of eastern Long Island. In a late application of T.E.M. analysis,

DEGREE OF DEVELOPMENT	VALUE	AREA OF DEVELOPMENT	VALUE
Dominant	5	Widespread over entire grain.	9-10
Abundant	4	Widespread over major grain portions.	6-8
Common	3	Present over regional grain areas	3-5
Present (Few)	2	Local	1-2
Rare	1		1
Absent	0		0

Table 4.3. Value assessment for quartz sand micro-textures (After Setlow and Karpovich, 1972).

dominant glacial, beach and solution textures were graphed against their occurrence on grains from different latitudes (Blackwelder and Pilkey, 1972). They concluded that glacial textures declined in dominance with decreasing latitude, the two samples south of eastern Long Island being classified as low-energy beach and beach-solution.

At a time when S.E.M. publications were declining (Bull, 1981a), the publication of 'The atlas of quartz grain sand surface textures' (Krinsley and Doornkamp, 1973), provided an opportunity for the technique to become much more readily accessible to potential users. The directness of their methodology and the clarity of their illustrated textures proved to be appealing to workers for more than a decade. Although there was a lack of objective qualification in the mid 1970's, S.E.M. became a useful descriptive and illustrative adjunct to broader studies where electron micrographs could be used to illustrate previously unseen phenomena. Grain preparation techniques and quartz grain surface texture recognition and interpretation described by Krinsley and Doornkamp (1973), were used in the present study in order to prepare and scan grains and in the drawing up of a suitable checklist.

Exceptions to the generally non-quantitative nature of S.E.M. publications in the mid 1970's were provided by Margolis and Krinsley (1974), and Whalley and Krinsley (1974), the latter throwing more light on the problems of interpreting glacial textures. The impact of the Pleistocene epoch on modern unconsolidated terrestrial and shelf sediment textures were reflected in the persistent thread of research concentrating upon glacial textures. Whalley and Krinsley (1974), pointed out the problems of lumping all glacially derived grains together, and that superglacial and subglacial regimes may produce distinct and separate textures.

An important paper by Margolis and Krinsley (1974), served to clarify environmental textural assemblages and related them to the crystallographic properties of quartz. Based on the environmental occurrence of 22 diagnostic surface features described by Margolis and Kennett (1971), 12 environments were characterised in terms of varying texture frequency observed on samples of grains studied over the previous 10 years. Their work represented a form of checklist approach used later by Bull (1978a), Goudie and Bull, (1984). It was claimed that cleavage did exist in quartz, although rarely observed, in seven forms: r($10\bar{1}1$), z($01\bar{1}1$), m($10\bar{1}0$), c($00\bar{1}1$), a($11\bar{2}0$), s($11\bar{2}1$) and x($51\bar{6}1$). Rhombohedral cleavage was considered to be of a higher quality than that on the prism (Margolis and Krinsley, 1974).

Conchoidal or brittle fractures were interpreted as cup shaped surfaces left after grain shattering as a result of compressional stresses, the ideal shape being a dish shaped concavity produced by uniformly distributed concentrated pressures during aeolian transport (Margolis and Krinsley, 1974). Small ripple like markings (parallel arc shaped steps), and irregular crack propagation caused by accoustical wave phenomena produced characteristic microfractures which could be used to reconstruct the fracture process and the conditions under which it occurred (Margolis and Krinsley, 1974). Below a critical grain size, cleavage would become prominent creating flatter grain shapes (Margolis and Krinsley, 1974).

V shaped grooves, straight and curved grooves and rounded grain edges were grouped together as textures representing grain collisions in a subaqueous medium. MV pits were seen as notches cut in the tops of cleavage plates, with a saturation limit of 7 V's per μm^2. More than one MV pit may result from a single collison, smaller chips being used as tools during tangential movement (Margolis and Kinsley, 1974). At lower energies, for example such as those that may exist during fair weather conditions on Long Island's south shore beaches, grains may slide over each other creating fine splinters and crushing, which may form fine pits (Margolis and Krinsley, 1974).

One of the first clear examples of the relationships between members of a textural group was explained in terms of increasing energy conditions in a subaqueous medium (Margolis and Krinsley, 1974). Apparently, low energy beach environments caused shallow widely spaced V pits to form as a result of low pressure rubbing and splintering as grains slide over each other. An increase in energy would produce cracking and greater densities of larger V pits as well as curved grooves, leading eventually to conchoidal fractures at very high impact velocities (Margolis and Krinsley, 1974). Whether such high velocities may be reached on beaches was not certain, but energy levels would be adequate during basal glacial grinding and source rock breakdown (Margolis and Krinsley, 1974).

A byproduct of such abrasion processes was the tendency for small chips and splinters to go into solution (abrasion solution), disordering and hydrating quartz surface layers by continued impacts providing finely divided amorphous silica of the disrupted lattice type (Margolis and Krinsley, 1974). It may be concluded from this explanation that abrasion in low to moderate energy beach environments may encourage solution-precipitation features.

In the latter half of the 1970's and the beginning of the 1980's, existing strands of S.E.M. research persisted but with less . . ity than had been the case in the early 1970's. New workers brought alternative approaches with much greater emphasis upon quantitative analysis applied to environments which had not figured very largely in previous S.E.M. studies (Bull, 1976, 1977, 1978a, 1978b, 1981b; Culver and Bull, 1979). Bull and other workers focussed attention on a variety of environments ranging from caves (Bull, 1978a), to archaeological sites (Bull, 1981b), and glacial lacustrine deposits (Culver and Bull, 1979), as well as soils (Bull and Bridges, 1978).

Following on from discussions regarding the nature of quartz cleavage and microfracturing and their relationships to loess production in the early 1970's, further research was carried out on the exact nature of microfracturing events involved in aeolian transport and their relationships to upturned plate lithology and quartz crystallography (Bond and Fernandes, 1975; Nieter and Krinsley, 1976; McKee et al, 1979; Wellendorf and Krinsley, 1980; Krinsley and Wellendorf, 1980; Krinsley and Smith, 1981).

Bond and Fernandes (1975), observed that a texture as small as upturned plates could still be detected after the superimposition of fluvial polishing and etching episodes on redeposited Kalahari type sand grains. Nieter and Krinsley (1976), found that wind velocities as low as 10 m.p.h. and very small (silt sized) particles, 62 μm or less, may combine to abrade larger sand grains. Thus aeolian abrasion in glacial areas such as eastern Long Island may produce upturned plate lithologies on sand grains, contributing a good deal of clay sized quartz to deposits in the vicinity (Nieter and Krinsly, 1976).

Great detail regarding wind speed thresholds, silt and clay production, and their relationships to upturned plates and quartz crystallography (McKee et al, 1979), was uncovered.

Apparently such partial Hertzian cracks may be semi-circular (producing small flat chips), or polygonol (producing blocky chips) if crystal structure control was dominant (McKee et al, 1979). Directly normal impacts would produce a slightly depressed central peak surrounded by semiparallel or parallel and radiating straight microfractures like offset ridges (McKee et al, 1979). Clearly it is tempting to translate such aeolian textures to beach environments, but deductions on this basis would not be valid because of the cushioning effect of water and the fact that aeolian transport may transport sand grains several hundred times faster than in water (Bagnold, 1941).

In a classic example of grain surface texture reconstruction, Wellendorf and Krinsley (1980), used an X ray precession camera and an S.E.M. to produce a large photomosaic from 1,000 photographs in order that upturned (cleavage) plates and blocky areas could be measured accurately in terms of their angular relationships. They confirmed dish shaped concavities, blocky areas and upturned plates as diagnostic aeolian textures, and related upturned plates to cleavage parallel to $r(10\bar{1}1)$ and $z(01\bar{1}1)$ on the rhombohedron (Wellendorf and Krinsley, 1980). Blocks were bounded by a system of fractures parallel to the prismatic C axis of quartz and probably represented cleavage parallel to $m(10\bar{1}0)$.

Krinsley and Wellendorf (1980), used an aeolian simulation paddle device designed for Martian wind simulation experiments (Krinsley et al, 1979a, 1979b), in order to relate modern Saharan wind speeds and their resultant textures to ancient Permian sands, thus illuminating the palaeogeography and palaeoclimatology of such deposits in the geological record. Similar research at the time included the work of Krinsley and McCoy (1978), who supplemented S.E.M. analysis with high resolution transmission electron microscopy (H.R.T.E.M.), Kaldi et al (1978), and Krinsley and Smith (1981). Krinsley and McCoy (1978), pointed to the differences between active dune grain textures consisting of upturned plates, large conchoidal fractures, surface cracking and grain rounding and non active dune textures. The latter may be characterised by smooth flattish areas produced by nocturnal desert dew solution of grain surface-disrupted lattice layers produced by abrasion fatigue. Subsequent evaporation would lead to reprecipitation of amorphous silica as opal or silicic acid, masking previous wind formed mechanical textures (Krinsley and McCoy, 1978).

The downward trend in S.E.M. publications in the late 1970's was arrested sharply by Whalley's edited publication (1978a). A total of twenty nine papers were presented across a wide range of S.E.M. applications. They included studies of ancient rock porosities (Mirkin et al, 1978; Walker, 1978); microfabric analysis of fine sediments (Osipov and Sokolov, 1978; Derbyshire, 1978); palaeontological and organic studies (Antia and Whitaker, 1978; Scott and Collinson, 1978); cave sediment studies (Bull, 1978a); diagenetic studies and weathering (Wilson, 1978; Waugh, 1978; Whalley, 1978b, 1978c).

Although glacial and aeolian environments were treated (Eyles, 1978; Mycielska-Dowgiallo, 1978), littoral environments were conspicuous in their absence from the contents (Whalley, 1978a).

By the late 1970's, several adjuncts to S.E.M. analysis had been developed. Cathodoluminescence (C.L.) and its applications were described by Grant (1978), and have been employed in several studies to determine subsurface morphologies of quartz grains masked by silica coatings (Krinsley and Hyde, 1971; Krinsley and Tovey, 1978; Tovey and Krinsley, 1980).

When used in conjunction with the S.E.M. in emissive mode, cathodoluminescence studies allowed previous grain surface modifying episodes to be identified, whereas in the emissive mode textures were related to the last episode (Tovey and Krinsley, 1980).

Fine sediments have been studied using high voltage electron microscopy (H.V.E.M.) e.g. Hammond et al (1973), Smalley and Moon (1973), Moon (1978), especially post glacial tills and clays. An example of current research at that time was the paper presented by Krinsley (1978), describing five ongoing strands of research in his laboratory and reviewing future prospects in the light of past work. His projects included quartz silt and clay surface texture analysis and environmental reconstruction, cathodoluminescence, quantitative measurement of mechanical and chemical surface textures, the use of consolidated or semi-consolidated sand deposits for environmental reconstruction, and finally isotopic dating of quartz grains and surface textures (Krinsley, 1978).

In his account of quartz particle production in nature Krinsley (1978), stressed the importance of source granite and granite gneiss microfractures in fostering grain shattering in granite grains. The stresses in such quartz grains would be caused by volume decreases associated with $\beta - \alpha$ quartz transition at 573°C in a cooling pluton

(Krinsley, 1978). This explanation was preferable for loess quartz silt grain genesis compared with a glacial grinding mode of origin.

Krinsley's (1978), notion of quantitative measurement was confined to the use of sized plastic spheres and stereo-pair photographs, an approach well suited to an in-depth study of only one or two textures. One of the problems of this approach was that diagnostically valid environmental indicators still need to be analysed in terms of their grain surface distribution, dominance and position in grain history cycles. A solution to this problem was suggested in Goudie (1981), by the use of image analysing instruments which facilitated rapid multiple quantification of a variety of parameters using S.E.M.'s.

One important European Source of S.E.M. research was the contribution of Le Ribault and his coworkers. Building upon the grain surface analysis studies of Cailleux (1942, 1943), and Cailleux and Tricart (1959), Le Ribault (1978), employed more sand surface textures than many other workers. From the early 1970's Le Ribault and Tourenq (1972), Le Ribault (1972a, 1972b, 1974, 1975), acknowledged the groundwork prepared by Krinsley and if the study of grain inclusions (endoscopy) is included over 100 quartz sand grain surface textures have been identified (Le Ribault, 1978).

In a progressive categorisation Le Ribault (1978), grouped grains into: quartz in non-weathered rocks (original quartz grains), quartz from soils and weathered rocks, aeolian quartz, quartz from continental aqueous environments, quartz from marine environments and quartz with a complex history. Endoscopy was used to determine provenance on the basis of inclusion morphology and composition

(Le Ribault, 1978).

Non-evolved quartz crystals from non-weathered source rock would proceed to receive environmentally indicative suites of surface texture modifications beginning with weathering and soil forming processes (Le Ribault, 1978). Environments may be subdivided according to their silica dissolving or silica precipitating properties. Peeling off and orientated solution features typified grain hollows during solution, while globular silica, splintery layers and oriented flows characterise silica precipitation (Le Ribault, 1978). Protected surfaces occur at points of grain contact, while silica flowers may precipitate in confined zones under particular conditions on such surfaces (Le Ribault, 1978).

Le Ribault (1978), pointed to amorphous silica and quartz undersaturation in sea water as the most important factors influencing textures in marine environments, the higher the energy level the greater the degree of dissolution. Infratidal zones were characterised by geometric solution features which first appear on grain edges, in contrast to weathering environments, because water currents prevented collections of aqueous solutions in pockets and hollows. Intertidal zones, such as beaches, resembled infratidal zones on a flood tide, except for the addition of impact features on high energy beaches, but would resemble weathering horizons on an ebb tide as progressive evaporation of sea water in grain surface hollows precipitated globular deposits rich in NaCl and diatoms (Le Ribault, 1978).

As far as littoral quartz sand is concerned, we may deduce from Le Ribault's ideas (1978), that clean polished edges with impact pits (M.V.'s) and oriented triangular etch pits suggest higher energy beach conditions and surf action, whereas a concentration of solution features in hollows suggest immobilisation of grains in a pedology horizon. Intertidal quartz grains may also exhibit globular silica and cemented diatoms preserved in hollows as a product of ebb tide conditions (Le Ribault, 1978). An example was presented of a grain with a complex history, which obtained an assemblage of geometric solution features on grain edges during a long sojourn in an infra-tidal environment (offshore), but the presence of a clean washed surface with impact pits on edges and cemented diatoms in older solution hollows indicated an onshore movement to a beach environment (Le Ribault, 1978).

In a study which bears a resemblance to the present study, Combellick and Osborne (1977), used S.E.M. analysis to determine sand sources supplying southern Monterey Bay beaches, California, as part of a wider battery of techniques including analyses of grain size, colour, roundness, lithology, etc.. Although no quantitative S.E.M. analysis was presented, they found that offshore sands were polished and exhibited slightly curved grooves, irregular breakage patterns, and a large number of V shaped impact pits (Combellick and Osborne, 1977). Their conclusions are pertinent to the aims of the present study in that such beach modified textures on sands from the offshore zone may be indicative of beach origins and that known offshore sand transport (Dorman, 1968; Arnal et al, 1973), in the area, may be returned as onshore sand transport as well as that of offshore relict sands (Combellick and Osborne, 1977).

Other subaqueous studies in the mid and late 1970's include those of Subramanian (1975), and to a certain extent, Baker (1976).

Subramanian (1975), performed etch studies on small grains (20 μm to 63 μm), and described sub-varieties of geometric solution features: triangular pits on prismatic faces and crystallographically oriented V or U shaped pits on rhombohedral faces, with a possible transformation of triangular to V shaped pits.

Baker (1976), was one of several workers at this time who called for a more quantitative approach (Tovey et al, 1978; Krinsley, 1978). Baker (1976), aimed to test the notion that certain surface textures which had been described as 'grossly diagnostic' of processes as different as ice, surf and wind, were in fact sufficiently sensitive to use as palaeoenvironmental tools. Owing to the highly subjective character and time consuming nature of estimating percentages of grain surface areas exhibiting various textures, a simple presence-absence approach was adopted for ten textural features (Baker, 1976). Only 20 grains per sample were scanned on the strength of small variations in results when numbers of 30, 40 or 50 were used (Baker, 1976).

The checklist used was selective in its design, the aim being to discriminate between marine and aeolian grains in general (Baker, 1976): mechanical features - grooves and scratches, mechanically formed V shaped pits, conchoidal fracture, blocky breakage, mechanically formed upturned plates, and chemical features - precipitated upturned silica plates, irregular solution-precipitation surface, smooth precipitation surface, irregular or polygonal cracks (a form of shrinkage crack after Lucchi(1970)), and chemically etched V forms.

Baker (1976), concluded that statistical analysis supported claims that subaqueous and aeolian textures in fact occurred on grains from these environments (Krinsley and Doornkamp, 1973), but that it would not be possible to distinguish these environments on the basis of such textures using a presence-absence checklist approach. However, chemically etched V's, mechanical V's and grooves and scratches may be used tentatively as indicators of proximity to a marine environment (Baker, 1976).

Baker (1976), noted that one of the grain surface textural assemblages described in the literature as grossly diagnostic may be applied also to glacial environments. More detailed studies of glacially derived sediments were presented in the late 1970's in attempts to establish more subtle relationships between grain surface textures and causal mechanisms bearing in mind the problems of the efficiency of glacial transport and inherited source and weathering textures (Margolis, 1975; Whalley, 1978a, 1978d; Eyles, 1978; Culver et al, 1978; Flageollet and Vaskon, 1979).

Margolis (1975), was one of many workers who attempted to use evidence derived from the large scale Deep Sea Drilling Project in order to infer palaeoclimatic conditions using deep sea sediments (Margolis and Kennett, 1971; Krinsley and McCoy, 1977). S.E.M. analysis was used to identify quartz sand grains of glacial origin from Leg 29 in order to infer Antarctic palaeoglacial history (Margolis, 1975). A cautionary note in his paper (Margolis, 1975), described the importance of checking for quartz composition in grains which could easily be mistaken for sanidine or feldspathic glass by experts using a binocular microscope.

Culver et al (1978), used the S.E.M. to confirm a probable glacial origin for infracambrian sediments in Sierra Leone. Eyles (1978), made a comparative study of 'high level' (supraglacial and englacial) debris and low level debris derived at the ice-bedrock interface and transported as a thin (<20cm) ice/debris suspension as a distinct sole. High level debris transported by medial moraines showed typical 'glacial' textures: high relief, conchoidal breakages, arc steps and irregular cleavage surfaces with dominant grain morphologies of large planar or undulating cleavage faces intersecting at highly angular sharp edges (Eyles, 1978). Conchoidal breakages and arc steps were superimposed upon these features.

Additional textures found on grains recently released from bedrock were bright rimmed hollows (Krinsley and Doorkamp, 1973), and surface cracks (Riezebos and Van der Waals, 1974), and it was found to be impossible to distinguish between englacial and supraglacial moraine textures (Eyles, 1978). Apparently, no textural downstream changes occurred upon medial moraine grain surfaces (Eyles, 1978).

Low level debris resembled high level debris except for the presence of microblock structures (described by Krinsley and Doornkamp, 1973), and severely disrupted and broken cleavages on over 30% of grain surfaces (Eyles, 1978). In general, low level grains were free of cemented surface debris with no evidence of silica solution-precipitation. From Eyles' (1978), evidence it seems that grain angularity and large conchoidal fractures have been inherited from initial periglacial release from bedrock and that broken cleavage plates and microblocks are the only two grain to grain, or grain to bed fractures produced by glacial transport. Microblock features presented by Eyles (1978), and described by Krinsley and Doorkamp (1973), are represented in the present study by large breakage blocks (>10 μm).

Some of the more problematical areas of grain feature interpretation include those of diagenesis and weathering. Diagenesis comprises those processes which involve the transformation of a sediment into rock (Strakhov, 1953, 1960), during which time new minerals are formed, various substances are redistributed and recrystallised and finally lithified. Le Ribault (1978), described primary quartz grains as non-evolved, their earliest elements of geological memory being ascertained by endoscopy. Diagenesis occurs after weathering processes have released quartz crystals, and transportation and deposition of detrital grains have occurred.

However, many detrital sediments may not be first cycle materials, but derived from rocks or unconsolidated sediments which have themselves experienced several cycles of transportation and deposition, perhaps in completely different environments. Longman (1980), described diagenesis as a complex and variable process because it involved not only variability of process type, but variability in time, crystallography and not least the severity of process. Le Ribault (1978), has also pointed out that protected surfaces may exist where no textural modifications may occur (in soil horizons).

In the 1960's and early 1970's many workers tended to subdivide grain surface textures into mechanical and chemical, the latter being ascribed to general syn-depositional chemical processes or diagenesis and weathering (Margolis, 1968; Krinsley and Margolis, 1969;

Smalley et al, 1973; Krinsley, 1972; Margolis and Krinsley, 1973).

Krinsley and Donahue (1968b), recognised four main classes of diagenetic texture: crystal surfaces, solution surfaces, pressure solution striations and fracture surfaces. Margolis (1968), found that the degree and expression of a diagenetic pattern of fine pits connected by a network of anastomising lines was a function of, "the length of time that the grain has been exposed to circulating meteoric and groundwaters .... (as well as other factors like) .... climate chemical composition of groundwaters, pH, silica saturation of the waters and sediment permeability (Margolis, 1968, p.248).

Margolis (1968), equated a fine stippled pattern of anastomising lines with diagenesis, whereby silica was removed rapidly and indiscriminately from entire grain surfaces thus discouraging oriented features. Oriented etch pits were indicative of low energy marine conditions and slow solution on the basis of varying solution strength etching experiments (Margolis, 1968). Krinsley and Margolis (1969), altered the textures named to wavy etched patterns and low relief solution surfaces for diagenetic patterns.

In their study of the Kaiserstuhl loess, Smalley et al (1973), found the reactivity of small particles whose surfaces had been disordered by abrasion solution may encourage weathering followed rapidly by cementation. The layered or stepped weathered features produced may be linked to crystal structure and upturned plates (Smalley et al, 1973).

Krinsley and Doornkamp (1973), presented a detailed account of diagenetic textures. Solution and redeposition of silica was prominent and may occur over the entire grain surface or (as in the case of pressure solution), may vary on different parts of the same grain. The dominant effect of solution was to reduce relief and even out projections (Krinsley and Doornkamp, 1973). Precipitation features were grouped according to rapidity of process:

(i) Rapid precipitation produced an overall undulating smoothed grain surface topography as typified by aeolian grains (described in photographs as smooth capping layer).

(ii) Moderate precipitation included the formation of upturned plates or enlargement of plates along cleavage traces.

(iii) Slow precipitation produced a very fine coating which reflected the underlying topography in detail, even on quartz crystal terminations.

Solution textures included wavy patterns and worn low relief solution surfaces (Krinsley and Doornkamp, 1973). The former was represented by irregular wavy anastomising lines found in depressions from which they grow outwards smoothing out relief. The latter were represented by smooth flattish monotonous surfaces gradually obliterating existing mechanical textures. Silica plastering, involving a flattish surface of precipitated particles formed on the grain surface (and often bent over grain angularities), was a diagenetic pattern caused by post depositional movement, which may be duplicated by glacial pressure (Krinsley and Doorkamp, 1973).

Although diagenesis has been defined by many authors (Pettijohn et al, 1973), some S.E.M. workers have described chemical features on sand grains in general which may be related to processes operating within the current environment (such as etched triangular pits), and these have occasionally been incorporated into references about diagenesis. The present work includes within diagenesis those processes which operate at or near the earth's surface, for example as defined by Whalley (1978b). This would apply to sample 1 (Fig. 2.4) from Montauk till which has been unaffected by transporting agents for thousands of years, apart from possible weathering agents. It may also apply to samples 19 to 22 (Fig. 2.4) from the shelf off-shore, depending on the degree of reworking by currents and the chemical effects of sea water.

In a study of pressure solution phenomena and quartz overgrowth in sandstones, Pittman (1972), found that in the early stages, secondary quartz formed small incipient blob-like overgrowths, or as isolated larger growths with well formed crystal faces. Such early overgrowth forms may form well developed larger crystals either by merging or overlap of overgrowth subunits, or envelopment of small subunits by a well formed masking outer shell (Pittman, 1972). Ultimately the quartz grain may adopt the form of a large crystal, an overgrowth, or syntaxical rim, in optical continuity with the original grain nucleus (Pittman, 1972).

An important contribution to S.E.M. studies of diagenesis in geologically young sediments was made by Tankard and Krinsley (1975). They divided solution features into those controlled by crystallographic structure and those that were independent of internal symmetry. Slow solution at high pH produced oriented triangular etch pits on trigonal faces and rhombohedral (almost rectangular) grids along rhombohedral cleavage planes. The textures formed nested structures, small forms occurring inside and sometimes sharing common sides with larger forms (Tankard and Krinsley, 1975). Solution along cleavage expressions produced parallel steps or deep oriented cavernous textures.

Those etchings independent of internal symmetry were located in weak, low density areas and they agreed with Krinsley and Donahue's (1968b), threefold stage cycle of solution (Tankard and Krinsley, 1975). Other textures described included expansion fracturing of chemically etched cleavage plates, branching furrowed networks and deep pits containing later cycle solution plates from high energy chemical environments (Tankard and Krinsley, 1975).

Reprecipitation textures of stacks, arches and caves and new crystal face growth were in optical continuity with the original grain structures (Tankard and Krinsley, 1975). A problem which is rarely described in depth in the literature, especially when viewing reprecipitation textures with an S.E.M. is how to distinguish between solution and precipitation textures, since both occur simultaneously on the grain surface (Krinsley, pers. comm). Tankard and Krinsley (1975), concluded that the amount of energy in the chemical environment was probably more important than the time factor.

Friedman et al (1976), studied quartz dissolution in the Red Sea and reported three kinds of surface textures.

(i) Oriented V shaped and prismatic patterns.

(ii) Spongy surfaces produced by increased etching and coalescence of depressions.

(iii) Non orientated irregular depressions produced by differential etching.

Waugh (1970), studied diagenetic textures in the Penrith sandstone, his stages of secondary quartz overgrowth being confirmed by Pittman (1972). Waugh (1978), described diagenetic textures in contrasting rock types: mineralogically immature first cycle arkosic alluvium from southwestern U.S. deserts to represent initial diagenetic phases, and mineralogically mature aeolian and fluvial Permian sandstones to illustrate the end products of diagenesis. Additional papers include the works of Werle and Schneider (1978), and Whitaker (1978). Whalley (1978c), proposed wet-ground silica particle dissolution as a method of supplying silica for cement and overgrowths in shallow seated sediments, as opposed to pressure solution.

As stated above, the problem of using diagenetic textures of ancient and geologically young near-surface sediments is their notorious unreliability as environmental indicators, especially when earth surface diagenesis may be compounded by weathering processes. Nevertheless ancient sediments may provide valuable surface texture assemblages that facilitate reconstruction of palaeoenvironments (Bull, 1981a).

This account of S.E.M. studies in the 1970's ends fittingly, with the efforts of Bull and his co workers and the development of a quantitative approach coupled with detailed statistical analysis.

In one of his earlier papers Bull (1976), adopted a 22 feature checklist devised by Margolis (1971), and Margolis and Kennett (1971), shown in Table 4.2. Presence-absence of grain surface features was noted and used to deduce conditions of deposition in Agen Allwedd cave and the palaeoenvironmental characteristics of the surrounding area. Bull's (1976), methods were based on the premise that, "certain surface features of quartz grains caused either by mechanical or chemical agencies are diagnostic of a particular set of energy conditions. Furthermore, those energy conditions were characteristic of particular environments, and when certain combinations of these surface features were present in statistically significant percentages, they became highly diagnostic of that particular environment" (Bull, 1976, p.7).

In a broader application of S.E.M. analysis to cave studies Bull (1977, p.16), postulated it was possible to deduce from a particular grain surface under study that, "it was initially subjected to glacial action, perhaps being eroded from the parent rock by glacial activity, and was deposited by the melting glacier, whereupon the sediment underwent the diagenetic process of amorphous silica precipitation. Erosion by a stream, perhaps of its channel banks, then led to the turbulent transportation and final deposition of the sand within a cave system, "much in the style of Krinsley and Smalley (1972).

In summing up, Bull (1977), called for more care during sample retrieval and preparation, and stressed the importance of statistically significant examinations by noting presence-absence of a range of textures on all grains under study.

Bull (1978a), took the checklist approach and subsequent statistical analysis several steps further in S.E.M. studies of cave sediments, still using the 22 features of Margolis (1971), and Margolis and Kennett (1971), (Table 4.2). The absence of previous cycle features on Millstone Grit sand grains was interpreted as a hallmark of the destructive efficiency of first and second cycle diagenesis and its associated solution-precipitation of euhedral quartz and amorphous silica (Bull, 1978a).

Surface feature variability plots of soil exposure textures showed abundances of rounded grains with medium relief, crystallographically oriented etched pits and crystal overgrowths, and second phase silica plastering (Bull, 1978a). Reference to Bull (1975), revealed the last texture to be a form of patchy amorphous silica precipitation, described by Krinsley and Doornkamp (1973), as indicative of diagenesis or glacial action.

Statistical analysis of cave sediments involved initial grouping procedures through cluster analysis, followed by linear discriminant analysis in order to test the degree of similarity or difference between groups and the statistical significance of such groupings (Bull, 1978a). Finally, multiple discriminant analysis was used in order to extend initial cluster analysis and subsequent L.D.A. and allow further categorization of previously unidentified samples. (Bull, 1978a).

In his conclusion, Bull (1978a,p.220), placed the role of quantitative analysis and statistical treatment in perspective when he stated, "The generalizations achieved by quantitative analyses do not substitute in any way the necessary descriptive analysis that identify the sequence of events upon a sand grain." However, "the quantitative method of analysis proved invaluable for evaluating trends which require the simultaneous assessment of 22 surface features on 20 sand grains in 50 samples." (Bull, 1978a, p.220).

In a study of late Pleistocene rock basin lakes in South Wales, Culver and Bull (1979), used semi-quantitative S.E.M. analysis to distinguish between lacustrine quartz grains with few disoriented V shaped impact pits and modern high energy subaqueous marine sands with higher MV densities. Both glacial and littoral-marine grains may produce one of the most contrasting surface feature assemblages that can be identified on quartz sand grains (Culver and Bull, 1979).

4.V SCANNING ELECTRON MICROSCOPY - POST 1981

In his conclusion, Bull (1981a), made several salutary comments regarding the degree of success achieved by S.E.M. sediment studies in the 1960's and 1970's. He pointed to the problem of instant results coupled with attractive photographs attracting the 'instant paper.' Attention was drawn to the importance of the subject's rationale, analytical and interpretative procedures (Bull, 1981a).

In particular, sediment type, grain size and sample size were important factors as well as the use of a reasonably large number of textures and their quantitative treatment. It comes as a surprise therefore to find workers disagreeing over the recognition and interpretation of such a well documented grain surface texture as hertzian cracks in the late 1980's.

In his reply to the criticisms by Johnson et al (1989), that certain textures found in St. Peter sandstone had been mistakenly interpreted as diagenetic in character, Grutzeck (1989), pointed out that it was impossible to tell the state or nature of the original sand grain surface before deposition and that Johnson et al had mistaken the findings because of the differing magnifications used. Johnson et al (1989), found it necessary to present an account of mechanisms responsible for hertzian and partial hertzian crack formation. A full hertzian cone crack extended downward and outward from the elastically deformed contact region at the point of grain to grain impact. Partial hertzian cracks did not form complete circles and dipped more steeply (Johnson et al, 1989). Grain surface morphology at the point of contact, relative grain motion, kinetic energy and internal grain structure were cited as important controls, partial hertzian cracks being ascribed to obliquely impacting irregular grains (Johnson et al, 1989).

Work in the late 1980's has focussed upon grain shapes (Mazzullo and Magenheimer, 1987; Haines and Mazzullo, 1988; Mazzullo et al, 1988). In a study of the original shapes of quartz sand grains in the 125 μm to 180 μm size range, Fourier analysis and S.E.M. were used to distinguish four types of quartz sand using 20 grains per sample (Mazzullo and Magenheimer (1987).

(i) Quartz from crystalline rocks - these had angular, highly non-spherical outlines with many crystal nodes, grain embayments and fractures produced by crystallization and deformation at high temperatures and pressures.

(ii) Quartz from wind transported rocks - such grains were highly rounded with abraded surfaces.

(iii) Quartz from quartz cemented sedimentary rocks -

these grains possessed moderately angular outlines with well defined quartz overgrowths. Such features were the product of cementation in deep burial settings.

(iv) Quartz from water transported sedimentary rocks with no secondary quartz cement - these grain shapes were relict and inherited from sources of the water transported sedimentary rocks. Such grain surfaces would not reflect the lithology or genesis of the present source and may be indistinguishable from quartz grains from other sources. The reason given for this relict character was that fluvial and marine subaqueous transport modes were incapable of sufficient abrasion levels (Mazzullo and Magenheimer, 1987).

The last point is of some importance to the present work in that samples have been scanned for grain shape, edge roundness and high energy breakages from the known source at Montauk Point (Fig. 2.4), to Democrat Point at the western tip of Fire Island (Fig. 2.3). Gradual changes in such features alongshore with increasing distance of transport would tend to conflict with the findings of Mazzullo and Magenheimer (1987).

Six textures were used in their S.E.M. analysis (Mazzullo and Magenheimer, 1987):

(i) Crystalline nodes - large blocky projections covering a quarter to one third of the grain surface with roughly crystalline shapes.

(ii) Grain embayments - large hollows forming the moulds of departed grain contacts.

(iii) Crescentic fractures (>10 μm approximately) - these resemble arc shaped steps and partial hertzian cracks.

(iv) Euhedral crystals - secondary quartz overgrowth.

(v) Oriented V pits.

(vi) Plastered amorphous silica.

Both features (v) and (vi) were associated with chemical weathering and did not influence particle shape. The percentage categories used to classify quartz grain types were:

Abundant - >75% of grains

Common - 25 to 75%

Rare - <25%

Clearly, Mazzullo and Magenheimer were more interested in textures which directly influenced grain shape, since many small fractures used by previous workers (Bull, 1978a, 1984), were not included. Further, their grain size range was relatively small and on these two points differs from the nature and aims of the present study.

In a similar vein, Haines and Mazzullo (1988), used S.E.M. analysis and Fourier series in the closed form to determine sources of terriginous silt in marine sediments. They distinguished four major silt producing source rock types which generated different and distinctive shapes and surface textures:

(i)a Weathered schists - first cycle quartz grains were subangular-subrounded forming a crystalline mixture possessing crystal nodes and embayments.

(i)b Weathered granite and gneiss - first cycle quartz grains were fractured with angular extremities. Such fractured grains were characterised by deformation sheets (thin lamellae formed by closely spaced sets of microfractures with subparallel and subplanar breakage surfaces), and fracture faces (reopened microfractures with broad subplanar surfaces and angular edges bounding grains). Elongate grains were characterised by two sets of crosscutting microfractures, while equant shapes possessed three crosscutting microfracture sets (Haines and Mazzullo, 1988). Conchoidal fractures were rarely observed on quartz silt.

Such weathered granite-gneiss fractured grains were produced by brittle deformation during faulting, folding or rock forming processes at or near surface temperatures and pressures (Haines and Mazzullo, 1988). On the other hand, the weathered schist grains were produced by late crystallization or recrystallization and subsequent crystal growth interference.

(ii) Quartz cemented sedimentary rocks - overgrown grains with subangular-angular outlines were formed by quartz cementation in the parent bedrock. Less abundant rounded grains were the product of aeolian abrasion which was the only mode capable of abrading quartz silt grains (Haines and Mazzullo, 1988).

(iii) Glacial moraine - fractured grains similar to those produced by first cycle weathered granite and gneiss exhibited deformation sheets and fracture faces, but the former were often ruptured to form microblocks (angular blocky fragments 5 to 20 μm). This agreed with Eyles (1978), who also found that microblocks characterised low level glacial moraine produced by glacial grinding.

(iv) Quartzose multicyclic sediments - many rounded abraded grains with weathered surfaces inherited from the previous cycle (Haines and Mazzullo, 1988).

They concluded that applications of grain shape analysis of terriginous quartz silt demanded a priori knowledge of the sedimentary source lithology and origin (Haines and Mazzullo, 1988). Further silt studies using S.E.M. analysis were carried out (Mazzullo and Peterson, 1989), one of which was based on surficial sediments on the northeastern shelf of the U.S.A. (Mazzullo et al, 1988). In both cases rounded, overgrown, crystalline and fractured grain types were used. In the continental shelf off north east U.S.A. Mazzullo et al (1988), recognised three end members:

(i) End member 1 - rounded and subrounded weathered silt characterised by solution-precipitation textures formed by weathering in the hot humid climate and organic rich soils probably derived from the Atlantic Coast Plain. Their dissolution features included oriented V pits and linear-curvilinear invaginations along preexisting grain defects such as partly healed fractures. Precipitation textures included peaked globules and flat or hummocky sheets of amorphous plastered silica (Mazzullo et al, 1988).

(ii) End member 2 - fractured angular grains derived from glacial tills.

(iii) End member 3 - crystalline grains and overgrown grains derived from the Appalachians.

In the papers mentioned above, there has been no mention of quartz cleavage as a phenomenon controlling grain shape and breakage features. Their findings at the end of the 1980's extend and support earlier work in the late 1970's on the nature and shape of small sedimentary quartz particles (Moss and Green, 1975; Smalley et al, 1978; Bull, 1978b). The mechanism of deformation sheeting as a form of fracture was proposed by Moss and Green (1975), by which a variety of quartz particle shapes were allowed to form depending on the degree of microfracturing during the latter stages of crystalline rock formation and possible subsequent brittle deformation and fracture.

Bull (1978b), described the presence of high energy breakages such as conchoidal fractures, breakage blocks, arcuate stepping, meandering ridges and randomly oriented scratches on equant silt sized quartz grains demonstrating that other mechanically induced processes other than glacial grinding may be used to explain such features.

Mazzullo and Magenheimer (1987), stated that subaqueous transport cannot effectively alter grain shape, whereas Blatt (1970), suggested that between sedimentary input and equilibrium outgo, sedimentary processes may reduce mean quartz grain size from approximately 670 μm (0.67mm or 0.6 Ø) to 60 μm (0.06mm or 4 Ø). This involved a reduction of 90%, the sand-silt size range reducing processes being known collectively as the Blatt interval.

Goudie et al (1984), in a study of the Tajik loess described rounding of small quartz particles by both mechanical (presumably aeolian) and chemical processes, although they did suggest that subaqueous mechanical modification may also be responsible for grain rounding.

Some attention has been paid to studies of smaller quartz grains in this survey because they clarify the nature of quartz microfracturing and have implications for the shapes of larger sand grains which form the samples under study. The 1980's was marked by a noticeable paucity in the numbers of S.E.M. studies of sand grains.

Aeolian environment studies continued (Hardisty and Whitehouse, 1988; Betzer et al, 1988; Greely et al, 1987). Simulations of extra terrestrial wind erosion continued with the work of Greely et al (1987), in a study of low velocity wind transport and erosion on Venus using the S.E.M. and a Kevex multichannel X ray analyser. Particle surface assessments were made using a Tencor Alpha step 200 profilometer accurate to within 5nm (Greely et al, 1987). Clearly improved technology has allowed the use of far more sophisticated tools as adjuncts to S.E.M. analysis and vice versa. Hardisty and Whitehouse (1988), introduced a new concept of grain transport known as impact induced gravity flow whereby vibrating grains energised by saltation impacts may move downslope on a dune into the wind which was responsible for the initial energisation.

Betzer et al (1988), during studies of the large scale A.D.I.O.S. project (Asian dust input to the oceanic system), reported an unusual natural phenomenon when over 83% of mass flux particles over 20 μm recorded on one occasion were mainly quartz particles over 75 μm. The mechanisms responsible for transporting such large particles over large distances were unknown.

Investigations into quartz solubility described the importance of other agents which had catalytic effects upon the rate and amount of dissolution (Morris and Fletcher, 1987; Callot et al, 1987; Bennett and Siegal, 1987). Morris and Fletcher (1987), found that reactions in the presence of iron compounds in tropical wet-dry conditions produced more rapid quartz dissolution than would be predicted from known quartz solubilities in water.

During the wetting phase of a cycle, normal reducing conditions produced ferrous reactions on quartz grains creating ultra-thin hydrous ferrous silicate reaction layers which limited further dissolution (Morris and Fletcher, 1987). During ensuing drying phases, oxidising conditions changed the hydrous ferrous silicate into ferric hydroxide and amorphous silica by hydrolysis, leading to a rapid release of silica, with quartz solubility reaching well beyond normal values by as much as a factor of 10 compared with amorphous silica. A return to wetting conditions caused the cycle to begin again (Morris and Fletcher, 1987). Thus, the chemically frosted character of desert sand grains as a result of precipitated ferric hydroxide may be the result of a reaction layer rather than a deposit or tarnish.

Callot et al (1987), attempted to show how weathering in cold, dry polar climates and deserts may be promoted by the synthesis of siderophores in the cell membranes of micro-organisms such as siderobacteria and siderofungi. Bennet and Siegal (1987), also favoured the presence of organic compounds as agents which facilitate quartz solution. They found that etched oriented triangles, pits and channels which were normally associated with very alkaline environments, may be produced in the presence of dissolved organic carbon obtained by biodegradation of a petroleum (Bennett and Siegal, 1987). They concluded that although it was commonly thought that the source of silica cement in sandstones was the dissolution of quartz grains by pore water with a high pH, or from pressure dissolution (pressolution), "organic acids formed by the biodegradation of marine or fresh water organic material could complex, mobilise and transport silica during diagenesis at neutral pH and near-surface environmental conditions" (Bennett and Siegal, 1987).

There were more broadly based studies in the mid to late 1980's e.g. Cater (1984), Goudie and Bull (1984), Bull (1984), Williams et al (1985). Cater (1984), used a checklist of twenty two features supported by texture superimposition indices and feature abundancies in order to unravel depositional environments of Neogene sediments. Samples of twenty microcrystalline quartz grains, 200 μm to 400 μm in diameter, were selected if they exhibited euhedral faces, the latter being thought to be products of first cycle weathering. Estimates of the percentage of each grain surface covered by each of the twenty two features were made as follows:

Abundance	Numerical Record
Absent	0
<10% Coverage	1
10-50% Coverage	2
>50% Coverage	3

The checklist was derived from previous workers and contained some features and combinations not reviewed so far (Cater, 1984). Conchoidal fractures were not size categorised and grinding collision possibly in a fluvial environment was represented by arc-stepped furrows (Cater, 1984). Mechanical V forms were categorised into shallow (<5 μm in diameter), shallow (>5 μm in diameter) and steep sided and deep (>5 μm).

Cater (1984), appreciated the importance of feature superimposition in attempts to unravel previous depositional and transportation episodes. To this end, thirteen criteria were described representing crosscutting relationships and the processes responsible, silica globules and flowers being ascribed to silica precipitation during transport (Cater, 1984). Subaqueous collisions were categorised as follows:

Process	Texture or superimposed Texture
High energy subaqueous (cushioned) collisions	V's >5 μm, highly abraded edges abundant grooves.
Moderate energy subaqueous (cushioned) collisions.	V's <5 μm, grooves and abraded edges present.
Low energy subaqueous (cushioned) collisions.	Few V's <5 μm, no abraded edges or grooves.

Bull (1984), and Goudie and Bull (1984), both used the check-list approach employing the same thirty four grain surface feature categories apart from feature 1 which changed from intensive cracks in Goudie and Bull (1984), to complete grain breakage in Bull (1984), as shown in Table 4.4.

Goudie and Bull (1984), used progressive edge abrasion as a discriminating texture in samples from colluvia in Swaziland and were able to develop a model of slope evolution on tors and grus from their results. They stated, "One surface feature, usually a

	Surface Feature Categories	
34	Chattermarks	chemical alteration
33	Euhedral silica	
32	Amorphous precipitated silica	
31	Carapace	
30	Scaling	
29	Solution crevasses	
28	Solution pits	
27	Dulled surface	
26	Anastomosis	
25	Oriented etch pits	
24	High relief	Grain relief and roundness
23	Medium relief	
22	Low relief	
21	Angular	
20	Subangular	
19	Subrounded	
18	Rounded	
17	Dish shaped concavities	mechanical breakages
16	Mechanical V pits	
15	Curved scratches	
14	Straight scratches	
13	Meandering ridges	
12	Fracture plates	
11	Adhering particles	
10	Imbricate grinding	
9	Parallel striations	
8	Arcuate steps	
7	Straight steps	
6	Conchoidals (>10 μm)	
5	Conchoidals (<10 μm)	
4	Breakage blocks (>10 μm)	
3	Breakage blocks (<10 μm)	
2	Edge abrasion	
1	Complete grain breakage	

Table 4.4 Checklist surface feature categories (after Bull, 1984).

rather minor texture, has proved to be of utmost importance in identifying not only a process change through time in each of the sections, but also serves as a very good differentiating factor...." (Goudie and Bull, 1984, p.294). They concluded that mechanically induced edge abrasion in colluvium may be effected over a distance of only a few hundred metres. Unusually, post depositional solution of quartz in colluvia was almost totally absent, despite severe weathering of feldspars and mica (Goudie and Bull, 1984).

In a study of sediments from Pontnewydd cave Bull (1984), used S.E.M. analysis to determine the palaeoenvironmental history of selected cave deposits. In his discussions Bull (1984), made the following points regarding grain surface texture interpretations:

(i) Whereas textures 3 to 15 in Table 4.4 represented glacially modified debris, a lack of features 7 to 15 in Table 4.4 which represent minor mechanical features argued against a well crushed, subglacial source.

(ii) Features 3 to 7 in Table 4.4(conchoidals and blocks) without features 7 to 15 were more likely to be indicative of provenance material. This supports Eyle's (1978), findings.

(iii) Euhedral silica was ascribed to a previous diagenetic phase of grain alteration.

(iv) Complete grain breakage was not a random event and developed only in response to specific environmental conditions such as those present during glacial grinding and ice loading, turbidity currents, or intense chemical activity. Since these did not apply at Pontnewydd cave, Bull (1984), postulated a debris flow transport origin during sediment emplacement within the cave.

(v) Small scale grain surface textures which recur together as minor assemblages and which would be unlikely to survive diagenesis were good indicators of last cycle transportation or depositional episodes.

Williams et al (1985), attempted to discriminate between dune, base of dune and beach quartz sand grains along Fire Island using a semiquantitative approach outlined by Setlow and Karpovich (1972). It was felt that operator variance was too great using such a method making results difficult to interpret reliably, although S.E.M. analysis had allowed a degree of differentiation based on semi quantitative results (Williams et al, 1985).

In a study of Long Island's south shore and offshore samples from beaches, the offshore glacial lobe and Fire Island dunes were analysed using a checklist approach and the results represent preliminary findings of the present study (Williams and Morgan, 1988).

Manickam and Barbaroux (1987), produced an interesting study using S.E.M. analysis where they attempted to distinguish between seasonal flow levels in the Loire river. Only a few large and small grains were obtained from suspension populations because of severe limitations during floods. Three grain types were selected for analysis:

(i) Type 1 - a small population of unbraded quartz grains with regular pits, fissures, cracks and silica slices derived from volcanic rock.

(ii) Type 2 - grains derived from soils with neogenic silica on one side and solution pits on the other.

(iii) Type 3 - V pitted grains of marine origin.

Those grains exhibiting dominantly physically induced textures were ascribed to winter floods where increased energy stirred the bed load into intermittent turbulent suspension. Such grains were more angular, with conchoidal fractures and other breakages (Manickam and Barbaroux, 1987). Those grains dominated by chemical textures were ascribed to summer low flow. Solution pits and vermicular textures were created by dissolution or chemical destablilisation when the pH was greater than 8.3 (Manickam and Barbaroux, 1987). Silica flowers, neogene silica coating and trapped diatoms were representative of chemical growth when pH was less than 8.

A useful evaluative study was carried out by Frihey and Stanley (1987), in order to interpret the nature of modern sand surface textures and to examine their usefulness in interpretations of the palaeoenvironmental origins of Holocene and Pleistocene sands from borings in the Nile Delta region. Samples were taken from what amounted to an environmental transect: desert – coastal dune – river – beach – nearshore sands – offshore shelf. Using a fifteen feature checklist they employed a semiquantitative approach whereby average percentages of feature counts on the fifteen grains in each sample were calculated, (Frihey and Stanley, 1987). Unlike other workers, they included adhering particles within those surface features ascribed to chemical processes in the checklist.

Highest percentages were used to represent those textures most indicative of their environment as follows:

Desert Dunes - high % of dish shaped concavities, solution crevasses, adhering particles, surface cracks and smooth precipitation surfaces.

Coastal Dunes - higher % of MV's, mechanical pits, conchoidal fractures and upturned plates than desert dunes, and the highest % of upturned plates, meandering ridges and flaking.

Rivers - highest % of MV's, mechanical pits, straight and curved grooves and adhering particles. River textures were most similar to beaches.

Beaches - highest % conchoidal fractures, oriented triangles and solution etching, and MV's and solution etching were dominant.

Nearshore sands - highest % dish shaped concavities with MV's, solution etching and adhering particles also dominating.

Offshore Shelf - highest % of mechanical pits, dish shaped concavities and solution-precipitation textures with MV's, straight and curved grooves and adhering particles also dominant.

Frihey and Stanley (1987, p.254), concluded that S.E.M. analysis was a useful technique in palaeoenvironmental interpretations, "where mature sands are usually devoid of mineral, faunal and floral components diagnostic of specific depositional settings."

Hodel et al (1988), attempted to use similar principles to those employed by Frihey and Stanley (1987), in the sense that they studied progressive textural changes on sand grains from unmodified relict-glacial types to those influenced by increasing aquatic and aeolian abrasion and chemical action. They employed a subjectively devised eightfold grain-type scale representing successive stages of change (Hodel et al, 1988). Their relict-glacial type exhibited angular sharp outlines with high relief and high energy fractures such as arced steps, conchoidal fractures, parallel steps and large blocks.

They concluded that increased abrasion was a product of increased fluvial transport and that grain fractures were related to both moderate littoral and ice related sedimentary processes (Hodel et al, 1988).

The 1980's were marked by a more varied application of S.E.M. analysis as technological improvements allowed new areas of study to open up. Bull (1981b), attempted to reinforce the proven ability of S.E.M. analysis in grain surface studies by applying it to environmental reconstruction in archaeological sites. The micromorphology of phytokarst developed in cave entrances in Sarawak was revealed in greater detail casting more light on its formation (Bull and Laverty, 1982).

Computerised image analyses of T.E.M. and S.E.M. micrographs were used to reveal the complexities of clay and carbonate sediment fabrics and porometries, such approaches possibly proving useful in the future for quantifying fabric parameters and providing a statistical basis for fabric descriptions (Bennett et al, 1989). Henrich et al (1989), used dissolution studies of the foraminifera N.pachyderma in order to interpret glacial-interglacial cycles in sediment facies in the Norwegian Sea. Mairette et al (1987), used S.E.M. analysis to analyse Greenland ice micrometeorites in a study of extra terrestrial dust from the Greenland ice cap.

The use of back scattered electrons (B.S.E.M.) and E.D.X.A. analysis to study thin polished sections of sedimentary rocks by Pye and Krinsley (1984), continued to develop.

Quate (1988), reported the development of electrons that make waves and the advent of scanning tunnelling microscopes (S.T.E.M.'s). These are high resolution devices that trace grain or metal surface form using an atomic scale tip to reveal atomic and molecular details. Pethica (1988), described the S.T.E.M. as possibly one of the principal gedanken tools for nanotechnology i.e. the proposed direct manipulation of matter, especially biological, on the atomic scale. However such innovations are of fringe interest at present as far as sedimentological studies are concerned.

An important paper examining a single feature in detail was that of Middleton and Kassera (1987), which related MV abundance not only to sediment transporting processes, but also to grain size. As far as intertidal sand bars were concerned MV abundance and density were probably related to tidal currents rather than to wave activity

(Middleton and Kassera, 1987). Owing to the time consuming method of MV quantification their results were based on a single sand sample, which brings to mind the cautionary note reiterated by Bull (1981a), regarding the importance of statistically significant percentages of grain-feature combinations as a basis for interpreting results with any confidence.

They found that consistent operational procedures, size of the measured area, magnification and grain size were important controls of MV density values (Middleton and Kassera (1987). Grain angularity - roundness did not appear to significantly influence V density. MV density increased with grain size increase from medium to coarse sand, however after a critical grain size, MV density trends flattened out (Middleton and Kassera, 1987), to form a plateau.

The cause of such a plateau in MV densities was postulated to be a product of the degree of exposure of grains to impacts in the zone of concentrated grain dispersion found in flows close to the bed, rather than of the turbulence (Middleton and Kassera, 1987). Grains of this critical size were sheltered by larger grains when not in motion, while large grains spent less time in suspension close to the bed. Finer grains spent more time in suspension reducing grain impacts at the upper levels of concentrated grain dispersion (Middleton and Kassera, 1987).

An important paper validating the use of a multifeature checklist approach was produced by Culver et al (1983). Five S.E.M. operators studied eight coded samples using thirty two grain surface features. Subsequent canonical variate analysis was able to discriminate between all samples (Culver et al, 1983). It was found that no single grain surface feature was able to achieve such discrimination, rather thirteen variables were found to be important upholding the contention that surface feature combinations were desirable in sand grain surface texture studies (Culver et al, 1983). Their results also showed that while operator variance may be considerable during surface feature recognition, providing strict operational procedures were adhered to such variance was negligible in sample discrimination using binary data (Culver et al, 1983).

Williams and Scott (1985), also attempted a statistical analysis of sedimentary statistical parameters (moment measures) of sand suites from five known environments - beach, dune, washover, flood tidal inlet and flood tidal deltas from Long Island's south shore barrier chain. Using the Mahalanobis D^2 statistic,differences could be detected between all environments, but linear discriminant analysis, although only partially successful for distinguishing between water based environments, for aeolian/aqueous differentiation was 100% successful (Williams and Scott, 1985).

Finally, Williams and Thomas (1989), used a thirty six feature checklist in order to discriminate between five Long Island south shore environments: Washover fan, Inlet, Flood tidal delta, Aeolian and Beach. A sample from the buried offshore palaeodrainage channel H (Huntington - Islip Channel in Fig. 2.3), and from adjacent offshore sediments further west were included in the S.E.M. analysis in order to examine the possibility of a generic link with nearshore samples (Williams and Thomas, 1989).

They attempted a more subtle subdivision of grain surface morphology by categorising grain surface relief from very high to smooth on topographically positive and in topographically negative areas (Williams and Thomas, 1989). Presumably the superimposition of small final cycle textures (both mechanical and chemical in origin) upon inherited gross grain relief were more likely to be detected and as Bull (1984), pointed out, such minor textural assemblages would be unlikely to have survived diagenesis and would provide good indicators of the most recent events.

Williams and Thomas (1989), also employed concave upward and convex upward conchoidal fractures with an edge abrasion categorisation ranging from cracks to mild abrasion, but did not include late stage complete grain breakage in their checklist.

Their Montauk beach sample exhibited a predominance of angular grains (70%) with only 20% rounded grains. Cracks were abundant (76%) as were MV's and large blocky topographic development was reported (Williams and Thomas, 1989). Offshore lobe deposits (Channel H in Fig. 2.3) contained a mixture of angular, spherical and elongate grains, reduced edge abrasion and MV's.

In an attempt to relate grain surface textures to causal mechanisms, Williams and Thomas (1989), were confronted with the same problems as previous workers in the 1970's and 1960's, viz: the lack of substantive research into the relationships between grain transport, grain-grain interaction and resultant surface features as far as subaqueous environments were concerned. The publication of 'Clastic Particles' edited by Marshall (1987), placed S.E.M. grain research on a more rigid and quantifiable footing, in the same way as the publication edited by Whalley (1978a) had in the late 1970's.

There is still uncertainty as to the precise nature and degree of development of grain surface textures and their relationships to hydrodynamic parameters such as flow conditions, shear stresses and transport stages for grains from subaqueous environments. The greater ease with which aeolian simulation experiments may be controlled has led to far more experimentally verified work within that field, as has already been described above.

SUMMARY

In the 1960's T.E.M. and later S.E.M. studies opened up a new field of grain surface research allowing hitherto hidden grain characteristics to be observed and attractively portrayed by electron micrographs. The trails made by pioneering workers such as Krinsley and Takahashi (1962a, 1962b, 1962c, 1962d), Krinsley et al (1964), Biederman (1962), and Porter (1962), have had a great influence on later research. Bull (1981a),described the many diverging strands of S.E.M. research in its two first formative decades.

There has been a hiatus in the popularity of S.E.M. studies since its peak in the early 1970's and a survey of the literature in the 1980's shows only sporadic increases of interest (Bull, 1984; Culver et al, 1983; Goudie and Bull, 1984; Goudie et al, 1984; Middleton and Kassera, 1987; Williams and Morgan, 1988; Williams and Thomas, 1989). In most of these works, the quantitative approach and subsequent statistical analysis called for by Bull (1978a) is evident.

The late 1980's has witnessed an increase in grain shape and particle microfracturing studies through the work of Mazzullo and

Magenheimer (1987), and Haines and Mazzullo (1988) and others. However, the superabundance of subaqueous deposits in the geological record demands that S.E.M. studies must provide the sort of grain surface feature - causal mechanisms data for subaqueous deposits and other deposits as for aeolian environments, if it is to survive into the next decade with a creditable future. Up to now, the severe difficulties involved in duplicating marine, fluvial and glacial processes have been a major stumbling block.

CHAPTER 5

METHODOLOGY

METHODOLOGY

5.I INTRODUCTION

Studies of sedimentary particle characteristics have long been an integral part of Sedimentology and Geomorphology in general and coastal studies in particular. Not only do particle properties lend themselves readily to techniques of accurate measurement and statistical analysis, but it has long been considered that results allow workers to distinguish between sedimentary environments and their sediment types (Culver et al, 1983; Mazzullo and Magenheimer, 1987).

Properties such as particle shape, as well as mass properties such as fabric, porosity and permeability are well known. Mineral content has also been used as an indicator, not only of sediment source, but also of the history of transportation and deposition. As early as 1933, Rubey showed that heavy mineral percentages depended upon the nature of depositional processes and grain parameters such as size, density and shape.

The last three decades have witnessed a revolution in the development and application of microtechnology as a tool in the observation, description, analysis and interpretation of sedimentary particles. This has proceeded hand in hand with the development of computers, ushering in a new age in the field of particle measurements and their quantification hitherto considered impossible. An explosion in the amount and variety of data stimulated the introduction of the statistical techniques needed to make sense of a growing mass of information. Previously hidden patterns and relationships were discovered, old theories and models discarded or strengthened, and new ones postulated. The net result has been a more scientific approach and a more rigorous, quantifiable body of theory.

The present study has its roots in the 1950's and 1960's with the development of Transmission Electron microscopy and later the Scanning Electron microscope. Workers like Krinsley and Takahashi, (1962a, 1962b, 1962c) pioneered S.E.M. techniques in grain micro-texture analysis which have been expanded and developed in the 1970's and 1980's(Bull, 1978a;1984.) The present study has used S.E.M. techniques in an attempt to discriminate between sediment samples taken from mid-tide locations along Long Island's south shore, from glacial bluffs at Montauk Point, and from sites proximal and distal to buried channel glacial deposits offshore (Fig. 2.3 and Fig. 2.4).

5.II SAMPLE SITES

Choice of sample sites was determined by and designed for a decision to investigate the possibility of onshore sediment transport from offshore sources on the continental shelf to the south as described in Chapter 3 on sediment sources.

The inherent problem in sample site choice was to obtain 'known' distinctive examples of quartz sand grains from an offshore source. Because of the similarity which existed between offshore sediments and onshore beach grains in general (Taney, 1961b), it was decided to use grab samples from glacial-fluvioglacial sands preserved in a buried palaeodrainage channel. These are samples 20 and 21 taken from Channel H, the Huntington-Islip channel (Fig. 2.3.), described by Williams (1976). Distinctive glacial textures

(Krinsley and Doornkamp, 1973), which may be preserved on grain surfaces, may appear as 'intruders' within normal beach textures characterising onshore sand grains.

In order to assess the dynamic changes in quartz, sand grain surface textures westward from Montauk Point, a second 'known' sample type (Sample 1), was taken from the moraine bluffs in the Headlands section (Fig. 2.4), the erosion of which by wave action has been claimed to be the principal sediment source for beaches downdrift (Taney, 1961a; Williams, 1976; Panageotou et al, 1985). These grains would represent 'known' glacial deposits from the Ronkonkoma terminal moraine and associated Montauk Till (Rampino, 1978). It was surmised that Channel H sand grains (Samples 20 and 21), although of glacial or fluvioglacial origin (Williams, 1976), would differ from Sample 1 grains by virtue of the fact that they had been buried offshore in a marine environment or may have been partially reworked, or may even have been derived from a different source rock in the first place.

Samples 19 and 22 (Fig. 2.3), were taken from locations on either side of Channel H sand grains and as a second offshore sediment type for comparative purposes with onshore grains.

Samples 2 to 18 represent surf abraded beach grains between Montauk Point and Democrat Point (Fig. 2.4). According to Krinsley et al (1964), the high relief and coarse breakages which characterised Ronkonkoma moraine bluff sediments were progressively removed by abrasion during transport westward. Of the smaller breakages which replaced them, gradually rounding edges and mechanically smoothing grain surfaces, V shaped impact pits were the most obvious and easiest to quantify (Krinsley et al, 1964).

If such progressive changes did indeed take place, samples 2 to 18 should reflect a changing textural continuum from 'known' glacial moraine to beach environments. East of Fire Island, samples were taken at regular intervals (samples 2 to 7 in Fig. 2.4). As the offshore location of Channel H (Fig. 2.3), was approached in central Fire Island the intervals at which samples have been taken are smaller increasing the probability of onshore samples 'showing up' offshore glacial lobe grains. These included samples 8 to 18 (Fig. 2.4).

This sampling design produced two 'control' textural assemblages in the forms of sample 1 (terminal moraine), and samples 20 and 21 (Channel H, glacial lobe deposits), with a progressively changing beach textural continuum between them (samples 2 to 18). Any upset in the beach textural continuum in central Fire Island (samples 10 and 11 onshore from sample 19; and samples 13 to 16 onshore from samples 20, 21 and 22), by the introduction of glacial textures, would suggest an onshore sediment transfer from Channel H lobe deposits.

Mid-tide locations were chosen for beach sample sites as the most representative of the intertidal foreshore zone actively worked by surf during successive tides (Bascom, 1954; Williams, 1971). In all cases samples were obtained several centimetres beneath the beach surface, the scooped material being bagged and labelled for laboratory preparation. Sample 1 (Montauk Bluff, Fig. 2.4), was taken from fresh material in the moraine cliff face and samples 19 to 22 offshore were provided by courtesy of J. Williams which he obtained in association with his study of the inner continental shelf south of Long Island (Williams, 1976).

5.III GRAIN PREPARATION

Grain preparation techniques used to clean and mount samples were those outlined by Krinsley and Doornkamp (1973). About 300 to 400 sand grains were selected from the +1ø sieve size (500 μm or 0.50mm), for each of the 22 samples (Krinsley, pers. comm). Sediments were sized using standardised sieve sizes which can be converted into the phi (ø) scale in which: $\phi = -\log_2$ grain diameter in millimetres, using readily available conversion charts (Tickell, 1965). In the case of the present study it was important to obtain grains of the same size, as different sized grains may behave differently in transporting media and textures would vary as a result (Krinsley et al, 1976). Margolis and Krinsley (1971), found that frosting of experimentally abraded grains in an aeolian medium increased with grain size, upturned plates being formed only on grains smaller than 200 μm (<2.3 ø). In a study of mechanical V pit densities, Middleton and Kassera (1987), randomly selected grains from a range of -1ø to 2ø (250 μm to 2mm).

Prior to mounting, grains were cleaned by boiling in dilute hydrochloric acid after which they were washed in distilled water and boiled in concentrated stannous chloride before a final wash in distilled water. The treatment for each sample lasted about ten minutes by which time extraneous, loose surface deposits had been removed. Grains were then left to dry.

As a rough and ready guide to the verification of unicrystalline quartz grains, portions of each cleaned sample were viewed under a petrological microscope. Grains were arranged in rows on a slide and the table rotated with crossed nichols. It was not possible to use normal thin section techniques in order to observe quartz's commonly undulatory extinction, because of the irregularity of grain shape, dimensions and random orientation of crystallographic axes. However, it was found that rotation produced a regular extinction pattern of the whole of most grains, whereas polycrystalline grains showed more than one extinction pattern, and these were out of phase with each other in different parts of the same grain. Such grains were discarded.

The reason for this unicrystalline selection technique was based upon the notion (Krinsley and Takahashi, 1962a), that unnecessary complexities may occur along crystal boundaries in polycrystalline grains, since breakage patterns and chemical etching/ precipitation were crystallographically controlled. During microscope examination other grains considered to be non quartz were also discarded.

Culver et al (1983), have stressed the problems of operater variance and subconscious, subjective operator bias in S.E.M. analysis. It was felt that even at this stage, great care had to be exercised in the choice of grains from the microscope slide plate. A preference for one particular grain size, shape or lustre compared with others on the table was avoided by choosing each grain in sequence as they were tested for unicrystallinity. This removed one more small step in the analysis open to the possibility of subjective operator bias. Had unicrystalline properties been determined en bloc in the first place and then followed by grain choice, results for grain shape etc. may have varied.

Quartz grains were chosen in preference to others because of their mechanical and chemical resistance to breakdown (Bull, 1981a), which would preserve textures inherited from upbeach or from a previous depositional environment. In addition, the absence of a well developed cleavage in quartz crystals would produce a series of textures which could be related more strongly to energy regimes and environmental processes rather than the degree of crystallographic control and as such have been used by many workers (Bull, 1978a; Krinsley and Doornkamp, 1973).

Twenty five unicrystalline quartz grains were mounted on an aluminium stub with the aid of tweezers and a magnifying glass. They were arranged in a grid of 5 x 5 on a square of double sided adhesive tape, the origin being marked by a blob of silver conductive paint at the top left hand corner. This allowed grains to be viewed in sequence beginning with number 1 (top left), and horizontally in rows ending with number 25 (bottom right), grains being numbered in ascending order from left to right in each row. Such a grid allowed each grain to be identified at a later date from notes, should photographs or extra examination be necessary.

The non-conductive nature of quartz grains necessitated sputter coating using an eccentric rotating table inside a vacuum chamber. A layer of about 40 $\mathring{A}$ of gold would conduct a build up of surplus electrons on the specimen surface to earth. If earthing does not occur grain surfaces become negatively charged, distorting and repelling incoming primary electrons. This would excite secondary electrons emitted from grain surfaces, producing a glowing distorted image on screen.

Once mounted, the identification of each of the 22 samples was kept hidden from the operator and an alphabetic code used to remove all possibility of accidental discovery of sample stub identity. Such double coding has been recommended (Culver et al, 1983), as being essential to remove subconscious subjective operator bias in ascribing pre-held notions of textures to known sample sites.

Finally, before scanning each sample, grains were verified for their quartz composition using an Edax Links Systems 860 Energy Dispersive Analyser.

Since the early 1960's, when Krinsley and his co-workers pioneered T.E.M. and later S.E.M. techniques, there has been debate on the appropriate sample size needed to produce statistically significant results. Early work was often devoted to exploring the possibilities and establishing the applications of S.E.M. analysis in order to determine whether sand grains could be useful in the study of sand deposit origins and histories (Krinsley and Takahashi, 1962a, 1962b, 1962c, 1962d). At that stage, 12 grains or so per sample were considered to be satisfactory (Krinsley and Takahashi, 1962a).

By 1968 Margolis was using 50 grains per sample in his attempts to examine possible correlations between wave energy and sand grain surface textures (Margolis, 1968). Later workers used a variety of sample sizes: Hey et al (1971), 35 grains; Coch and Krinsley (1971), 10 to 15 grains. Bull (1978a), stated that the number of grains 'generally used' (15 to 20), would be sufficient.

The number of grains used per sample in this study is 25. This was considered to be sufficient (Krinsley pers. comm.), although some recent workers (Cater, 1984), have used smaller samples (20 grains), on the grounds that this was permissible if grains had a known common origin and probable single cycle of deposition. Middleton and Kassera (1987), used 15 to 20 grains.

Clearly, there should be a rationale established to determine sample size. A factor rarely mentioned, with the exception of Bull (1978a), is the combination of grain number and feature number if using a checklist approach. Even if a statistically significant sample size were established, how could the results for an optimum number of grains scanned for 20 textures be compared with the results where fewer grains were scanned for 40 textures, or more grains scanned for 15 textures?

The present study used 25 grains per sample to scan 40 textures per grain, which amounted to 1000 observations per sample. Questions regarding grain number and checklist texture number need careful thought and close liaison between workers in order to devise formulae that may be applied to S.E.M. analysis of different sediments for different purposes.

5.IV SCANNING PROCEDURES

IV.A INTRODUCTION

Bull (1981a), has presented a detailed survey of the trends, methods and cautionary criticisms associated with S.E.M. analysis development. New workers in the field have either received tuition in S.E.M. analytical techniques from established proponents as part of their studies, or have acquired expertise at a later date through liaison with, and involvement in projects involving S.E.M. analysis. The stages undertaken in this project were:

(i) Methods, techniques and background information were obtained from previous research work published in journals, magazines and textbooks. This stage tended to throw up more questions than answers by virtue of the diversity of methods and techniques and proliferation of terms which different workers in different countries have used in the last twenty years.

(ii) Grain samples from Fire Island dunes and beaches were scanned over a period of time in order to develop accurate and efficient techniques. A major problem for a new worker in the field was that precise details of techniques were difficult to establish e.g. feature recognition at different scales, scanning sequences, optimum tilt of the stage, desirability of stage rotation, use of the graticule and the cost in time of different techniques. Many photographs were taken at this stage and compared with published examples of grain textures.

(iii) Established workers in the field of S.E.M. analysis were visited and some training was given with 'hands on' experience. At this point it was possible to confirm existing ideas, the recognition of features and more complex textures and the viability of different approaches. Misconceptions were exposed and discarded. It is important that this stage continues throughout a research project, as there is no substitute for up to date discussion with other workers in the field in order to obtain constructive criticism and contrasting opinions. However, the prospect of scanning 40 textures on 450 grains meant that once designed, the study's scanning procedures could not be changed mid-stream.

IV.B CHECKLIST APPROACH

During preparatory training scans of Fire Island dune and beach grains, a routine was developed in which the order of textures and appropriate scales was established for each grain. It was found to be important that textures were arranged in descending order of the magnification needed (ascending scale) and families of textures were grouped together (Table 5.1). In order to do this, size ranges for all textures had to be determined from the literature and established S.E.M. workers and the appropriate magnifications at which each texture size could best be viewed.

The result determined checklist orders as seen in Table 5.1. Grain shape, edge shape, relief and large breakages (Features 1 to 23 in Table 5.1) may be viewed satisfactorily from the smallest magnification (x 20), up to medium magnification (x 500). Occasional increases in magnification were needed for the presence of certain textures, e.g. edges polished mechanically by small scale breakages; cracks; steps and scratches.

Once large scale features were scanned at low magnifications, medium and small scale features were scanned using 'left to right' sweeps across each grain from top to bottom. It was found necessary to regularly switch to low magnifications to determine overall major

QUARTZ GRAIN SURFACE TEXTURES IN MAIN CHECKLIST SCAN

TEXTURE NO.	TEXTURE DESCRIPTION
GRAIN SHAPE	
1	Very Angular
2	Angular
3	Sub-Angular
4	Sub-Rounded
5	Rounded
6	Well Rounded
EDGE SHAPE	
7	Edge Abrasion
8	Angular Edges
9	Sub-Angular Edges
10	Sub-Rounded Edges
11	Rounded Edges
RELIEF	
12	High Relief
13	Medium Relief
14	Low Relief
LARGE BREAKAGES	
15	Late Stage Complete Grain Breakage
16	Cracks
17	Large Conchoidal Fractures
18	Large Blocks
19	Large Smooth Flat Fractures
20	Medium Conchoidal Fractures
21	Meandering Ridges
22	Steps
23	Large Scratches
SMALL BREAKAGES	
24	Small conchoidal Fractures
25	Small Blocks
26	M.V's.
27	Small Straight Grooves
28	Small Arcuate Grooves
29	Chatter Marks
CHEMICAL FEATURES	
30	Large Solution Pits
31	Very Coarse Etching
32	Coarse Etching
33	Fine Etching
34	Amorphous Precipitation
35	Very Fine Precipitated Particles
36	Euhedral Precipitation
37	Oriented Solution - Precipitation Surface
38	Adhering Particles
39	Dulled Surface
40	Oriented Triangular Etch Pits.

Table 5.1. Checklist textures and surface feature groups used in the main checklist scan.

textures, in order to appreciate probable locations of small scale textures and their relationships. Magnifications needed to view certain textures such as cracks, mechanical V pits, euhedral precipitation and oriented triangular etch pits did not always match the advice given by established workers. In some cases, increased magnifications (x 2000 or more) were necessary to verify relationships.

Clearly, the amount of magnification determined lengths of scanning time needed for each grain, since increased magnification decreased the field of view, ensuring that more sweeps were needed. Although an apparently mechanical procedure which may be taken for granted at the onset of scanning, it took some time and planning to ensure that small scale textures were not omitted during horizontal sweeps across grains. Several grains were viewed twice during the training scan and values compared in hindsight to ensure that results were consistent.

Similar principles were applied to scans of chemical textures (Table 5.1). Large solution pits, coarse etching and dulled surfaces could be scanned at low or medium magnifications (whole grain x 50), and part grain (x 200). Some features had to be scanned at much higher magnifications owing to their small sizes, e.g. fine etching, euhedral precipitation, oriented triangular etch pits etc., (Table 5.1). One difficulty which was met during the main scan was that some textures varied a great deal in size and hence in the magnification needed to establish presence or absence. If anything, the main checklist scan in this project erred on the side of too high a magnification, which increased the cost in time but guaranteed that textures were absent given some operator variance, when recorded as such.

Detailed notes were made during checklist scans in order to establish background detail and textural relationships which could help to reveal grain history. Important trends, patterns and textures were noted so that they could be reexamined at a future date for photographs or measurements using the grain grid system.

The checklist approach has been adopted because it lends itself to quantitative analysis using multivariate statistical techniques (Bull, 1981a; Culver et al, 1983). Checklist scans record the presence or absence of textures, recording the information as 1 (present), or 0 (absent). The creation of two such values (1 and 0) has led to results being referred to as binary data (Bull, 1978a). The method is a valid approach with proven techniques (Culver et al, 1983).

The use of as many as 40 textures in a checklist creates a large net which may uncover unexpected textural discriminators hitherto considered relatively unimportant in previous studies. Providing that feature recognition is accurate and consistent, checklist scans produce raw data which accurately represents the grain population, within the limitation of the checklist design.

Subsequent interpretation of the raw data depends upon many factors, such as the nature of the statistical techniques employed, how they are related to environmental regimes specific to sample site locations, and not least, the validity of each texture as an environmental indicator of grain history. Nevertheless, if analytical procedures proved to be erroneous, the raw data still provides a basic quantitative record of samples which can be used in other ways to yield results.

The recording of only presence-absence allows the absence of textures to enter analyses. What is not present may be as significant as what can be seen and may be used in interpretations of grain history using environmentally diagnostic textural assemblages generated by other workers. A checklist approach must be qualified by making detailed notes in order to identify feature dominance, position in texture cycles and as a record of important general trends and patterns within each sample. In the same way, photographs are an important backup and visual record of samples and allow more detailed observations and measurements to be made.

An alternative contrasting approach is to use a single texture, or small group of textures and to trace their variations from sample to sample (Krinsley, pers. comm). Such an approach would have advantages in view of its simplicity and because it would contribute more specifically to the success or failure of individual features as environmental indices. The choice of a texture such as mechanically formed V pits and a study of its size and density variations could be related to other parameters such as wave energy (Krinsley, pers. comm).

Although V shaped impact pits have been identified for multiple discriminant analysis as being a major discriminatory texture (Bull, 1978a),individual textures have been considered to be of little use as palaeoenvironmental indicators (Bull,1981a). Many workers have stated the importance of suites of textures as environmental indicators (Margolis and Kennett, 1971), and when combinations of surface features have been examined statistically, sand grains from glacial environments may exhibit unique combinations of characteristics (Margolis and Krinsley, 1973).

Other semiquantitative techniques were tried out in the training scan, especially those based upon the work of Setlow and Karpovich (1972). They ascribed arbitrary value scales to the qualities of degree of development and area of development of 22 microtextures on each grain (Williams et al, 1985). It was found that there were many operator problems involved in putting such a procedure into practice which would result in a lack of consistency in results. It would have been difficult to place any confidence in the semi-quantitative results so obtained.

A great deal of emphasis was placed upon the work of Krinsley and Doornkamp (1973), and on checklist textures in Bull's work (Bull, 1978a; 1984), and the work of others (Culver et al, 1983; Goudie and Bull, 1984).

Features were arranged in the checklist according to ease of viewing from low to high magnifications, as well as in crude genetically related groups (Table 5.1). Features 1 to 6 (grain shape), and 12 to 14 (relief), represented morphological attributes; features 7 to 11 (edges), and features 15 to 22 (breakages) represented mechanical modifications. Remaining textural features (29 to 40), represented chemical modifications (Goudie and Bull, 1984), with the exception of adhering particles (38).

Any probelmatical textures such as chatter marks (Bull, 1977), were placed between groups.

The practice of confining S.E.M. analytical designs to procedures and parameters developed by tried and tested methods has been well established. If we apply this analogy to the use of checklist textures, the type and number of textures used in new projects would be strongly influenced by the practices of established workers in that field, viz. Krinsley and Doornkamp (1973), Whalley and Krinsley (1974), Le Ribault (1977), Bull (1978a, 1984). On the basis of advice from established workers (Grant, Whalley, pers. comm.), it was decided to allow sample characteristics to have an influence upon texture choice.

Edge shape (features 8 to 11), and oriented solution-precipitation surfaces (feature 37), in Table 5.1 were introduced specifically for grains from the study area. During the training scan, new site-specific terms were devised to describe textures, or varieties of textures which were peculiar to Fire Island beaches. It was felt that this allowed sand grains to throw up textural varieties which characterised them, rather than to impose a net of textures derived from different sediments in a different region. In the event, few survived the finished checklist, but have been used to illuminate grain history interpretations in the section on Results which follows this chapter.

(a) Grain Shape

Grains were scanned for roundness (surface textures 1 to 6), using Powers' (1953), roundness scale. A selection of sample grain roundnesses have been presented in Plates 5.1 to 5.6. On the basis of shape alone, it is almost impossible to interpret the history of a particle (Friedman and Sanders, 1978). However, glacial grain shapes have been described as being irregular and jagged (Hey et al, 1971; Krinsley and Hyde, 1971; Krinsley and Doornkamp, 1973). On a cautionary note, glacial grain shapes may be duplicated in other sedimentary environments of deposition or in grus (Margolis and Krinsley, 1973), and glacially transported grains may, in some cases, have escaped grinding (Whalley, pers. comm.).

The viewpoint adopted in this project is that glacial grains do not in general possess rounded shapes, but are characterised by irregular, jagged and variable outlines. Grains from Ronkonkoma moraine at Montauk Point (Fig. 2.2), making up sample 1 (Fig. 2.4), and those from offshore glacial or fluvioglacial sediments preserved in buried palaeodrainage Channel H (Fig. 2.3), should exhibit more angular outlines than those from onshore beaches.

Krinsley et al (1964), found that irregular edges and grain surface relief typical of moraine-derived grains at Montauk Point were smoothed by the superimposition of small breakages such as mechanical V pits as they were transported westward. Combellick and Osborne (1977), found that beach grain surfaces showed a high degree of rounding associated with small breakages and impact pits.

It is assumed in this project that normal processes of attrition and corrasion take place as grains collide in the surf. This would cause breakages and pitting of protruding edges and corners, rounding and smoothing grain shapes on a small scale. As a result, beach grains from distances well downdrift of Montauk Point (Fig. 2.2), may be reasonably expected to have slightly rounder shapes which may be detected in a checklist scan.

A point of interest regarding grain shape is that, after discussions with other workers (Grant, Krinsley), it is possible that some of the samples may be derived from a rather distinctive source of stressed metamorphic rock located in New England to the north. Grains in the initial scan were observed to have a wide variety of shapes, and Bull (1978a), has drawn attention to the importance of stress patterns in first cycle quartz as initiators of microfractures which may control particle shape, roundness and size.

(b) Edge Abrasion and Edge Shape

Edge abrasion has been universally recognised as a feature of grain to grain collisions during turbulent or high energy transport modes. The processes of attrition and corrasion result in progressive rounding and smoothing of grain surfaces with increasing distance of transport (and time) in the surf.

Plates 5.7 to 5.12 show varying types of abrasion at work on grain edges from selected samples. Even at a superficial level it is clear that edges vary a great deal in the amount and type of abrasion which they suffer. Some exhibit very angular shapes, modified by medium and large breakages, the latter being modified themselves by smaller impact pits (Plate 5.8). A more advanced, more mature stage of edge abrasion (Checklist feature 7 in Table 5.1), is shown in Plate 5.9. In both cases, small breakages are a distinct suite separate from larger breakages, the latter producing high grain edge relief and the former working to reduce this.

It was assumed that beach grains would show ubiquitous edge abrasion, whereas glacial grains (Samples 1, 20 and 21 in Fig. 2.4), would throw up some grains which had not suffered any degree of abrasion. Backup notes would illuminate the nature and degree of edge abrasion types and maturity when interpreting the results.

Edge shape was included for several reasons. During the initial scan and as a result of discussions with other workers (Grant and Krinsley), many grains showed a wide variety of shapes and edge types, possibly derived from a strained source rock. This may be reflected in edge shapes. Also, it was felt that edge abrasion alone would not have been a good environmental discriminator for most of the beach samples since it was expected that virtually all grains would have exhibited this texture to a greater or lesser degree.

Edge shapes (checklist textures 8 to 11 in Table 5.1), were introduced as a refinement-backup to Edge Abrasion and are shown in Plates 5.13 to 5.20. Angular edges would be associated with grains which had suffered high energy breakages, or which had crystallographically controlled faces intersecting at sharp angles. Rounded edges would be associated with advanced surf abrasion, or extensive solution-precipitation. Whichever is the case, it was expected that edge shapes would achieve better discrimination of grain populations.

Classifications of edge shape categories were not found in S.E.M. literature, so a scale was adopted using principles underlying Powers' (1953), grain roundness categories (Fig. 5.1). Initially, the significance of edge shape variations and their validity in grain history interpretation were considered to be experimental and not based on previous tried and tested examples and studies. However, it was thought that providing the underlying rationale was sound and its application consistent, edge shape could prove to be a valid discriminating texture for sand grains in this study and

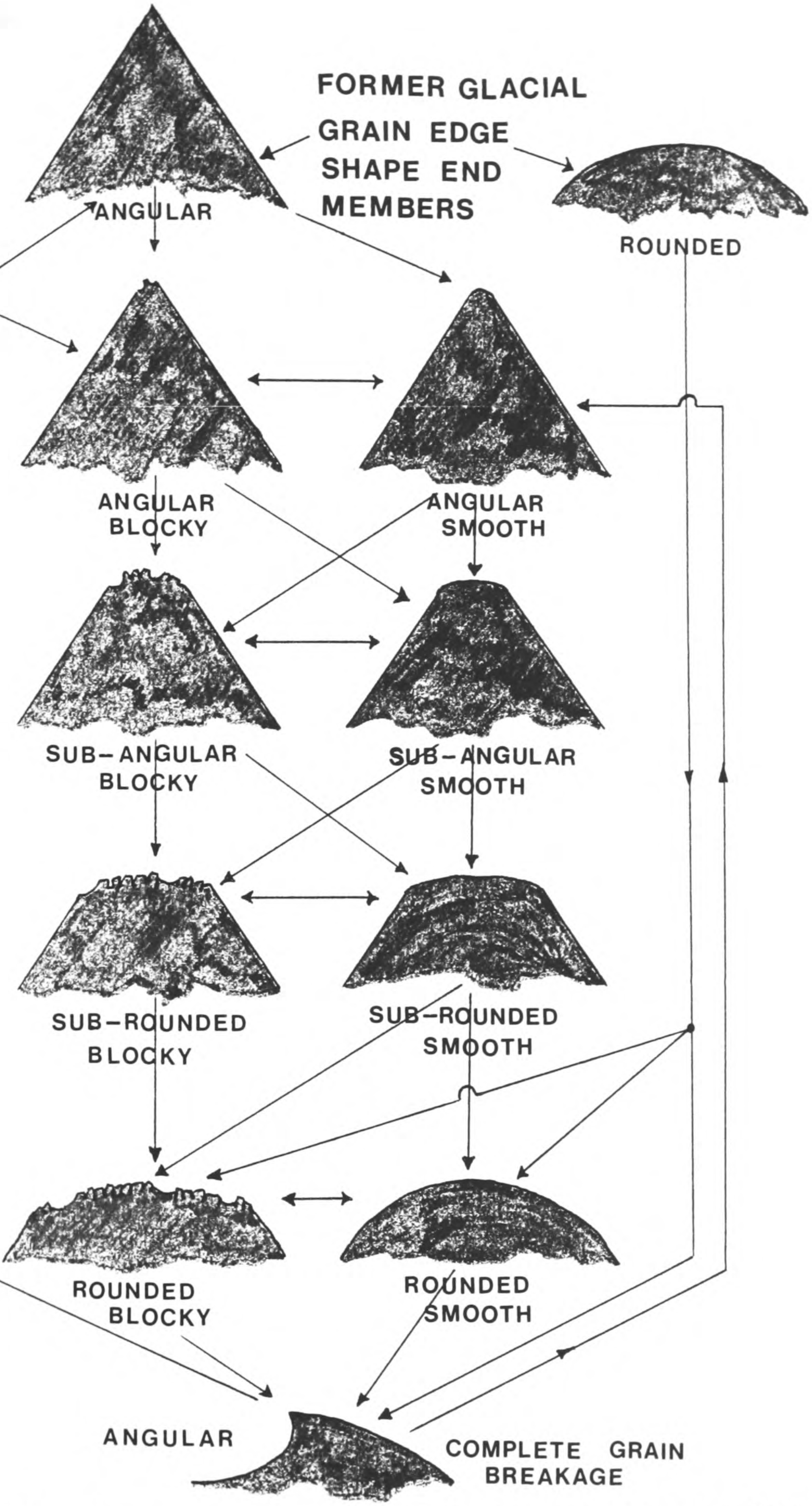


Fig. 5.1. A summary of edge shapes and possible linkages from original glacial shape end members for grains in samples 1 to 22.

for the aims of this project.

Fig. 5.1 attempts to relate edge shape end members found to be common on grains studied in this project to possible original glacial grain edges and their progressive development with modifications along Long Island's south shore beaches. The model depicted follows simple unidirectional modifications from possible initial angular and rounded original grain edge shapes. Two contrasting edge families may be observed. Blocky edges, whether rounded or angular, may be representative of high energy impacts and grinding. Smooth edges, whether polished by small impact pits or by solution-precipitation, may represent lower energy environments.

It was important that edges were viewed at the same magnifications to introduce a consistent framework within which comparisons could be made. Clearly, higher magnifications would tend to increase apparent edge roundness by flattening out the edge horizon and vice versa for smaller magnifications. In this study, magnifications of approximately x200 to x1000 were used, with an average of about x500. In practice, edge shapes vary as a continuum with combinations of blocky and smooth and Fig. 5.1 attempts to show the cyclical nature of edge development as complete grain breakage may produce an angular-edge-rounded edge combination once more. In each case, overall dominance of one edge shape was recorded in the scan and one value ascribed to each grain.

(c) <u>Grain Surface Relief</u>

Along with grain shape and to a certain extent edge shape, grain surface relief makes up those textures related to grain morphology (checklist textures 12 to 14 in Table 5.1). Surface relief has been taken to represent the macrotopography of grain surfaces. Glacial grains have shown very high and varied relief compared with grains from littoral and aeolian environments (Krinsley and Donahue, 1968 a) a fact which may be related to the large size of glacial particles and the large amount of energy available for grinding (Krinsley and Margolis, 1969). Krinsley et al (1964), described a maximum of 50 μm for surface relief typical of glaciation.

The significance of surface relief is not entirely clear as an environmental indicator, but Bull (1984), has suggested that grain surface modifications by conchoidal fractures and breakage blocks may be important influences. Provenance is also important and Goudie and Bull (1984), have described angular, high relief characteristic of first cycle grains on weathered slopes in Swaziland.

Accepted relief value-ranges have varied from worker to worker. Bull (1978 a) limited high relief to >1 μm, medium relief to 0.5 μm - 1 μm, and low relief to <0.5 μm. Preliminary studies of Fire Island beach grains showed that such low values were unacceptable as significant textural discriminators given the ubiquitous high relief found as a rule. It was decided to choose a relief range intermediate to Krinsley et al's values (1973), for glacial relief of 50 μm, and Bull's (1978 a) values.

High relief - >20 μm

Medium relief - 2 to 20 μm

Low relief - <2 μm

Examples of surface relief are presented in Plates 5.21 to 5.26. Equifinality of form produced by contrasting processes was found to be characteristic of relief textures. A grain dominated by very large, shallow conchoidal fractures may exhibit low relief in the same way as a well rounded grain smoothed by mechanical pitting and chemical solution and precipitation. This would make grain history interpretation problematic, unless extensive use is made of supporting notes and other textures such as grain shape.

It was considered that surface relief textures which were very varied, or dominated by high relief, may reflect either glacial sources, or some strained metamorphic source (Grant, pers. comm.). Some glacial grains with large, shallow conchoidal fractures and late stage, complete grain breakage may exhibit low smooth relief with broad curving meandering ridges.

Downdrift from Montauk Point (known glacial source), surf abrasion may be expected to reduce relief to a certain degree by the superimposition of small impact pits such as M.V.'s (Krinsley et al, 1964). It was also anticipated that high varied relief may be preserved as a grain surface texture in samples 20 and 21 in the buried offshore lobe (Williams, 1976), reflecting their glacial-fluvioglacial origin.

(d) Late Stage Complete Grain Breakage and Cracks

These two textures are represented as features 15 and 16 in Table 5.1, and photographic examples are provided in Plates 5.27 to 5.30. In order for a quartz sand grain to be broken in half, or at least fractured completely over a quarter to a third of its volume, very high energy levels would be needed. Such levels have been known in only a few environments: these include glacial grinding and crushing when ice loading imparts local stress enough to fracture a grain; high energy saltation in underwater sediment chutes in deep seas (Bull, 1984).

Should complete grain breakage be characteristic of grains found along Long Island's south shore beaches (Plate 5.27), they may be inherited from the glacial source at Montauk Point, or from off-shore glacial lobes (Fig. 2.3). Another hitherto unsupported explanation may be that energy levels in the surf during violent extra tropical storms may be high enough to cause complete breakages and large fractures, superimposed upon a suite of smaller breakage textures produced under normal surf conditions. This may be possible if grains already possessed stress microfracturing.

Cracks described in this work are not those which are limited to surface layers but which penetrate the grain body. They may form in a variety of ways. Krinsley and Smith (1981), found arcuate or polygonal cracks on smaller grain surfaces (90 μm to 200 μm), caused by a combination of physical and chemical weathering (possibly salt crystallisation).

Cracks have also been considered to be an important diagnostic feature of grain impacts during aeolian transport (Krinsley and Smith, 1981). In a study using cathodoluminescence in order to examine textures masked by thick silica coatings, Krinsley and Hyde (1971), found that glacial and glacial-beach grains had more cracks and a more varied crack pattern than grains from other environments.

Cracks were included as a checklist texture in anticipation that they would discriminate between glacial and non-glacial samples. They may also be expected to reflect a certain degree of aeolian input to beaches, since there has been found to be a certain amount of beach-coastal dune interchange (Leatherman, 1988; Williams and Morgan, 1988). Offshore north westerlies may transport considerable amounts of sand onto the beach periodically (Leatherman, 1988).

(e) Large Conchoidal Fractures

Concave upward, curved fracture surfaces with an arcuate fan shape have been well documented in the literature. Margolis and Krinsley (1974), stated that an ideal form of conchoidal fracture would be represented by dish shaped concavities, created by the collision of two particles with uniformly distributed concentrated pressures. Beach conchoidal fractures may be smaller and more uniform than their glacial counterparts, but have a greater surface area to depth ratio than aeolian concavities (Krinsley and Margolis, 1969). Glacial conchoidal breakage patterns may vary considerably according to size range (0.25 μm to 500 μm), (Krinsley et al, 1973).

Conchoidal fractures in this project's samples varied a great deal in size and shape. Plates 5.31 and 5.32 show typical examples. Plate 5.32 was included as a textbook example, with parallel arc shaped steps grading outwards from the point of percussion, crossed in the upper left part by straight radiating stepped blocks. It may be that high velocity collisions need a great deal of energy dissipation quickly, which results in shock waves penetrating grain cleavage producing rough blocky conchoidals. Slower collisions may produce smoother surfaces (Grant pers. comm).

Represented as checklist feature 17, large conchoidal fractures have been included as those over 50 μm in radius. Various size parameters have been used: Goudie and Bull (1984), used 10 μm as a cut off point dividing small and large conchoidals; Cater (1987), did not attempt to distinguish between conchoidal size. The current study used a size range based upon conchoidals which had been seen to characterise grain samples in the initial training scan, as well as being related to values presented by Krinsley et al (1973).

Along with medium conchoidals (10 μm to 50 μm), and small conchoidals (<10 μm), it was considered that they would be better discriminating tools for glacial, glacial-beach and beach grains. The variety and size of fracture may be used to distinguish beach from glacial grains (Krinsley and Margolis, 1969).

(f) Large Blocks

Krinsley and Margolis (1969), included breakage blocks as one of seven grain surface textures, four or more of which over large areas of a single grain, "may be taken as adequate evidence of a glacial origin," (Krinsley and Margolis, 1969, p.470). Blocks may be related to high energy fractures associated with glacial grinding, subaqueous and aeolian transport. They have frequently been observed in conchoidal fractures where arc shaped steps (harmonic fractures), intersect with straight, parallel or radiating steps and may represent quartz cleavage-step interference (Grant pers. comm.). Closer spacings of harmonic fractures nearer the point of percussion may produce smaller blocks.

Shown as feature 18 in the checklist (Table 5.1), large blocks are those above 10 μm across (Goudie and Bull, 1984), and may be either upstanding blocks or the blocky depressions between them. They often show rectangular or rhombohedral straight sided shapes.

It was anticipated that large breakage blocks and a wide variety of block sizes would characterise grains of glacial origin, described by Krinsley et al (1973), as having size ranges of 2 μm to 20 μm. One of the best descriptions of blocks was provided by Krinsley and Wellendorf (1980), who described them as being angular positive areas ranging from about 6 μm to 20 μm, and bounded by small conchoidal fractures and flat surfaces on aeolian grains.

Blocks were found to be oriented with respect to their flat sides and longer dimensions and often were parallel or sub-parallel to longer lineations. Together with crosscutting straight line fractures (possibly microfaults), block margins may be related to, and a surface expression of the known cleavage parallel to m $(10\bar{1}0)$, (Krinsley and Wellendorf, 1980). However, Krinsley and Wellendorf's study (1980), was related to aeolian grains and the applicability of the results from one environmental study to the textures found on grains from another environment is debatable.

Blocks on littoral grains have been described as an occasional texture, increasing in relief and size with increasing wave intensity (Krinsley and Donahue, 1968a), and may be smaller and more uniform than their glacial counterparts. Obviously, a major problem of surface texture interpretation is the fact that the same textures are found on grains from different environments, which seriously reduced their discriminating powers.

Margolis and Krinsley (1973), accepted the fact that blocks, as one of seven diagnostic textures indicative of glacial environments, needed to be observed on statistically significant percentages of grains. So called 'glacial textures' have been observed on source rock, first cycle grains from blockfields and screes (Whalley and Krinsley, 1974). In a study of contemporary grains transported by the Berendon glacier in B. Columbia, Canada, Eyles (1978), distinguished between high level (englacial and supraglacial) moraines and low level moraine formed at the basal sole. Eyles (1978), found that high level (medial Moraine), transport was passive and that so called 'glacial textures' were inherited from source rock after initial preglacial release. He (Eyles, 1978), recommended that the term 'glacial' should be dropped for such grains and replaced by some other term such as 'proto texture'. A similar sentiment has been expressed by Whalley (pers. comm.), who preferred the term 'original' to 'glacial'.

However, low level debris revealed a distinct texture of intensely mechanically disrupted cleavage plates and microblocks, reflecting grain to grain or grain to bed contact (Eyles, 1978). He described blocks as cuboidal nodules (Plate 5.34) where grinding impacts were closely controlled by cleavage.

As far as this project is concerned, Ronkonkoma terminal moraine at Montauk Point (Fig. 2.4), is considered to contain such low level glacially ground grains. Even if 'glacial' textures derived from source rock which are virtually indistinguishable from glacier base grains are present on any high level-transport grains in the terminal moraine, their discriminatory powers would be similar with the checklist approach. Grains from the buried channel offshore may have suffered reworking by meltwater streams and as a result would have suffered further comminution and edge abrasion to a degree which may allow them to be discriminated from Montauk Point grains in Sample 1 (Fig. 2.4).

(g) Large Smooth Flat Fractures

Large smooth flat fracture surfaces have been included in the checklist (texture 19 in Table 5.1), as a form of high energy breakage (Krinsley, 1972). Plates 5.35 and 5.36 show examples of flat surfaces, often ledged and over 100 μm in length. The notion of flat sides or surfaces as a glacial texture has been described in Krinsley's (1972), work on the deep sea drilling project.

The term 'fractures' was used instead of 'large smooth, flat surfaces' in order to distinguish them from curved conchoidal fractures and original crystal forms. Many large smooth flat surfaces were observed on sand grains from the study area in the initial training scan.

It is inferred that they represent considerable crystallographic control, described as cleavage, on a macroscale which typified this study's grains. They are often located as the inside walls of V shaped blocky depressions which extend across a large portion of a grain (Plate 5.35 centre right). Large internal structure-controlled ledges terminate parallel plates. (Plate 5.36).

At grain edges they form similarly sharp angles and steps (Plate 5.35). Curved fracture surfaces and original crystal faces were not included in this texture. In the 1960's and 1970's there was some discussion as to the existence of cleavage in quartz. (Margolis and Krinsley, 1971, 1974; Krinsley and Wellendorf, 1980; Wellendorf and Krinsley, 1980). Established mineralogy textbooks do not include cleavage as a diagnostic text for quartz. Bull (1978b), postulated that existence of microfractures in first cycle quartz as a result of stress patterns could influence breakage phenomena in a similar manner.

Whether large smooth flat fractures represent source features, or high energy modifications of stressed, well cleaved quartz during glacial transport, they warrant inclusion in the checklist on the basis that they occur as a noticeable texture in this project's samples. It is anticipated that they may characterise sample 1 (Ronkonkoma moraine at Montauk Point in Fig. 2.4), and samples 20 and 21 (buried offshore fluvioglacial deposits in Fig. 2.3). Edge abrasion and small breakages in the surf may modify the freshness of such surfaces and ledges.

(h) Medium Conchoidal Fractures

Plates 5.37 and 5.38 portray conchoidal features intermediate in size between small and large conchoidal fractures. Size parameters have already been discussed (10 μm to 50 μm for medium conchoidals). Although breakage size variety has been used to distinguish glacial grains, this study equates small breakages such as medium conchoidals with lower energy levels should large conchoidals be absent from grain surfaces. Abundancies of grains with medium conchoidals as the upper limit of fractures may be more indicative of beach modifications and possibly an aeolian input should large conchoidals be absent.

(i) Meandering Ridges

In early T.E.M. work, meandering ridges were recognised as being an important texture for diagnosing aeolian environments (Krinsley and Takahashi, 1962d). They represented curved conchoidal fracture intersections produced by chips from particles colliding with each other during saltation. They may be transitional textures formed as breakage blocks are worn away by grain impacts (Krinsley and Donahue, 1968a).

Shown as checklist texture 21 (Table 5.1), and in Plates 5.39 and 5.40, meandering ridges represent by-products of conchoidal textures. They are established grain surface features and have been included in checklists into the 1980's. (Goudie and Bull, 1984; Cater, 1984), as examples of brittle fracture.

In this project, intersections of small scale blocks and conchoidals forming meandering ridge type textures over small areas were not recognised as meandering ridges in 'sensu stricto'. Only intersections of large and medium scale conchoidals seen at relatively low magnifications ($\frac{1}{4}$ to $\frac{1}{2}$ grain size), were recorded, and as such may be grouped with features 15 to 22 (Table 5.1), as diagnostic of high energy breakages or source material.

(j) Steps

Like several other textures, steps of one kind or another have been named initially as a result of their physical appearance rather than in relation to their genetic relationships to causal processes: semiparallel steps (Krinsley and Takahashi, 1962a; Krinsley and Donahue, 1968a; Krinsley et al, 1972); graded arcs (Krinsley and

Donahue, 1968a).

In the 1980's Bull (1984), and Goudie and Bull (1984), distinguished between straight steps, arcuate steps and imbricate grinding. Cater (1984), used arcuate steps, arc-stepped furrows and linear steps as textures diagnostic of Neogene carbonate sediments in the Finestrat Basin, south east Spain. Photographs of parallel or subparallel steps have been produced to show the textures of mechanically crushed hydrothermal Brazilian quartz (Kaldi et al, 1978), which have undergone no glacial or subaqueous transport.

In this project, no distinction has been made between arcuate steps and straight steps, whether semi-parallel, parallel or graded. In the initial training scan they were found to be virtually ubiquitous on all grains and it was considered that to subdivide them would simply increase the checklist size without appreciably increasing sample grain discrimination.

Textures which come under the umbrella of steps in the present work include arcuate steps (Plates 5.43, 5.44), straight steps (Plate 5.43 where straight blocky steps radiate from the point of percussion), and arcuate blocky steps (Plate 5.41). Krinsley and Margolis (1969, p.470), stated, "It is probable that semiparallel steps, arc shaped steps and imbricate breakage blocks grade into each other."

Krinsley and Takahashi (1962a, 1962b, 1962c, 1962d), Krinsley and Donahue (1968a),and Krinsley and Margolis (1969), attributed semi parallel steps to probable shear stress, while parallel steps upto a maximum length of 50 μm may be indicative of glaciation (Krinsley et al, 1973). Graded arcs forming a fan shaped pattern may represent percussion fractures (Krinsley and Margolis, 1969).

Parallel or subparallel suites of furrows or long blocky steps may be produced by grinding (Kaldi et al, 1978), possibly glacial grinding (Goudie and Bull, 1984). They may also represent high energy percussions caused by grain collisions (Grant, pers. comm.), in association with conchoidal fractures and in this sense may reflect the effects of violent extra tropical storms in the study area.

The diagnostic importance of steps and their relationships to harmonic fractures, cleavage and grinding can only be fully appreciated when their presence in varying percentages is related to other breakage textures which reflect site-specific energy conditions on Long Island's south shore.

(k) Large Scratches

In earlier works, the term striation was used instead of scratching, which seems to imply the formation of a groove or furrow caused by the sharp edges of one grain scraping or grinding against another (Krinsley and Funnell, 1965). The precise mechanism has not always been made clear, cleavage having been included with gouging as a possible control (Krinsley and Margolis, 1969). Parallel striations (Krinsley et al, 1973), with a maximum length of 50 μm have been cited as diagnostic of glacial action.

Application of this texture has not always been consistent. Bull (1978a), used 'straight grooves or scratches', 'curved grooves' and 'randomly orientated striations' in his study of cave sediments (after Margolis and Kennett, 1971). Cater (1984), used 'linear or curved grooves,' while Bull (1984), and Goudie and Bull (1984), used 'parallel striations', 'straight scratches' and 'curved scratches,' as mechanically derived features.

In this project care was taken to record only those scratches which may be thought of as true striations caused by interparticle movement with one sharp edge scratching the surface of another, whether they be single or in parallel groups. In this sense they may reflect a glacial source, or possibly first cycle quartz. It is difficult to differentiate them from crystallographically controlled grooves and larger modified straight or curved crack features. They may not have particularly sharp clean edges, but reveal small indentations where abrasion has occurred, giving a 'levee and notch' margin.

Large scratches have been included as the last texture (feature 23), in the checklist in the Large Breakages category and are illustrated by Plates 5.45 and 5.46.

(1) <u>Small Conchoidal Fractures and Small Blocks</u>

Represented as features 24 and 25 respectively in the check-list (Table 5.1), they are the first of the smaller breakage categories which may be used to distinguish beach modifications. In the initial training scan, both small conchoidals and small breakage blocks were associated with each other as features of edge abrasion. In this project they are recognised as smaller versions of their larger counterparts (features 17 and 18 in Table 5.1), and may represent lower energy conditions.

Texture size variety has been recognised as an important indicator of grains from source and glacial origins (Margolis and Krinsley, 1973; Krinsley and Doornkamp, 1973). Small conchoidal fractures (<10 μm), and small breakage blocks (<10 μm), may not represent lower energy conditions per se if larger fractures are present, but if they are most abundant they may show the replacement of higher energy regimes by lower energy regimes (glacial by beach). The rationale for using 10 μm as a size parameter has already been discussed and they accord with values used by Bull (1984), and Goudie and Bull (1984).

Small conchoidal fractures are presented in Plates 5.47 and 5.48, both of which provide good examples of edge abrasion and chemical etching.

Small breakage blocks are illustrated in Plates 5.49 and 5.50. In both photographs it may be noticed that at this scale, breakage blocks do not seem to be as regular in outline as their larger counterparts and take on polygonal often triangular deep shapes.

(m) <u>Mechanical V's, Small Straight Grooves and Small Arcuate Grooves.</u>

These represent possibly the most frequently cited textures diagnostic of subaqueous environments (Krinsley and Takahashi, 1962b; Margolis, 1968; Krinsley and Doornkamp, 1973; Goudie and Bull, 1984; Middleton and Kassera, 1987; Williams and Morgan, 1988). They are grouped together for discussion at this point as textures 26, 27 and 28 in the checklist (Table 5.1), because they were ubiquitous textures responsible for the recognition of edge abrasion on most grains.

Examples of edge abrasion are presented on Plates 5.51 and 5.54, but many more may be observed on previous plates e.g. Plates 5.9, 5.10, 5.18 and Plate 5.34.

Originally termed 'small pyramidal indentations' by Krinsley and Takahashi (1962c), mechanically formed, V shaped impact pits have been measured and quantified a great deal (Krinsley and Takahashi, 1962c; Krinsley et al, 1964; Margolis and Krinsley, 1974; Middleton and Kassera, 1987).

In this present study mechanical V's are those which are non-orientated and thus distinguishable from oriented triangular etch pits (feature 40 in the checklist, Table 5.1). Their dimensions have been described in detail: 0.25 μm to 2 μm (Krinsley et al, 1973),with densities ranging from 2.3 per μm^2 (Krinsley and Takahashi, 1962c), to a saturation limit of 7 per μm^2 (Margolis and Krinsley, 1974). Middleton and Kassera (1987), found that M.V. density varied with grain size, the smaller particles (2 ϕ) showing values of 1 to 2 per μm^2, and coarser particles (-1 ϕ) showing values of 3 to 4.5 per μm^2.

Whereas earlier workers have tried to relate M.V. size and density to increasing energy levels (Krinsley and Donahue, 1968a), Middleton and Kassera (1987), related their M.V. pit values to intensity of shearing of concentrated grain suspensions.

Middleton and Kassera (1987), found that coarser grains belonging to the traction population (bed contact load), received impacts from saltating grains, especially the larger more exposed particles. These had lower M.V. densities than smaller grains belonging to the zone of high-concentration grain dispersion close to the bed. Of such intermittently current-suspended grains, those of mid-size values received greatest densities because larger particles spent more time on the contact bed and finer particles spent longer in suspension (Middleton and Kassera, 1987).

Small straight grooves and small arcuate grooves have been well described in the literature (Krinsley and Donahue, 1968a; Krinsley and Margolis, 1969; Krinsley and Doornkamp, 1973). Shown as checklist features 27 and 28 (Table 5.1), grooves are illustrated on Plates 5.53 and 5.54, and good examples may be seen in Plates 5.10, 5.41 and 5.47.

Their sizes have been based on parameters developed by previous workers: 2 μm to 15 μm (Krinsley and Donahue, 1968a; 1 μm to 15 μm (Krinsley and Margolis, 1969; Krinsley et al, 1973); <25 μm in length and 1 to 5 μm wide (Margolis and Krinsley, 1974). An upper limit of about 25 μm was used in the recognition of textures 27 and 28 (grooves), but more important were their shapes and relationships with impact pits and edge abrasion.

Bull (1975), used a texture described as small fractures caused by crack propagation, while Bull (1984), used curved scratches and straight scratches to identify straight and slightly curved grooves, as did Goudie and Bull (1984). Cater (1984), used the term linear or curved grooves, grouping them together as one texture.

Margolis and Krinsley (1974), were amongst the earliest of workers to formally link M.V.'s to straight and curved grooves. They found that they were less common and less abundant than M.V.'s, and were found mainly on grains from moderate to high energy levels. At low impact velocities in high energy river and low energy beach environments there would be fewer, gentler impacts resulting in more sliding and rubbing. This produced fine splinters and little rounding, M.V.'s being characteristically shallow and widely spaced (Margolis and Krinsley, 1974).

At higher impact velocities (high energy surf such as Long Island's south shore beaches during extratropical storms), rubbing and splintering mechanisms progressed to cracking grain surfaces. This would produce an increase in M.V. density and the initiation of a new texture, viz - straight and curved grooves. M.V.'s cut across expressions of cleavage on edges (upturned plates (Grant, pers. comm.)), giving a sawtooth effect. When seen at different angles M.V.'s will present a variety of shapes (Grant and Whalley, pers. comm.), and their density and degree of non-orientation may be related to small scale variations in quartz grain strength as determined by dislocations and cracks within the grain crystal structure at a given point (Margolis and Krinsley, 1974).

At very high impact velocities (which may include extratropical storm conditions in the study area, but more probably aeolian storms), brittleness and cleavability may be more important (Margolis and Krinsley, 1974). In this case conchoidal fractures form, but probably not in the case of smaller grains (<400 μm) in water because of its cushioning effect (Margolis and Krinsley, 1974).

As for the relationship of texture formation to causal mechanisms, both energy levels (Margolis and Krinsley, 1974), and grain size (Margolis and Krinsley, 1974; Middleton and Kassera, 1987), have been considered to be important controls in a subaqueous medium. Middleton and Kassera (1987), did not relate M.V. density to grain roundness, except in the sense that rounded grains present more topographic grain-surface highs on which M.V.'s may form.

One control which may also be considered is that of grain shape. Velocity of impact must obviously play a part in order for turbulent grain transport to reach a critical threshold level above which bed load and intermittent suspension load will begin to move. Angular grains will have more pointed projections and sharp edges, so only small area or point impacts may result in the formation of small M.V.'s and percussion chips.

Increased transport in littoral drift (such as that from Montauk Point westward along Long Island's south shore), may result in edge abrasion and polishing by M.V.'s, rounding grain edges so that subsequent impact areas increase in size. Margolis and Krinsley (1974), described the perfect conchoidal fracture as one approaching a dish shaped concavity. Its form may be related to the impact of two rounded grains which would strike each others' surfaces normally resulting in uniformly distributed, concentrated pressures.

If a similar analogy is applied to beach transport, M.V.'s may increase in size and develop into a new texture: arcuate or sickle shaped hertzian fractures. Evidence that M.V.'s and straight and slightly curved grooves are related may be seen on many plates, e.g. Plate 5.10 (lower grain edge), and Plates 5.47 and 5.51. Straight or slightly curved, sharp edges of such cracks on one side often grade into a convex upward steep fracture surface on the other with V shaped notches knocked out (satellite V blocks).

If angular grains collide in a subaqueous medium at high velocities, the impact of a rapidly moving and rotating grain surface projection may form an irregular pit with several M.V's radiating in different directions (Plate 5.51, centre left). This project recognises M.V's and straight and slightly curved grooves as evidence of waterborne abrasion and edge polishing textures. They should be absent or rare on Sample 1 (Montauk Point), grains and should increase in density alongshore to the west (Krinsley et al, 1964), gradually wiping away Ronkonkoma moraine (Sample 1), glacial (or original) textures.

Samples 20 and 21 from the buried fluvioglacial deposits in Channel H (Fig. 2.3), may have suffered reworking of their glacial textures by meltwater streams (Williams, 1976), and may be expected to show more subaqueous markings on grain edges (M.V.'s and straight and slightly curved grooves). If these have moved onshore, wave induced and tidal currents may have caused M.V's to form on grain edges (Middleton and Kassera, 1987). The degree of edge rounding and polishing may, however, not be as advanced in samples 10 to 18 for a certain percentage of beach grains which may have moved on-shore from a possible offshore glacial source.

Samples 10 to 18 (Fig. 2.4), represent onshore beach sands, opposite or downdrift from Channel H (buried lobe deposits shown in Fig. 2.3). It may be possible that there is a mixture of grains along this shore fronting Fire Island, where more rounded edges on grains derived from greater transport westward from Montauk Point have created denser M.V. patterns and more grooves. These may contrast with a smaller percentage of grains derived from glacial/ fluvioglacial deposits offshore which may be less rounded, with lower M.V. densities and fewer hertzian fractures.

(n) Chatter Marks

As the name implies, chatter marks have been considered to represent one particle skipping or chattering over another. They have been illustrated as single patches and trails (Bull, 1978b; Bull et al, 1980). They have been seen as a series of subparallel indentations averaging about 0.5 μm long, produced by a grain edge skipping across another (Krinsley and Margolis, 1969). Represented as checklist texture 29 (Table 5.1), an example from the study area is shown on Plates 5.55 and 5.56. The latter plate (5.56), in particular shows the problem of interpreting this texture.

They may be produced by grinding abrasion (Grant pers. comm.), and represent glacial origins (Folk, 1975). A detailed description has been presented by Bull (1978b) and Bull et al (1980). In a study of non-glacial grains from beaches and dunes, they found that chattermarks varied in width from <3 μm to 20 μm, with <5 to >20 individual curved grooves per trail (Bull et al, 1980).

They suggested (Bull et al, 1980), multiple origins for chattermarks involving mechanical, chemical and mechanical/chemical mechanisms. They may be related to structural weaknesses in grains such as internal dislocations (leading to dislocation etching), quartz microfractures, and the development of coaxial fractures (Bull et al, 1980).

Chattermarks were observed on grains in the initial scan, but varied considerably depending on chemical modification. Some surfaces could be described merely as 'chattery' (Plate 5.56). Their environmental significance may be considered to be indeterminate, however their inclusion in the checklist (Table 5.1), may be justified in the event that they may prove to be an important environmental discriminator. Bull (1984), and Goudie and Bull (1984), included chattermarks as a last texture at the end of their chemical textural group.

(o) Large Solution Pits.

Checklist texture 30 (Table 5.1), illustrated in Plates 5.57 and 5.58, is problematical as an environmental indicator (Bull, 1981a). Cluster analysis using only chemically derived surface textures on quartz sand grains provided no discernible pattern or significant grouping (Bull, 1978a), which agreed with Krinsley and Funnell (1965). Indeed Bull (1981a), discussed in detail the problems associated with the validity of using chemical textures to interpret grain history and suggested that they were notorious for their independence of any discrete environmental modifications.

In this project, large solution pits are those which are isolated from suites typical of spongy pitted surfaces. They may be bright rimmed (first described by Doornkamp, 1974), although Bull

(1978b), has ascribed the bright rimmed character to charging effects. Such deep isolated solution pits may be straight sided or rounded (Bull, 1981a), and have been found on grains from a variety of environments such as first cycle quartz, diagenetically altered quartz, aeolian and tropical environments.

In the initial training scan, large isolated solution pits were observed on both mechanical and chemical surfaces and may be located at points of structural weakness, dissolved mineral inclusions, and salt crystal growth (Krinsley and Doornkamp, 1973). Le Ribault (1978), has termed the study of mineral inclusions as endoscopy and suggested that they allowed the nature of the source rock to be ascertained.

Tankard and Krinsley (1975), presented a detailed description of diagenetic surface textures found on quartz grains. They (Tankard and Krinsley, 1975), suggested a three stage cycle for solution surface development:

1. Rounded forms and surfaces.
2. Irregular pit development.
3. Deeply etched terrains produced by extreme etching.

Diagenetic chemical etching has been recognised on non-marine young Pleistocene sediments subjected to a prolonged standstill in a cave pool (Tankard and Krinsley, 1975). The alkaline solution and pH in the cave pool would have been similar in origin to alkaline sea water and this could influence the textures of intertidal and infratidal samples in the study area.

(p) Chemical Etching

In general terms solution should not be separated from precipitation as texture generating mechanisms because both occur simultaneously, either at the same location, or at different locations on quartz grains (Krinsley, pers. comm.). It is clear that chemical modifications may either be contemporaneous with a process currently at work in the environment from which grains are extracted, or are inherited. Of chemical textures included in the checklist (Table 5.1), only oriented triangular etch pits have been linked to contemporaneous low energy marine environments with any certainty (Margolis and Krinsley, 1971; Krinsley and Smalley, 1972; Krinsley, 1972; Margolis and Krinsley, 1974).

Two forms of etching have been recognised by Tankard and Krinsley (1975), in a diagenetic environment:

1. Crystallographically controlled oriented triangular and rhombohedral pits, and cleavage solution steps and grooves.

2. Solution surfaces independent of internal symmetry.

Checklist textures 30 to 33 are included in the second category.

Amorphous silica may dissolve in fresh or marine water to the extent of 100 to 140 ppm at ordinary temperatures, while quartz has a lower solubility range of 6 -14 ppm at ordinary temperatures (Krauskopf, 1959). Although silica solubility increases with temperature, it may not increase with pH until values over 9 have been reached (Krauskopf, 1959), the latter being caused by ionization of H_4SiO_4 (monosilicic acid).

Friedman et al (1976), have agreed with Krauskopf's (1959), findings and reported pH levels of 9 to 9.5 in modern beachrock waters. Friedman et al (1976), also claimed that pH micro levels of 10 to 10.5 may occur in thin gel-like films, or monomolecular layers clinging to the surfaces of reef organisms (the skin effect), which may trigger off quartz dissolution. In addition, algae (through photosynthesis and uptake of CO_2 and respiration), may cause fluctuations in sea water pH, causing an increase in alkalinity and quartz dissolution (Friedman et al, 1976).

In this project, the significance of very coarse to fine etching as environmental indicators will depend upon their positions within grain texture cycles. Sample 1 (glacial till at Montauk Point), may have suffered diagenetic first cycle weathering and possibly secondary weathering cycles before being released into the south shore beach system. Pits may have formed at any time before wave erosion.

A similar but more complex model is needed for buried glacial-fluvioglacial sediments in channel H offshore (Fig. 2.3), as they may be derived from older moraines and have experienced a stand-still in marine waters. The scheme adopted has been to ascribe irregular pits to more rapid solution mechanisms than oriented pits and the larger the etch pit the greater the amount of chemical energy or time involved (Tankard and Krinsley, 1975). In this sense, small pits (texture 33), may grade into larger etch pits (textures 32 and 31), with increased time or chemical energy. Deep large pits (texture 30), and extreme examples of very coarse etching such as that shown in Plate 5.60 may be ascribed to diagenesis. The term diagenesis in its general sense is taken to include those processes, chemical and physical, which may affect the sediment after deposition and up to the lowest grade of metamorphism (Whalley, 1978b).

Goudie and Bull (1984), used textures such as 'anastomosis,' 'solution pits,' and 'solution crevasses' to denote degrees of etching. In this project, anastomosis described as curved, branching, irregular, wavy etched lines (Krinsley and Doornkamp, 1973), and crevasses fall under the headings of coarse and very coarse etching, although Krinsley and Smalley (1972), have described fine anastomising etch patterns on Californian beaches. They ascribed these textures to the drying out of alkaline solutions during intertidal subaerial exposure, or possibly to slight diagenesis (Krinsley and Smalley, 1972).

Etching textures 31 to 33 (Table 5.1), are illustrated in Plates 5.59 to 5.64. In general, virtually all grains in the study usually showed some form of etching, the most common form being that of undulating, sugary, or low relief pitted surfaces, but most edges also exhibited etch pits (Plate 5.63).

(q) Amorphous Precipitation.

Krinsley and Doornkamp (1973), classified diagenetic precipitation textures into three groups:

1. Rapid Precipitation - an overall undulating topography smoothing grain surfaces, especially notable on aeolian grains.

2. Moderately Rapid Precipitation - the formation or enlargement of upturned plates.

3. Slow Precipitation - a very fine coating reflecting in detail the underlying topography and even fine projections, including quartz crystal terminations.

In this project, amorphous precipitation (checklist texture 34 in Table 5.1), does not include upturned plates, but only thick or thin varieties of a smooth or undulating capping layer (Plates 5.65 and 5.66). Plate 5.68 shows a sugary coating variety of silica precipitation. Plate 5.70 illustrates a good example of incomplete capping layer reflecting underlying relief.

Krinsley and Smith (1981), identified large smooth solution-precipitation surfaces as being typical of smaller grains (of aeolian origin), invoking greater transport in suspension with fewer impacts as the cause. In the present study there are large grains (>500 μm), with wide development of smooth areas which are characterised by smooth capping layers (Plates 5.66 and 5.69). Bull (1981a) described such amorphous precipitation as crystocrystalline sugary coatings.

Possible sources of silica for amorphous capping layers may include biochemical sources, thermal springs, volcanic activity, pressure solution and silicate weathering (Waugh, 1970). In view of the fact that sample 1 (glacial till at Montauk Point), and samples 20 and 21 (buried glacial-fluvoglacial sediments offshore), have been exposed to diagenetic, as well as pedogenetic and weathering processes (at least in their surface layers), the capping layer silica-source may have come from silica saturated solutions in groundwaters (Le Ribault, 1978). The Long Island shelf would have been exposed to subaerial weathering for long periods before sea level rose (Leatherman, 1985b).

Another possible silica source associated with grain kinetic energy is abrasion solution (Gees, 1969), which may produce a disrupted lattice layer. Grain surfaces may be disordered and hydrated by continuous impact in the surf resulting in a high concentration of silica in water layers in contact with the quartz (Gees, 1969). This has been supported by Whalley (1978b), who cited the existence of wet-ground particles small enough to go into solution.

Methods of distinguishing capping layers produced or modified in two such different ways will depend upon their relationships to other textures and grain cycle history. The question remains whether there is enough time for capping layers of amorphous silica to form between Montauk Point and beaches further west, given that the varieties shown in this project's grains seem to obey Krinsley and Doornkamp's (1973), slow precipitation rule for mirroring of underlying relief.

(r) Very Fine Precipitated Particles

These have been included in the checklist (feature 35 in Table 5.1), primarily because they were a noticeable texture observed during the training scan. The term coined to describe them at that stage was 'snow.' They differed from adhering particles associated with mechanical abrasions (especially glacial grinding), as illustrated by Krinsley and Doornkamp (1973), and silica plastering.

Plate 5.71 and 5.72 show examples of very small white opaque particles either adhering to or growing from relatively smooth hollows and fracture surfaces. They varied little in size and may represent small amorphous silica growths, especially when some orientation is present, or very small adhering fragments generated by mechanical abrasion.

(s) Euhedral Precipitation

Whalley (1978b),described varying forms of euhedral crystal growth and cited a texture of epitaxially growing small grains which resembled the 'surface coalescence' described by Waugh (1970). Their photographic illustrations resemble Plate 5.76, which is taken to represent poorly formed protocrystals. Very sharp V shaped formations in the underlying mat terminate in globular stacks aligned from top left to bottom right (Plate 5.76). They may also represent reprecipitation arches and stacks and caves described by Tankard and Krinsley (1975).

Waugh (1970), described euhedral crystals as secondary silica growth and Bull (1984), related them to an inherited diagenetic phase. They may represent a much slower more ordered form of silica precipitation inherited from previous deposition episodes (Krinsley and Doornkamp, 1973). They did not occur on a large scale and were only located in hollows at high magnifications. Cater (1984), noted that triangular etch pits may sometimes be confused with interference patterns formed by incomplete euhedral growths e.g. Plates 5.74 and 5.75.

(t) Oriented Solution-Precipitation Surfaces

Texture 37 (Table 5.1), has not been described as such in the literature, but is taken in this project to represent a variety of crystallographic-control expressions, often located in large smooth hollows. The problem of quartz cleavage has been examined in some detail (Krinsley and Margolis, 1969; Coch and Krinsley, 1971; Margolis and Krinsley, 1971; Krinsley et al, 1976; Wellendorf and Krinsley, 1980).

Cleavage expressions have been variously described as oriented fractures (Grant, pers. comm.); parallel upturned plates (Coch and Krinsley, 1971); parallel ridges (Krinsley et al, 1976). Their dimensions have varied: 1 μm with 5 μm spacing for crushed quartz to 0.1 μm in height from tropical desert dunes (Margolis and Krinsley, 1971), up to 10 μm or 20 μm thick (Margolis and Krinsley, 1974).

Several modes of formation have been cited, varying from crack propagation in aeolian sands (Krinsley and Margolis, 1969; Coch and Krinsley, 1971; Margolis and Krinsley, 1971), to chemical formation (Margolis and Krinsley, 1974). Most papers cite upturned cleavage plates as diagnostic of aeolian transport, although Margolis and Krinsley (1971), produced plate dimensions for a variety of environments including crushed quartz experimentally abraded in an aeolian medium.

Krinsley and McCoy (1978), reiterated the presence of abrasion fatigue as a creator of a disrupted lattice layer consisting of particles <3nm in diameter. Its lower density than the underlying quartz (2.2 as opposed to $2.6g/cm^3$), and increased solubility may favour reprecipitation in the immediate locale on a grain surface. This may be encouraged by evaporation between tides, an irregular layer of either opal or silicic acid smoothing out existing fractures.

In this project, Plates 5.77 and 5.78 illustrate elongated, oriented ridge and furrow textures where cleavage and solution-precipitation have appeared to be dominant controls. The feature was not recorded on grain protrusions and edges where impact pits dominated.

(u) Adhering Particles

Shown as feature 38 in the checklist (Table 5.1), adhering particles have been included in several works using the checklist approach (Bull, 1984; Goudie and Bull, 1984). They represent comminution debris produced by mechanical abrasion (grinding or possibly impacts), and some may be plastered onto grinding surfaces (Krinsley and Doornkamp, 1973).

Plate 5.79 shows a range of debris sizes preserved in deep chemically modified hollows, some smaller fragments adhering to grain edges which have rounded chemically and mechanically. Feature 38 was originally placed in the chemical textures group because the author first met the texture in accounts of diagenesis (Krinsley and Doornkamp, 1973). Bull (1984), and Goudie and Bull (1984), ascribed this texture to mechanical abrasion modifications in their checklists.

(v) Dulled Surfaces.

As the term implies, dulled-surface grains (feature 39 in Table 5.1), have had their fresh mechanical breakages modified chemically (Grant, pers. comm.). The texture is recorded as a whole grain phenomenon in this study in order to distinguish between beach grains which are being impacted and abraded continuously and non-beach grains.

Plate 5.80 shows a grain from sample 1 (Montauk Point), with broadly angular, generally unabraded edges and a 'faded' appearance.

(w) Oriented Triangular Etch Pits

The last texture in the checklist (feature 40 in Table 5.1), has been one of the more documented textures in the literature. Margolis (1968), identified two forms of etch pits controlled by crystal structure, displaying a strong degree of orientation. Straight sided triangular etch pits have been experimentally produced on the prismatic faces of quartz crystals, planar views producing isosceles-triangle shapes with apical angles of 38° to 45°, and basal angles of 65° to 75° (Margolis, 1968). Rectangular to rhombohedral pits have also been observed with angles corresponding to those measured on quartz crystal rhombohedral faces (Margolis, 1968).

Such grains may be diagnostic of low energy beaches (Krinsley and Donahue, 1968b), and their sides may reach 50 μm in length (Krinsley and Margolis, 1969). Other experimental etch studies (Subramanian, 1975), used hydrofluoric acid and NaOH to reinforce previous findings, although his rhombohedral face pits were V or

U shaped.

In a study of California shelf sand, Nordstrom and Margolis (1972), were able to distinguish between turbulent subaqueous abrasion on beaches (as a result of mechanically formed textures), and palimpsest sediments from the inner shelf (where mechanical abrasions were being replaced by oriented etch pits). Le Ribault (1978), has cited greater dissolution of quartz at higher energy levels and has compared the 'well known geometric solution features' which characterise grains from infratidal zones with mechanical breakages found on intertidal grains. He explained the differences by contrasting swell and submarine currents as transporting agents in the nearshore with higher energy flood tide conditions on beaches (Le Ribault, 1978).

As with other chemical textures, oriented triangular etch pits have been recorded from several environments: soils (Doornkamp and Krinsley, 1971; Le Ribault, 1975); rivers (Bond and Fernandes, 1975; Spalletti, 1977); lakes (Margolis, 1968; Steiglitz, 1969); and as a result of diagenesis (Tankard and Krinsley, 1975). This makes their validity as environmental discriminators rather problematical.

Plates 5.80 and 5.81 show typical examples from the study area. Plate 5.80 shows two contrasting surfaces, the right half representing what at first appears to be well developed mechanical V blocks linked by cracks and the left half chemically formed upturned plates. Note the consistent parallelism of triangle sides facing the viewer. Plate 5.81 shows oriented triangular etch pits being modified on either side by larger fresh breakages.

Oriented triangular etch pits may be inherited from earlier diagenetic or weathering cycles, but research into sea water solution is convincing enough to accept the possibility of their formation on beaches. In this study the method employed for determining grain history using oriented triangular etch pits will follow the same rules as for other textures. Textural combinations and their relationships with fresh breakages and edge abrasion and relative chronological position within the overall grain texture mosaic will be deduced from crosscutting relationships.

5.V STATISTICAL ANALYSIS

V.A INTRODUCTION

Raw binary data based on grain surface feature presence (scored as 1), and absence (scored as 0), was treated statistically using canonical discriminant analysis, factor analysis and cluster analysis with the SPSSX or Statistical Package for the Social Sciences (Nie et al, 1975), and ARTHUR. This form of multidiscriminant analysis was advised for S.E.M. grain surface texture studies by Bull (1978a), and validated by Culver et al, (1983). Multivariate discriminant analysis was used by Williams and Thomas (1989), in a study of samples from Long Island's south shore and offshore.

V.B DISCRIMINANT ANALYSIS

The aim of discriminant analysis is to examine the extent to which it is possible to distinguish between members of various groups on the basis of observations made upon them. Such a multivariate technique is applicable when two or more variables are

ed either as independent (predictor) or dependent (outcome) variables (Harris, 1975).

The data consists of 22 samples of 25 grains which were scanned for 40 features. Using the language of Culver et al (1983), there were h = 22 groups (samples), and p = 40 variables (surface features). An overall measure of the relationship between the two sets of variables is provided by canonical R:

$$Wi = \sum wjXij$$

$$\text{and} \quad Vi = \sum vi.Yij$$

where the X's are predictor variables and the Y's are outcome measures (Harris, 1975). Heuristically the wj and vj are called canonical coefficients for the predictor and outcome measures respectively and are obtained by trying out different sets of weights until that pair of sets of weights which produces the maximum possible value of canonical R has been obtained.

Canonical correlation can be considered as a special case of multivariate analysis of variance when one of the two sets of variables consists entirely of dichotomous group-membership end members (Harris, 1975). In the major classes of variables dichotomous variables are classified on the basis of how many values they can assume, the minimum number being two. A dummy dichotomous variable is formed by converting a qualitative variable into a binary variable (1 or 0) of the characteristic (Kachigan, 1986), which is suited to S.E.M. analysis.

Of the two techniques most suited to the use of dichotomous variables logistic regression has been described as outperforming discriminant analysis, but not by a large amount (Press and Wilson, 1978).

Canonical variate analysis emphasises the difference between mean vectors in a p-dimensional space, the first canonical axis being placed as closely as possible to the ends of the mean vectors with succeeding axes being placed at right angles. Where $p > h$ in this study: $40 > 22$), there are only $h - 1$ (in this study: $22 - 1 = 21$) possible canonical variates (Culver et al, 1983).

Stepwise discriminant analysis determines the set of variables that maximise discrimination using the Mahalanobis D^2 statistic (Mahalanobis, 1927). The D^2 statistic is:

$$D^2 = \frac{1}{p} \sum_{i=1}^{P} \left(\frac{\bar{x}_{1i} - \bar{x}_{2i}}{\sigma 1} \right)^2$$

where $\bar{x}_{1i}$ = mean of i'th variable, group 1.

σ_i = standard deviation of the i'th variable.

The D^2 measures the 'distance' between the multivariate means of two sample clusters from which F values are obtained. The latter are a measure of the statistical significance of the amount of separation produced as a result of the inclusion of a variable (surface feature) and as such are indicators of the degree of discrimination achieved (Flores and Shideler, 1982; Williams and Scott, 1985). Specifically, F tests the null hypothesis that the two means are equal or that the distance between them is zero (Bull, 1978a):

H_o : $(Dj) = 0$ against

H_1 : $(Dj) > 0$

V.C FACTOR ANALYSIS

Canonical variate analysis involves relationships between sets of variables. Both principal components analysis and factor analysis examine relationships within a single set of variables. Both techniques (principal components analysis has been considered often to be a type of factor analysis), can be used to reduce the dimensionality of a set of variables such that the new variables (components, factors) provide a description of the 'structure' of the original set of variables (Harris, 1975).

The first P.C. is that linear combination of the original variables which maximally discriminates sample variables i.e. - whose sample variance is as large as possible. The second P.C. is that linear combination of the original variables which has the maximum possible sample variance subject to the constraints that:

i. the sum of the squares of the weights involved equal unity.

ii. scores on P.C.2 are uncorrelated with those on P.C.1.

Factor analysis corrects the shortcomings of P.C.A. by the separation of unique variance from common variance within variable sets. Factor analysis searches for the minimum number of independent dimensions needed to account for most of the information of similarity coefficients (Klovan, 1966). It assumes that observed variables are linear combinations of some underlying hypothetical or observable factors, some of which are interpreted to be common to two or more variables and some are taken to be unique to each variable (Davis and Willaims, 1985). The latter are assumed to be orthogonal to each other.

Identification of the underlying covariance structure is possible providing factor loadings are known. The factor matrix is rotated by the Varimax rotation (with Kaiser normalisation) in order to make variable axes co-linear with the principle axis (Davis and Williams, 1985). The tranformations are achieved by solution of the eigen-values and eigen-vectors of the full correlation matrix, therefore eigen-value length indicates the amount of common variance accounted for by each axis.

This may be done by erecting mutually orthogonal areas in multidimensional space in such a way that the first axis accounted for most of the information in the cosematrix, while the second accounted for most of the remaining information and so forth. The number of axes required to explain most of the information allows the minimum number of dimensions in which to portray sample vectors to be determined. The mutually orthogonal axes are the factor axes (Klovan, 1966).

Vector projection onto the axes determines the sample vectors position in relation to rotated factor axes. These projections are called factor loadings and the sizes of the numbers indicate the extent to which each factor controls the position of each sample vector. The sum of the squared loadings for specific sample vectors is known as their communality. This is the percentage of its variance held in common with other variables (Harris, 1975), and reflects the degree to which that sample vector has been explained by the set of factor axes. A communality of 1.0 indicates a perfect explanation (Davis and Williams, 1985). Matrix eigen-values pick out the important factors, the criterion for significance being a value of >1.0 (Croxton et al, 1967).

In order to determine the significance of the actual loading on an individual variable for a given factor the Burt Banks formula is used:

$$\text{It is significant if } > r\sqrt{\frac{n}{n - c + 1}}$$

where n = number of factors

c = position of factor (rank)

r = correlation coefficient at the 0.1 level.

The factors themselves are no more than mathematically derived reference coordinates and the task of assigning them some geomorphological significance still remains.

V.D CLUSTER ANALYSIS

Cluster analysis is a simple method of displaying similarities between observations resulting from the total interaction of all variables. The data may be represented as a matrix as follows:

	Variable 1	-	Variable 2	-	Variable j	-	Variable p
Observation 1	x(1,1)	-	x(1,2)	-	x(i,j)	-	x(1,p)
Observation 2	x(2,1)	-	x(2,2)	-	x(2,j)	-	x(2,p)
Observation i	x(i,1)	-	x(i,2)	-	x(i,j)	-	x(i,p)
Observation n	x(n,1)	-	x(n,2)	-	x(n,j)	-	x(n.p)

This matrix consists of 'n' rows by 'p' columns. A cell entry represents a measurement for the value of the element 'x' of observation 'i' on variable 'j'. In the present study a comparison of 22 samples and the 40 variables made up of grain surface features in the checklist would involve the following number of computations:

(21 x 40) + (20 x 40) + (19 x 40) + ... (2 x 40) + (1 x 40) +

(20 x 40) + (19 x 40) + ... (2 x 40) + (1 x 40)

etc.. ....

There are various types of cluster analysis available to statistically compare data variables all of which compute the various relationships in a different manner producing slightly different groupings. The method used in the present study within the S.P.S.S.X. package was Hierarchical cluster analysis with a complete linkage agglomeration schedule using the Euclidean distance equation.

The technique forms classes which are themselves subclassified at different levels producing a tree-like diagram called a dendrogram. Distinct groups may be seen with different levels of similarity, 0.0 on the similarity coefficient scale being regarded as identical and subsequent values from 0.0 being similar proportional to the value of the similarity coefficent computed.

Dendrogram groupings are broken at various points during subsequent qualitative analysis, so that they mark the most similar linkages. Further linkages connect groupings which are less similar at higher similarity coefficients (lower levels of significance). Completion of the dendrogram finishes the clustering process to show two basic groups which link at the highest similarity coefficient values (or lowest levels of significance).

CHAPTER 6

QUALITATIVE RESULTS

QUALITATIVE RESULTS

6.I INTRODUCTION

Results presented below are based on observations of the presence-absence of 40 textures on 25 grains in the 22 samples under study. The raw data is presented in Appendix A for site 1 (Montauk Cliff), to site 22 (offshore). Grains were computer coded according to sample site and position within the 5 x 5 grain grid such that grain A01 represents grain 1 in sample 1 and B25 represents the last grain in sample 2. Grain surface textures are shown as features reading from left to right. This is the way in which observations will be presented on computer printouts during subsequent statistical analysis.

Checklist observations were supported by detailed notes made during the main scan and photographic evidence. The first part of the results presentation describe visual trends for surface texture variability with distance westward from Montauk Point. Graphs (Fig. 6.1 to 6.13), have been drawn tracing changes in individual texture abundancies across all samples. Trends and relationships between textures and samples are described and discussed and micrographs presented as visual evidence of such patterns.

It was felt that whatever degree of success subsequent statistical analysis might achieve in discriminating between samples, qualitative descriptions and observations provide an important primary source of information and framework from and within which deductions and interpretations may be made.

6.II DESCRIPTIONS OF SURFACE TEXTURE VARIABILITY WITH DISTANCE DOWNDRIFT FROM MONTAUK POINT AND OFFSHORE

Fluctuations in the relative abundance of individual textures alongshore for all samples is presented as a surface feature variability chart (Fig. 6.1). Reading across the chart from left to right presents a picture of surface feature variability for each sample and hence relates it to distance of littoral drift transport, while reading vertically down each column presents a profile of surface texture variability for individual samples. Offshore samples 19 to 22 were included in the last four columns on the right and are not located in their correct geographical positions opposite onshore beach samples owing to difficulties of drafting the chart (Fig. 6.1).

Each texture or textural group is described in sequence with families of textures being grouped periodically in order to note salient overall patterns and trends and their relationships to sample site locations. This is followed by references to electron micrographs illustrating and supporting descriptive results for all samples.

II.A GRAIN SHAPES

Grain shape (surface textures 1 to 6 in Fig. 6.1), varied a great deal alongshore (Figs. 6.2A, 6.2B and 6.3A). A noticeable shift in density shadings can be seen from the top left in the grain shape band (Fig. 6.1) representing angular grains, to the bottom right representing more rounded grains. This suggests an increase in grain roundness in general, with increasing distance of transport

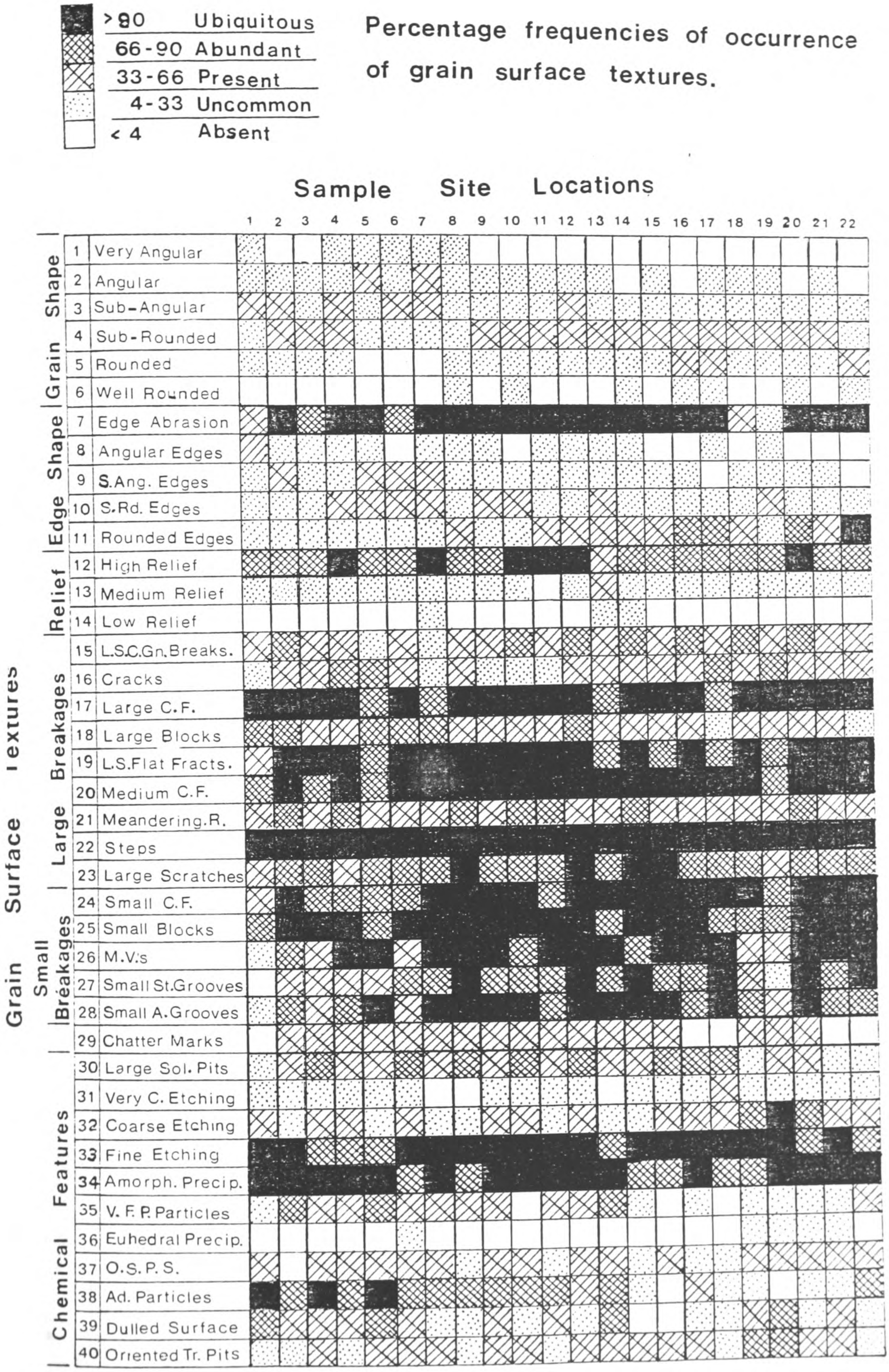


Fig. 6.1. Surface feature variability chart for the south shore, Long Island, N.Y..

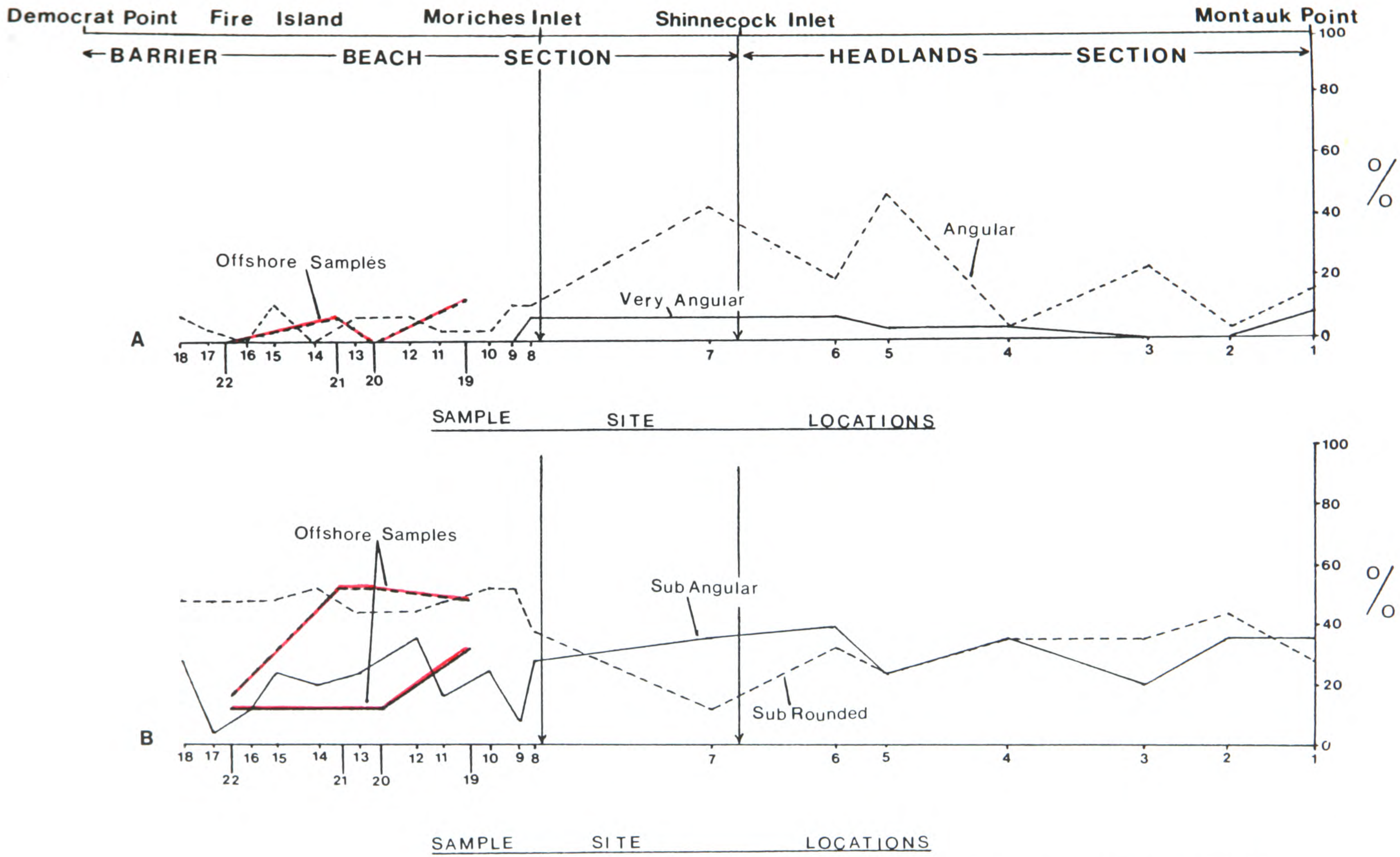


Fig. 6.2A. Angular and Very Angular; B. Sub-angular and sub-rounded-grain shape variations with distance downdrift of Montauk Point.

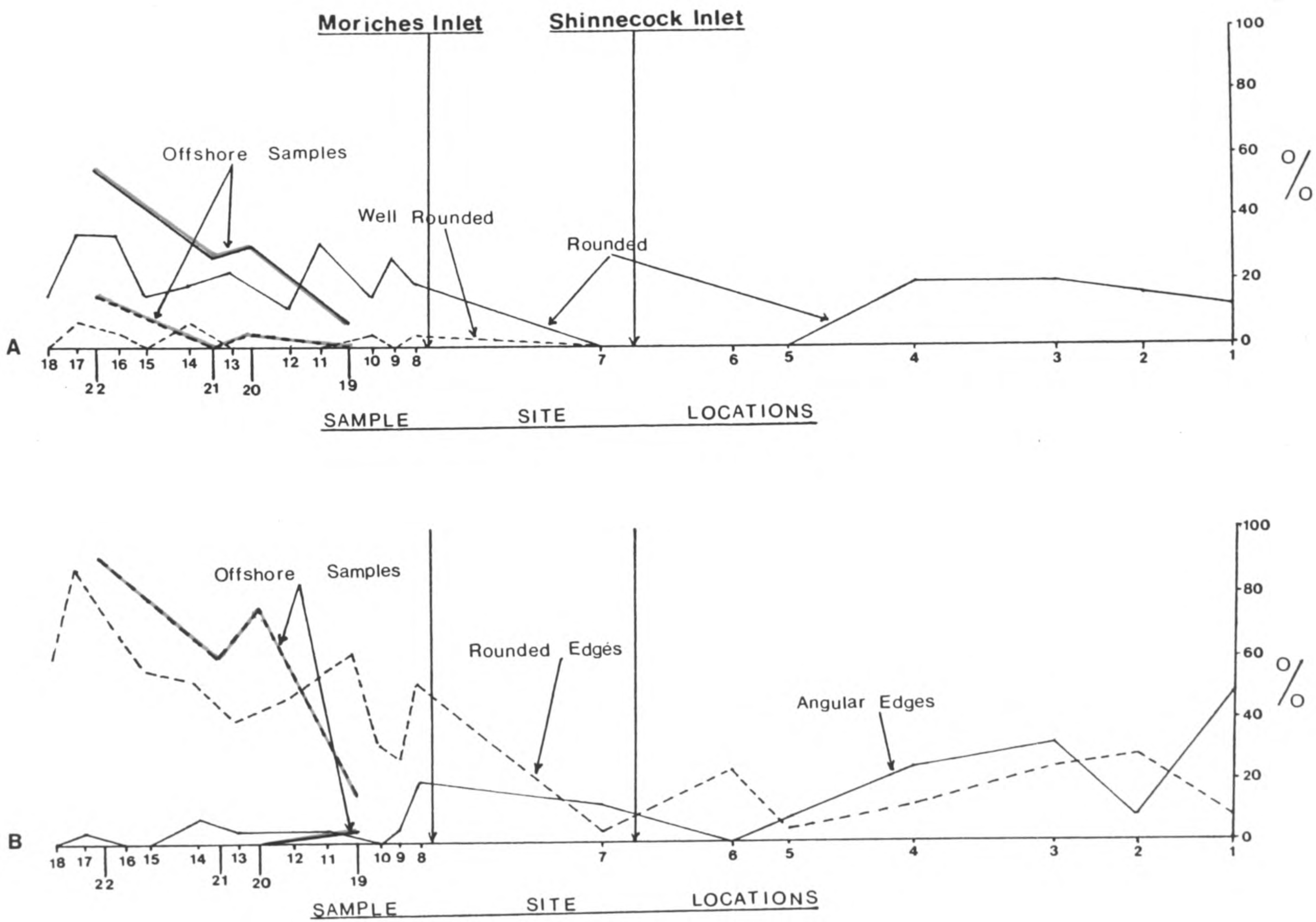


Fig. 6.3 A. Rounded and Well rounded grain shape;
B. Edge shape - Variations with distance downdrift of Montauk Point.

westward from sample 1 (Montauk Cliff). Offshore samples are shown in the last four columns in Fig. 6.1 (samples 19 to 22), and although they are out of position in terms of their distance locations west of Montauk Point (Fig. 2.4), they also have a greater percentage of subrounded and rounded grains.

Greater detail is presented on individual grain shapes in Figs. 6.2A, 6.2B and 6.3A. It must be borne in mind when percentage figures are quoted for surface texture variations that 4% represents 1 grain in terms of the frequency of occurrence within a sample. Table 6.1 represents percentage values of the checklist raw data and was the source from which subsequent diagrams were drawn and from which values may be obtained for all-feature variations for all samples.

On no samples were there more than two grains (8%), present which were very angular (Fig. 6.2A). Apart from complete absence of very angular grains at sample sites 2 and 3 (in the bluffs unit and connecting Headlands section beach unit in Fig. 2.4), Fig. 6.2A shows little variation in surface texture 1 (very angular grain) percentages. A feature worth noting is that no very angular grains were observed west of sample 8 on eastern Fire Island immediately downdrift of Moriches Inlet (Fig. 6.2A).

Angular grain percentages (surface texture 2) show considerably more variation (Fig. 6.2A). Samples 2 and 4 (Montauk beach and Easthampton respectively), show up as troughs in what may be a gradually increasing trend westward as far as sample 7 (Quogue), on Westhampton beach (Fig. 2.4). Apart from sample 6 near Southampton

QUARTZ GRAIN SURFACE TEXTURE

SAMPLE SITE LOCATIONS	GRAIN SHAPE						EDGE SHAPE					RELIEF			LARGE BREAKAGES								
	Very Angular	Angular	Sub-Angular	Sub-Rounded	Rounded	Well Rounded	Edge Abrasion	Ang. Edges	Sub-Ang. Edges	Sub-Rd. Edges	Rd. Edges	H. Relief	M. Relief	L. Relief	L.S.C.G.B.	Cracks	Large C.F.	L.S.F. Fracts.	Large Blocks	Med. C.F.	M.R.	Steps	L. Scratches
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Site No. 1	8	16	36	28	12	0	40	48	32	12	8	84	16	0	48	20	92	40	84	72	44	96	64
2	0	4	36	44	16	0	96	8	44	20	28	76	24	0	68	44	96	92	80	96	80	96	80
3	0	24	20	36	20	0	88	32	32	12	24	84	16	0	52	52	100	96	60	84	52	96	84
4	4	4	36	36	20	0	92	24	24	40	12	92	8	0	44	72	96	96	56	100	76	100	60
5	4	48	24	24	0	0	100	8	48	40	4	72	24	0	24	68	80	88	68	84	48	100	68
6	8	20	40	32	0	0	88	0	36	40	24	80	20	0	36	56	96	92	80	92	52	100	88
7	8	44	36	12	0	0	100	12	44	40	4	92	4	4	16	24	88	100	68	96	56	100	80
8	8	12	28	28	20	4	100	20	4	24	52	84	16	0	60	60	96	96	64	92	76	92	100
9	0	12	8	52	28	0	96	4	24	44	28	84	16	0	56	24	96	92	56	92	60	100	84
10	0	4	24	52	16	4	100	0	16	52	32	92	8	0	88	24	96	100	56	100	84	100	88
11	0	4	16	48	32	0	100	4	16	24	56	100	0	0	60	32	96	92	48	96	68	96	80

TABLE 6.1 Checklist raw data converted into percentage values

QUARTZ GRAIN SURFACE TEXTURE

SAMPLE SITE LOCATIONS	GRAIN SHAPE						EDGE SHAPE					RELIEF			LARGE BREAKAGES								
	Very Angular	Angular	Sub-Angular	Sub-Rounded	Rounded	Well Rounded	Edge Abrasion	Ang. Edges	Sub-Ang. Edges	Sub-Rd. Edges	Rd. Edges	H. Relief	M. Relief	L. Relief	L.S.C.G.B.	Cracks	Large C.F.	L.S.F. Fracts.	Large Blocks	Med. C.F.	M.R.	Steps	L. Scratches
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Site No. 12	0	8	36	44	12	0	100	4	16	32	48	92	8	0	80	64	100	100	76	96	56	100	92
13	0	8	24	44	24	0	96	4	8	48	40	48	44	8	36	52	88	80	48	92	48	100	84
14	0	0	20	52	20	8	100	8	12	28	52	84	12	4	68	52	96	100	60	100	80	100	92
15	0	12	24	48	16	0	100	0	16	28	56	80	20	0	48	44	100	84	56	100	52	100	92
16	0	0	12	48	36	4	100	0	8	24	68	68	32	0	68	60	100	100	44	96	44	100	80
17	0	4	4	48	36	8	100	4	0	8	88	76	24	0	36	76	88	88	24	100	60	96	72
18	0	8	28	48	16	0	40	0	12	28	60	76	24	0	68	64	92	96	44	92	44	96	72
19	0	12	32	48	8	0	20	4	32	48	16	88	12	0	56	76	100	84	52	88	36	100	40
20	0	0	12	52	32	4	100	0	4	20	76	92	8	0	80	48	96	96	56	100	68	92	80
21	0	8	12	52	28	0	92	0	16	24	60	76	24	0	64	44	100	100	56	96	52	100	72
22	0	0	12	16	56	16	96	0	0	8	92	76	24	0	36	48	100	92	24	100	48	100	72

TABLE 6.1 Checklist raw data converted into percentage values

QUARTZ GRAIN SURFACE TEXTURES	SMALL BREAKS						CHEMICAL FEATURES										
	Small C.F.	Small Blocks	M.V.	Small S.G.	Small A.G.	C.M.	Large Sol. Pits	V. Coarse Etch	Coarse Etch	Fine Etch	Amorph. Precip.	V.F.P.P.	Eu. Precip.	Or. S.P.S.	Adh. Parts	Dull Surf	O.T.
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Site No. 1	64	72	8	0	4	0	28	12	40	100	100	12	0	56	96	80	24
2	92	92	88	36	72	4	60	8	24	96	92	76	0	0	72	52	24
3	84	96	52	40	48	16	72	12	36	72	96	60	0	56	96	48	60
4	88	100	96	40	80	16	52	20	40	88	100	56	0	36	76	36	28
5	76	80	100	56	92	16	60	8	24	84	100	84	0	36	100	68	44
6	88	96	36	72	64	20	68	20	48	96	88	56	4	36	88	64	56
7	92	96	96	80	92	20	44	0	28	96	96	32	0	64	88	28	60
8	100	100	100	92	92	12	68	0	12	96	80	60	0	20	76	20	20
9	100	100	96	68	92	20	40	4	48	96	96	48	0	44	80	56	44
10	100	100	84	80	92	4	68	12	40	100	92	0	0	52	80	12	56
11	80	96	96	76	76	8	44	12	20	100	100	40	0	12	88	64	16

SAMPLE SITE LOCATIONS

TABLE 6.1 continued. Checklist raw data converted into percentage values

	QUARTZ GRAIN SURFACE TEXTURES																
	SMALL BREAKS						CHEMICAL FEATURES										
	Small C.F.	Small Blocks	M.V.	Small S.G.	Small A.G.	C.M.	Large Sol. Pits	V. Coarse Etch	Coarse Etch	Fine Etch	Amorph. Precip.	V.F.P.P.	Eu. Precip.	Or. S.P.S.	Adh. Parts	Dull Surf	O.T.
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
SAMPLE SITE LOCATIONS — Site No. 12	100	100	100	100	100	32	72	20	44	100	100	4	0	48	60	4	48
13	92	88	100	76	96	16	52	0	16	80	100	88	0	40	88	72	36
14	100	96	96	100	100	12	48	16	28	96	84	12	0	20	24	0	48
15	100	100	88	72	96	16	72	20	36	100	84	0	0	44	92	0	56
16	100	100	96	76	88	0	76	20	40	100	92	20	0	32	64	8	40
17	100	76	100	92	96	4	68	36	60	100	80	0	0	32	28	28	20
18	96	80	60	52	72	8	32	24	72	96	88	24	4	36	16	52	68
19	72	80	44	24	48	4	44	16	92	92	96	24	8	44	0	76	76
20	92	92	100	100	100	4	52	20	68	80	92	16	12	52	8	20	52
21	92	92	96	80	80	0	32	8	36	100	100	4	4	48	20	50	48
22	100	92	92	92	88	0	28	8	40	80	96	40	0	40	88	20	24

TABLE 6.1 continued. Checklist raw data converted into percentage values

(Fig. 2.4), with only 20% angular grains, the western Headlands section and Westhampton beach represent the most angular of all samples with 48% and 44% of angular grains respectively in samples 5 and 7 (Fig. 6.2A). As with very angular grains, angular grain shapes also fall sharply downdrift of Moriches Inlet in eastern Fire Island (Fig. 6.2A and 2.4).

As expected subangular and subrounded grains (surface textures 3 and 4 respectively), generally show greater frequencies on average (Fig. 6.2B). Both grain types vary little in frequency east of Fire Island apart from a trough of 12% for subrounded grains on Westhampton beach (sample site 7, Fig. 6.2B). Once more a marked change in trend occurs in eastern Fire Island (sample 9, Fig. 6.2B). Subangular grain percentages fall sharply as subrounded percentages increase at this point. In essence the whole of Fire Island (Fig. 2.4) is characterised by almost 50% subrounded grains (Table 6.1).

Rounded grains (surface texture 5), increase very gently from a frequency of 12% at Montauk Cliff (sample 1 in Fig. 2.4), westward in the Headlands section (Fig. 2.4), but no rounded or well rounded grains were present in samples 5, 6 and 7 (Figs. 6.1 and 6.3A), in the western Headlands section and at Quogue on Westhampton beach (Fig. 2.4).

Well rounded grains (surface texture 6) present almost a mirror image of the pattern shown by very angular grains in eastern Long Island (Figs. 6.3A, and 6.2A). Well rounded grains were exclusive to Fire Island and are present in only five samples (Table 6.1), qualifying as uncommon (Fig. 6.1), in only samples 14 and 17 in western Fire Island (Fig. 6.3A).

In general offshore samples followed a similar trend to onshore beach samples on Fire Island (Figs. 6.2A, 6.2B and 6.3A). There were no very angular and few angular grains even, subangular grain percentages falling below beach values (Fig. 6.3A). Offshore sample grains were dominantly rounded or subrounded, subrounded grain shapes comprising approximately 50% of sample totals apart from sample 22.

Having observed individual variations in each of the six surface textures representing grain shape (Figs. 6.2A, 6.2B, 6.3A), and as no individual shape category dominated samples, i.e. reached 'abundant' proportions (Fig. 6.1), two other graphs illustrating grain shape were drawn (Figs. 6.4 and 6.5).

Both graphs (Figs. 6.4 and 6.5), helped to isolate samples into groups using a broader blunter approach to grain shape. Fig. 6.4 combines grain shape end members, very angular/angular, well rounded/rounded as well as their submembers. All but three of the samples are grouped near the right apex indicating subangular-subrounded/rounded-well rounded dominant shapes. Although there are many ways in which such groups may be subdivided visually an arbitrary twofold division into 'Fire Island beach' and 'other beach' sample groups further east alongshore was drawn (Fig. 6.4). Fire Island beach grains form a tight group except possibly for sample 8 (eastern Fire Island), and sample 17 (western Fire Island).

The Headlands section and Westhampton beach (Fig. 2.4), did not form a cohesive group (Fig. 6.4), but appear distinct from Fire Island samples apart from sites 2 and 4 (Fig. 6.4). The glacial

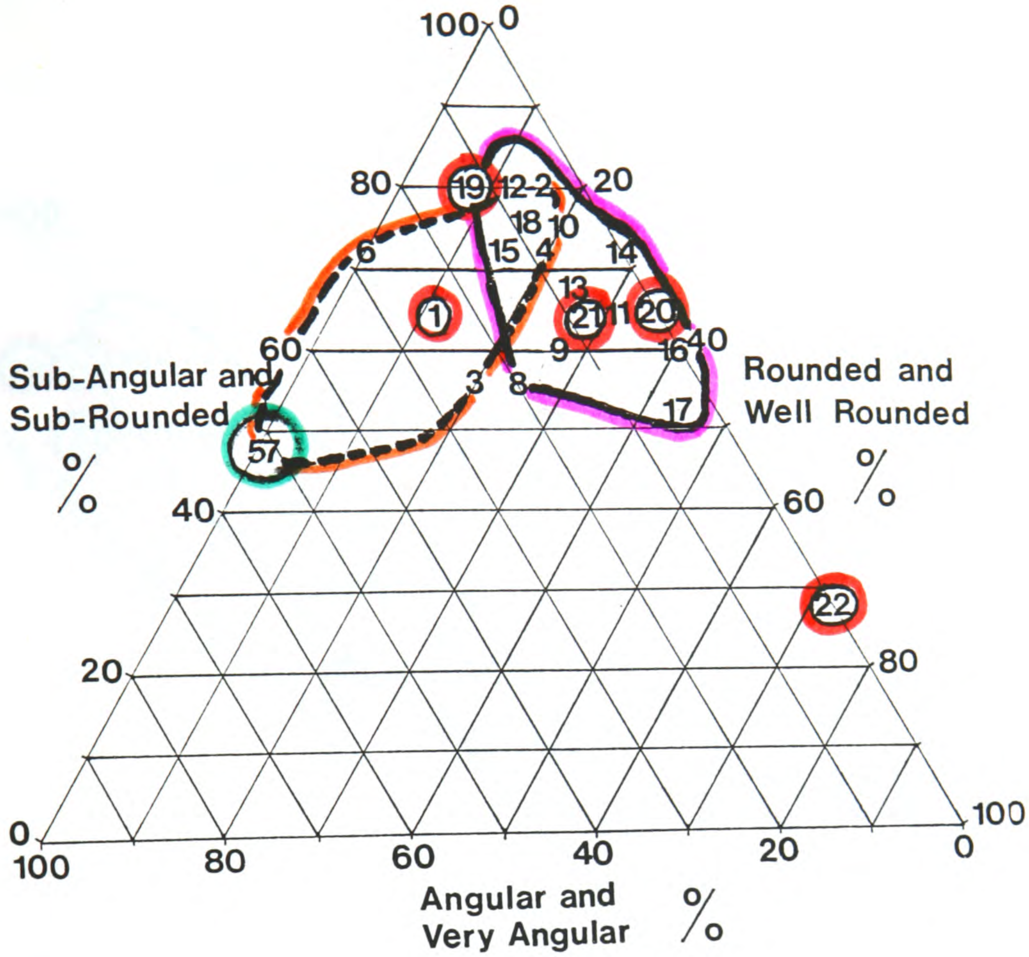
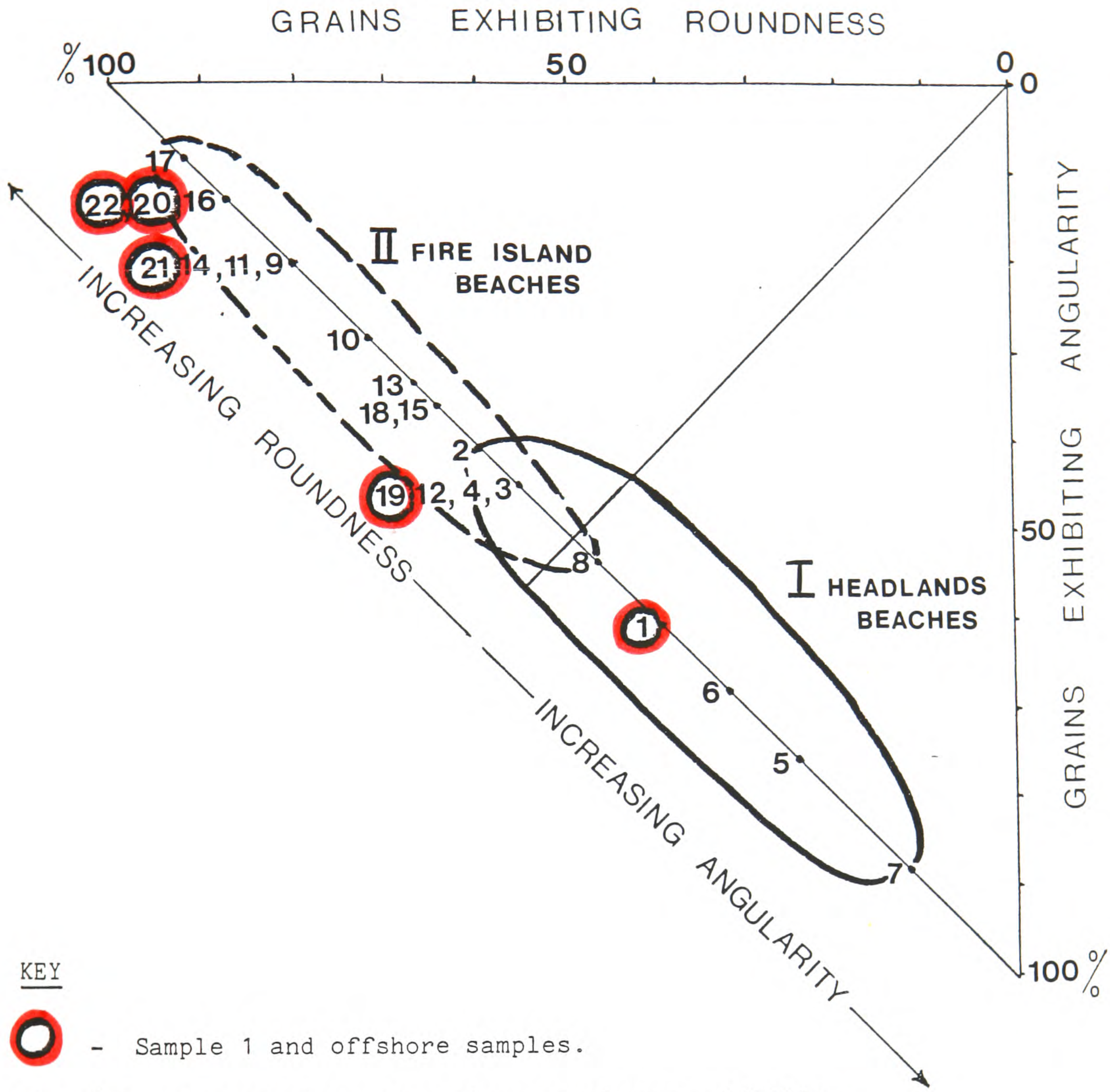


Fig.6.4 Comparison of the three elements of Grain Shape for Sample Sites 1 to 22.

KEY

- Sample 1 and offshore samples.
- Samples 5 and 7.
- Fire Island beach samples (Group II).
- Other beach samples (Group I).



KEY

- Sample 1 and offshore samples.

Fig. 6.5. A comparison of grain percentages exhibiting angularity and roundness.

sample from Montauk Cliff (sample 1), is not as closely associated with the other beach samples (Group I), in the same way as offshore samples 19, 20 and 21, east of Channel H and proximal to Channel H respectively are to Fire Island samples (Group II).

Using such a threefold grain shape grouping, sample 5 and 7 (east of Fire Island), and sample 22 (west of Channel H), seem anomalous (Fig. 6.4) and distinct from each other as well as the main groups. Samples 5 and 7 have already been described above as representing mainly angular grain shapes whereas sample 22 appears as the most rounded of samples (Fig. 6.4).

Reducing the finesse of grain shape categories even further (Fig. 6.5), then samples may be plotted according to grain texture occurrence frequencies exhibiting angularity in the broadest sense (combining shape textures 1, 2 and 3 in Fig. 6.1) and those exhibiting roundness (combining shape textures 4, 5 and 6 in Fig. 6.1). It is appreciated that such broad groupings provide little detail on the basis of which individual sample grain variations may be discussed with any accuracy. Nevertheless Fig. 6.5 affords an opportunity for straightforward linear ranking of samples on the basis of angularity or roundness.

Using the same arbitrary groupings as Fig. 6.4, Group I comprising samples updrift of Fire Island (Fig. 2.4), emerges as distinct from Group II on Fire Island (Fig. 6.5). An overlap occurs in the groupings at sample sites 2, 3 and 4 (eastern Headlands section), 8 (eastern Fire Island), 12 (central Fire Island) and 19 (offshore east of Channel H) (Fig. 6.5).

Care must be taken when interpreting trends and relationships from such crude shape categorisation as illustrated in Fig. 6.5. More accurate fluctuations in individual shape textures may be seen in Figs.6.2A, 6.2B and 6.3A. Nevertheless it is a useful vehicle for a form of sample ranking on the basis of grain angularity and roundness in the broadest sense.

In summary the following salient points should be noted regarding grain shape variations alongshore west of Montauk Point (Fig. 2.4), as far as qualitative results are concerned.

(a) The general trend is one of increasing grain roundness (Fig. 6.1), which may or may not reflect surf induced modifications during transport in littoral drift.

(b) Sample 1 (Montauk Cliff in Fig. 2.4) is a distinctive sample on the basis of shape with one of the most mixed grain shape populations: 8% very angular, 16% angular, 36% subangular, 28% subrounded and 12% rounded. No well rounded grains were observed (Table 6.1). In view of the importance of grain angularity as a diagnostic feature of glacial sediments (Krinsley and Doornkamp, 1973), Montauk Cliff glacial moraine is characterised more by variety of shape, although 62% of the sample range in shape from subangular to very angular. An example of sample 1 dominantly subangular-subrounded grain types is shown on Plate 6.1.

(c) Immediately downdrift from Montauk Cliff (sample 1), samples 2 and 4 show marked declines in angular and very angular grain shape combinations (4% and 8% respectively) compared with 24% for sample 1.

(d) Within the Headlands section as a whole, grain shapes are subangular-subrounded (Fig. 6.2B). However, maximum grain angularity frequencies are achieved in western Headlands' beaches and Westhampton beach (Fig. 2.4). This is surprising in that surf modifications are not generally held responsible for increasing grain angularity (Margolis and Kennett, 1971). It may be possible that an increase from 16% (sample 1) to 48% (sample 5) and 44% (sample 7) in angular grain shapes represents an input in eastern Long Island of another more angular sediment source than Montauk Cliff. Fig. 2.3 shows bifurcations of another two ancient palaeo-drainage channels with possible glacial-fluvioglacial sediments (Channels J and K), in eastern Long Island updrift of the central Headlands section (Williams, 1976). Plate 6.2 shows an example of the angular grain Headlands section population.

(e) All grain shape trends show a marked break immediately downdrift of Moriches Inlet in eastern Fire Island (Figs. 6.2A, 6.2B, 6.3A and 2.4). Very angular grains disappear and angular grains fall sharply at this point (Fig. 6.2A). Subangular grains and subrounded grains part company markedly and rounded grain types reappear after an absence since sample 4 at Easthampton (Fig. 2.4). It is at this point that rounded grains appear for the first time (Fig. 6.3A).

(f) Fire Island beach samples are dominantly subrounded to rounded (Fig. 6.3A) as shown by samples 8 to 18 (Fig.2.4). Plates 6.3, 6.4, 6.5 and 6.6 show the character of subangular-subrounded grain populations along most of the south shore from samples 2, 3, 8 and 13 respectively. Plate 6.7 shows a subrounded grain from sample 14 in central Fire Island (Fig. 2.4), which has had its angularity enhanced by complete grain breakage on the left hand side.

(g) Considering the fluvioglacial or glacial origins of sediments infilling Channel H (Williams, 1976), their grains are subrounded to rounded (Table 6.1; Figs. 6.1, 6.2A, 6.2B, 6.3A).

(h) Samples 20 and 21, proximal to Channel H (Fig. 2.3) closely resemble each other in terms of the six shape categories (Figs. 6.1, 6.2A, 6.2B, 6.3A). Both samples consistently follow similar trends to Fire Island beach samples (Group II in Figs. 6.4 and 6.5).

(i) Sample 19 is distinguishable from sample 22 (east and west of Channel H respectively in Fig. 2.4), by its high subrounded -subangular grain shape percentages (80%), whereas sample 22 is the roundest of all samples with 72% of grains in rounded-well rounded categories (Table 6.1). Plates 6.8 and 6.9 show elongated smooth grains from samples 20 and 21 respectively. Plate 6.10 illustrates a subrounded grain from sample 22.

II.B EDGE SHAPE

Surface textures 8 to 11 represent a fourfold categorisation of edge shape (Fig. 6.3B, 6.6, 6.7). Angular edges (Fig. 6.3B) decrease from a maximum of 48% at Montauk Cliff (sample 1, Fig. 2.4), to a fluctuating low of 4-8% on Fire Island. Two troughs in this downward trend occur at sample 2 in the Bluffs unit and sample 6 on the western edge of the Headlands section (Fig. 6.3B). Rounded edges exhibit a fluctuating trend of 8% to 24% in the Headlands section (Fig. 6.3B) then increase rapidly in abundance westward

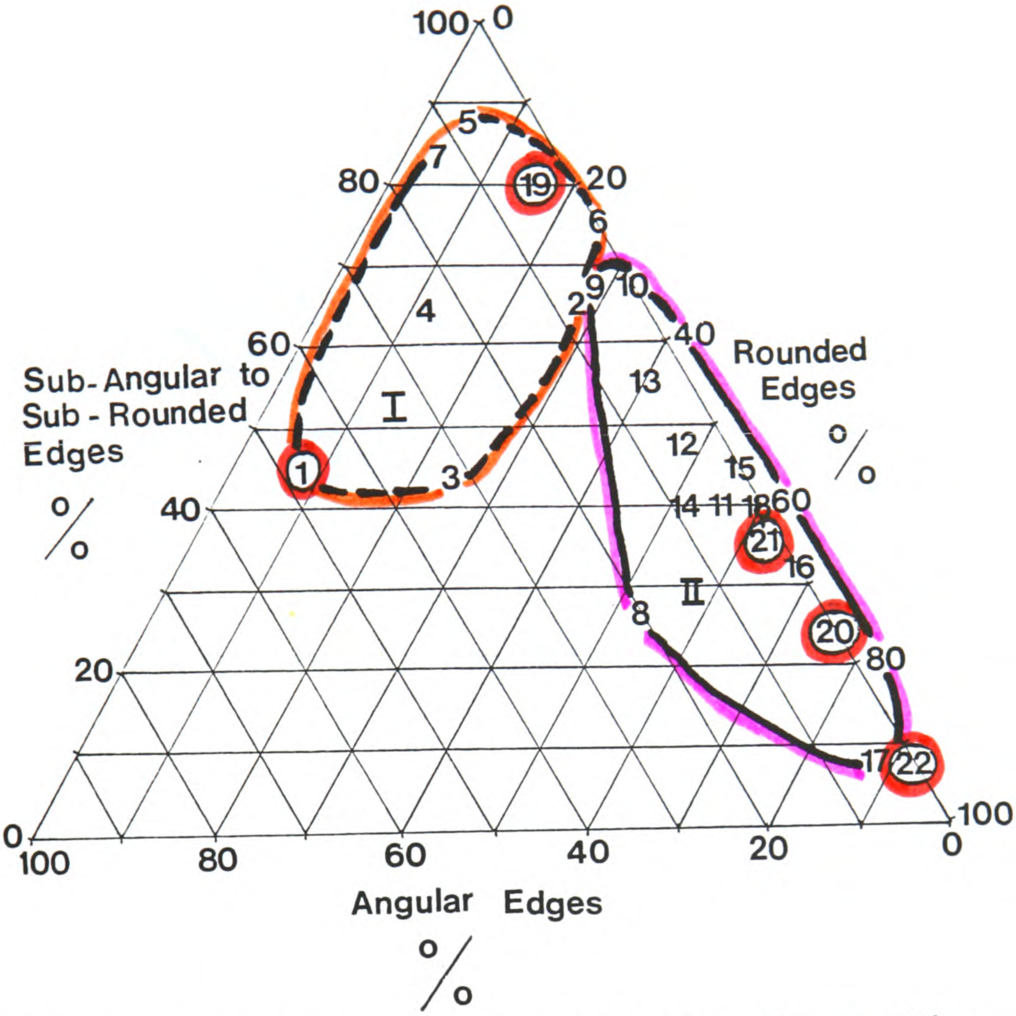
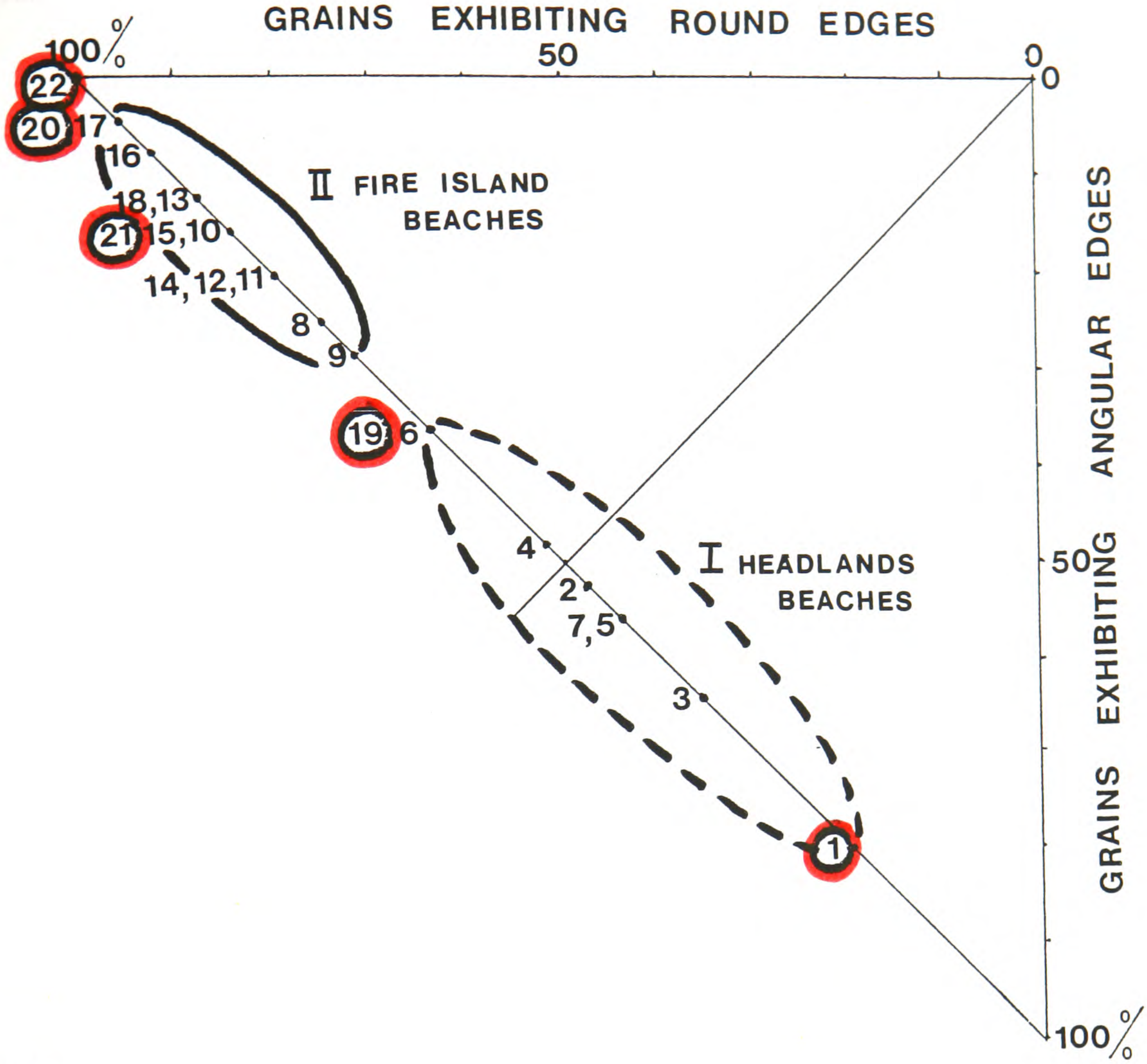


Fig. 6.6 Comparison of three main elements of Edge Shape for Samples 1 to 22.

<u>KEY</u>

- Sample 1 and offshore samples.
- Other beach samples (Group I).
- Fire Island beach samples (Group II).



KEY

- Sample 1 and offshore samples.

Fig. 6.7. A comparison of grain edge percentages exhibiting roundness and angularity.

along Fire Island achieving a peak of 88% at sample site 17.

Combined angular-subangular edge shapes dominated the Bluffs unit and Connecting beach (Fig. 6.3B), in eastern Long Island (samples 1 to 3) while subangular-subrounded edges dominated west of site 3 to site 7 on Westhampton beach (Fig. 6.3B, Table 6.1). Subrounded-rounded percentages dominated beach samples from eastern Fire Island (sample 8, Table 6.1) and from sample 11 westward rounded edges exceed 50% in virtually all cases (Table 6.1, Fig. 6.3B).

A shift in texture abundance from top left to bottom right in the edge shape band (angular to rounded), may be seen in Fig. 6.1, following a similar pattern to grain shape.

An attempt to discriminate samples on a visual basis using edge shape was made as for grain shape (Figs. 6.6, 6.7). Subangular and subrounded edges were combined in value and graphed against rounded edge and angular edge percentages (Fig. 6.6). Edge shape also separated grains into two groups (Fig. 6.6). The Headlands section in eastern Long Island (Fig. 2.4) and Westhampton beach do not form any sort of cohesive group and are located in the dominantly subangular-subrounded apex (Group I in Fig. 6.6). Fire Island beach samples form a tighter grouping along the right hand side of Fig. 6.6 shown as Group II.

Angular-subangular percentages were graphed against rounded-subrounded edge percentages (Fig. 6.7). Again Fire Island and samples updrift separated into two groups (Group I and Group II, Fig. 6.7). Such a graph (Fig. 6.7) has more credence than Fig. 6.5 owing to the reduced combination of groupings, but the same care must be taken in drawing any conclusions regarding finer detail from a two feature category graph based on a four feature category check-list. It must also be pointed out that it is not suggested that Groups I and II (Figs. 6.5 and 6.7), form natural groups, only that they separate when a geographically derived net is thrown over plotted samples.

Offshore samples (21 and 22) follow a similar if more rounded trend to onshore beach samples on Fire Island (Figs. 6.3B, 6.6, 6.7). Samples 20 and 21 occupy locations transitional to sample 19 and sample 22 as shown in Fig. 6.3B.

The following points should be noted regarding edge shape variations downdrift of Montauk Point and offshore:

(a) Grain edge angularity decreases west of Montauk Cliff (Fig. 2.4) and grain roundness increases in general terms (Figs. 6.3B, 6.1). This resembles the gross pattern for grain shape (Figs. 6.1, 6.2A, 6.2B, 6.3A).

(b) Progressive grain edge rounding is much smoother and persistent westward of Montauk Cliff (sample 1, Fig. 2.4), on combining edge shape pairs: angular-subangular dominate from samples 1 to 3, subangular-subrounded from samples 3 to 7, sub-rounded-rounded from samples 8 to 11, and rounded edges from sample 11 westwards (Table 6.1). Such a smooth progression is more likely to represent the influence of a single modifying process with transport in littoral drift westward from Montauk Cliff (Fig. 2.4).

(c) Sample 1 is distinct from samples 20 and 21 reinforcing grain shape results in that the moraine at Montauk Point is different from buried channel lobe deposits offshore on the basis of edge shape.

(d) Moriches Inlet and eastern Fire Island serve as a marked boundary between beach samples updrift to the east and downdrift to the west with angular-subrounded shapes dominating in the east and subrounded-rounded dominating in the west.

(d) Increase in edge roundness along Fire Island is remarkable for its rapidity (Fig. 6.3B). The roundest edges are located on offshore sample grains (Fig. 6.3B, Table 6.1). In fact sample 17 (Fig. 2.4) immediately downdrift of sample 22 (the roundest of all samples with 92% rounded grain edges), has 88% rounded edges, 20% and 28% more than sample 16 updrift and sample 18 downdrift (Table 6.1). This may suggest an input of round edged grains from offshore to onshore beaches in central and western Fire Island.

Plate 6.11 shows an example of contrasting grain edges from sample 3 in the eastern Headlands section (Fig. 2.4), the lower right position being well rounded while remaining edges are more angular. Plate 6.12 shows an equant grain from sample 7 (Westhampton beach, Fig. 2.4), dominated by very large fractures, curved and subplanar surfaces and extremely coarse parallel and subparallel blocky steps and striations in the lower half. The increase in grain roundness and edge roundness along Fire Island from east to west is shown on Plate 6.13 (sample 8), and on Plate 6.14 (sample 13, Fig. 2.4).

Plates 6.15 and 6.16 illustrate rounded edges typical of sample 21. Typically clean and smooth higher magnifications of a protrusion show mainly chemical etching, some oriented with some M.V. pits and small percussion features (Plate 6.16).

Sample 22 (Plate 6.17), provides a good example of a well rounded edge similar to sample 21 (Plate 6.16).

II.C EDGE ABRASION

Interpretations of environmental modifications on the basis of checklist results of edge abrasion and indeed most mechanical breakages (surface textures 7, and 15 to 28 in Fig. 6.1), again must be made with care. Only presence-absence was noted during the scan so age categories were not included in Fig. 6.1. As a result all worn-edge abrasions modified chemically would receive the same checklist weighting as fresh final cycle breakages. In addition the nature of edge abrasion, whether it be dominantly high energy 'blocky' or lower energy M.V. pit in character, may not be deduced from the graph shown in Fig. 6.8A.

A cursory glance at edge abrasion trends west of Montauk Point (Fig. 2.4) shows that it is unlikely to be a useful grain-sample discriminating texture (Fig. 6.8). Fig. 6.1 shows edge abrasion to be virtually ubiquitous (>90% abundance) except for five samples.

Sample 1 shows the lowest abundancies (40%, Table 6.1) along with sample 18 in western Fire Island (Fig. 2.4). Samples 3 and 6 in the Headlands section fall barely below 90% and 88% each (Table 6.1), but offshore sample 19 falls to 20%, an unusually low figure given that edge abrasion ubiquity in other offshore samples is so high (Fig. 6.8A).

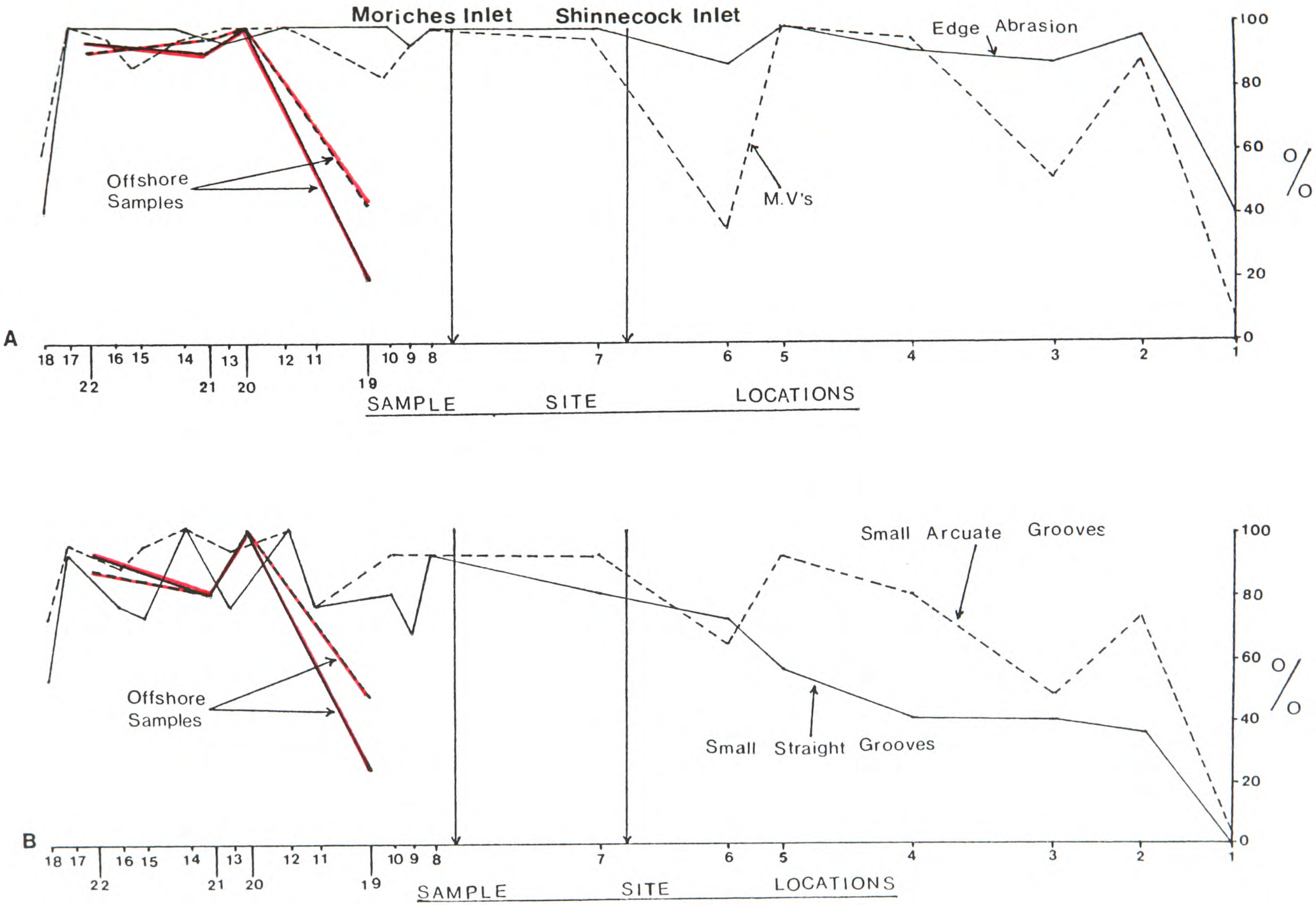


Fig. 6.8. A. Edge abrasion and M.V. pit; B. Small arcuate and straight grooves variation with distance downdrift of Montauk Point.

Edge abrasion has long been taken as evidence of modifications induced by attrition during turbulent transport (Goudie and Bull, 1984), so the trend for most of Long Island's south shore in the study area (Fig. 2.4) can be expected. The glacial origin of sample 1 may be expected to produce reduced edge abrasion abundancies (Eyles, 1978), but sample 18 (western extremity of Fire Island) and offshore sample 19 are less easy to explain.

A variety of edge abrasion types is presented on Plates 6.18 to 6.24. Plate 6.18 shows an example of a dulled grain surface from sample 1 showing little evidence of edge abrasion and dominant chemical precipitation-solution modifications (on the right hand side). Sample 21 (Plate 6.19), shows an example of only minor apparently surf induced edge abrasion, with chemically induced corrosion from samples 3, 8 and 12 respectively (Fig. 2.4). In each of these examples irregular and to a certain extent oriented fine etch pits intermingle with arc shaped cracks percussion chips and M.V. pits.

Plate 6.23 illustrates a lack of edge abrasion on two edges radiating from a smooth projection on the left, the whole surface being covered by oriented triangular etch pits highlighted by the black discolouration (sample 18). Sample 21 (Plate 6.24), provides a contrast with a broad well rounded edge densely pitted with chemical etch pits (often orientated), and a variety of fresh cross-cutting V blocks, straight grooves and impact pits.

II.D MECHANICAL V PITS

Edge abrasion and M.V. pits follow similar trends (Fig. 6.8A, surface textures 7 and 26 in Fig. 6.1). Both have low values at Montauk Cliff (sample 1) and western Fire Island (sample 18), with ubiquitous values between those two points (Fig. 6.8A). However, mild downward fluctuations in edge abrasion at sample sites 3, 6 and 9 (Fig. 2.4), are much magnified in the case of M.V. pits (Fig. 6.8A).

The rapid increase in M.V. pit abundance is to be expected from sample 1 to sample 2 (Fig. 6.8A), as this represents a transfer from glacial moraine cliff to the beach several kilometres downdrift at Montauk Beach. In fact values for M.V. pit abundance (Table 6.1) increase from 8% to 88% as we move from sample 1 to sample 2. Krinsley et al (1964), had already noted the increased turbulence and sediment size variability at this point on the shore.

There are marked downward fluctuations at sample sites 3 and 6 remarkable for their abruptness in an otherwise high value trending plateau along the south shore (Fig. 6.8A). Offshore samples 20 and 21 and sample 22 follow onshore Fire Island beach M.V. pit abundancies very closely (Fig. 6.8A). However offshore sample 19 has low values for M.V. pit abundance to the same extent as samples 3 and 6 further updrift on the beaches in the Headlands section (Figs. 6.8A, 2.4, Table 6.1).

Any discussion which purports to interpret M.V. pit abundance along Long Island's south shore must take cognizance of the fact that M.V. pits have been almost universally accepted as a diagnostic grain surface modification indicative of turbulent subaqueous transport (Krinsley, pers. comm.). M.V. pit densities have been said to increase alongshore westward from sample 1 at Montauk Point (Krinsley et al, 1964). Apart from Montauk Point, energy conditions in the surf along the shore in Long Island have been described as uniform (Krinsley et al, 1964). There seems to be no mechanism therefore in the study area, which may reduce M.V. pit abundance by as much as 36% for sample 3 and 52% for sample 6 (Fig. 6.8A).

Plates 6.25 and 6.26 illustrate the relative absence of surf abraded edges in sample 1 at Montauk Point. Plate 6.27 shows a close up of an edge on grain 1, sample 1 which is rounded chemically, the smooth surface grading into considerable chemical etching on the right in the hollow, some of the pits in the lower centre being mechanical in origin. Plate 6.28 exhibits a similar edge from sample 1 grains with an absence of mechanical pit polishing typical of beach grains. The edge is dominated more by irregular undulating capping layer precipitation and solution.

On sample 1 edges occasional mechanical pits are present but the general background of the grain surfaces is one of dominantly dulled chemical precipitation lacking the clean pitted surface textures of grains farther west. It may be pertinent to point out at this juncture that the presence of one large conchoidal fracture carries some impact as far as the mosaic of that grain's surface textures are concerned. However the presence of one, or a few M.V. pits with other minor defrosting mechanical abrasions such as straight and curved grooves, irregular pits, cracks and microblocks, do not carry as much weight and this is the framework within which photographs are presented for interpretation.

A good example which illustrates this point is shown on Plate 6.29 where a grain edge from sample 1 separates contrasting grain surfaces. The surface to the left of the edge is fresh and smooth with traces of subparallel cracks modified lightly by very small precipitation platelets and opaque white adhering particles. The surface to the right of the edge (Plate 6.29), shows moderate precipitation-etching and a degree of crystallographic control. The edge itself has a broken appearance with some V shaped notches, but lacks the assemblage of edge-polishing surf abrasions typical of grains further west.

Sample 2 in the Bluffs unit just downdrift from Montauk Cliff (Fig. 2.4) has cleaner edges dominated by small blocky fractures (surface texture 25), M.V. pits and chemical etching (Plate 6.30). A contrast is presented on Plates 6.31 and 6.32 from sample 3, where the dominant fractures are high energy breakages (Plate 6.31), and edges are lightly pitted mechanically and chemically, etched major surfaces being masked by smooth capping layer (surface texture 34).

Proceeding westward, mechanically induced edge rounding combines intimately with chemical solution (Plate 6.33 from sample 4, Plates 6.34 and 6.35 from sample 5 and Plate 6.36 from sample 8). This represents a traverse alongshore as far west as Fire Island. Sample 12 in central Fire Island is portrayed on Plates 6.37 and 6.38. High magnifications of x10,000 reveal densely pitted surfaces dominated by fine etching and only several M.V. pits forming the edges of microblocks (Plates 6.37, upper centre, lower centre right).

Grain edges and other surfaces sometimes show irregular growth of thin films of silica precipitation over etched or mechanically pitted surfaces underneath. This is itself finely pitted and may produce a curious fine pitted texture which is very dense, clean and difficult to interpret (Plates 6.39, 6.40 and 6.41) from sample 21.

Plate 6.39 exhibits a smoothly rounded edge with its central portion abraded by curved cracks, M.V. pits and curved grooves (surface textures 20, 26 and 28 in Fig. 6.1). These grade into chemical etch pits in the centre and at the margins. Plate 6.40 shows small conchoidal fractures and steep sharp blocky pits surrounded by elongated subparallel almost chattery etch pits (upper left) from sample 21.

A close up of such an edge (Plate 6.41), reveals at first glance a smashed microblocky surface at the smallest scale but there are flat platelets of smooth precipitated silica gradually smothering what may be an etch modified subsurface (shallow hourglass hollow well left of centre). The curved crack on the right of plate 6.41 would be interpreted as mechanical in origin, as would some of the irregularly oriented blocky V pits. The section under chemically induced grain surface modifications will describe some unusual textures related to this from sample 21 offshore.

II.E SMALL ARCUATE GROOVES AND STRAIGHT GROOVES

Along with M.V. pits (surface texture 26), small arcuate grooves (surface texture 28) and small straight grooves (surface texture 27) formed textural associations related to mechanically polished and rounded edges. They usually occurred as the smaller of a two tier size breakage pattern, the larger breakages being represented by small blocks (surface texture 25), and small and medium conchoidal fractures (surface textures 24 and 20 respectively).

Sample 1 small arcuate grooves and straight grooves are classified as 'absent' on the surface feature variability chart (Fig. 6.1). As is the case with M.V. pits and edge abrasion (surface textures 26 and 7 respectively), grooves quickly increase in abundance immediately they experience a relatively short transportation distance westward in the surf to sample 2 (Fig. 2.4). For reasons already mentioned, this is to be expected from a glacial source (sample 1) to a turbulent beach (Krinsley et al, 1964).

In much of the Headlands section small arcuate grooves resemble the abundancies typical of M.V. pits (Fig. 6.8B), whereas straight grooves were less common. Small arcuate grooves also dip in frequency at sample site 3 along the Connecting beach and sample 6 near Southampton (Fig. 2.4), in the same way as M.V. pits (Fig. 6.8A, and 6.8B), suggesting a closer relationship to M.V. pits than straight grooves (surface texture 27).

From the western Headlands along the beach downdrift to Democrat Point small arcuate grooves and straight grooves follow very similar patterns (Fig. 6.8B) with abundancies in excess of 66% (Fig. 6.1). Straight grooves vary much more than arcuate grooves along Fire Island (Fig. 6.8B).

Sample 18 at the western end of Fire Island differed from the main Fire Island trend, values for both arcuate and straight grooves both falling from over 90% to 72% and 52% respectively (Table 6.1).

The pattern for arcuate and straight grooves for offshore samples 19 to 22 are virtually identical in Figs. 6.8A and 6.8B.

Offshore samples 20 and 21 and sample 22 show a much closer relationship between arcuate and straight grooves and sample 19 differs markedly from the other offshore samples (Fig. 6.8B).

II.F SMALL CONCHOIDAL FRACTURES AND SMALL BREAKAGE BLOCKS

Grain surface textures 24 and 25 (Fig. 6.1), complete the textural assemblage associated with edge abrasion in sample grains scanned in the present study (Fig. 6.9A). Sample 1 at Montauk Cliff does not stand out as clearly from beach samples to the west on the basis of small conchoidal and blocky breakages, as they do on smaller edge breakages (surface textures 26, 27 and 28). Fig. 6.9A shows a gradually increasing trend for both small conchoidals and breakage blocks from values of 64% and 72% respectively at Montauk Cliff (sample 1), to maximum abundancies of 100% at sample site 8 in eastern Fire Island (Fig. 2.4). Small breakage blocks are slightly more abundant than small conchoidals along the Headlands section (Fig. 6.9A) with small downward fluctuations at sample site 5 near Southampton (Fig. 2.4).

The offshore samples show a close relationship to onshore Fire Island beach samples (Fig. 6.9A) although the same relationship would appear for most of the beach samples updrift, values being 'abundant' or 'ubiquitous' in most cases (Fig. 6.1). Samples 18 and 19 both exhibited slightly lower abundancies for small breakage blocks and samples 19 and 11 for small conchoidals.

It is pertinent to summarise the combinations of edge abrasion textures 24 to 28 (Fig. 6.1) in order to discern any westward evolving patterns downdrift from Montauk Point.

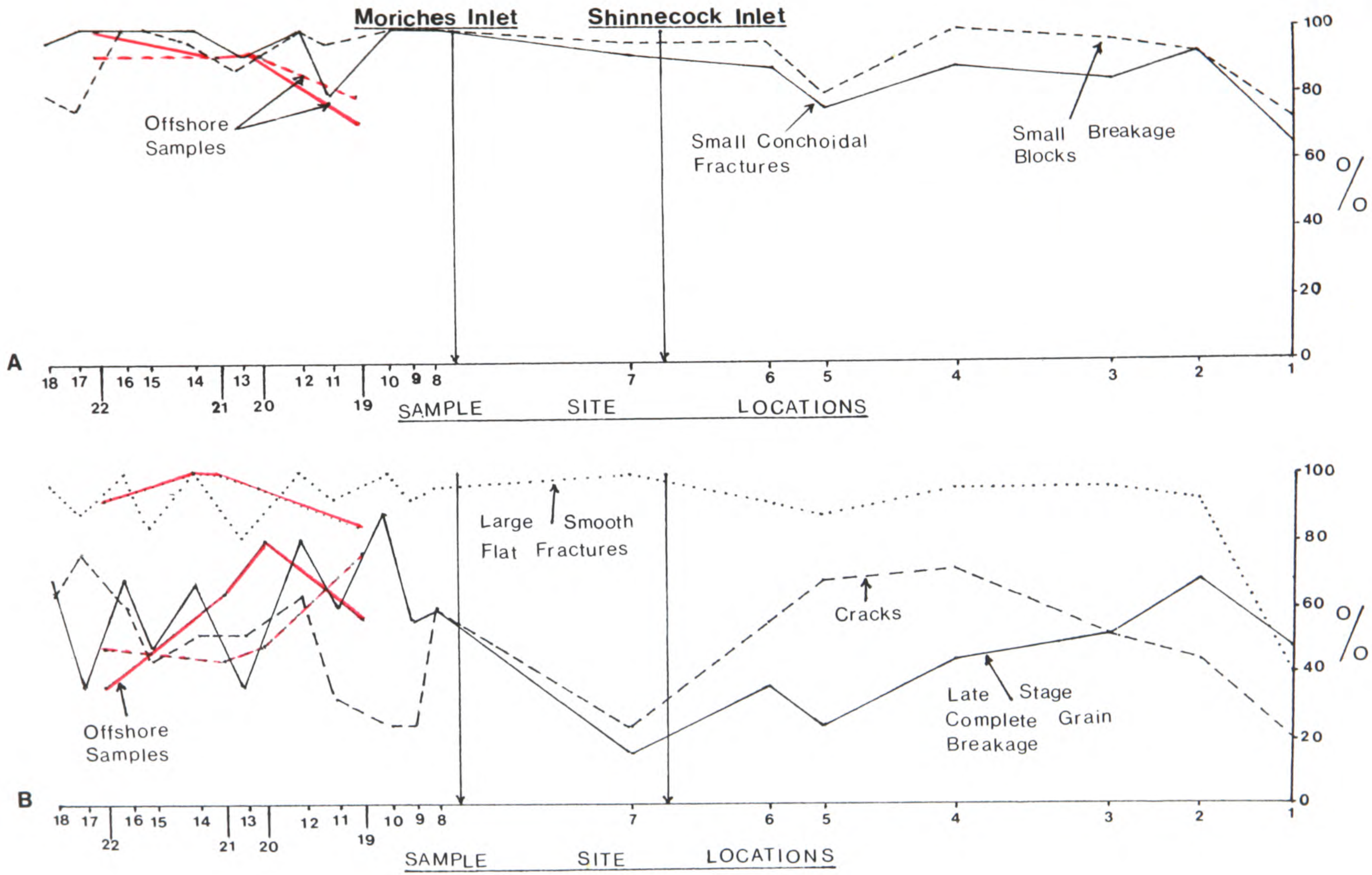


Fig. 6.9. A. Small conchoidal fractures and breakage blocks.
B. Large smooth flat fracture, cracks and late stage complete grain breakage, variations downdrift of Montauk Point.

(a) Sample 1 has emerged as a distinctive glacial source with angular-subangular edges which have suffered relatively little edge abrasion (Figs. 6.1, 6.3B, 6.6, 6.8A). As expected, associated small breakages such as M.V. pits and arcuate and straight grooves are low in abundance (Figs. 6.8A, 6.8B). This pattern is reinforced by small conchoidal fractures and small breakage blocks although frequencies of occurrence for these are not so low (Fig. 6.9A).

(b) Beach samples west of sample 1 in the Headlands section are characterised by subangular-subrounded grain edges generally increasing in roundness westward (Figs. 6.1, 6.3B, 6.7). Samples 3 on the Connecting beach and 6 in the western Headlands represent departures from the main Headlands section trend with lower M.V. pit and straight and curved groove abundancies (Figs. 6.1, 6.8A, 6.8B). All edge abrasion breakages increase either sharply or gradually west of Montauk Point (Figs. 6.8A, 6.8B, 6.9A).

(c) Samples taken from Fire Island beaches form a distinct group on the basis of edge shape (Figs. 6.6 and 6.7), with closely related characteristics which appear distinct from the Headlands section, the latter being less coherent as a group (Figs. 6.6, 6.7). Fire Island grains are more rounded (Figs. 6.1, 6.3B), with high edge abrasion and associated breakage texture frequencies (Figs. 6.8A, 6.8B, 6.9A). Moriches Inlet appears to be a marked divide in Long Island's south shore beach grains on the basis of grain shape and edge shape (Figs. 6.2A, 6.2B, 6.3A, 6.3B).

(d) Offshore samples 20 and 21 and sample 22 are rounder than onshore beach samples in terms of edge shape (Fig. 6.3B) but resemble them very closely as far as edge abrasion and associated breakages are concerned (Figs. 6.8a, 6.8B, 6.9A).

(e) Sample 18 in Western Fire Island and 19 offshore depart from general Fire Island and offshore trends as far as edge abrasion is concerned (Figs. 6.8A, 6.8B, 6.9A).

Further examples of edge abrasion and their associated breakages are illustrated on Plates 6.42 to 6.48. Plate 6.42 (sample 13) shows a well rounded smooth edge with small isolated V block fractures (lower left) and conchoidal fractures (lower right). The surface background is dominated by a series of M.V. pits, irregular breakages and curved grooves (upper right). The edges of such fractures have been corroded by chemical action (Plate 6.42).

Sample 8 in eastern Fire Island was typified by smooth rounded edges with a variety of mechanical pits and fractures grading from M.V. pit size up to medium conchoidals (Plate 6.43). Fresh higher energy conchoidals and blocks cut into the smoother pitted surface indicating their freshness. Many of the elongated pits represent chemical etching (Plate 6.43). Plate 6.44 (sample 13) shows a curved crack (arcuate groove, surface texture 28), at the top end of the size range with two satellite V block fractures possibly representing the impact of two rounded grains. The grid is presented as an example of one way in which surface textures may be measured and quantified, the bar scale being adjusted with the zoom lens to equal the sides of two squares.

Plate 6.45 (sample 21) illustrates an example of the superimposition of one textural assemblage upon another creating a two-tier surface texture association. The densely pitted smooth edge dominated by irregularly oriented etch pits and etch modified M.V. pits has been shattered by exceptionally fresh, angular blocky fractures. Note the upstanding block (centre left), with a horst-like remnant of the old pitted surface still preserved. Crystallographic control (or cleavage) does not appear to influence these blocks (Plate 6.45).

A close up of the smooth pitted surface on Plate 6.46 reveals a similar textural mosaic to Plate 6.41, both representing sample 21. The very dense pitting, cleanness and low relief with no adhering comminuted particles surrounds a sharp sided tapering blocky depression bounded by two diverging cracks cutting the surface at a steep angle. Other shallow pits are curved or irregular. V pit edges are parallel to the blocky cracks showing crystallographic control, but the surface is not typical of oriented triangular etch pits. If such dense pitting were originally mechanically formed there would be evidence of small comminuted debris particles. Grain preparation techniques are unlikely to have removed these since they are present on other samples. If the photograph is inverted to gain an alternative perspective the V pits are aligned toward the bottom of the photograph but not regularly as in the case of oriented triangular etch pits (surface texture 40).

Such a surface (Plate 6.46) contrasts sharply with Plate 6.42 (sample 13) and is interpreted as representing dominantly etch modified pits cutting into a thin film of smooth capping layer which has also been subjected to low energy conditions in the surf. As will be seen later, offshore samples revealed an unusual combination of crystallographically controlled etching and incomplete precipitation of a fine smooth capping layer (surface texture 34), of which this may be an early stage (Plates 6.41 and 6.46).

Finally Plate 6.47 (sample 22) shows a mosaic of moderately large etch pits, some oriented and intimately linked with some M.V. pits and grooves and a variety of crosscutting small conchoidal fractures and blocky pits.

II.G LARGE SMOOTH FLAT FRACTURES

Fig. 6.9B shows westward variations alongshore of high energy breakages on a large scale (surface textures 15, 16 and 19). Large smooth flat fractures (surface texture 19) are categorised as 'present' on the surface feature variability chart (Fig. 6.1) for sample 1 at Montauk Point with an abundance of 40%. The trend increases sharply to one of 'ubiquitous' presence (Fig. 6.1) along the rest of the south shore.

Surface texture 19 (large smooth flat fractures), did not vary much and as such may possibly be interpreted as a poor discriminating texture when used in statistical analysis, apart from sample 1 (Fig. 6.9B). Offshore samples 19 to 22 follow onshore beach sample trends very closely (Fig. 6.9B) and there was no evidence of progressive modifications or fluctuations indicative of an additional sediment source input.

Large smooth flat fractures were included in the checklist in order to represent source or glacial characteristics and the rapid increase from glacial moraine (sample 1, Fig. 2.4), to beach (sample 2) was not expected. However, if a stressed quartz grain source with inherent microfracture weaknesses was released by freeze-thaw periglacial conditions, transported in glaciers and possibly exposed to subsequent subaerial weathering, its exposure to turbulent surf conditions at Montauk Point with a wide variety of shore particles and increased turbulence may trigger the release of large grain fragments leaving large flat surfaces.

II.H LATE STAGE COMPLETE GRAIN BREAKAGE

When grains are subjected to the most violent of energy regimes whole fractions may be broken off. Surface texture 15 (late stage complete grain breakage) represents such an event and is interpreted in this study as the most extreme form of large, high energy fracture but with no crystallographic control. Breakage surfaces were usually observed as large conchoidal fractures terminating in a series of smaller blocks and conchoidals.

Initially the trend was similar to that for large smooth flat fractures, rising from frequencies of occurrence of 48% at sample site 1 (Montauk Cliff), to 68% on the beach immediately downdrift at sample site 2 (Table 6.1, Fig. 6.9B). Westward of Montauk Beach (sample 2) completely broken grains become less common in the Headlands section (Fig. 2.4) until the lowest value was reached at sample site 7 on eastern Westhampton Beach (Fig. 6.9B).

Fire Island beach samples (8 to 18, Fig. 6.9B), increased sharply from sample site 7 on Westhampton Beach to value ranges of 48% to 88%, although samples 13 and 17 both exhibit frequencies of 36% (Table 6.1). The conditions necessary to break grains are not frequently met in nature although glacial grinding has been included in this category, so an increase of 72% from sample site 7 (16%) on Westhampton beach to sample site 10 (88%) on eastern Fire Island represents a remarkable trend considering broken grain frequencies updrift of Moriches Inlet (Fig. 6.9B).

Fig. 2.3 reveals two major buried palaeodrainage channels along Fire Island, the Huntington-Islip Channel (Channel H) extending offshore between sample sites 14 and 15 and the Smithtown-Brookhaven channel extending offshore just east of sample site 8. Previous breaks in westward trends of grain surface textures have been noted immediately downdrift of Moriches Inlet at sample site 8 for grain shape (Figs. 6.2A, 6.2B, 6.3A), and edge shape (Fig. 6.3B). The increase in broken grain occurrences reinforces this break in Long Island south shore grain surface texture trends which is difficult to explain in terms of shore processes and trends updrift to the east.

An examination of broken grain abundancies on offshore samples 20 and 21 show equally high values of 80% and 64% respectively (Table 6.1, Fig. 6.9B). This confirms the possibility of an additional source of broken grains from offshore contributing to increased Fire Island beach values compared with the Headlands section (Fig. 6.9B). The very high values at sample sites 10 and 12 may possibly be related to the Smithtown-Brookhaven Channel (Fig. 2.3).

II.I <u>CRACKS</u>

Both cracks (surface texture 16) and late stage complete grain breakage (surface texture 15) follow similar trends (Fig. 6.9B). Sample 1 at Montauk Point exhibited the lowest abundancies of 20%, increasing gradually to a maximum value of 60% in the west central

Headlands section (samples 4 and 5 in Fig. 6.9B). The western Headlands (Fig. 2.4), showed reduced frequencies of occurrence until a low of 24% was reached at sample site 7 on Westhampton beach (Fig. 6.9B). Cracked grain percentages fluctuate a good deal along Fire Island beaches with a marked trough in values ranging from 24% to 32% between samples 9 and 11 (Table 6.1).

As is the case with large smooth flat fractures and late stage complete grain breakage (surface textures 19 and 15 respectively), cracks may occur as a result of high velocity impacts. The effects of water cushioning between colliding grains have not been as well documented as crack propagation in an aeolian medium, nor as in glacial grinding, but the increase in cracked grain frequencies along the Headlands section between samples 1 and 4 must either relate to surf modifications or an additional supply of cracked grains from another source. Secondary increases in cracked grain percentages from sample 7 to sample 8 and from sample 11 to 12 are more difficult to explain in terms of process owing to the homogeneity of energy conditions on the beach west of Montauk Point (Fig. 6.9B).

The Headlands section trend may possibly be related to the release of prestressed quartz grains from a passive episode in Montauk Till onto the beach and differential surf exploitation of inherited weaknesses such as microfractures, but this may be supposition with no data from samples offshore to the south of eastern Long Island.

In general Fire Island samples exhibited greater fluctuation of surface texture trends than further updrfit (Fig. 6.9B). It must be realised that compression of the sampling framework here so that sites are much closer may produce greater apparent variability than in the Headlands where sample sites were more widely spaced. Nevertheless, variability of graph trends still require an explanation, especially in the light of one of the initial assumptions in the present study, viz: that processes along south shore beaches would progressively and smoothly induce surf modifications on grain edges (Krinsley et al, 1964). Some control other than process variability in surface texture abundancies (Fig. 6.9B) is needed.

Offshore samples 20 and 21 resemble onshore beach samples in terms of cracked grain values. Sample 22 had fewer cracked grains (Fig. 6.9B).

Plate 6.48 (sample 4) shows an example of late stage complete grain breakage, a complete grain part having been removed on the left lower side. The top part of the breakage surface on the underside of the angular projection represents a large smooth flat fracture (surface texture 19). Late stage complete grain breakage is also illustrated on Plate 6.7 on the left hand side (sample 14), as well as on the lower left side of the grain shown in Plate 6.11 (sample 3).

Sample site 5 from the beach fronting headlands (Fig. 24), provides an example of late stage complete grain breakage leaving a low relief smooth fracture surface intersecting the old grain surface along an angular edge running north-south in the centre (Plate 6.52). Sample 9 in eastern Fire Island shows a rather tabular grain (Plate 6.53) bounded by high energy fracture surfaces on the right, the lower edge appearing to represent the truncated surface of a broken grain in the form of a large smooth flat to curved surface.

The rectangular patterns formed in the smooth capping layer on the facing grain surface (Plate 6.53), represent an unusual geometric control in the growth of amorphous precipitation which is repeated in several forms and described later.

Plate 6.54 (sample 21) exhibits several large flat fracture surfaces oriented from top left to bottom right as an integral part of high energy breakages such as conchoidal fractures and associated stepped blocks. A contrast may be made between their fresh appearance and the rounded mechanically pitted edge on the upper left which they appear to postdate (Plate 6.54).

A similar example to Plate 6.50 is Plate 6.15 (sample 21) in the lower half where a diagonal crack terminates on the upper right with a curved fractured portion about 70 μm across. A similar feature occurs on the left hand side at the base of the rounded protrusion.

II.J LARGE CONCHOIDAL FRACTURES

A cursory glace at the trend for large conchoidal fractures (surface texture 17) in Fig. 6.10A reveals a uniform plateau of 'ubiquitous' occurrence on virtually all samples. It would appear at this stage to be of little use as a discriminatory texture for samples under study. There are mild downward fluctuations at sample site 5 in the western Headlands but no more than a small percentage fall (Fig. 6.10A).

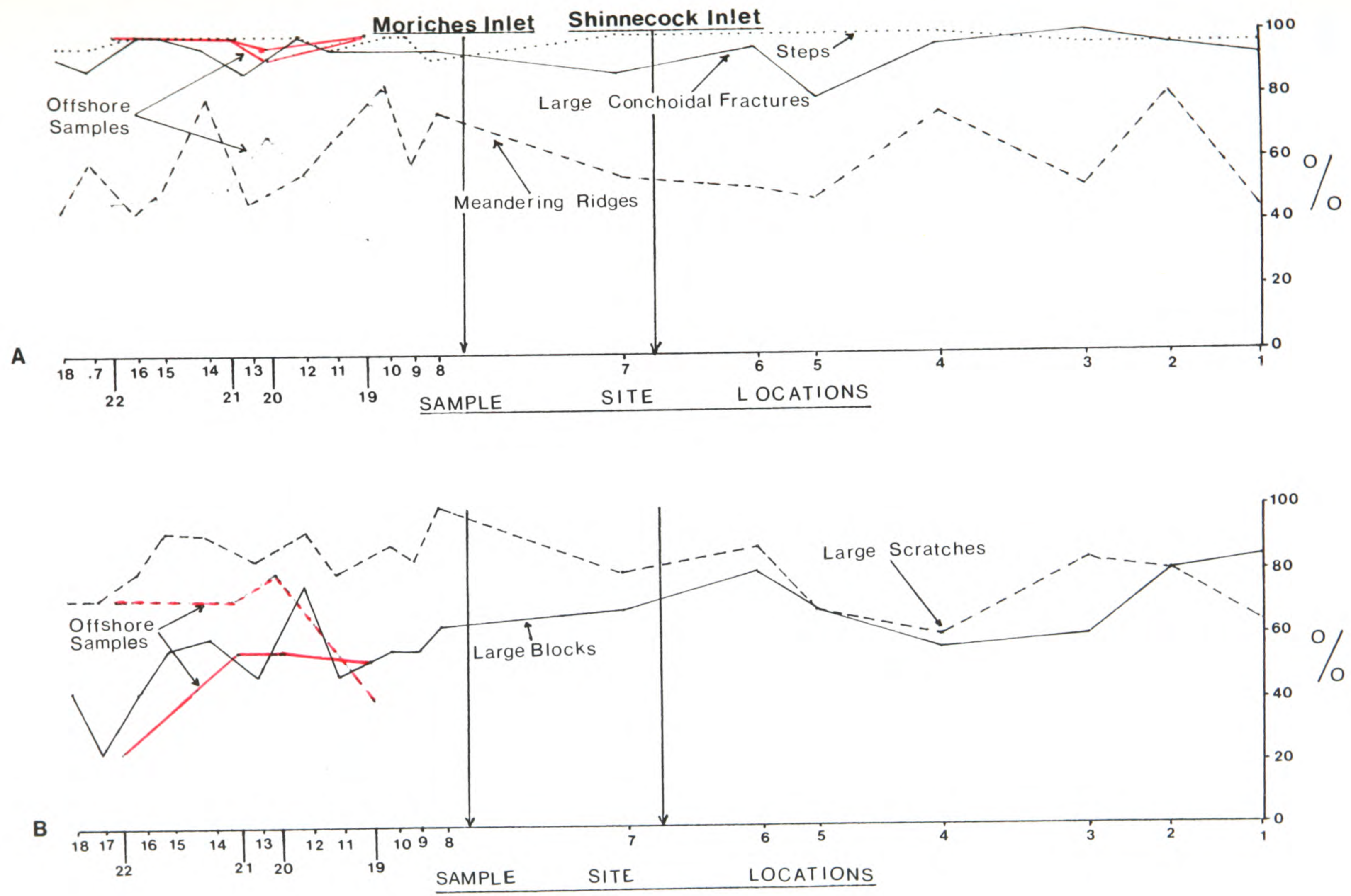


Fig. 6.10. A. Large conchoidal fracture, steps, meandering ridges;
B. Large Scratch, Large Blocks - variations with distance downdrift of Montauk Point.

The diameter and depth of each fracture were not elements that were incorporated into the checklist (Fig. 6.1), nor was relative age, so a single large conchoidal fracture relatively dulled by chemical modifications would carry the same weight as a mosaic of smaller fresh conchoidals on other samples. Only reference to supporting notes reveals differences in conchoidal fracture character.

II.K MEANDERING RIDGES

Conchoidal fractures were intimately associated with meandering ridges (surface texture 21, Fig. 6.1), the latter representing intersections between the flanks of conchoidals with each other, or the grain surface. Meandering ridges were less common than conchoidal fractures registering as 'present' and 'abundant' on the surface feature variability chart (Fig. 6.1). They also showed greater variability with distance downdrift of sample 1 at Montauk Point, but no increasing or decreasing trend (Fig. 6.10A).

Sample 1 values increased sharply from 44% to 80% at sample site 2 immediately downdrift on Montauk beach only to decrease to 52% at Napeague (sample site 3), then to increase once more to values of over 70% at Easthampton representing sample site 4 (Table 6.1). Fire Island samples display similar fluctuating trends (Fig. 6.10A).

II.L STEPS

In the original checklist arcuate steps were scanned as a separate texture from straight steps but have been presented as a single texture in the surface feature variability chart (Fig. 6.1, surface texture 22) because of their intimate genetic association with each other and conchoidal fractures and their ubiquitous occurrence. Merging their texture frequencies had virtually no effect on value ranges since the single combined steps value ranges were no more ubiquitous than separate steps value ranges.

Fig. 6.10A shows steps to be even more abundant than conchoidal fractures (surface texture 17) with virtually no variability with distance westward from Montauk Point (sample 1, Fig. 6.10A). For both arc shaped parallel steps and straight steps values never fell below 92% abundance in every sample.

II.M LARGE BLOCKS

Both conchoidal fractures and their associated harmonic fractures have been ascribed to high energy conditions along with large breakage blocks. Unlike the former large blocks (surface texture 18, Fig. 6.10B), did in fact show a gradually decreasing trend from a maximum value of 84% at Montauk Point (sample 1) to a minimum value of 24% at sample site 17 in Western Fire Island (Fig. 6.10B).

The gradually declining trend in large blocks to the west of Montauk Point may be related to south shore processes if blocks of the cuboidal projections type are considered to be a product of glacial grinding (Eyles, 1978). Their progressive removal by turbulent subaqueous transport would fit the expected trend (Fig. 6.10B). Apart from very large V shaped blocks, high energy grain collisions in the surf may be producing conchoidal fractures and associated breakages whereas lower energy conditions may be producing smaller M.V. pits and small hertzian cracks.

II.N LARGE SCRATCHES

No discernible process-related increase or decrease in large scratch abundancies may be observed with distance westward from Montauk Point (sample 1, Fig. 6.10B). This grain surface feature (texture 23, Fig. 6.1) increased gradually from 64% in sample 1 to 100% in sample 8 in eastern Fire Island (Fig. 6.10B). There is a broad but marked downturn along the west central Headlands section from sample 3 to 6 (Fig. 6.10B) where values resemble those of sample 1. Fire Island samples are characterised by a variable but marked decline from frequencies of 100% at sample site 8 in the east to 72% in sample 18 in the west.

The homogeneity of wave energy conditions along Long Island's south shore would appear to preclude the likelihood of grain surface texture variations related to mechanical breakages. Some other environmental control may be at work, in this case the possibility of additional sediment supplies from offshore sources such as buried palaeodrainage channel deposits lying offshore south of the Headlands section and Fire Island (Fig. 2.3).

Examination of offshore sample values in Figs. 6.10A and 6.10B show a close link with onshore Fire Island beach trends as far as samples 20 and 21 are concerned. In the case of steps (surface texture 22) and large conchoidal fractures (surface texture 17) the relationship is very close (Fig. 6.10A) but the same may be inferred for samples updrift.

Large scratches (surface texture 23) were less abundant in offshore samples and especially so in the case of sample 19 (Fig. 6.10B). If one considers the possibility of the onshore transfer of glacially derived sediments from offshore lobes then in each case (sample 1 to sample 3, offshore south of Montauk Point onshore to the central Headlands slightly downdrift in samples 4 and 5; offshore south of Fire Island to onshore beaches), there is a common increase in striation abundancies (Fig. 6.10B).

The following points should be noted with regard to trends in high energy breakages with distance westward from Montauk Point (sample 1).

(a) Large conchoidal fractures (surface texture 17, Fig. 6.1) and steps (surface texture 22) do not vary over virtually all samples whether glacial terminal moraine (sample 1), fluvioglacial -glacial offshore deposits (samples 20 and 21), or onshore beach samples 2 to 18, (Fig. 6.10A). This may suggest that they are produced in glacial, fluvioglacial and beach environments or that they are a glacial-fluvioglacial inheritance on beach grain surfaces, or that they are even older.

Observations during scanning suggested that they may be produced in each of the environments mentioned above, at least they were often fresh in the case of some beach grains representing a late stage cycle.

(b) Sample 1 derived from Ronkonkoma terminal moraine (Montauk Till) at Montauk Point was a distinct sediment source on the basis of high energy breakage abundancies (Figs. 6.9B, 6.10A, 6.10B). Lower than average values were recorded for large smooth flat fractures (surface texture 19), cracks (surface texture 16), with marked increases in frequencies from the moraine bluff at sample site 1 to Montauk beach (sample site 2) for surface textures 15, 16, 19 and 21 (Figs. 6.9B, 6.10A, 6.10B). In the case of large blocks sample 1 exhibited the greatest abundancies (Fig. 6.10B).

(c) A marked break in high energy breakage trends was evident on eastern Fire Island (sample 8) for cracks, late stage complete grain breakage (Fig. 6.9B) and large scratches (Fig. 6.10B).

(d) Offshore samples 20 and 21 formed closely related textural groups showing a strong genetic link. They were most distinct from sample 1 on the basis of large smooth flat fractures, cracks, late stage complete grain breakages and large blocks (Figs. 6.9B, 6.10B) They frequently displayed value ranges which differed from samples 10 to the east and 22 to the west (Figs. 6.9B, 6.10A, 6.10B).

(e) Preconceived notions prior to scanning that results would reveal a decline in 'so called' glacial textures (large conchoidal fractures, steps, cracks, broken grains, blocks and larger scratches) with distance transported westward in the surf were not borne out except for the case of large blocks.

(f) Apart from large smooth flat fractures (Fig. 6.9B), large conchoidal fractures and steps (Fig. 6.10A), surface texture trends on quartz sand grains revealed a variability often reversing updrift trends (cracks and late stage complete grain breakage in Fig. 6.9A, and large scratches in Fig. 6.10B), that were not in keeping with uniform wave energy conditions alongshore. Other controlling influences must be sought.

II.0 MEDIUM CONCHOIDAL FRACTURES

This texture (20 in Fig. 6.1) has not been graphed, but abundancies may be observed in Table 6.1. Its inclusion in the checklist was designed to detect lower energy conditions in the west of the study area but the presence of large conchoidal fractures (surface texture 17) in 'ubiquitous' proportions in all samples (Fig. 6.10A) and the abundance of small conchoidal fractures (Fig. 6.9A) considerably reduced its diagnostic importance. Values were ubiquitous for virtually all samples except for sample 1 at Montauk Point where occurrences fell to 72% (Table 6.1).

Plates 6.55 to 6.70 illustrate examples of surface textures 17, 18, 20 and 21 to 23 (Fig. 6.1). Plates 6.55 and 6.56 contrast samples 1 and 2 (glacial moraine and Montauk beach, Fig. 2.4). Sample 1 (Plate 6.55) shows little evidence of surf rounded edges, the edge abrasion consisting of large shallow conchoidals (left and lower right edges). Note the chemical dulling and heavy masking by amorphous silica precipitation in the right hollow. Plate 6.56 (sample 2) shows a strong contrast with cleaner rounder edges pitted mechanically with a very large conchoidal fracture on the left, possibly complete grain breakage, intersecting the upper grain surface as a notched 'arete' like edge. A straight step radiates downwards from the point of impact and meandering ridges occur in the upper right area (Plate 6.56).

Another two samples from the eastern Headlands section are portrayed on Plates 6.57 and 6.58. The intensely fractured grain portion on Plate 6.57 (sample 3), with a wide variety of coarse blocky steps cuts across an older more rounded pitted surface seen on the lower left. Plate 6.58 (sample 4) illustrates a good example of a well formed medium conchoidal fracture or partial hertzian crack cutting across a mechanically and chemically pitted smooth edge.

A similarly smashed edge to that shown in Plate 6.57 (sample 3) is presented on Plate 6.59 (sample 4), where the sharpness and freshness of intersecting blocky steps and lined fractures contrasts with chemical precipitation in the upper hollow. The fractures are being worn by mild pitting. Sample 5 on Plate 6.60 shows a curved scratch over 10 μm long in the centre of the edge with small blocky fractures, etch modified M.V. pits and irregular solution pits.

The point of impact on a grain edge from sample 7 and its associated small and medium conchoidal fractures are shown on Plate 6.61 with a superimposed grid. Note the pitted smooth upper background surface. The well rounded grain portrayed on Plate 6.62 shows several dish shaped concavities on the left (surface texture 17) and other minor impact pits on the upper surface. Such well rounded grains may have been supplied from dunes farther inland (sample 8, Plate 6.62).

Plates 6.63 to 6.65 show examples of medium and high energy fractures found on sample 8 in eastern Fire Island. Plate 6.63 portrays a subangular grain with macroblocks over much of its surface thickly draped in amorphous silica precipitation. Plates 6.64 and 6.65 show small and medium conchoidal fractures, hertzian cracks and pitted edges. A large scratch arises on the grain edge immediately to the right of shallow oriented triangular etch pits (surface texture 40), on the extreme left of Plate 6.65. An interesting contrast occurs here where a suite of flat floored oriented triangular etch pits on the left are found in the same area as flat precipitated triangles on the upper part of the photograph seen in the background (Plate 6.65).

Closer examination of the precipitated triangles reveals a coalescence of their apices to enclose oriented triangular depressions. This seems to represent an origin for oriented triangular etch pits which the present author has not met in the literature. The flat bottomed pits on the left on Plate 6.65 may represent a more advanced stage of coalescing precipitated triangular plates enclosing triangular depressions.

An example of a very coarse blocky surface is shown on Plate 6.66, subsequently modified by solution-precipitation and smaller breakages rounding off blocks to give a characteristic knobbly appearance (sample 21). A close up of one of sample 21's edges shows a smooth chemically pitted surface with some M.V. pits and grooves surrounding a recent V profile blocky fracture with sub-parallel faint steps inside (Plate 6.67).

A similar pattern occurs on Plate 6.68 with smooth rounded grain projections recently broken by large conchoidal fractures (sample 21). A curiously geometric maze of flat silica precipitation occurs on the left.

Sample 22 shows well rounded edges pockmarked by fine chemical pits, M.V. pits and straight and curved grooves across which medium conchoidal fractures (surface texture 20), and large blocks (surface feature 18), have been inflicted (Plate 6.69). A large scratch or crack follows the lower centre edge. Plate 6.70 from sample 22 shows large blocky fractures cutting into a deeply pitted surface of chemical origin.

II.P GRAIN RELIEF

Grain relief is a morphological attribute of grain surfaces and could be a product of original source and subsequent weathering-glacial modifications if grain surface relief is high (surface texture 12). Medium and low relief may be a product of the wearing away of grain edges and projections during turbulent transport or by solution, or by a combination of both. However, grains may occur at source with low relief and round outlines.

In the present study high relief is interpreted as an inherited characteristic from previous source, weathering or glacial transport episodes. Transport in littoral drift alongshore was expected to reduce relief and any upward trends in grain relief may be interpreted either as indicative of an influx of such grains from another source or as evidence of a process operating on south shore beaches with sufficient energy to achieve this increase.

Samples 1 to 7 in the Headlands section show a straightforward pattern of slightly fluctuating high relief dominating all samples (Fig. 6.11A). High relief abundancies range from 72% to 92% while grains with medium relief are far less common, abundancies for the latter ranging from 4% to 24% (Table 6.1, Fig. 6.11A). Smooth low relief grains are absent from samples 1 to 6 in the Headlands section, only reaching 'uncommon' proportions in sample 7 on

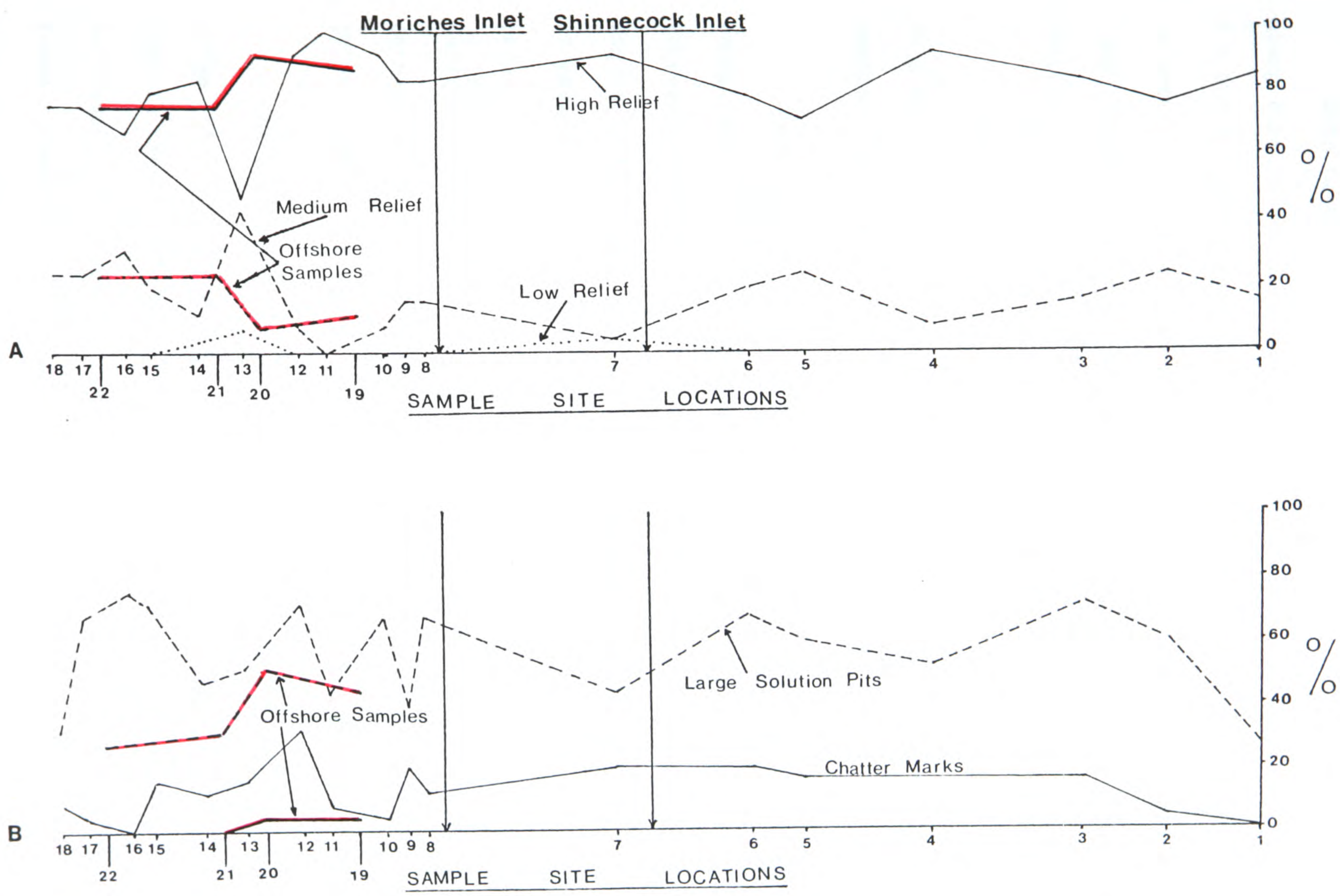


Fig. 6.11. A. Grain Surface Relief.
B. Large Solution Pits and Chattermark - variations with distance downdrift to the west of Montauk Point.

Westhampton beach (Figs. 6.1 and 6.11A).

Both high and low relief grains fluctuated more in abundance along Fire Island and low relief grains were rare or absent (Figs. 6.1 and 6.11A). Marked trend divergence was noted at sample site 13 in central Fire Island where grains acquired much reduced relief (32% increase in medium relief compared with sample 12), the situation returning to 'normal' farther downdrift (Fig. 6.11A).

Offshore samples 19 to 22 do not contribute to the reduction in grain relief at site 13, but resemble the rest of Fire Island samples' beach grain relief trends (Fig. 6.11A).

Any interpretation of such a localised reduction in relief cannot ascribe the phenomenon to south shore grain surface modifying processes because the trend is not continued to a great enough degree west of sample site 13 (Fig. 6.11A) and there is no evidence of greater edge abrasion at that point (Fig. 6.8A). It may be the product of a site specific infrequent event such as the influx of dune sand grains channelled shoreward at that point topographically perhaps using a preexisting blowout when offshore winds occurred prior to sampling.

One conclusion which may be drawn from grain relief trends along the south shore Long Island is that with the relief parameters used in the present work, edge abrasion does not appear to be able to reduce surface relief enough to show up as a prominent westward trend. However, it may be responsible for increased edge rounding and hence grain shape roundness (Figs. 6.2B, 6.3A, 6.3B).

Plate 6.71 shows an example of high grain relief on the upper surface with much lower relief in the curved fracture in the lower right (sample 10). A large crater on the upper surface may be a grain embayment, high energy fractures with intervening meandering ridges occurring on the lower right (Plate 6.71). Previous plates which illustrate high relief from other samples include Plates 6.1 (sample 1), 6.3 (sample 2), 6.5 (sample 8), and 6.11 (sample 3).

Medium relief is not such an easy surface texture to categorise e.g. Plate 6.72 shows a partially rounded grain from sample 21 which would be classified as medium relief even though there are breakages on the facing grain surface which could be defined as high relief. A similar problem is posed on Plate 6.73 on which a grain from sample 22 presents an upper surface with low relief and high relief vertical grain sides. Such a grain would be classified as medium relief, reconciling the dominance of both textures (Plate 6.73). An example of low grain relief is shown on Plate 6.51 from sample 13 in central Fire Island.

II.Q LARGE SOLUTION PITS

Large chemically etched pits (surface texture 30, Fig. 6.1) increase markedly in abundance from sample 1 at Montauk Point (28%), to sample 3 at Napeague where values reach 72% (Fig. 6.11B). Further west of the central Headlands section (Fig. 2.4), values do not show a dominant trend, fluctuating within a 40% to 70% or 'present' to 'abundant' frequency range (Fig. 6.1).

Variability appears to be greater along Fire Island (Fig. 6.11B), but this may be a product of the compressed sampling framework since the magnitude of variation is of the same order as that for updrift samples. Offshore samples 19 to 22 exhibit similar abundancies to onshore Fire Island beach samples although samples 20 and 21, proximal to Channel H, diverge from each other by 20% (Fig. 6.11B).

Plates 6.74 to 6.77 illustrate types of large isolated solution pits (surface texture 30). Some are straight sided and polygonal in form and may represent the leaching out of grain inclusions (Plates 6.74 and 6.75 from samples 14 and 22 respectively). Plate 6.74 portrays contrasting grain surfaces which intersect along an angular edge at an immature stage of edge rounding. The pit on Plate 6.75 is set in a protected depression where solution-precipitation has created a lozenge shaped pattern of intersecting hollows and ridges. Fine pitting (surface texture 33) occurs over much of the low relief solution-precipitation surface to the left and above (Plate 6.75).

Sample 3 (Plate 6.76) presents an example of a large isolated solution pit, or bright rimmed hollow, on a flat smooth capping layer surface. The oriented triangular etch pits (surface texture 40) which are restricted to the thin capping layer (surface texture 34) do not appear to be etching the grain surface below.

Plate 6.77 exhibits a well rounded edge with a dense carpet of chemical etch pits and edge abrasions (sample 14). The deep pits on the lower right are chemical in origin, the cause for their formation possibly being localised chemical weaknesses such as inclusions. What appears to be an inclusion located in situ occurs on the lower left hand margin of the micrograph forming the round flat floor of a shallow circular depression over 10 μm in diameter (Plate 6.76).

II.R CHATTERMARKS

Chattermarks (surface texture 29) gradually increase in abundance from zero occurrence in sample 1 at Montauk Point to 'present' values along the Headlands section (Fig. 6.1), although no sample exceeded 32% (sample 12) in abundance. Glacial and fluvo-glacial-glacial samples at Montauk Point and offshore (samples 1 and 19 to 22 in Fig. 6.11B) do not contain chattermarked grains in any abundance. Sample 1 was noted as the most dulled and chemically altered of all samples in supporting notes and contained no well developed chattermarks.

There appears to be some link to south shore beach processes because there is a gradually increasing trend in the Headlands section. Fluctuations in abundance are most notable on Fire Island beach samples (Fig. 6.11B), although this does not seem to be attributable to any possible onshore movement of chattermarked grains from offshore, the frequencies of occurrence for the latter being very low.

There was never an abundance of chattermark dominated grains, the texture (29 in Fig. 6.1) being confined to isolated locations where both edge abrasions and chemical solution-precipitation combined.

Plates 6.78 to 6.80 attempt to relate chattermark development to other textures in samples 21, 11 and 4 respectively. Plate 6.78 from sample 21 shows what appear to be patterns of small elongated and crenulated fractures in the upper part of the micrograph. It is difficult to say at this stage whether they are fractures, etched fractures or purely chemical solution features in the smooth capping layer background (Plate 6.78). At a further stage (Plate 6.79), a chattery type of texture on a well rounded edge which has clearly been abraded can be seen at the top right portion of the micrograph. The larger scale curved cracks mark the steep sides of block-like features (Plate 6.79, centre) which may postdate the etched surface.

Finally, Plate 6.80 shows an unusual chattermark trail on a smooth surface which has been interpreted in the present study as a combination of solution of previous etch or mechanically formed pits and subsequent incomplete precipitation over the area.

II.S CHEMICAL ETCHING

Grain surface textures 31 to 33 include increasing degrees of solutional effects on grain surfaces (Fig. 6.1), without apparent crystallographic control so geometric patterns are not included. Finely pitted surfaces (surface texture 33) are ubiquitous in virtually all samples (Fig. 6.1). The central Headlands section (samples 3 to 5) has fewer finely pitted grains than samples updrift and downdrift (Fig. 6.12A), but only by as much as 20%. Sample 13 in central Fire Island also shows a dip in abundance by about the same amount (Fig. 6.12A). It is possible that fine etching (surface texture 33) may be of little use in discriminating between samples in the same way as other ubiquitous surface textures e.g.- edge abrasion, large and medium conchoidal fractures and steps (surface textures 7, 17, 20 and 22).

Very coarse etching (surface texture 31) and coarse etching (surface texture 32) are less common on grain surfaces (Fig. 6.12A).

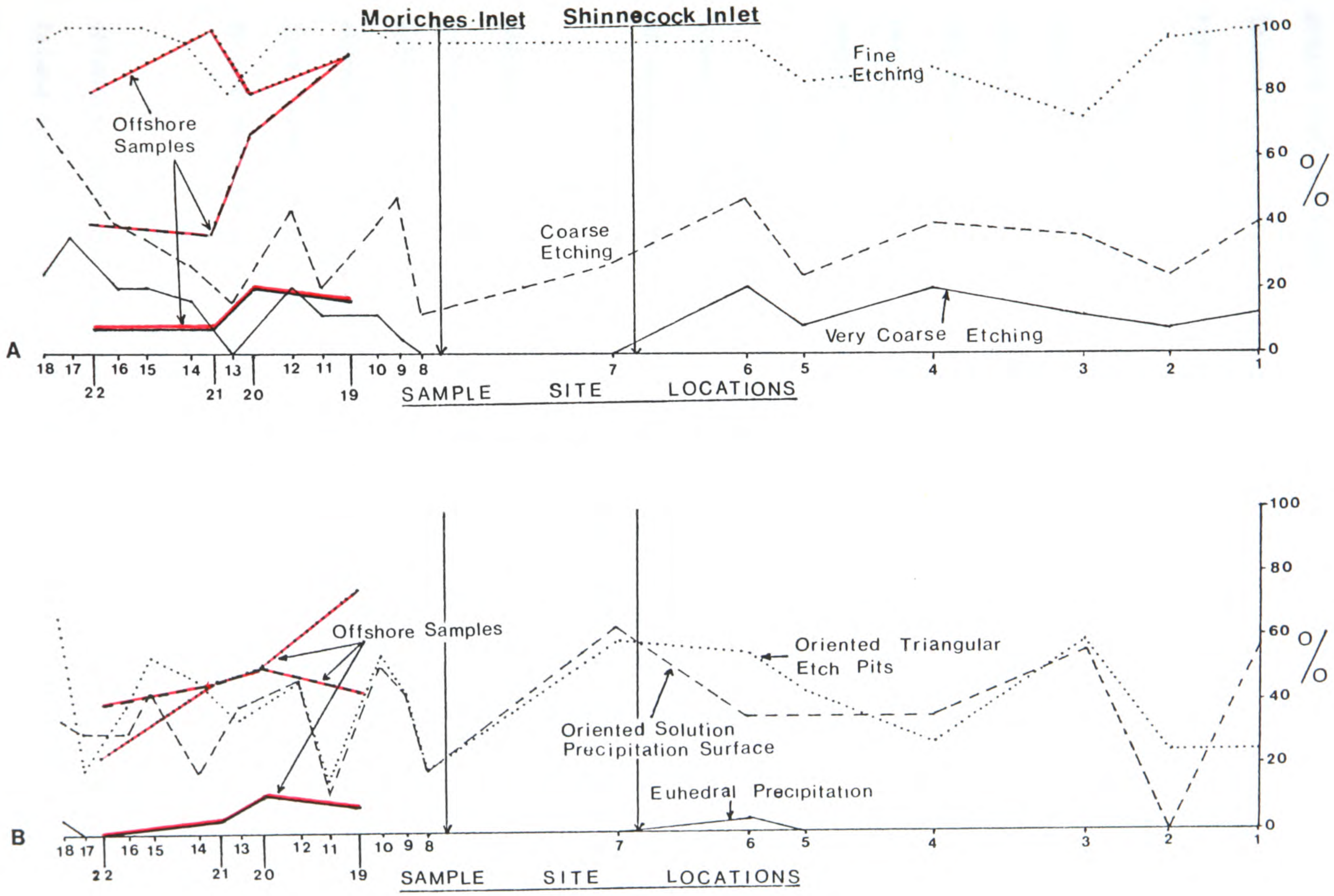


Fig. 6.12. A. Grain etching.
B. Oriented Grain Etching and Euhedral Precipitation- with distance downdrift of Montauk Point.

The former texture rarely exceeds 20% in abundance and varies little alongshore except for the fact that there were no coarsely etched grains between samples 6 and 9 on Westhampton beach and eastern Fire Island (Fig. 6.12A). The same applies to sample 13 in central Fire Island.

The parallelism between very coarse etching and coarse etching is exceptional in terms of frequency of occurrence (Fig. 6.12A), values for coarse etching varying between 20% and 40% for much of the Headlands section. Fire Island beach samples show greater variation with peaks at sample sites 9 and 12 and 16 to 18, the last sample reaching 72% in abundance.

Offshore samples 19 and 20 show values of 92% and 68% respectively (Table 6.1), while samples 21 and 22 have lower abundancies of coarsely etched grains of 36% and 40% respectively.

It is relatively straight forward to account for the greater abundance of coarsely etched grains on offshore samples (Fig. 6.12A), since they are derived from a lower energy environment constantly saturated with sea water. It is less easy to account for peaks in abundance at sample sites 9 and 12 and the high values along western Fire Island (Fig. 6.12A). Mechanical and chemical energy conditions do not vary enough alongshore to cause such fluctuations.

It is possible that coarsely etched grains may have originated offshore and moved onshore to account for peaks along western Fire Island in particular. However, a similar peak at sample site 6 in the western Headlands is just as difficult to account for although it shows similar abundance for coarse etching as sample 1, the main source for sediments in the Headlands section (Fig. 6.12A).

Very coarse etching (surface texture 31) was usually observed at grain sites previously broken or cracked mechanically and was invariably more common in protected hollows such as embayments. Plate 6.81 shows very coarsely etched grooves along the base of a fracture or grain embayment on the lower right. The blocky steps (lower centre) appear to be a suitable site for future chemical solution along cracked surfaces.

Plates 6.82 and 6.83 from samples 4 and 21 respectively show similar textures. Cracks may be seen on Plate 6.82 running vertically from top to bottom on the micrograph as well as from left to right, the vertical grooves have been etched deeply while the surrounding ridge-like plates are smoothed and rounded.

On Plate 6.83 grooves run down the centre of the micrograph separating ridged blocks which are linked by cross grooves. At a lower tilt the surface would appear as deeply ingrown oriented triangular etch pits.

Coarse to fine etching is portrayed on Plates 6.84 and 6.85 from samples 2 and 21 respectively and fine etching on Plates 6.86 and 6.87 (samples 8 and 22 respectively). On many of the sand grains under study, even well edge abraded surfaces usually had moderate to dense development of fine etch pits which were not oriented (surface texture 33). This may be a product of seawater solution.

II.T ORIENTED SOLUTION-PRECIPITATION SURFACES

Examination of Fig. 6.12B shows that oriented solution-precipitation surfaces (surface texture 37), follow similar patterns to oriented triangular etch pits (Fig. 6.12B), and coarse etching (Fig. 6.12A). This is to be expected since the texture was designed to include crystallographically controlled surfaces with geometric linearities not included in euhedral precipitation and oriented triangular etch pits (surface textures 36 and 40 respectively).

Values for oriented solution-precipitation surfaces fluctuate between 40% and 60% along the Headlands section (Fig. 6.12B), with a complete absence at sample site 2 and an elongated trough in values in the western Headlands. Abundancies decrease in general west of Westhampton beach (sample 7), although percentages fluctuate a good deal (Fig. 6.12B). Sample sites 8, 11 and 14 dip below Fire Island beach trends for oriented solution-precipitation surface values by up to 30% (Fig. 6.12B). Offshore samples exhibit similar percentage frequencies to onshore beach samples (Fig. 6.12B).

Examples of oriented solution-precipitation surfaces vary a good deal and are presented on Plates 6.82 and 6.83, which also represent coarse etching from samples 4 and 21 respectively. Plate 6.88 shows a very varied mosaic of mechanical and chemical textures (sample 4). The downward facing lower left grain face shows chemically modified V tipped grooves oriented down the grain face. Other textures found on the micrograph include edge abrasion, steps, cracks, large isolated solution pits and conchoidal fractures. The beginnings of oriented solution notching occur along the curved edge of a central fracture on Plate 6.88.

Plate 6.89 (sample 1), shows an example of a thick layer of silica on the left, plastered onto the surface below, while on the right coarse, discontinuous rounded microblocky plates occur showing considerable chemical solution-precipitation. Overriding this irregular undulating chemical surface is a texture of much smaller platelets oriented from lower left to upper right resembling textures described in the literature as upturned plates. This is interpreted as an oriented solution-precipitation surface at the smallest scale.

II.U ORIENTED TRIANGULAR ETCH PITS (O.T.'S)

As mentioned previously,oriented triangular etch pits (surface texture 40 in Fig. 6.1) follow a similar trend to oriented solution-precipitation surfaces (Fig. 6.12B) although abundance variability is less. Sample 1 from glacial moraine at Montauk Point increased markedly in texture abundance for o.t.'s by sample 3 on the Connecting beach (Fig. 6.12B). Apart from falling values at sample site 4, percentage frequencies are about 40% or more as far west as sample 7 on Westhampton beach (Fig. 6.12B).

Along Fire Island samples 8 and 11 in the east show values below that of sample 1 at Montauk Point, whereas sample 18 at the western extremity exhibits the second highest o.t. abundance after offshore sample 19 east of Channel H (Fig. 6.12B). Offshore samples in general (19 to 22 in Fig. 6.12B), resemble the rest of Long Island's south shore trends for o.t. abundancies apart from sample 19 which has the greatest percentages.

The rate of solution necessary to allow enough time for crystallographic control to exert an influence upon chemical etching seems to occur both offshore and onshore, as well as in Ronkonkoma moraine forming a part of Montauk till at sample site 1, unless the texture is able to survive as an inherited texture from pre-moraine deposition times. During periods when sea level was much lower sediments exposed as glacial outwash and moraine would have experienced subaerial weathering.

Any attempt to link possible onshore transfer of o.t. etched grains which revealed themselves in the form of increased abundancies along Fire Island beaches would be inappropriate in light of the irregularity of o.t. trends (Fig. 6.12B).

Oriented triangular etch pits (surface texture 40) were located in a variety of grain surface positions and took a variety of forms. Plate 6.23 from sample 19 shows a dense pattern of o.t.'s highlighted by the black discolouration preserved in depressions along a grain edge which has not been recently actively abraded. Plate 6.34 from sample 5 in the western Headlands section shows a suite of o.t.'s on the protected surface on the left below a clean well rounded and abraded edge above and to the right.

Plates 6.41 and 6.46 from sample 21 have already been described under small edge abrasions but illustrate the close link between etch pits and some form of edge abrasion on many south shore samples. Plate 6.90 shows a similar grain surface from sample 21 with better developed o.t. pits (centre, upper). A much finer, more densely pitted surface is presented on Plate 6.91 from sample 10 in eastern Fire Island. The surface in the lower right half of the micrograph forms a series of notched platelets aligned more across the photograph, whereas the etching trend is from top left to lower right (Plate 6.91).

Unusually geometric textures produced by solution-precipitation typified several south shore and offshore samples. Plates 6.92 to 6.96 illustrate regularly shaped gaps or windows in smooth capping layer (surface texture 34) which allow the underlying grain surface to be observed. In each case only the silica capping layer appears to be affected. Plate 6.92 exhibits triangular flat floored solution hollows with one side aligned from top left to bottom right (sample 21).

Plates 6.93 and 6.94 from the same sample show lozenge shaped 'windows' with thin peninsulas of amorphous precipitation extending across the underlying grain surface (Plate 6.93). Similar features were observed on other samples, Plates 6.95 and 6.96 showing different forms from sample 11 in eastern Fire Island.

Plates 6.97 to 6.101 illustrate a highly unusual grain surface texture showing greater dominance of an entire grain surface than most other textures (sample 21). Well formed hexagonal 'windows' occur over 50 μm across such that their sides are often parallel or subparallel. Plate 6.98 is a close up of the centre right portion of the grain on Plate 6.97, and Plate 6.99 a close up of the centre lower portion, both showing the development of interlinking fingers and fine pitting over a smooth capping layer and the underlying grain surfaces. Plates 6.100 and 6.101 show progressive close ups of this unusual texture. The smooth capping layer is about 3 μm thick with what appear to be vertical fractured edges (Plate 6.101). The whole capping layer surface on Plate 6.101 appears to be etched, but this probably represents a slow form of crystallographically controlled solution or precipitation.

Plate 6.100 illustrates how the capping layer mirrors perfectly what appear to be corroded parallel arcuate steps. The upward extending finger of capping layer merges smoothly with the grain surface on Plate 6.100, and the area to the left of the arcuate steps is gradually being covered by rounded plates resembling the surface of the capping layer.

The origin of such textures is problematical because of their size, hexagonal shape and mode of formation. If such textures were etched as has been suggested for Plates 6.92 to 6.96, the grain surfaces below should also exhibit etching. The sides of the hexagons in close-up on Plate 6.101 do not suggest this. It may be that the capping layer is more susceptible to solution but the size, regular distribution and parallelism demand a crystallographic control operating at a much larger scale than would be expected. Geometric regularity of form cancels out the probability of abrasion cracking the shell during subaqueous transport. A similar pattern is presented on Plate 6.53 from sample 9 on a grain which has experienced some high energy fractures.

Re-examination of Plate 6.65 (sample 8), shows triangular platelets of precipitated silica forming on the upper photograph portion, gradually coalescing to contain oriented triangular depressions the apices of which point in the opposite direction. It was suggested earlier that oriented triangular pits on Plate 6.65 (centre left) may represent an advanced stage of such coalescence. It may be that gradually encroaching precipitation of capping layer produces such an unusual texture and that the triangular flat floored hollows on Plate 6.92 are not truly etched o.t. pits.

A 'precipitation' origin has more credence if we examine the textures on Plates 6.102 and 6.103, also from sample 21. Plate 6.102 portrays a grain with large conchoidal fractures (surface texture 17), and coarse blocks (surface texture 18), on the right. The large central hollow exhibits an unusual maze with hexagonal patterns. Plate 6.103 shows a close-up of what may be silica flowers in the centres of hexagon-like rosettes. The surface on the right shows a texture of aligned well shaped small forms which may be crystal growth or crystallographically oriented precipitation centres.

Further growth may produce unusual patterns such as those on Plates 6.92 to 6.101, however such features may also be ephemeral which explains why they do not appear commonly on sand grains, or at least have not been reported as such for Long Island beaches. An important result of the textures however is that they are unusual grain surface features which typify offshore sample 21 and were only recorded on beach samples onshore along Fire Island (samples 8, 9 and 11 on Plates 6.65, 6.53, 6.95 and 6.96 respectively).

II.V EUHEDRAL PRECIPITATION

Examples of euhedral precipitation were rare and even when observed they were very small scale and localised (surface texture 36 in Fig. 6.1). Well formed growth was observed on only 5 samples (Fig. 6.12B). Sample 6 in the western Headlands had euhedral precipitation on one grain as did sample 18 in western Fire Island, and sample 21 offshore (Fig. 6.12B). Samples 19 and 20 contained 2 and 3 grains.

Interpretations of such an abundance amounting to a total of only 32% for all samples is problematical because of the paucity of the texture's occurrence and a lack of trend in other samples with which to compare frequencies. A noteworthy feature however is the fact that it occurs, albeit in very small proportions, on three of the four offshore samples (Fig. 6.12B), distinguishing that sediment source from onshore beach samples and sample 1 from Montauk Cliff. There is a single tenuous link with onshore beaches regarding off-shore samples 19 to 22 on the basis of euhedral crystal growth in the form of a small but significant presence of crystals on sample 18 on western Fire Island beaches (Fig. 6.12B).

Euhedral crystal growth has already been illustrated under the methodology section (Chapter 5) but less well formed precipitation may be seen on Plates 6.104 and 6.105 from samples 6 and 21 respectively (Fig. 6.12B). Plate 6.104 (centre), exhibits what were initially taken for large blocks, but the geometric congruity of faces perpendicular to the grain surface and the flat plates below them and to the right suggest well formed precipitation (sample 6).

Plate 6.105 portrays a surface which was initially interpreted as very coarse etching but the globular tops to geometrically aligned projections may represent an early stage in crystal growth such as silica globules (sample 21).

II.W AMORPHOUS PRECIPITATION

Amorphous silica precipitation (Texture 34 in Fig. 6.1) is either 'abundant' or 'ubiquitous' on all samples (Fig. 6.1). Its use as a discriminatory tool on the basis of presence-absence data is doubtful as a result of this since it is common to all samples on high percentages of grains (Fig. 6.13A).

Many plates too numerous to list have already been presented with examples of amorphous precipitation on a variety of scales and locations. Plate 6.106 portrays a large smooth clean subrounded grain from sample 5 in the western Headlands (Fig. 2.4), the surface of which is covered by satiny smooth capping layer (surface texture 34 in Fig. 6.1). The large conchoidal fracture (upper right) is relatively unaffected but what may be steps, a crack and a grain embayment to the left are gradually being smothered and the surface healed up (Plate 6.106).

Sample 11 (Plate 6.107) shows a grain which has been subjected to high energy fracturing (steps and blocks in the centre and lower right), edge abraded and chemically pitted, gradually blunting projections. However, the left surface and right surface have been progressively flattened and smoothed by amorphous precipitation, edge abrasion and etching probably postdating its formation.

Chemically modified grain surfaces in the extreme sense are presented on Plates 6.108 and 6.109 from sample 21. Plate 6.108 shows rounded irregular bulbous protrusions and coarse plastered silica. The upper face contrasts markedly with the etched rounded edges on the right.

Similarly contrasting surfaces are shown on Plate 6.109 from sample 21, e.g. the edge of the down-facing cavity on the right with conchoidal fractures and steps. Sample 8 in eastern Fire Island reflected several episodes of chemical and mechanical modifications

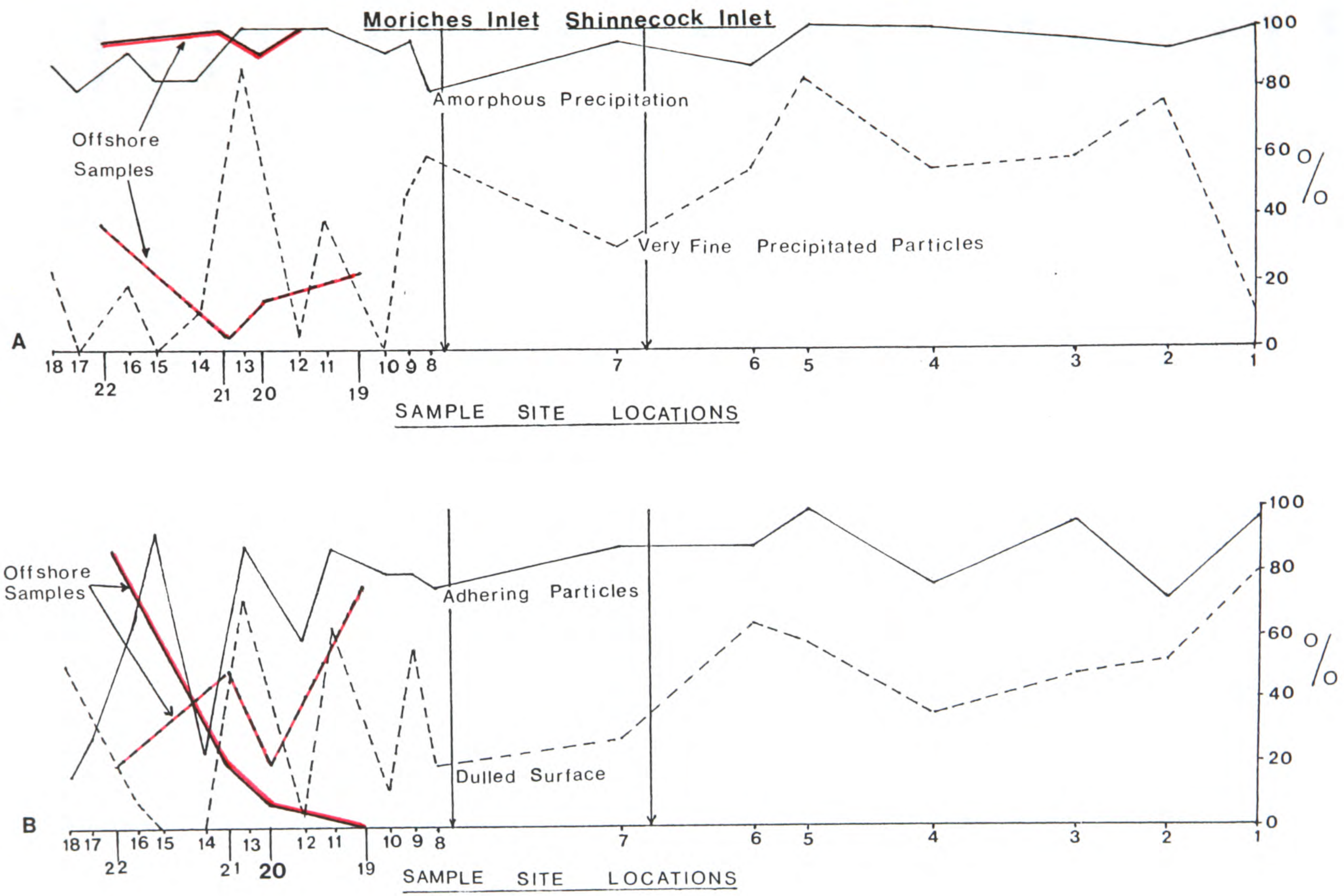


Fig. 6.13. A. Amorphous Precipitation, Very Fine Precipitated Particles;
B. Adhering Particles and Dulled Surface-Variations alongshore downdrift of Montauk Point and offshore.

on Plate 6.110. The well rounded edge has an incomplete smooth capping layer (surface texture 34) which may have been cracked off as seems the case in the hollow to the left. There are some small percussion chips and other edge abrasions but the rest of the edge is dominated by fine etching (texture 33 in Fig. 6.1).

Higher magnifications of some grain edges (Plate 6.111) display the growth and coalescence of discrete platelets. Solution and precipitation may take place simultaneously on the same part of a grain (Krinsley pers. comm.), with the former providing raw material for silica redeposition and secondary growth. Many of the chemical textures presented above are combinations of both processes and indeed may be chemically-modified mechanically-formed features. A noticeable feature of many beach samples has been the combinations of edge abrasions and various etch pits but especially textures 33 and 40 (Fig. 6.1).

II.X VERY FINE PRECIPITATED PARTICLES

The trends shown for surface texture 35 are shown in Figs. 6.1 and 6.13A. Much of the Headlands section and Westhampton beach (samples 2 to 8) display fluctuating values ranging from 'present' to 'abundant'. Sample 1 at Montauk Point increases in abundance sharply from less than 20% to almost 80% by sample 2 on Montauk beach (Fig. 6.13A). Abundancies fluctuate more noticeably along Fire Island from values of 0% at sample sites 10, 15 and 17 to a maximum for all samples of over 80% at sample site 13 (Fig. 6.13A).

Offshore samples do not fluctuate as much (samples 19 to 22 in Fig. 6.13A) and fall within the 0% to 40% frequency band which characterised most Fire Island beach samples (Fig. 6.13A).

II.Y ADHERING PARTICLES

Shown as surface texture 38 in Fig. 6.1 adhering particles have been included at the lower edge of the checklist because it was considered that they were chemically attached to grain surfaces, although they represent small comminuted particles. Goudie and Bull (1984), and Bull (1984), have presented this texture as a member of those associated with grain breakage. Whalley (1978b), has described such wet-ground particles as possible sources of dissolved silica and hence linked to silica precipitation and solution.

The trends for adhering particles are presented in Figs. 6.13B, and 6.1. Much of the south shore, including sample 1 at Montauk Point, show up as samples with 'abundant' or 'ubiquitous' percentage frequencies (Fig. 6.1). There is a gradual diminution in abundancies westward, samples 1, 3 and 5 containing 96%, 96% and 100% values respectively (Fig. 6.13B).

Fire Island contains samples with lower value ranges of 60% to 80% although there are marked fluctuations, samples, 14, 17 and 18 falling to 24%, 28% and 16% (Table 6.1). Offshore samples show the greatest variability of all ranging from 0% at sample site 19 to 88% in sample 22 west of Channel H. There appears to be no relationship between offshore sample abundancies and onshore beach values as far as adhering particles are concerned (Fig. 6.13B).

II.Z DULLED SURFACES

There is a close similarity between dulled surface (Surface texture 39 in Fig. 6.1), percentage occurrences and those for adhering particles (Fig. 6.13B) although the former have values of 20% to 50% less than the latter. Once more, Fire Island samples exhibit very marked fluctuations ranging from 0% at sample sites 14 and 15 to 72% at sample site 13 (Fig. 6.13B). Offhsore samples 19 to 22 in Fig. 6.13B exhibit similar value ranges to onshore Fire Island beach samples.

The trend for dulled surfaces follows what may be a predictable pattern in the study area in that once released from glacial moraine the dulling effects of dominantly chemical modifications would be removed by the superimposition of fresh fractures and abrasions in the surf. Using trend peaks, diminishing values for dulled grain percentages along the Headlands beaches updrift may be seen to be reversed suggesting a possible supply of dulled grains from a fluvio-glacial or glacial source offshore. However, the troughs which follow peaks for samples which are so close together would preclude such an option unless dulled surfaces are removed extremely rapidly in the surf zone. The eastern Headlands do not appear to exhibit such rapid dulled grain surface removal although greater spacing of samples in the Headlands may play a part in this picture.

It is worth summarising the combinations of more important chemically induced grain surface texture trends in order to detect any overall controls or patterns. The following points should be noted:

(a) Glacial moraine at Montauk Point is noticeable for its low abundancies of grains exhibiting large isolated solution pits

(28%), and chattermarks (0%, Fig. 6.11B). It has amongst the highest values for adhering particles and dulled surface abundance (Fig. 6.13B) and differs markedly from the nearest beach sample at Montauk beach (sample 2) in the cases of large solution pits (Fig. 6.11B), chattermarks (Fig. 6.11B), adhering particles and dulled surfaces (Fig. 6.13B).

(b) Both glacial and fluvioglacial sediment sources at Montauk Point (sample 1) and offshore (samples 20 and 21) did not exhibit chattermarks (Fig. 6.11B).

(c) In the cases of fine etching, oriented triangular etch pits and dulled grain surfaces (Figs. 6.12A, 6.12B and 6.13B) there appears to be a broad trough in value trends prior to a peak in the western Headlands.

(d) The gradual increase in chattermark frequencies west of Sample 1 at Montauk Point implies a relationship to distance transported westward in littoral drift.

(e) Euhedral precipitation is found at only a few sites offshore and at onshore sites 18 in western Fire Island and 6 in the western Headlands (Fig. 6.12B).

(f) Fire Island samples show marked variability of surface texture occurrences beginning at sample site 8, related to chemical solution-precipitation apart from amorphous precipitation (Fig. 6.13A) and fine etching (Fig. 6.12A). This may be related to closer sample spacing or an additional supply of sediments from a source exhibiting different surface texture characteristics to onshore beach samples. Beach processes may not cause such fluctuations owing to their relative homogeneity over short distances.

(g) Within Fire Island's textural variability trends,sample 13 in the central section appears to diverge from the general trend for solution-precipitation modifications more regularly than other samples e.g.- fine etching (Fig. 6.12A), as well as coarse and very coarse etching (Fig. 6.12A) and adhering particles and dulled surfaces (Fig. 6.13B).

(h) Offshore samples appear to fluctuate more markedly in terms of chemical modifications on grain surfaces compared with mechanically induced surface modifications.

6.III COMPARISONS OF SAMPLE VARIABILITY ON THE BASIS OF QUALITATIVE RESULTS

The preceding account has outlined variations in each texture or textural group with distance westward from Montauk Point. This has helped to illuminate important textural trends and to isolate those textures which may be related to increasingly prolonged transport in littoral drift and those which do not appear to be influenced as such on the basis of texture presence-absence. Cause and effect may be deduced in certain cases for glacial, fluvio-glacial and beach environments and their associated grain surface modifications.

The account that follows concentrates upon 'between-sample' variations in all forty textures in order to throw some light on the possibility of the existence of sample groupings which have been uncovered partly in the preceding section. It was anticipated that any contrasts and similarities which are confirmed using visual results and qualitative observations will complement later statistical results and aid in their computation and interpretation.

In order to achieve this, two sets of variability plots were drawn: surface feature variability plots for samples 1 to 22 and positive-negative surface feature variations between samples. These will be described in order using groupings already suggested in the previous section:

(a) Sample 1 V Headlands section and Westhampton Beach.

(b) Sample 1 V Fire Island.

(c) Sample 1 V Offshore.

(d) Adjacent Headlands samples.

(e) Adjacent Fire Island samples.

(f) Offshore V Offshore.

(g) Offshore V Cnshore Fire Island.

It was considered appropriate to focus upon 'between-sample' variations in greater detail using descriptive results in the event that statistical analysis may produce less than clear results when techniques were asked to discriminate between seventeen samples from basically the same coastal stretch which has relatively uniform wave energy conditions (Grant, Williams and Leatherman, pers. comm.). In addition, surface feature variability plots which are presented in Appendix B provide a precise 'within sample' profile of textural variability for each site, which may be used in other forms of statistical analysis if so wished using the shape of each profile.

Positive-negative between-sample surface feature variability was calculated on the basis of feature increase or decrease from one sample to another using the first sample as a base. Two identical samples would produce a flat trend near zero, the greater the fluctuations the greater the percentage variation between samples. Such graphs give no indication of grain abundancies only their percentage variation from base samples. Textures which scored lowly on the checklist abundancies may reveal increases of over 1000% e.g.- base sample abundance of 2 grains followed by a sample abundance of 10 grains would be shown as a percentage increase of 400% (rather than 500% which would only represent the ratio rather than % increase).

Percentage variations below the zero base line in Figs. 6.14 (i) to 6.14 (Liv) are by necessity confined to maxima of 100% e.g. base sample abundance of 4 grains followed by a sample abundance of 2 grains represents a percentage decrease of 50%. This is unavoidable owing to the fact that base sample values are always higher than subsequent sample values when decreases are concerned. Despite this drawback Figs. 6.14 (i) to 6.14 (Liv) provide an opportunity of comparing qualitative sample to sample variations. Each graph has been divided vertically into columns shown on the checklist (Fig. 6.1) as textural groups. Reading from left to right on each figure these include: grain shape, edge abrasion and edge shape, grain relief, large breakages, small breakages, chattermarks, chemical etching, chemical precipitation, others.

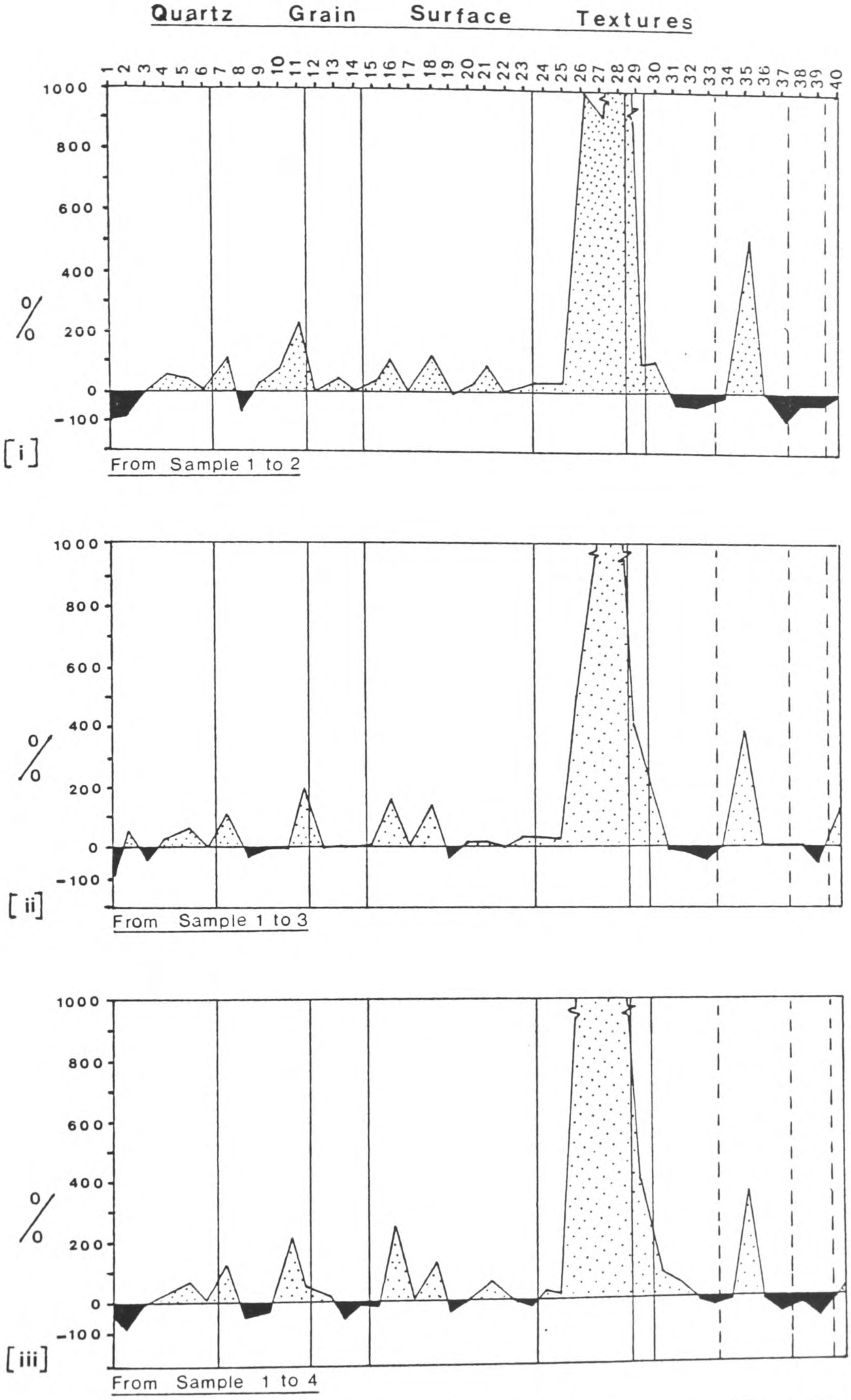
III.A <u>Sample 1 (Montauk Point) V Headlands Section and Westhampton Beach</u>

Percentage variations from sample 1 at Montauk Point to sample 2 at Montauk beach set the parameters on which other Headlands samples are interpreted because this represents the initial transfer of known glacial grains to the beach immediately downdrift (Fig. 6.14 [i]). Confirmation of the influence of surf action on glacial grain textures is shown by percentage increases of over 1000% for surface textures 26 to 28 (M.V. pits, small curved and straight grooves). This peak in small edge abrasions occurs on every graph (Figs. 6.14 [i] to 6.14 [xxi]) reaching a peak in samples 4 and 7.

Montauk Cliff (sample 1), grains move westward and it was expected that surf modifications would cause increased fluctuations toward sample 7 on Westhampton beach. If percentage variations are smooth and progressive it is reasonable to ascribe them to surf action alongshore. Trends of increasing grain angularity from sample 1 to sample 7, previously observed in the last section are confirmed, with samples 5, 6 and 7 (Figs. 6.14 [iv]-[vi]) showing decreases in grain roundness compared with sample 1. This clearly represents a reversal of trends for grain shape shown for samples 2, 3 and 4 and is the reverse of what would be expected.

Edge roundness in general, on the other hand increases from sample 1 to other Headlands samples although samples 5 and 7 show decreases in rounded edges compared with sample 1, as well as decreases in angular edges. It is tempting to claim that such a trend reversal demands the existence of an additional onshore transfer of angular grains from buried channel deposits south of eastern Long Island, but with no data on such offshore sediments this is supposition at the present time.

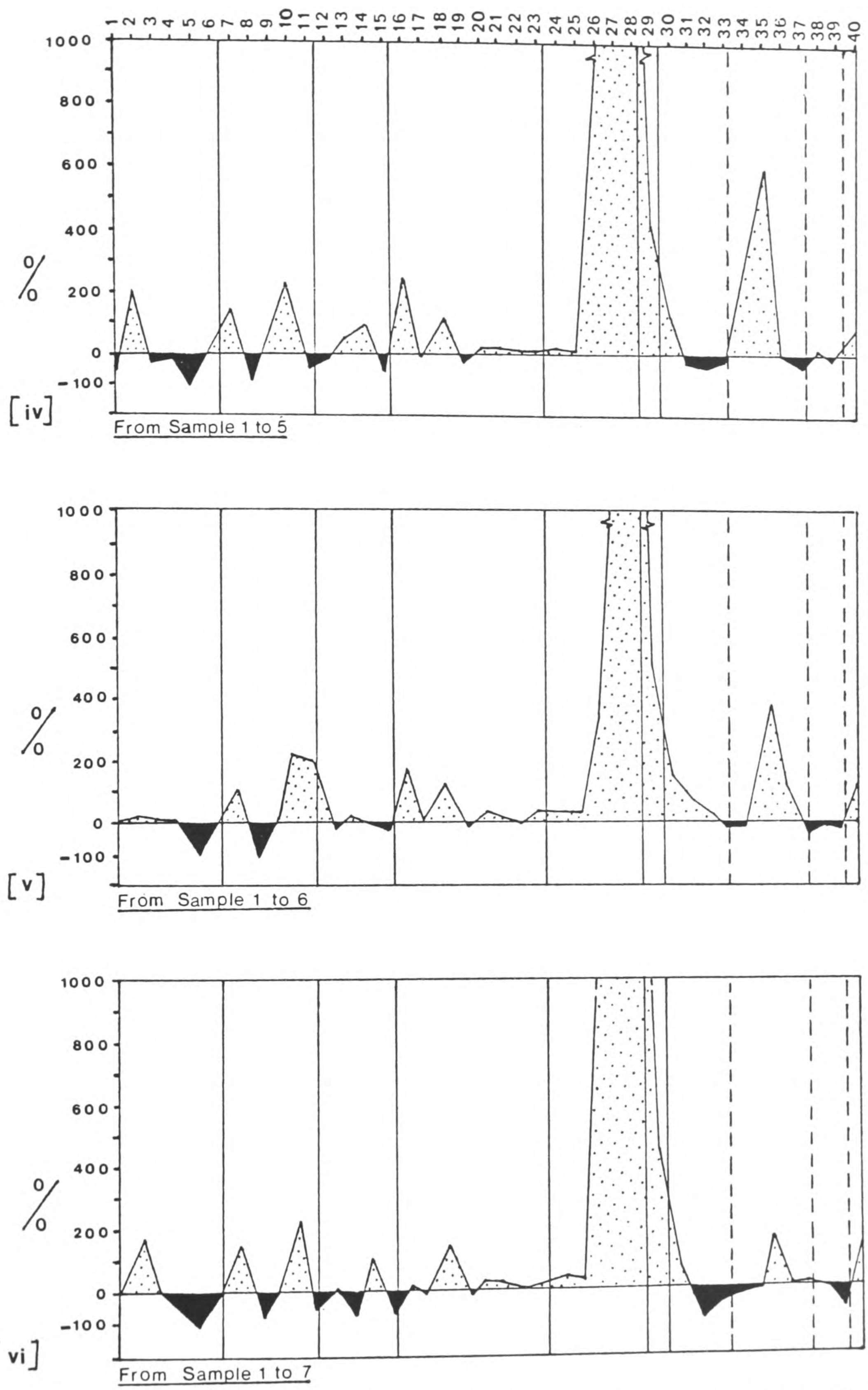
Apart from very fine precipitated particle increases (surface



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples compared with Sample 1

Fig. 6.14 [i]-[iii].

Quartz Grain Surface Textures



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples compared with Sample 1

Fig. 6.14 [iv]-[vi].

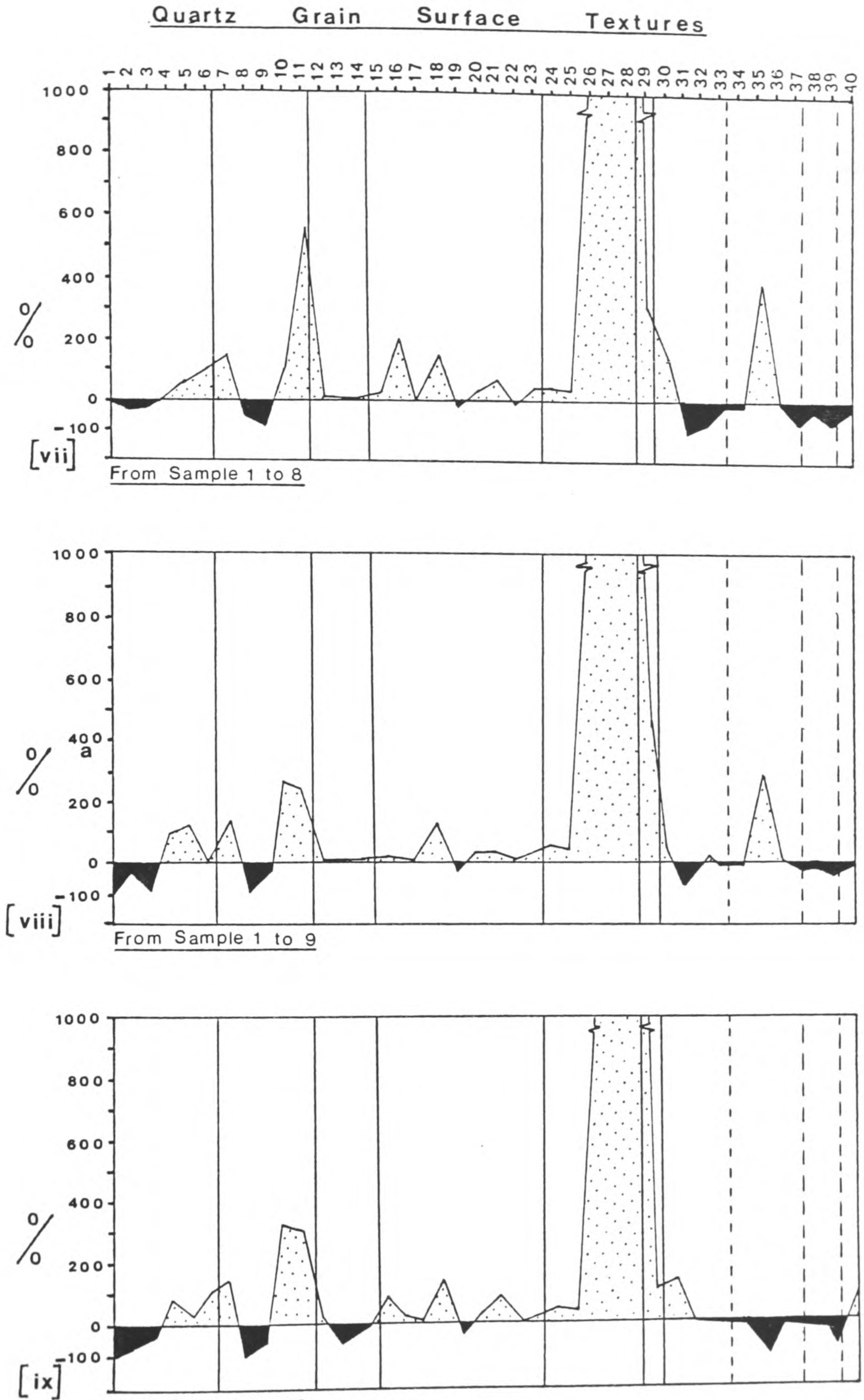
texture 35 in Fig. 6.1) other trends for textures do not reveal progressive increases or decreases. Surface feature variability plots for samples 1 to 7 are presented in Appendix B.

III.B Sample 1 (Montauk Point) V Fire Island Samples

Examination of Figs. 6.14 [vii] to [xvii] shows greater variation between Fire Island samples 8 to 18 and sample 1. No sample shows an increase in grain angularity on Fire Island compared with sample 1, in the same way as samples 5 and 7 from the Headlands section (Figs. 6.14 [vii] to 6.14 [xvii]). Grain edge roundness increases progressively. This is borne out by the persistence of the increased trend for small edge abrasions (surface textures 26 to 28 in Fig. 6.1), and a gradual shift toward increased chemical etching. The latter texture is viewed as an edge reducing process and apart from sample 13 in Fig. 6.14 [xii] percentage decreases decline along Fire Island and show positive increases from sample 16 westward (Figs. 6.14 [xv] to 6.14 [xvii]).

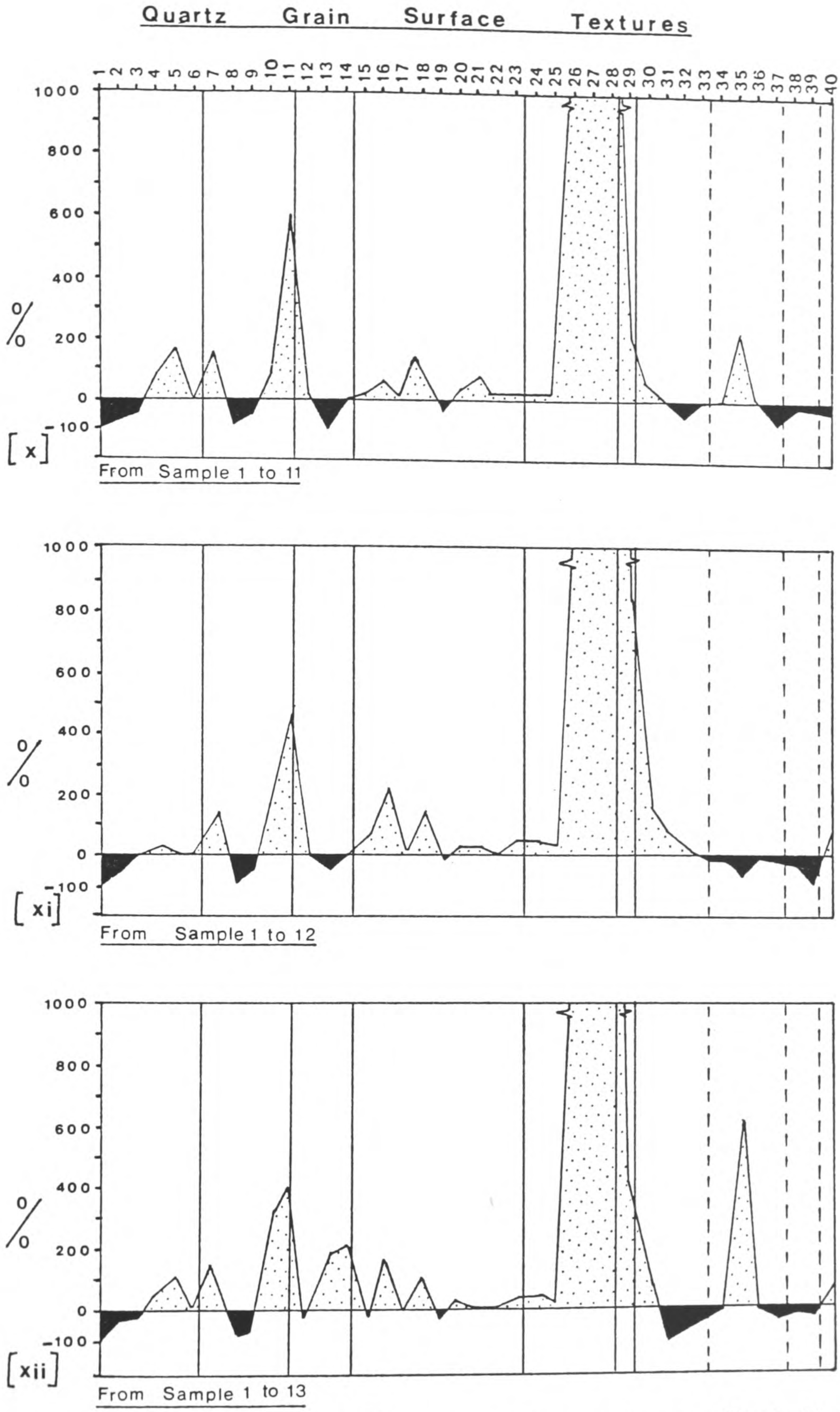
III.C Sample 1 (Montauk Point) V Offshore Samples

One of the assumptions implicit in this project's design was that glacial moraine at Montauk Point would produce a somewhat similar textural assemblage to fluvioglacial or glacial sediments from the buried palaeodrainage channel offshore (Fig. 2.3). Descriptions of sample surface texture trends alongshore and offshore in the preceding section do not appear to confirm such a similarity as yet. Figs. 6.14 [xix] and 6.14 [xx] show as much variation between the onshore moraine source (sample 1), and offshore lobe source (samples 20 and 21), as do Fire Island beach samples. Offshore lobe grains are more rounded, with rounder edges



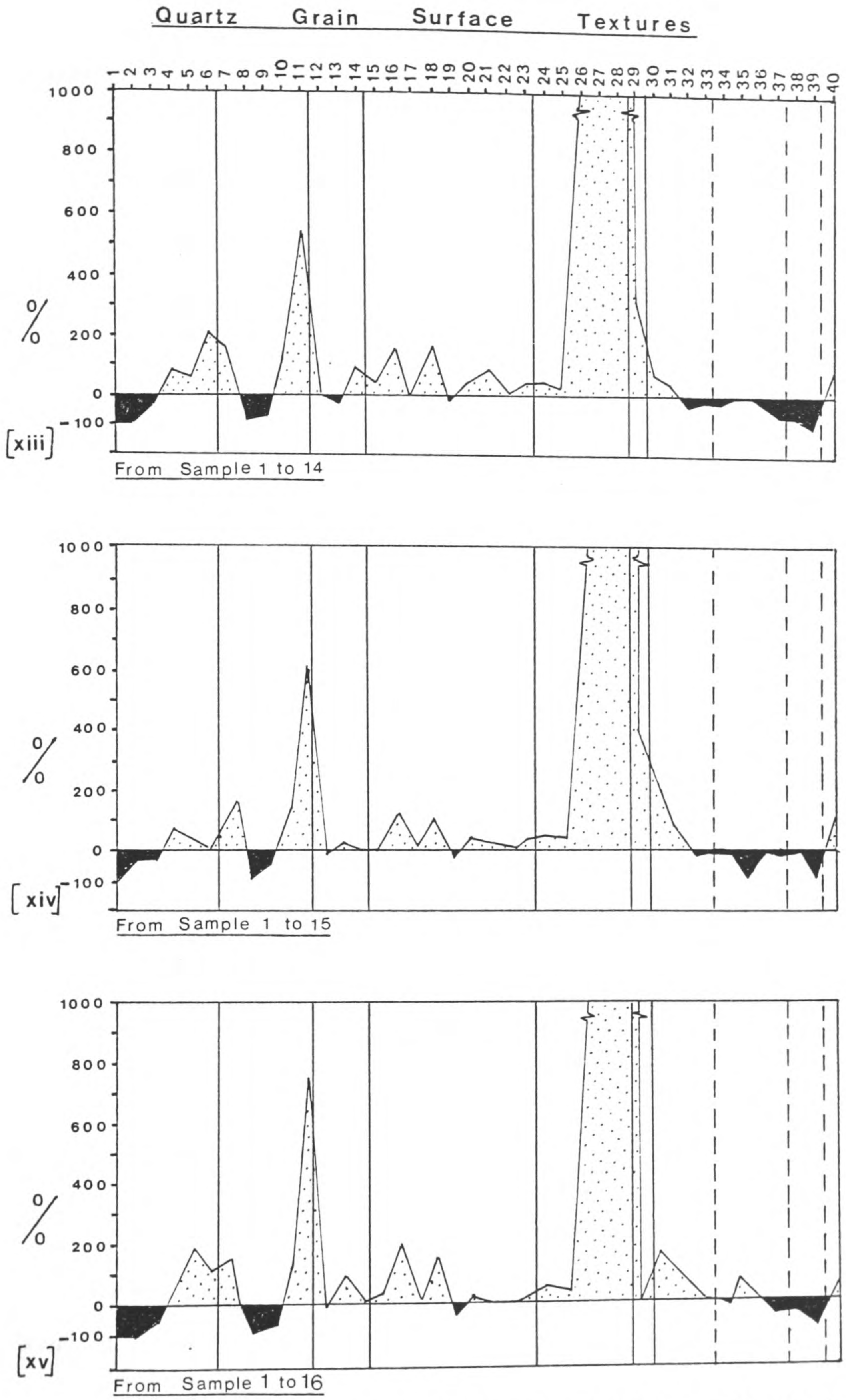
Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples compared with Sample 1

Fig. 6.14 [vii]-[ix]



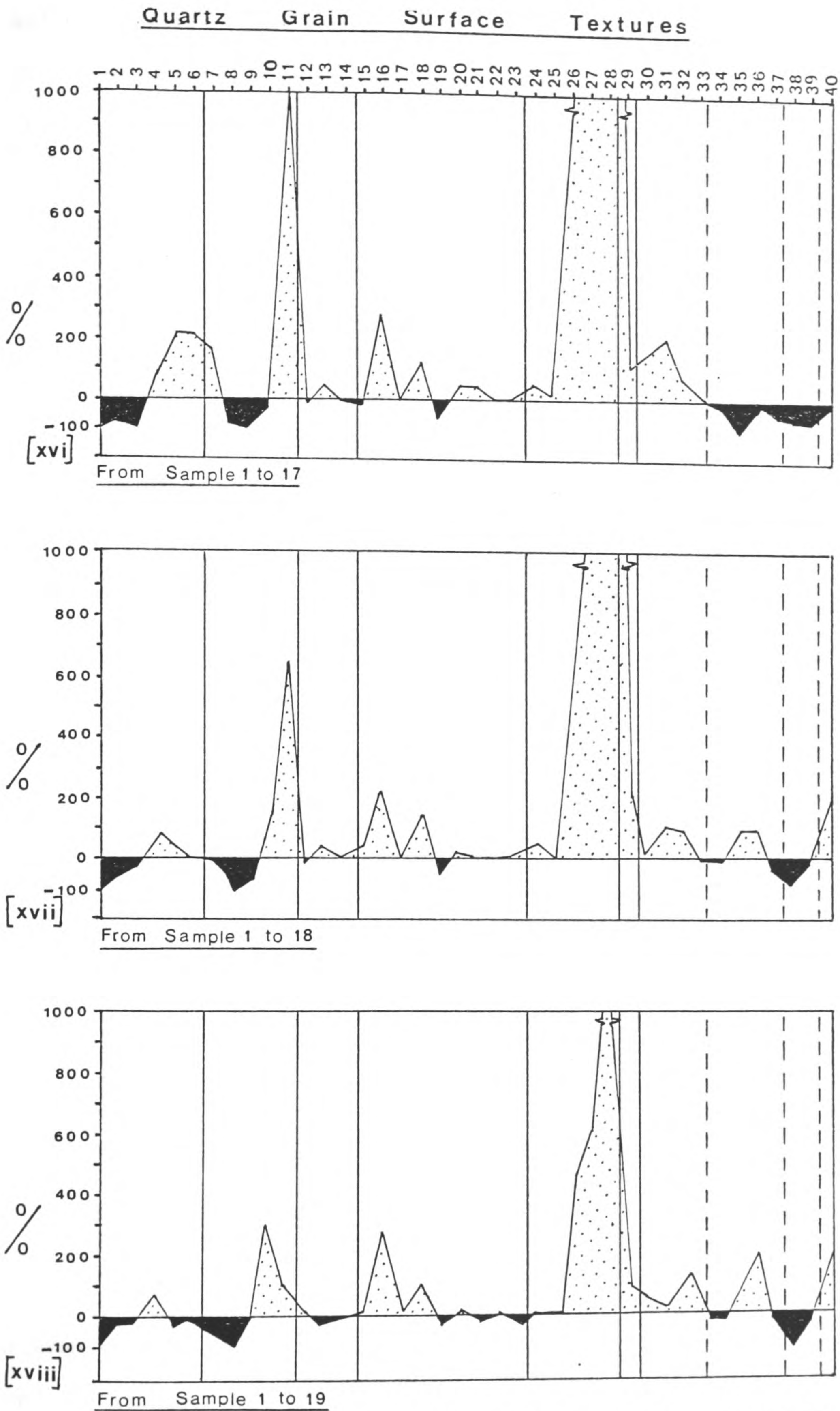
Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples compared with Sample 1

Fig. 6.14 [x]-[xii]



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples compared with Sample 1

Fig. 6.14 [xiii]-[xv]



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples compared with Sample 1

Fig. 6.14 [xvi]-[xviii]

and greatly increased small edge breakages (surface textures 25 to 28). They are more blocky and cracked with cleaner grain surfaces. Crystallographic control of surface texture is also more marked in the form of increased euhedral precipitation and oriented triangular etch pits.

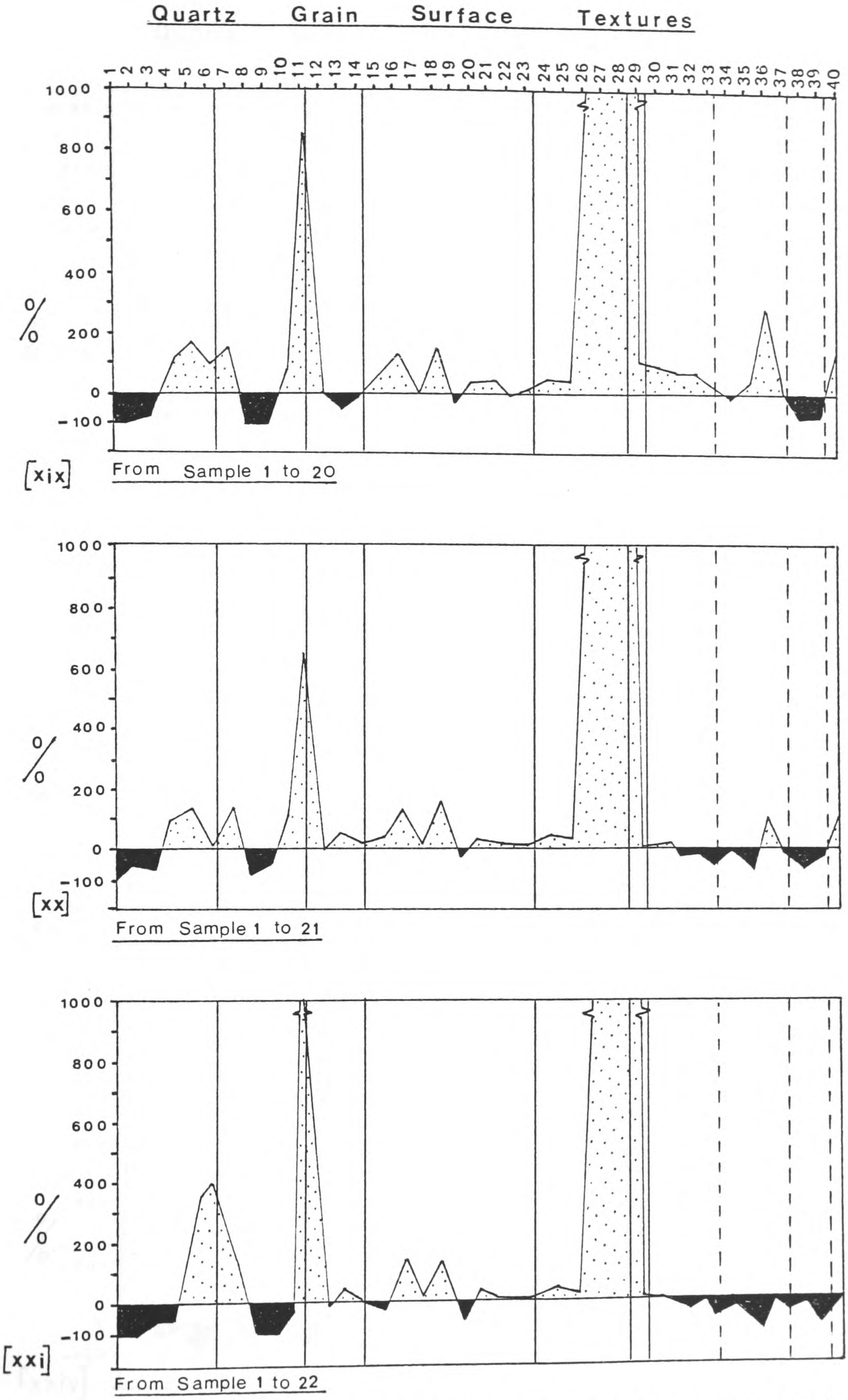
III.D Adjacent Headland Samples

Surface texture variations between adjacent samples in the Headlands section were expected to be minimal owing to the fact that they have been derived from the same glacial source at Montauk Point and have been subjected to surf action along the same stretch of coast. This is generally borne out in the case of both large and small mechanical breakages (surface textures 15 to 28 in Figs. 6.14 [xxii] to 6.14 [xxvi]).

However, the trend of increased grain angularity noted above is borne out sharply, there being an increase of 500% in angular grain occurrences in sample 3 compared with sample 2. This is repeated to an even greater degree from sample 4 to sample 5 (Fig. 6.14 [xxiv]). The pattern presented by edge shape variations is more diverse but from samples 4 to 5 and onto sample 7, grains are becoming lower in relief (Figs. 6.14 [xxiv] to 6.14 [xxvi]). Surface feature variability plots for samples 2 to 7 are presented in Appendix B.

III.E Adjacent Fire Island Samples

Percentage variations in grain surface texture abundance between samples are presented in Figs. 6.14 [xxvii] to 6.14 [xxxvii] for Fire Island. The most notable 'between-sample' variability occurs from sample 7 to sample 8 (Fig. 6.14 [xxvii]). There is a



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples compared with Sample 1

Fig. 6.14 [xix]-[xxi]

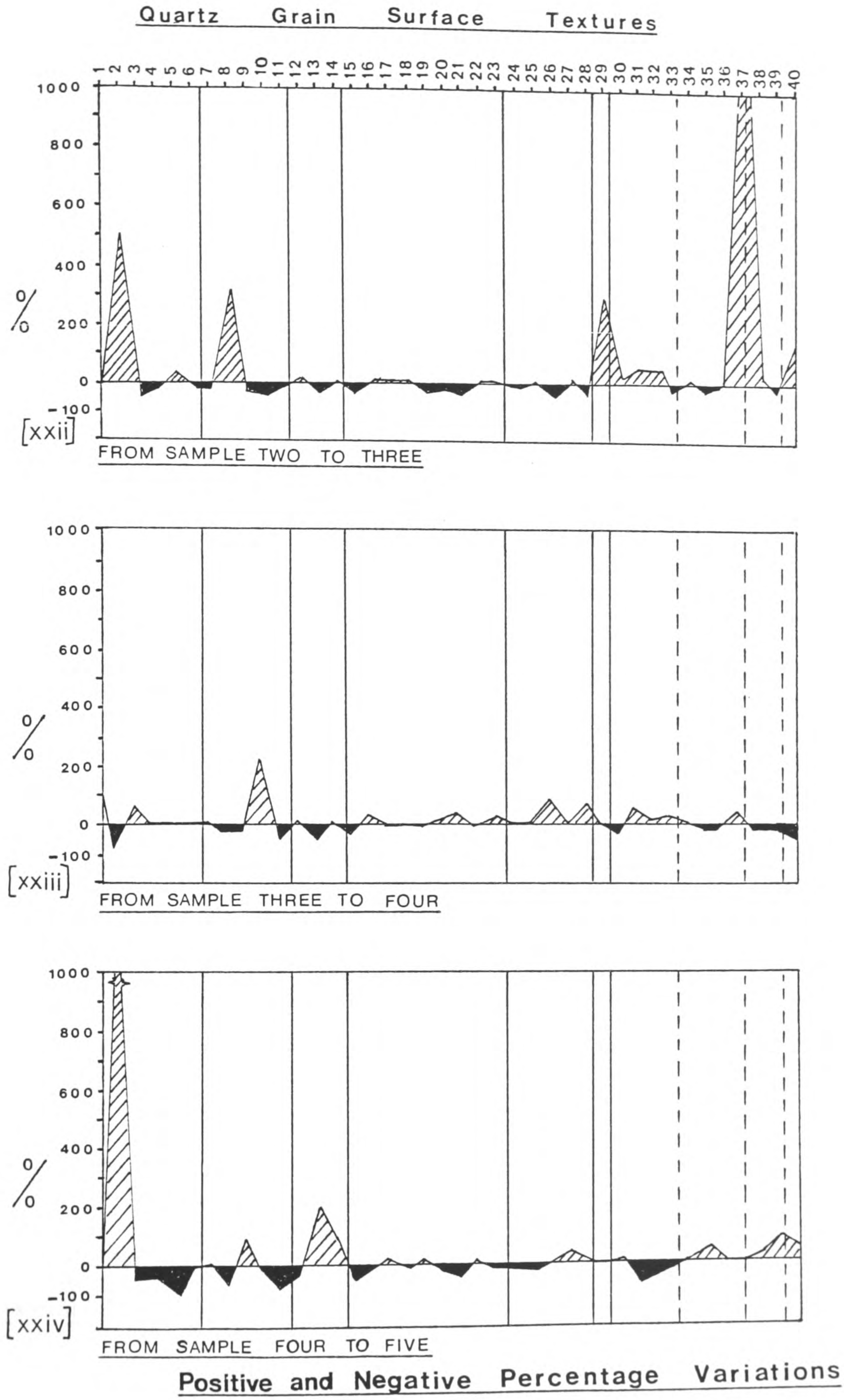
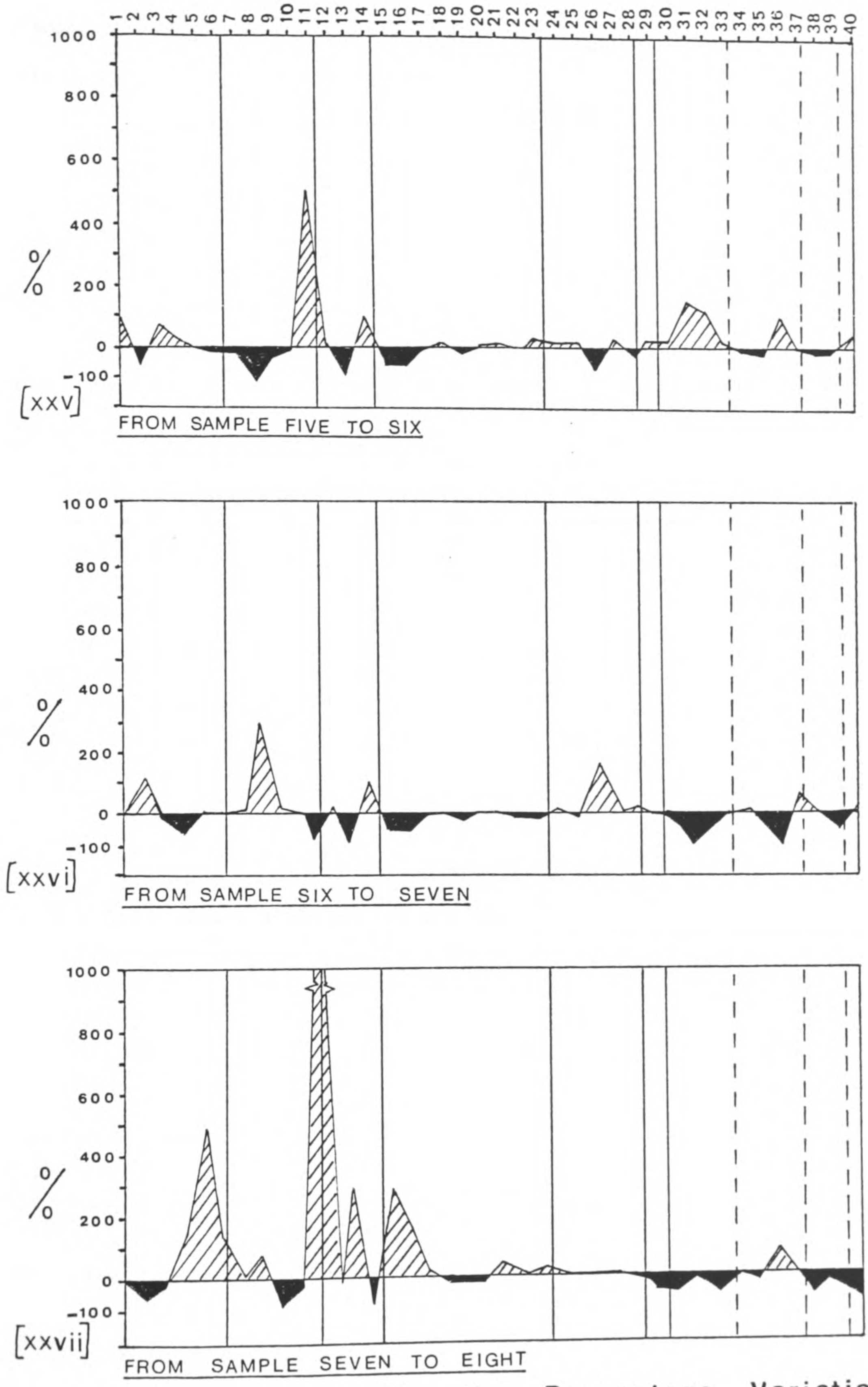


Fig. 6.14 [xxii]-[xxiv]

Quartz Grain Surface Textures



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [xxv]-[xxvii]

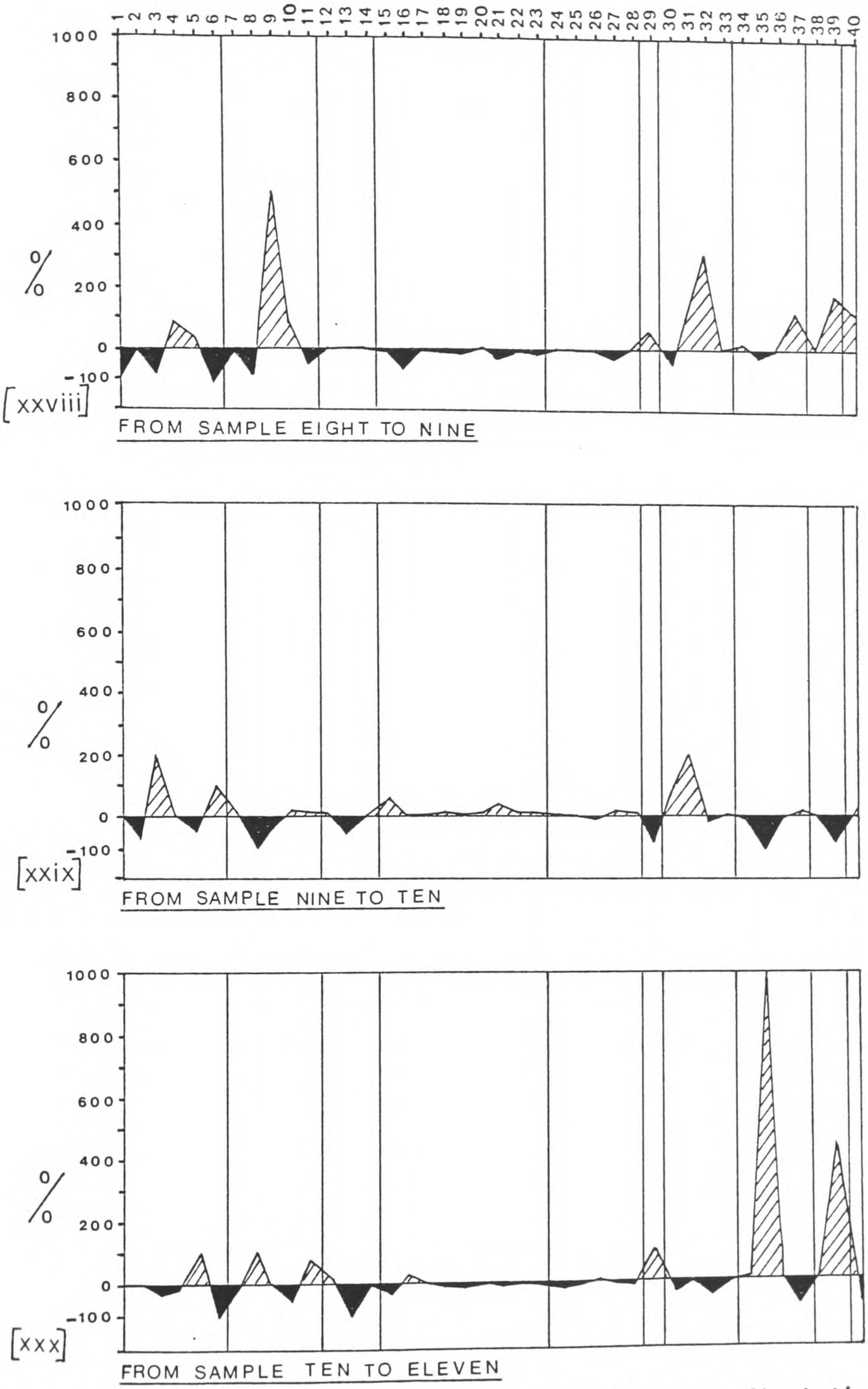
fivefold increase in the occurrence of rounded grains whereas angular edge shapes increase lightly and rounded edges increase more than tenfold. Increases in medium relief grains and broken grains (surface texture 15 in Fig. 6.1) also occur

The patterns for other high energy breakages and smaller fractures (surface textures17 to 28), in the transition from sample 7 to sample 8 are the same as those for the rest of Fire Island (Figs. 6.14 [xxvii] to 6.14 [xxxvii]), and indeed as those for the Headlands section. The dearth in subangular-subrounded edges in sample 8 compared with sample 7 in Fig. 6.14 [xxvii] suggests a mixed grain population increase, but this is rectified by sample 9 where such edge shapes increase by over 500% compared with sample 8.

Mid-Fire Island samples are also characterised by moderate to marked increases in medium relief, especially from sample 12 to sample 13, sample 12 containing twice as many grains with moderate relief than sample 11 (Fig. 6.14 [xxxi]). This trend is shown for samples 11 to 12 and 12 to 13 (Fig. 6.14 [xxxi] and [xxxii]). The ubiquity of fine etching (surface texture 33) and amorphous precipitation (surface texture 34) already noted in the previous section precludes the possibility of large percentage variations between samples on the basis of these textures. Other chemical textures which mark samples from each other are very fine precipitated particles (surface texture 35) and oriented solution precipitation surfaces (surface texture 37), in Figs. 6.14 [xxviii] to [xxxvii].

An important point from Fig. 6.14 [xxvii] is the confirmation

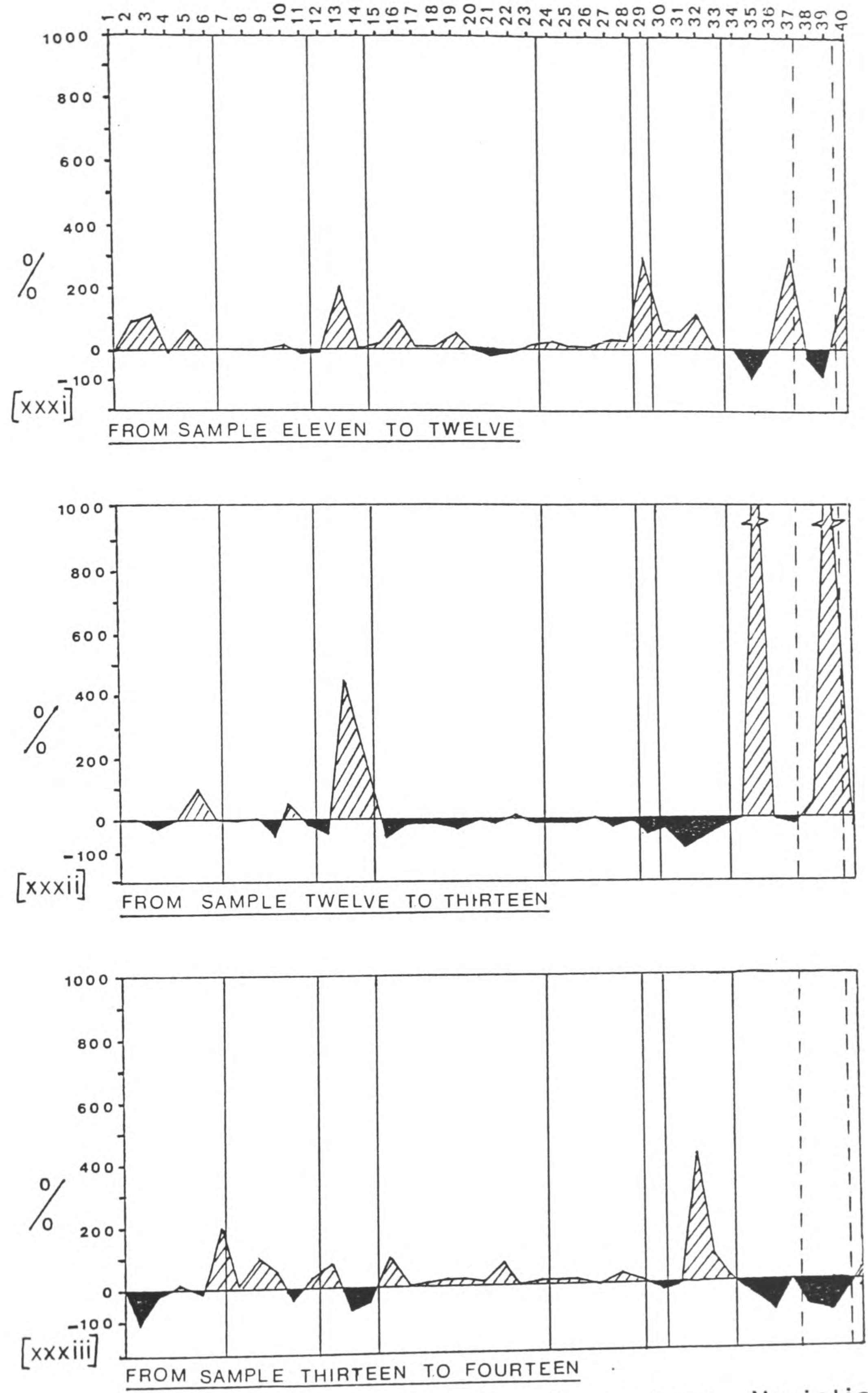
Quartz Grain Surface Textures



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [xxviii]-[xxx]

Quartz Grain Surface Textures



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [xxxi]-[xxxiii]

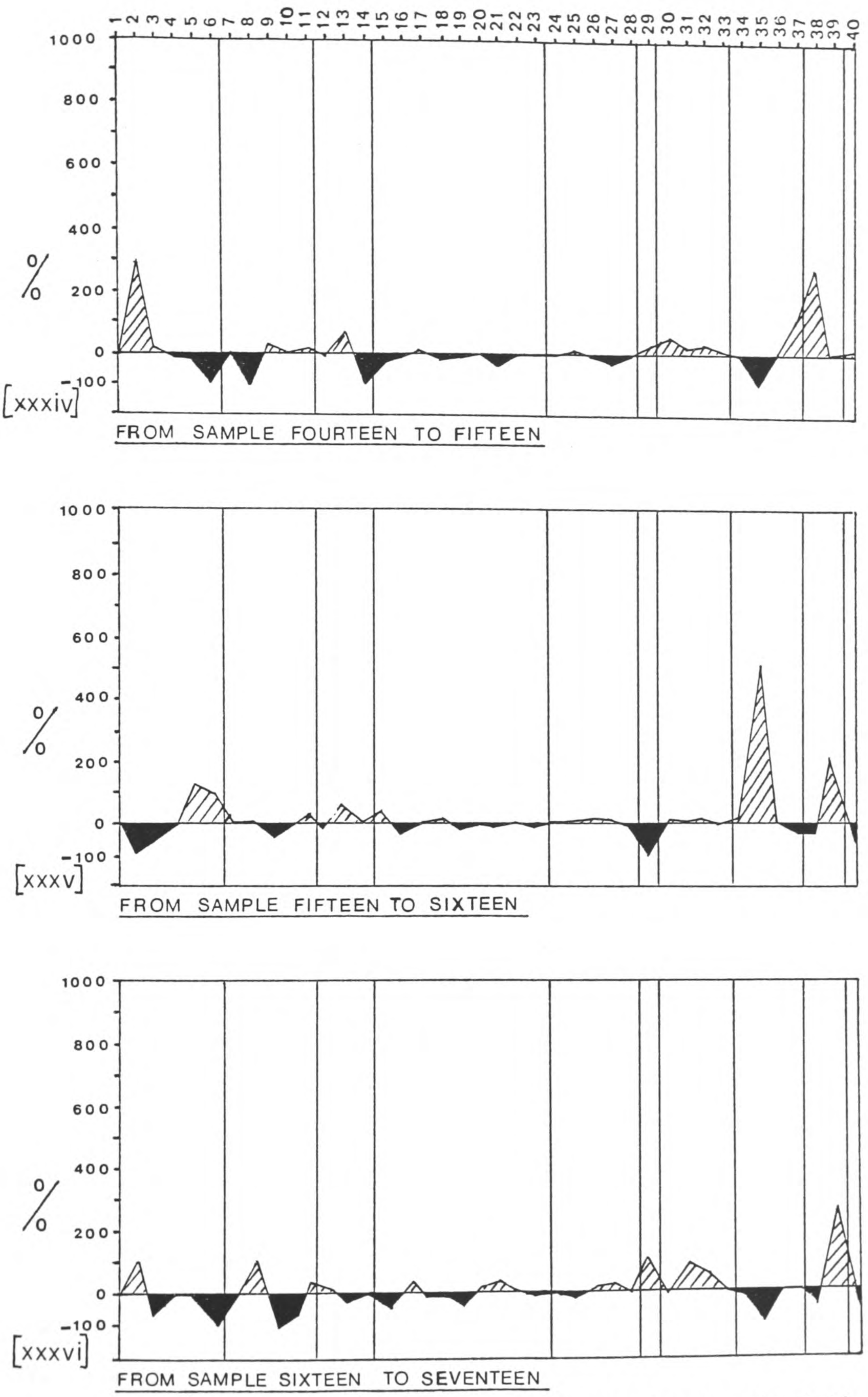
of Moriches Inlet as a marked divide along the south shore between Democrat Point and Montauk Point, already noted in the previous section. There may be more than one explanation for this phenomenon. It has already been suggested that the distinctiveness shown by eastern Fire Island samples in comparison with Headlands samples may represent an onshore transfer of distinctive grains from the Smithtown-Brookhaven channel (Channel I in Fig. 2.3). However, Moriches Inlet is the site of open marine- backbarrier lagoon sediment interchange which may also be a contributory factor.

Although there are generally net losses of sediment from the oceanward shore to bayside locations, ebbtidal deltas represent the return flow of sediment which has been absent from oceanward beaches and their associated surf actions. Grains may have been subjected to lower energy conditions in the lagoon leading to greater solution and precipitation rounding off grain edges and subduing relief. However, it is highly unlikely that such a temporary flux between ocean beach and lagoon would be sufficient to influence grain shape to the extent revealed from sample 7 to sample 8.

II.F <u>Offshore V Offshore</u>

Of the four offshore samples studied, samples 20 and 21 which were proximal to the buried lobe of fluvioglacial or glacial deposits were the two samples considered to be central to the project's design. Fig. 2.3 shows that sample 19 is well to the east and is located closer inshore and nearer to the Smithtown-Brookhaven channel (Channel I). Sample 22 is located west of the Huntington-Islip channel closer to the 10 fathom contour just east of the ridge and swale terrain (Fig. 2.3). On this basis it may be expected that

Quartz Grain Surface Textures



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [xxxiv]-[xxxvi]

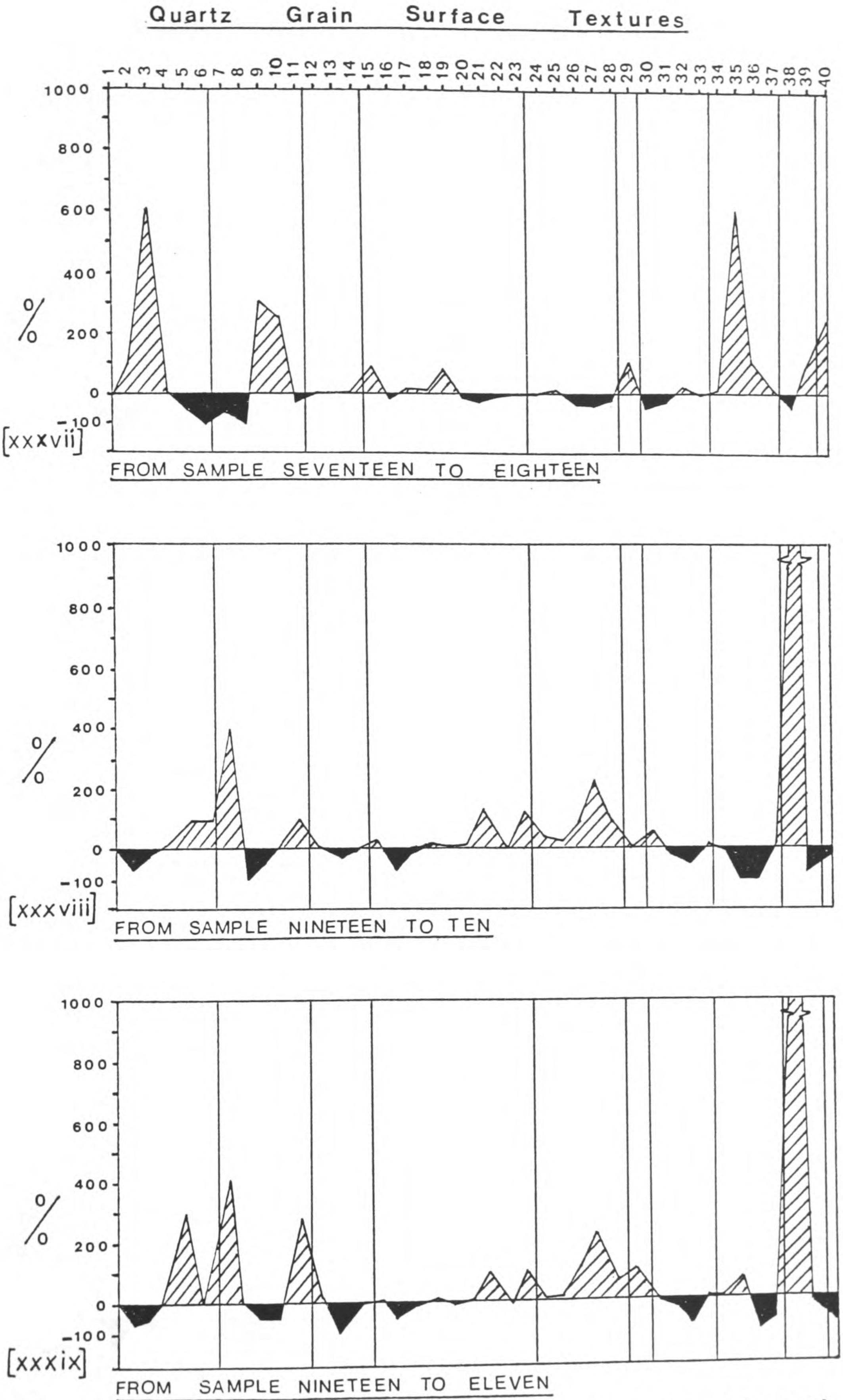
samples 20 to 22 would form closer relationships on the basis of their grain surface textures than they would with sample 19.

Figs. 6.14 [XL] to [XLii] tend to bear out this notion, the fluctuations between paired samples being greatest for samples 19 to 20. Grains from sample 20, proximal to channel H, are rounder with more edge-abraded rounded edges. This is confirmed by increases in large scratches (surface texture 23), meandering ridges (surface texture 21), and M.V. pits and grooves (surface textures 26 to 28).

There are fewer fluctuations in the sample 20 to 21, and sample 21 to 22 transitions (Figs. 6.14 [XL] to [XLii]) especially for both large and small breakages. Sample 21 contains more angular grains and subangular grain edges than sample 20 and a moderate increase in dulled grains with adhering particles. Sample 22 resembles sample 21 even more closely, although there are more well rounded grains and fewer grains with subangular-subrounded edges.

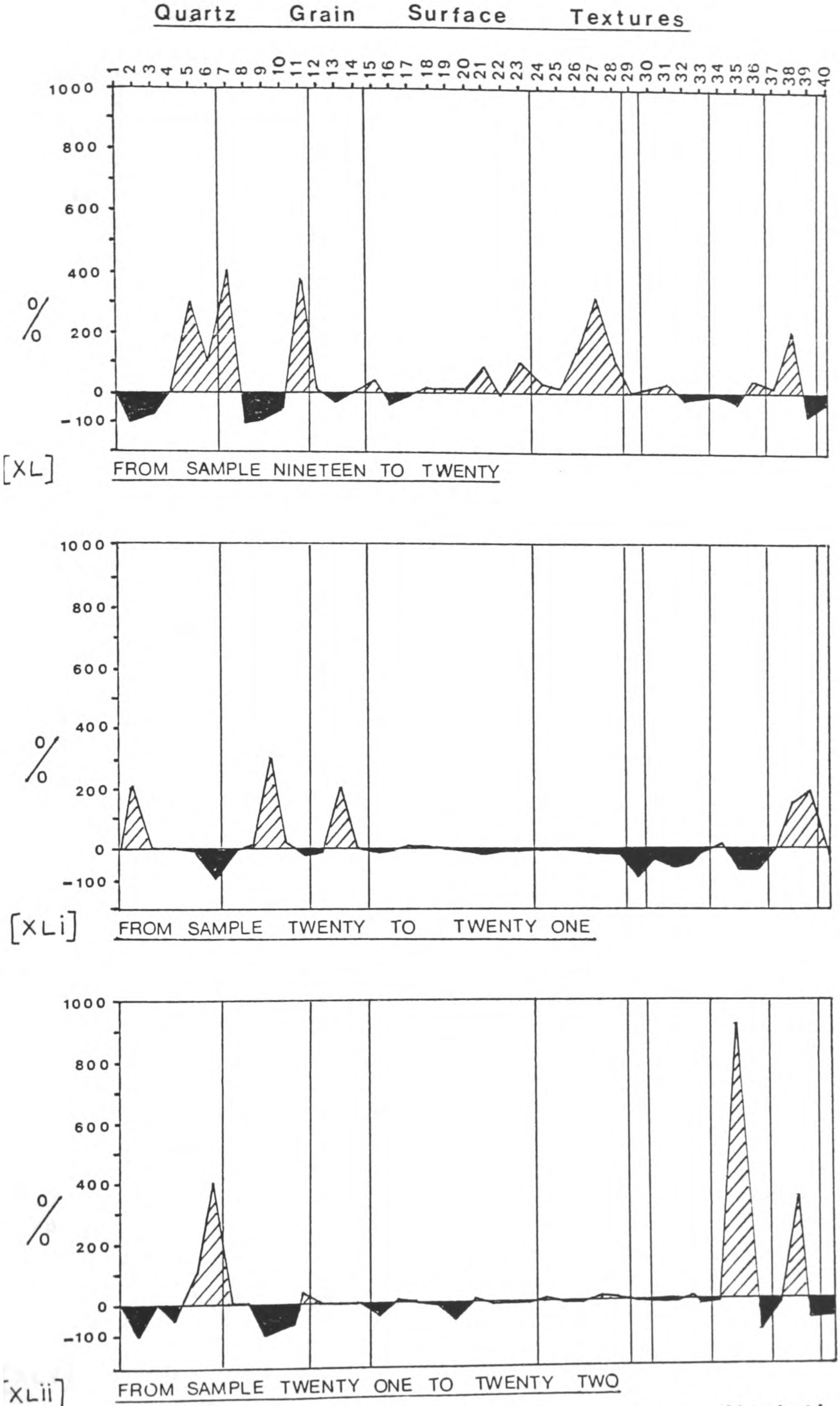
III.G Offshore V Onshore Fire Island

In order to examine the notion that grains were moving from offshore samples 19 to 22 onshore to Fire Island, between sample variability plots were drawn for onshore beach samples immediately opposite, downdrift and updrift of offshore sample locations (Figs. 6.14 [xxxviii], [xxxix] and [xLiii] to [Liv]). Since longshore drift is known to transport sediments westward more credence would be given to offshore-onshore similarities with onshore beach samples immediately downdrift. However, despite the greater energy of waves approaching the shore from the east, longshore drift does move in the reverse direction when waves approach obliquely from the south west



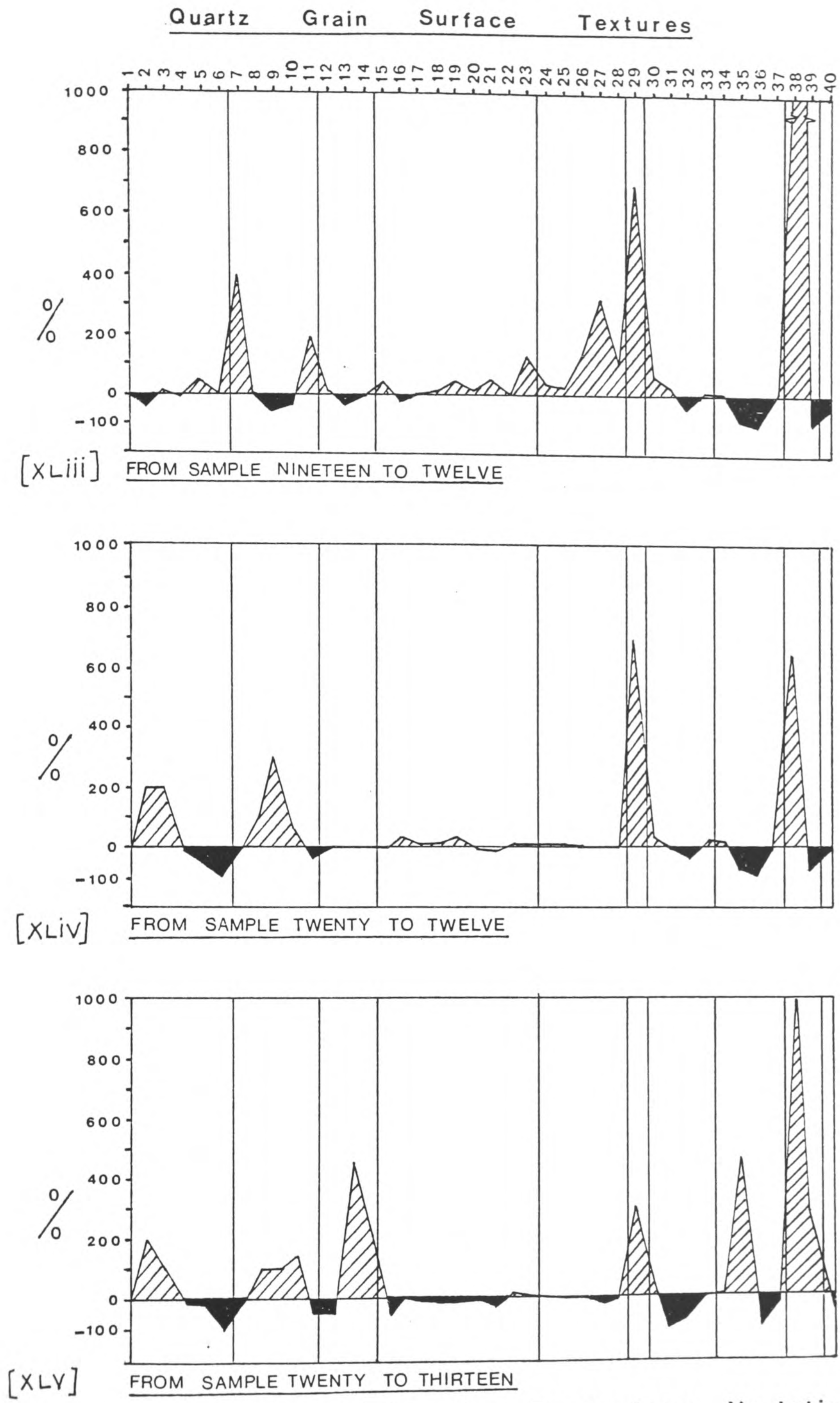
Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [xxxvii]-[xxxix]



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

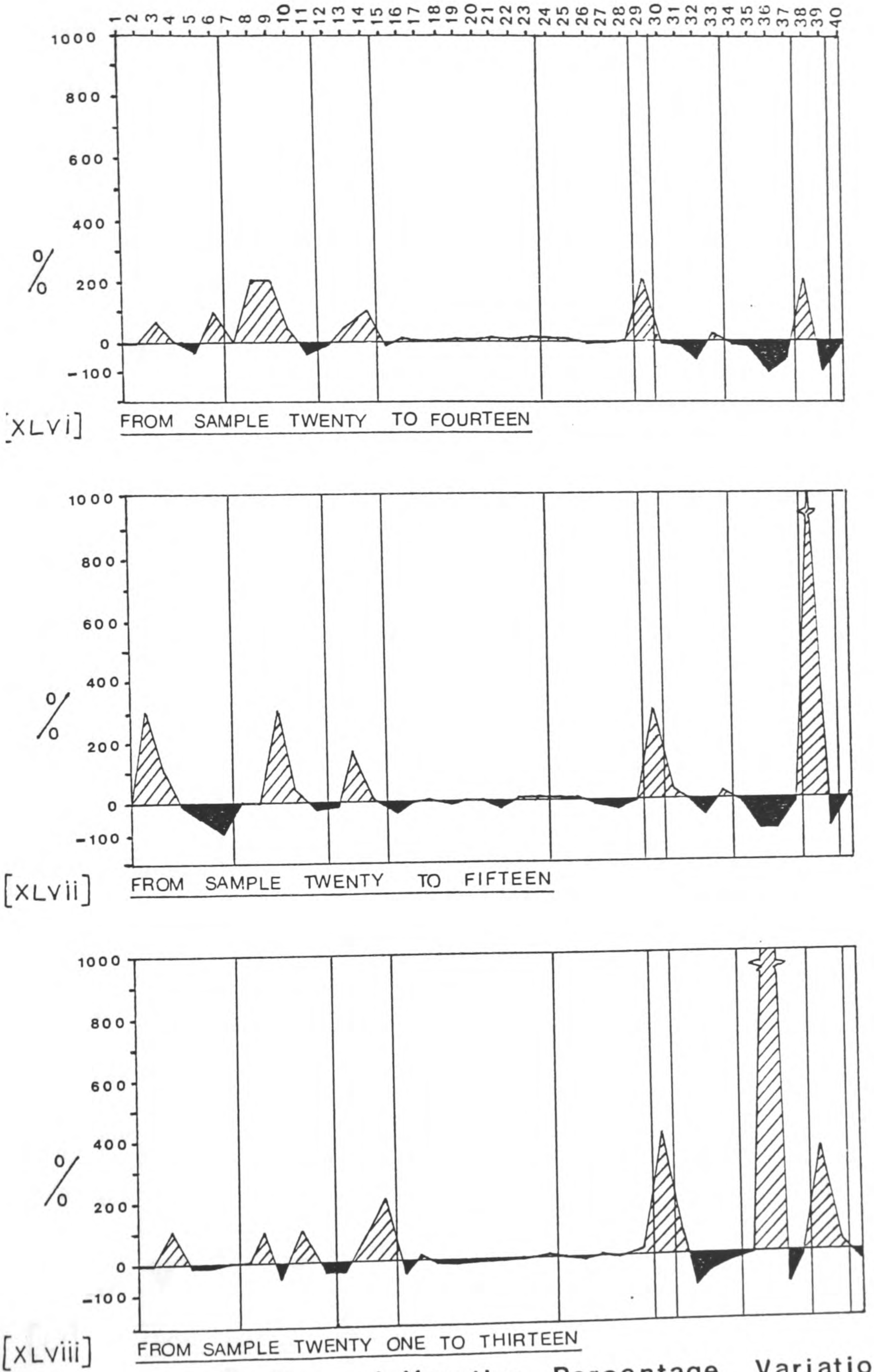
Fig. 6.14 [XL]-[XLii]



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

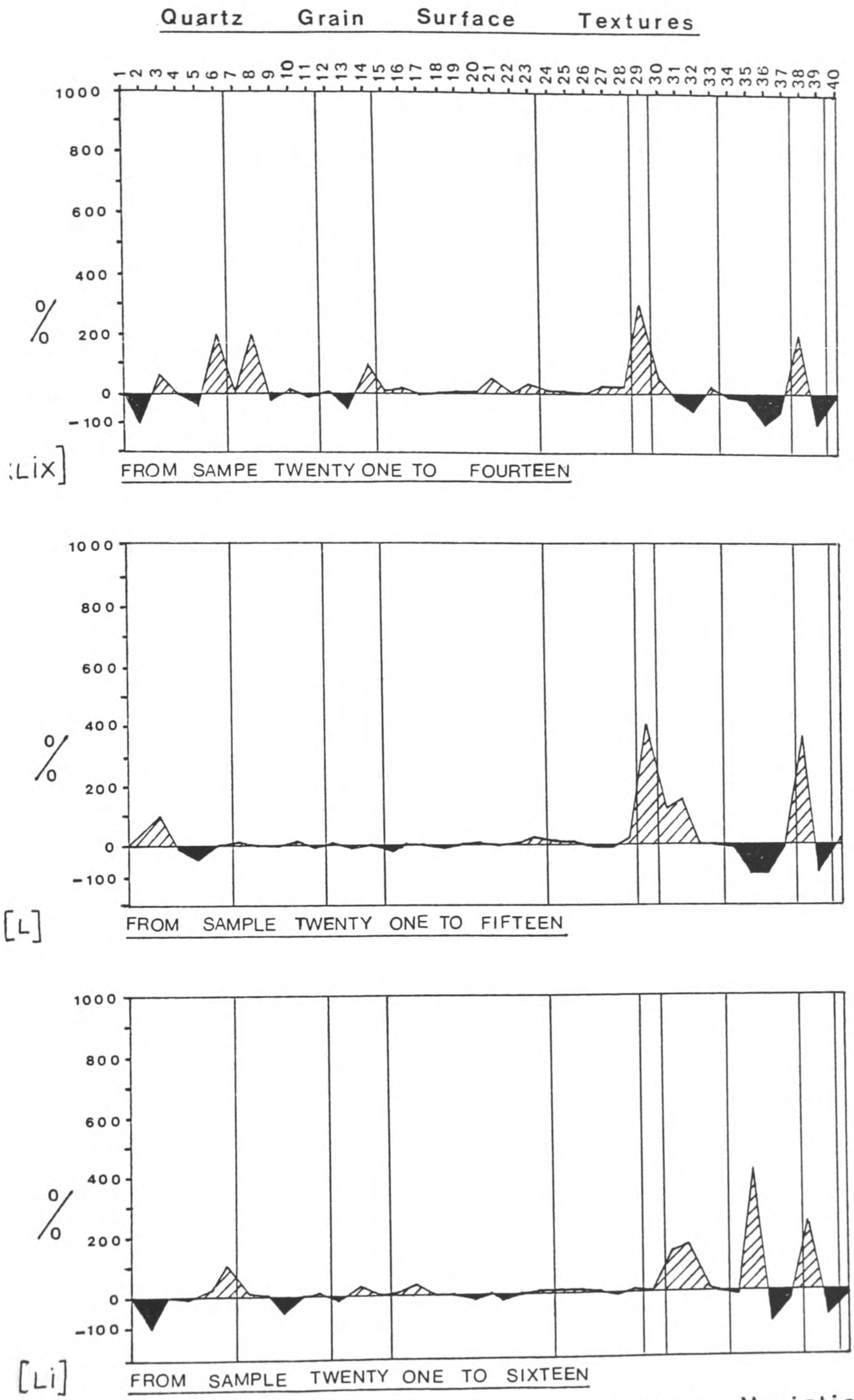
Fig. 6.14 [XLiii]-[XLV]

Quartz Grain Surface Textures



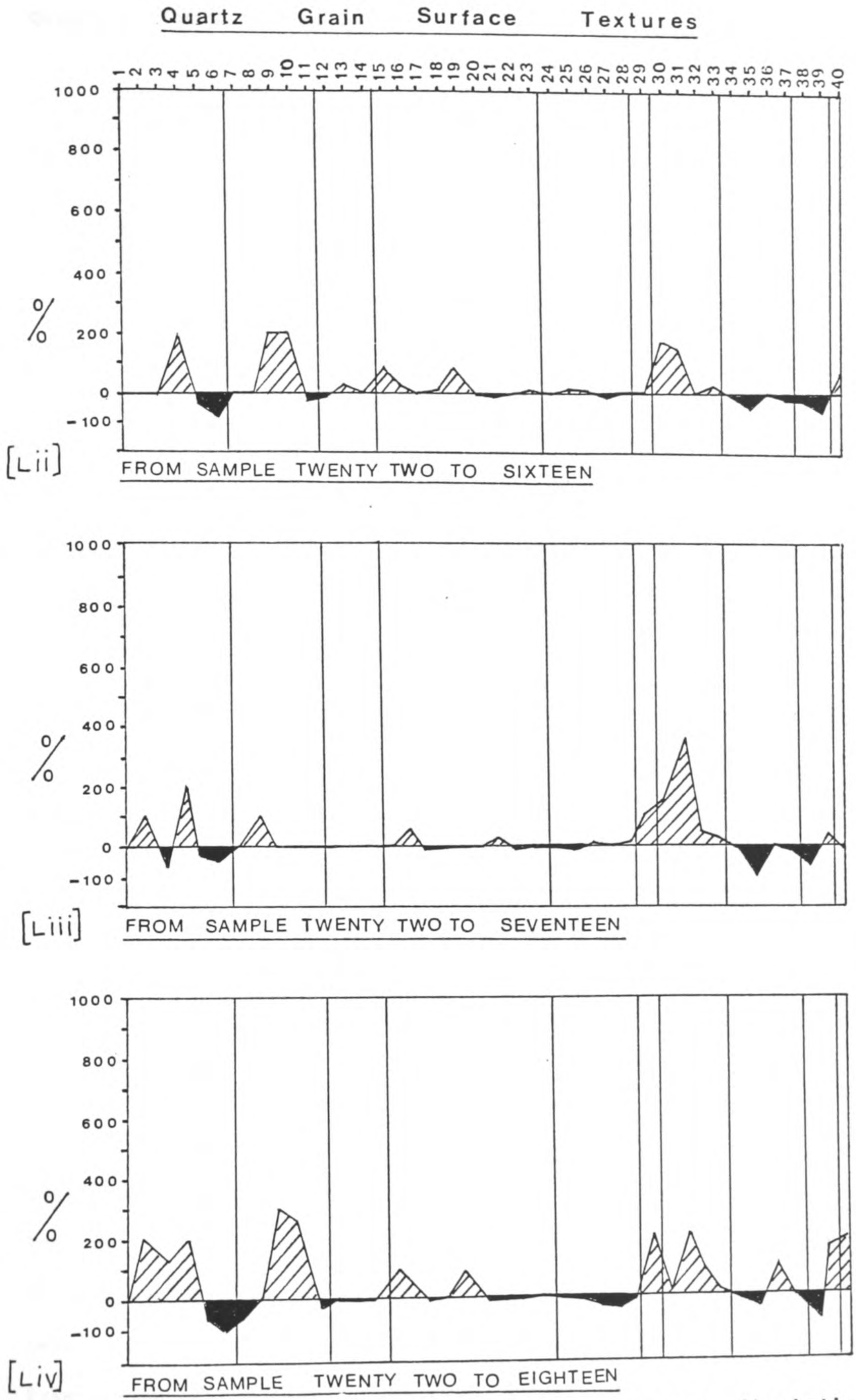
Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [XLvi]-[XLviii]



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [XLix]-[Li]



Positive and Negative Percentage Variations in Surface Textures of Adjacent Samples

Fig. 6.14 [Lii]-[Liv]

quadrant (Taney, 1961a, 1961b).

Sample 19, east of channel H was plotted against onshore beach samples 10 to 12 (Figs. 6.14 [xxxviii], [xxxix], [xLiii] and 2.3). The trends do not show a close relationship between onshore and offshore in these cases, with as much variation between samples being shown as elsewhere on the south shore. Sample 10 has more rounded grains and greater edge abrasion with more rounded grain edges. The effect of surf action on sample 10 shows up as moderate increases in meandering ridges (surface texture 21), which are associated with conchoidal fractures and small edge breakages, especially slightly curved and straight grooves (surface textures 27 and 28 in Fig. 6.14 [xxxviii]).A similar but even more pronounced pattern is displayed in samples 19 to 11, and samples 19 to 12 transitions.

Sample 20, proximal to channel H, was plotted against onshore beach samples 12 to 15 (Figs. 6.14 [XLiv] to [XLvii]). A similar pattern to the sample 19 to onshore beaches transition may be observed, but in sample 20's case there are no differences in large and small breakage percentages nor in edge abrasion. In all cases, onshore grains are more angular with a more varied population of angular-subrounded grain edges (Figs. 6.14 [XLiv] to [XLvii]) and lower relief.

A notable variation occurs in all cases in relation to chattermarks (surface texture 29) and adhering particles (surface texture 38), as shown in Figs. 6.14 [XLiv] to [XLvii]. In some cases there were six times more chattermarked grains onshore (sample 20 to 12) reinforcing the trend shown from sample 19 to 12. Examination of chattermark percentages in Table 6.1, shows that offshore samples do not contain chattermarked grains, an absence which is repeated in sample 1 at Montauk Point. A gradual increase in abundance of chattermarks westward from Montauk Point would seem to suggest a link between this texture (surface texture 29) and transport distance alongshore but there is a marked decline in eastern Fire Island only to be followed by a resurgence in abundancies in central Fire Island (Table 6.1).

Since offshore samples have only one or no grains which are chattermarked,onshore frequencies of 16% to 32% are bound to show large percentage increases using low offshore values as a base for the calculations. Nevertheless even small increases in a surface texture abundance may be significant in a low abundancy trend such as in the case of chattermarks.

Adhering particles show much greater percentage differences from sample 20 to onshore. This suggests that unless such particles are inherited as a grain surface texture from the glacial source updrift at Montauk Point, they may represent the products of edge abrasion and higher energy breakages actively taking place in the surf onshore. Fig. 6.13B shows adhering particles to be abundant or ubiquitous along the Headlands section, but to fluctuate a great deal in central Fire Island. Offshore samples 20 and 21 exhibit low abundancies of adhering particles and cannot be linked to onshore beaches using this texture although the increase in grain numbers with adhering particles may be a neutral factor if surf action may be the prime cause for their presence onshore.

The lowest percentage variations between any sample pairs occur between sample 21 (proximal to channel H) and onshore samples, especially for samples 14, 15 and 16 (Figs. 6.14 [XLix] to [Li]). In the cases of samples 15 and 16 immediately downdrift of sample 21 onshore grain surface textures 7 to 29 including edge abrasion, edge shape, surface relief, large and small breakages show virtually no differences. The plot is almost a straight line close to zero (Figs. 6.14 [L] and [Li]). There is less similarity between offshore sample 21 and samples 13 and 14 which are updrift onshore.

In both cases of samples 15 and 16 there are increases in chattermarks and coarse etching as well as adhering particles. A similarly low percentage variation is shown between sample 22, west of channel H, and onshore samples 16 and 17, more so in the case of the downdrift sample 17 (Fig. 6.14 [Liii]). However, increased 'between-sample' variations occur between offshore sample 22 and sample 18 immediately updrift of Fire Island Inlet (Fig. 6.14[Liv]).

It is not suggested that three or four plots which show small percentage variations between offshore and onshore samples demonstrate a link between the two. The same harmony in textural assemblage abundancies does not occur between the other buried lobe sample 20 and onshore. However, given the complexities and unpredictability of natural environments such as the Long Island south shore and offshore system, clearcut pictures are unlikely to be revealed given the close genetic relationships of the grains under study. The possibility of close similarities between single textures or small groups across samples is accepted, but in the case of a range of surface textures from edge abrasion to chattermarks (7 to 29), for two samples (15 and 16) this is enough to imply an [illegible] link from sample 21.

C H A P T E R 7

S T A T I S T I C A L R E S U L T S

STATISTICAL RESULTS

7.I INTRODUCTION

The probability of achieving successful discrimination between samples when seventeen of them are derived from the same stretch of shoreline between Montauk beach and the western end of Fire Island, may not be expected to be as high as when attempts are made to discriminate between samples derived from more discrete, different environments (Grant, pers. comm.). Even in the case of sample 1 from the known glacial source at Montauk Point, beach samples down-drift to the west (samples 2 to 18) are known to be derived from wave erosion of sample 1 material and as such will inherit many of sample 1 grain textures (Krinsley et al, 1964; Taney, 1961a).

Bearing these facts in mind, subtle differences and variations take on added significance when adjacent sample results are interpreted. Inspection of quantitative results and subsequent analysis should bear the following points in mind:

(i) Montauk till represented by sample 1 was expected to be discriminated reasonably well given its distinctive character (presented in the previous chapter on qualitative results) and glacial source.

(ii) Samples 2 to 18 from south shore beaches were expected to be misclassified for each other in the canonical discriminant analysis to a greater or lesser degree given their common origin and transportational history.

(iii) Samples 20 and 21, proximal to the glacial-fluvioglacial sediments in channel H offshore, were expected to be distinctive and possibly misclassified for onshore Fire Island samples should the lobe deposits form an additional offshore sediment source.

In one sense, the main aim of the present study would be achieved if statistical analysis did not discriminate between offshore samples and beach samples immediately onshore or slightly downdrift. Whether this goal is achieved or not is less important than the fact that the ability of discriminant analysis to differentiate between such generically linked samples is rigorously put to the test using results derived from an S.E.M. checklist study.

Because of the difficulties outlined above it was found necessary to run three sequential discriminant analyses.

(i) DISCRIMINANT ANALYSIS I - this includes canonical variate analysis, factor analysis and cluster analysis using all 40 grain surface features as variables. Results were found to be indeterminate and inconclusive as a result of which a separate statistical package, ARTHUR was used in order to reduce the dimensionality of the data by decreasing the number of grain surface features from 40 to a manageable and more significant group of variables.

(ii) DISCRIMINANT ANALYSIS 2 - this used only 10 grain surface features employing the SPSSX package.

(iii) DISCRIMINANT ANALYSIS 3 - this employed the 10 surface features and the SPSSX package and an independent computer generated variable to split the data into a test set and training set. Subsequent analysis proved useful in ranking the discriminating power of each of the 10 surface feature variables.

7.II DISCRIMINANT ANALYSIS 1.

II.A Canonical Variate Analysis 1.

In the first canonical variate analysis there were h - 1 = 21 possible canonical variates and eigen values. Grain surface feature 6 (well rounded grains) failed the tolerance test so results were based upon the remaining 39 surface textures.

Of the 21 eigenvalues the first 20 were significant at the 95% level, however only the first two canonical discriminant functions (hereafter referred to as canonical variates) had eigenvalues >1 and these accounted for only 53.01% of the variance (Table 7.1). The first 9 canonical variates had significance values of less than 0.000 (highly significant), but corresponding Chi Square (X^2) values were considered to be too large. X^2 is an indication of goodness of fit of observed (O) to expected (E) values and in this case O > E was unacceptably high.

The first 10 mean canonical variates are shown in Table 7.2. Mean canonical variate 1 (function 1), contrasts groups (samples) 8, 10, 11, 12, 14, 15, 16, 17, 20, 21 and 22 with the other samples. This is important since samples 8 to 18 represent Fire Island beaches and samples 20 and 21 represent channel H offshore deposits. It would be appealing to conclude that samples 1 to 7 from the Headlands section and Westhampton beach were distinct from the rest on this basis, but canonical variate 1 accounts for only 28.01% of

FUNCTION	EIGENVALUE	PERCENTAGE OF VARIANCE	CUMULATIVE PERCENTAGE
1	2.00238	28.01	28.01
2	1.78664	25.00	53.01
3	0.70357	9.84	62.85
4	0.55594	7.78	70.63
5	0.31463	4.40	75.03
6	0.27175	3.80	78.83
7	0.25502	3.57	82.40
8	0.23985	3.36	85.76
9	0.19309	2.70	88.46
10	0.17335	2.43	90.88

TABLE 7.1. The first ten eigenvalues with their percentage of Variabilities, Canonical Variate Analysis 1.

CANONICAL DISCRIMINANT FUNCTIONS EVALUATED AT GROUP MEANS (GROUP CENTROIDS)

GROUP	FUNC 1	FUNC 2	FUNC 3	FUNC 4	FUNC 5	FUNC 6	FUNC 7	FUNC 8	FUNC 9	FUNC 10
1	3.91528	-1.10384	-2.15172	-0.49488	0.10073	0.75319	0.20249	0.30400	-0.20118	-0.05674
2	0.55553	0.63800	0.43786	-0.88812	0.38641	0.12367	0.36577	-0.99381	0.52321	-0.16854
3	1.66011	0.80049	-0.27987	-0.21571	0.08432	-1.07707	-0.08677	-0.35383	-0.68814	0.67627
4	0.47392	0.88381	0.63349	-0.41159	0.90632	-0.52054	0.95953	-0.06403	-0.36082	-0.03325
5	1.31872	2.07799	1.69073	0.27537	-0.01761	0.47566	0.19392	0.58562	0.23691	0.47171
6	1.42903	0.29168	-0.14516	1.03961	-1.26541	-0.04448	-0.42753	-0.87650	0.47662	0.61752
7	0.50831	1.63373	0.22980	1.74742	0.23738	0.52200	-0.13313	0.57158	-0.51558	-0.28898
8	-0.71228	1.02342	-0.10688	-0.25041	-0.85702	0.34126	0.74703	-0.59064	-0.31122	-0.63515
9	0.17209	0.54452	0.21862	-0.03338	0.50831	-0.05050	-0.68855	0.06997	0.16236	-0.39879
10	-0.95356	0.13228	-0.99586	0.69351	0.51202	-0.33182	-0.31887	-0.10483	0.16529	-0.28776
11	-0.16084	0.69848	-0.40456	-0.97951	0.55901	0.39351	-0.42069	-0.28760	0.42118	-0.20095
12	-1.35528	0.17607	-0.35677	0.97021	0.27015	-0.25627	0.25880	-0.10567	-0.01304	-0.12116
13	0.48075	1.23329	1.12173	-0.93463	-0.59035	0.07693	-0.65657	0.23874	0.04414	-0.38320
14	-1.53472	-0.49261	-0.21893	0.37192	-0.05917	0.42063	0.39603	-0.34354	-0.42760	-0.24705
15	-0.71846	0.58719	-1.04673	0.86349	-0.05145	-0.44366	0.16530	0.42531	0.59803	0.03289
16	-1.34679	-0.06371	-0.39781	-0.31959	0.09894	-0.76237	0.10217	0.14231	0.60679	0.24965
17	-1.75435	-0.83942	-0.11120	-0.56209	-0.30904	0.69827	0.89371	0.66187	0.33059	0.80456
18	0.17986	-2.76792	0.69966	0.26703	-0.74674	-0.14121	0.07899	0.12004	0.23821	-0.66616
19	1.67236	-3.46551	1.34333	0.34349	0.35315	-0.53182	0.16395	0.18674	-0.00066	-0.06525
20	-1.91485	-1.29794	0.29873	-0.08313	0.04092	0.43151	-0.50554	-0.54630	-0.95779	0.54913
21	-0.96136	-1.15834	0.10465	-0.20660	0.69470	0.60765	-0.89199	0.07019	0.17930	0.30343
22	-0.95345	0.46835	-0.56312	-1.19241	-0.85555	-0.68456	-0.39805	0.89038	-0.50661	-0.15216

TABLE 7.2. Mean canonical variates (canonical discriminant functions) for the first 10 variates. Canonical Variate Analysis 1.

the total variability which is a relatively small value.

Canonical variate 2 (Table 7.2) contrasts samples 1, 14, 16, 17, 18, 19, 20 and 21 with other samples i.e.- the Headlands section (samples 2 to 6, Westhampton beach, and eastern Fire Island). However, C.V.2 accounts for only 25.00% of the total variability.

A plot of mean canonical variate 1 against mean canonical variate 2 is shown in Fig. 7.1. The plot shows sample 1, the known glacial source at Montauk Point as being clearly discriminated from the other samples, as is sample 18 at the western tip of Fire Island and sample 19 east of channel H offshore (Fig. 2.3). If the Headlands samples are circled in a purely arbitrary fashion and the same is done for Fire Island samples, a certain degree of discrimination is achieved between these two groups (Fig. 7.1). There is a degree of overlap at sample sites 11, 4, 2 and 13.

Channel H deposits (samples 20 and 21) are discriminated slightly from each other but are related to, or are on the margins of the Fire Island group (Fig. 7.1). Sample 14 is immediately downdrift onshore from sample 21 (Fig. 2.3).

Canonical discriminant function coefficients are presented in Table 7.3. Examination of these coefficients allows the identification of the variables (grain surface features) largely responsible for the discrimination. All 10 canonical discriminant functions (canonical variates) have been presented because they account for 90.88% of the variance.

The first canonical variate (C.V.1) shows grain morphology, in

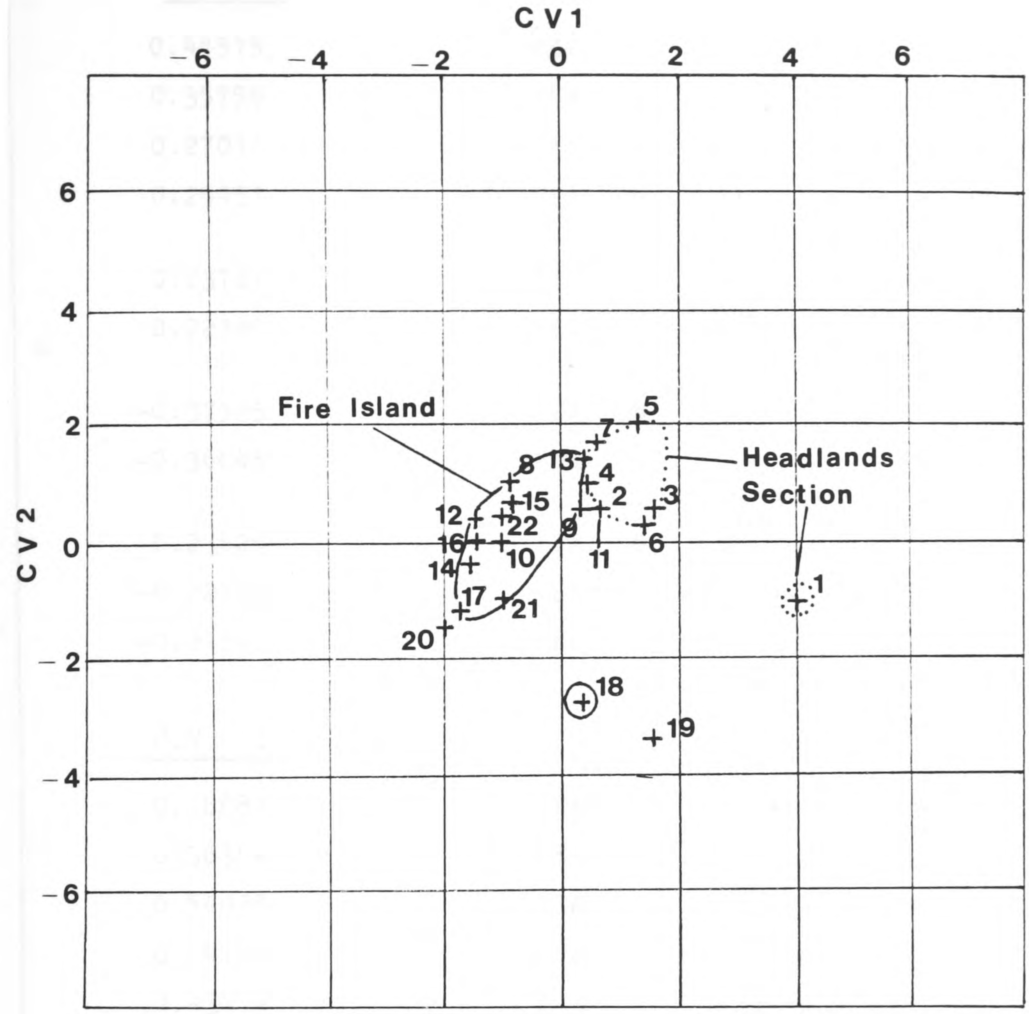


Fig. 7.1. Canonical Variate Analysis 1: plot of mean CV1 against mean CV2. Numbers refer to samples 1-22.

CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS	VARIABLES	
C.V. 1		
0.44515	FEA. 9	Subangular grain edges
0.35759	FEA. 8	Angular grain edges
0.27011	FEA. 10	Subrounded grain edges
0.25151	FEA. 35	Very fine precipitated particles
0.23727	FEA. 39	Dulled surface
0.22189	FEA. 4	Subrounded grains
-0.37535	FEA. 26	M.V.'s
-0.36045	FEA. 15	Late stage complete grain breakage
-0.23825	FEA. 18	Large Blocks
-0.22733	FEA. 7	Edge Abrasion
-0.21892	FEA. 27	Small straight grooves
C.V. 2		
0.58684	FEA. 10	Subrounded grain edges
0.56364	FEA. 38	Adhering particles
0.54930	FEA. 9	Subangular grain edges
0.54706	FEA. 7	Edge abrasion
0.43774	FEA. 11	Rounded Edges
0.42308	FEA. 8	Angular edges
0.34695	FEA. 12	High relief
0.27767	FEA. 35	Very fine precipitated particles
0.25524	FEA. 13	Medium relief
-0.26490	FEA. 32	Coarse etching
-0.22884	FEA. 15	Late stage complete grain breakage

TABLE 7.3. Canonical discriminant function coefficients and variables chiefly responsible for discrimination, Canonical Variate Analysis 1.

CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS	VARIABLES	
C.V. 3		
1.01223	FEA. 10	Subrounded grain edges
0.81903	FEA. 9	Subangular grain edges
0.70246	FEA. 11	Rounded grain edges
0.62094	FEA. 13	Medium relief
0.48731	FEA. 35	Very fine precipitated particles
0.44033	FEA. 12	High relief
0.41702	FEA. 2	Angular grains
0.36149	FEA. 8	Angular grain edges
0.33666	FEA. 26	M.V.'s.
0.30975	FEA. 4	Subrounded grains
-033677	FEA. 38	Adhering particles
C.V. 4		
0.76258	FEA. 3	Subangular grains
0.75458	FEA. 2	Angular grains
0.72595	FEA. 10	Subrounded edges
0.65775	FEA. 4	Subrounded grains
0.63955	FEA. 9	Subangular edges
0.44225	FEA. 12	High relief
0.40477	FEA. 11	Rounded grain edges
0.40465	FEA. 1	Very angular grains
0.31251	FEA. 40	Oriented triangular etch pits
-0.34336	FEA. 39	Dulled surface

TABLE 7.3. Continued.

CANONICAL DISCRIMINANT FUNCTION COEFFICIENT	VARIABLES	
C.V. 5		
1.52607	FEA. 12	High relief
1.22974	FEA. 13	Medium relief
0.47603	FEA. 26	M.V.'s
0.36007	FEA. 4	Subrounded grains
0.32110	FEA. 34	Amorphous precipitation
0.28318	FEA. 14	Low relief
0.24762	FEA. 7	Edge abrasion
-0.57018	FEA. 11	Rounded grain edges
-0.49074	FEA. 27	Small straight grooves
-0.31315	FEA. 35	Very fine precipitated particles
-0.24877	FEA. 16	Cracks
C.V. 6		
1.60114	FEA. 11	Rounded grain edges
1.58350	FEA. 10	Subrounded grain edges
1.40025	FEA. 9	Subangular grain edges
0.97770	FEA. 8	Angular edges
0.35764	FEA. 39	Dulled surface
0.31793	FEA. 1	Very angular grains
-1.82726	FEA. 13	Medium relief
-1.69938	FEA. 12	High relief
-0.38137	FEA. 14	Low relief
-0.34888	FEA. 38	Adhering particles
-0.32574	FEA. 17	Large conchoidal fractures
-0.32225	FEA. 18	Large blocks

TABLE 7.3. Continued.

CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS	VARIABLES	
C.V. 7		
1.20726	FEA. 12	High Relief
1.07922	FEA. 13	Medium relief
0.85167	FEA. 8	Angular edges
0.76098	FEA. 9	Subangular grain edges
0.75326	FEA. 10	Subrounded grain edges
0.66616	FEA. 11	Rounded grain edges
0.45639	FEA. 16	Cracks
0.27752	FEA. 30	Large solution pits
-0.35295	FEA. 39	Dulled surface
-0.33664	FEA. 4	Subrounded grains
0.30685	FEA. 37	Oriented solution-precipitation surface
C.V. 8		
1.69548	FEA. 10	Subrounded edges
1.69079	FEA. 11	Rounded grain edges
1.47909	FEA. 13	Medium relief
1.45221	FEA. 9	Subangular grain edges
1.36899	FEA. 12	High relief
1.02474	FEA. 8	Angular grain edges
0.39068	FEA. 14	Low relief
-0.41199	FEA. 3	Subangular grains
-0.39206	FEA. 4	Subrounded grains
-0.29726	FEA. 35	Very fine precipitated particles

TABLE 7.3. Continued.

CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS	VARIABLES	
C.V. 9		
1.59285	FEA. 11	Rounded grain edges
1.55672	FEA. 10	Subrounded grain edges
1.31862	FEA. 9	Sub angular grain edges
0.96547	FEA. 4	Subrounded grains
0.81070	FEA. 13	Medium relief
0.69274	FEA. 3	Subangular grains
0.54142	FEA. 2	Angular grains
0.53973	FEA. 5	Rounded grains
0.51714	FEA. 33	Fine etching
0.48998	FEA. 12	High relief
0.43870	FEA. 8	Angular grain edges
-0.31475	FEA. 37	Oriented solution-precipitation surface
C.V. 10		
1.54874	FEA. 11	Rounded grain edges
1.50834	FEA. 9	Subangular grain edges
1.50007	FEA. 10	Subrounded grain edges
0.88933	FEA. 8	Angular edges
0.59791	FEA. 7	Edge abrasion
0.36112	FEA. 30	Large solution pits
-0.69777	FEA. 12	High relief
-0.57773	FEA. 13	Medium relief
-0.37954	FEA. 14	Low relief
-0.26243	FEA. 26	M.V.'s

TABLE 7.3. Continued.

particular edge shape categories, to be most important along with M.V.'s and late stage complete grain breakage (Table 7.3). In fact edge shape and edge abrading features constitute six of the ten variables. This may suggest a measurable edge abrasion factor in modifying edge shapes westward from Montauk Point, although edge shape is strongly related to overall grain shape, since C.V. 1 contrasted the Headlands samples with Fire Island and offshore samples (Table 7.2).

The second canonical variate (C.V. 2), shows the first six important discriminating variables also to contain edge shape (in fact all four edge shape categories) as well as edge abrasion and adhering particles.

Throughout each of the canonical variates from C.V. 1 to C.V. 10 edge shape, grain shape, grain relief and mechanical breakages are consistently ranked as those variables most important for discrimination.

The SPSSX package lists the predicted group memberships for each observation which are produced as misclassification tables (Fig. 7.2). The results have been presented for canonical variate analysis 1 as % categories in Fig. 7.2. Both samples 1 (Montauk till) and 19 (offshore east of channel H) have been classified reasonably accurately with 84% of all grains being correctly assigned. Of the 4 grains which were misclassified from sample 1, one each was assigned to samples 3, 6, 9 and 10 which are located in the Headlands section or eastern Fire Island (Fig. 2.4). None of sample 19's misclassified grains were assigned to the other offshore

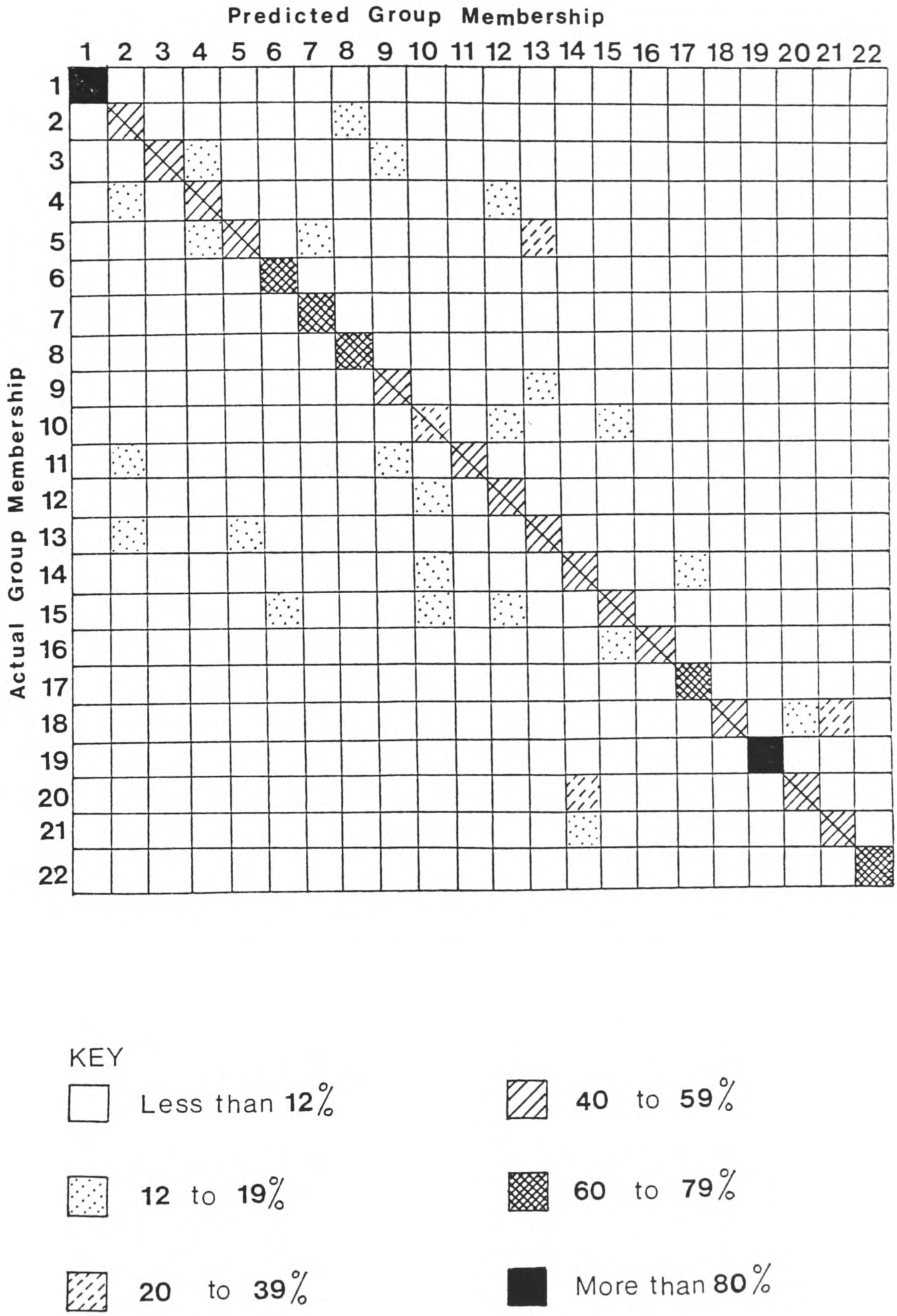


Fig. 7.2. Predicted group (sample) membership for each of the 22 samples. Canonical Variate Analysis 1.

samples 20 to 22.

As may have been expected large percentages of beach sample grains were misclassified but with no striking pattern (Fig. 7.2). Samples 20 and 21 (channel H deposits) obtained 52% and 44% correctly classified grains with 8% being misclassified for each other.

In the present study, misclassifications of offshore lobe sample grains are of as much interest as correct classifications. The largest single misclassified group was that of 20% which occurred three times.

(i) sample 5 for sample 13

(ii) sample 18 for sample 21

(iii) sample 20 for sample 14

In other words 5 of sample 18's grains from the beach in western Fire Island were statistically mistaken for sample 21 offshore proximal to channel H, whereas 5 grains from sample 20 from channel H deposits were misclassified in sample 14. If we examine Fig. 2.3 it can be seen that sample 14 is onshore and just downdrift of sample 21. Sample 21 had 12% of its grains misclassified in sample 14. However, no such onshore link showed up with sample 13. Conversely, the onshore beach sample 18 (west Fire Island) had only 48% of its grains correctly classified, and 40% of those misclassified grains were assigned to offshore samples 19, 20 and 21.

Despite the relatively low percentage of variance accounted for by the first two canonical variates, tenuous statistical links have been uncovered between offshore samples 20 and 21 (glacial-fluvioglacial lobe) and onshore beach samples in central Fire Island.

II.B Factor Analysis 1.

Canonical variate analysis 1 has pointed to certain textures as being dominant discriminators. These were determined from examinations of canonical discriminant function coefficients (Table 7.3). Subsequent factor analysis was carried out in order to examine the validity of C.V. analysis 1 results.

The dominant discriminating features in C.V. analysis 1 were: Edge shape, M.V.'s, late stage complete grain breakage, edge abrasion and adhering particles for canonical variates C.V. 1 and C.V. 2. Subsequent canonical variates depicted grain shape, grain relief and other mechanical breakage categories.

In factor analysis 1 all 40 grain surface features were entered in the analysis for 22 x 25 (550) observations. Initial principal components analysis (P.C.A.) extracted 15 factors. Eigenvalues and the percentage of variance are shown in Table 7.4. Eigenvalues >1 pick out the important factors (Croxton et al, 1967). However results were disappointing with only 21.4% of the variance being accounted for by the first three factors: factor 1 (8.9%), factor 2 (6.6%), factor 3 (6.0%). The other factors had eigenvalues <1.

Projections of sample vectors determine their positions in relation to factor axes after Varimax rotation with Kaiser normalization. Such projections constitute the factor loadings and the number sizes indicate the extent to which each factor controls the

FACTOR	EIGENVALUE	% OF VARIANCE	CUMULATIVE %
1	3.54425	8.9	8.9
2	2.63023	6.6	15.4
3	2.38007	6.0	21.4
4	1.76874	4.4	25.8
5	1.61546	4.0	29.8
6	1.53454	3.8	33.7
7	1.44377	3.6	37.3
8	1.34795	3.4	40.7
9	1.33083	3.3	44.0
10	1.26637	3.2	47.2
11	1.22450	3.1	50.2
12	1.15204	2.9	53.1
13	1.13275	2.8	55.9
14	1.07609	2.7	58.6
15	1.03211	2.6	61.2

TABLE 7.4. Eigenvalues and percentage of variance for the first 15 factors extracted by principal components analysis; Factor Analysis 1.

position of each sample vector. The actual loading on an individual variable (surface feature) for a given factor is only significant if it is:

$$>r\sqrt{\frac{r}{n-c+1}}$$

This is called the Burt Banks formula and has already been described under methodology. Thus the loading on an individual variable for factor 1 is significant if:

$$>0.0837\sqrt{\frac{15}{15-1+1}}$$

$$= 0.0837$$

For factor 2: $$>0.0837\sqrt{\frac{15}{15-2+1}}$$

$$= 0.0866$$

Their r values are given at the 0.05 level. A correlation coefficient at the 0.01 level would produce:

For factor 1: $$>0.1099\sqrt{\frac{15}{15-1+1}}$$

$$= 0.1099$$

Factor 2: $$>0.1099\sqrt{\frac{15}{15-2+1}}$$

$$= 0.1176$$

Factor 3: $$>0.1099\sqrt{\frac{15}{15-3+1}}$$

$$= 0.1268$$

Table 7.5 shows the most important feature variables, their correlation coefficients and communalities. The communality value is the sum of the squared loadings for a specific sample vector and reflects the degree to which that sample vector has been explained by the set of factor axes. A communality of 1.0 indicates a perfect explanation. The factors themselves are only mathematically derived reference coordinates. The task remains of assigning them some geomorphological significance which fits the environmental processes at work on Long Island's south shore.

Factor 1 may be labelled Edge Abrasion as features 7, 26, 27 and 28 are the most important variables accounting for the variance in factor 1 even though this amounts to only 8.9%. The communalities are reasonably good (Table 7.5) although below 1.0. Such an edge abrasion factor would account for the separation of relatively unabraded grains from sample 1 at Montauk Point from the rest as well as those from offshore. In addition, small mechanical breakages in the surf have been described as a feature central to the modification of glacial textures west of Montauk Point.

Factor 2 may be termed Grain Relief, given the high correlation coefficients of 0.95910 and -0.95762 for features 12 and 13 (high relief and medium relief), and their high communalities of 0.95087 and 0.93397 compared with feature 16 (cracks). Again, factor 2 is responsible for only 6.6% of the variance so not much weight may be placed on the importance of grain relief as an important variable. However, given the high relief recorded for sample 1, and indeed for many other samples, edge abrasion and its relief reducing function may be important factors for sample discrimination through the

GRAIN SURFACE FEATURE		CORRELATION COEFFICIENT	COMMUNALITY
FACTOR 1			
7	Edge Abrasion	0.75583	0.65595
26	M.V.'s	0.75673	0.61092
28	Small Arcuate Grooves	0.73475	0.60779
27	Small Straight Grooves	0.66106	0.55162
18	Large Blocks	0.42041	0.37190
FACTOR 2			
12	High Relief	0.95910	0.95087
13	Medium Relief	-0.95762	0.93397
16	Cracks	0.34356	0.43986
FACTOR 3			
15	L.S. Complete Grain Breakage	0.72173	0.58776
19	L.S. Flat Fractures	0.58610	0.51382
21	Meandering Ridges	0.45764	0.47106
9	Subangular Edges	0.45619	0.76835

TABLE 7.5. Surface feature variables dominantly responsible for separation on Factors 1 to 3; Factor Analysis 1.

contributions of progressive edge rounding alongshore.

Factor 3 consists largely of High Energy Breakages (Table 7.5) but apart from feature 15, correlation coefficients, while significant at the 0.01 level are lower with lower communalities.

In other words, the three main factors accounting for 21% of variance may be tentatively ascribed to edge abrasion, grain relief and high energy breakages. These reflect important grain surface modifying processes and perhaps the influence of inherited textures derived from glacial till at Montauk Point.

II.C Cluster Analysis 1.

The first cluster analysis used all 40 grain surface features in an attempt to reveal statistical groupings of grains on the basis of observations made upon them during S.E.M. analysis. An important point needs to be made at this juncture concerning the aims of the present study and the nature and order in which analyses have been made. Bull (1978a) used initial cluster analysis in order to classify cave sediment samples of unknown source in order that their transportational history and possible emplacement could be determined.

The results separated samples into divisions which were subsequently plotted on maps according to subjective inspection of the similarity coefficient link breakages (Bull, 1978a). What clustering did not achieve was identification of the degree of similarity between groupings. In order to remedy this, linear discriminant analysis was employed which required a priori knowledge of groupings designated by cluster analysis. Ensuing multiple

minant analysis provided a more precise extention of cluster groupings, identification of discriminant scores plus surface feature variable significance.

The order of statistical analyses in the present study were determined by the main aims. The origins of sample 1 (glacial till), samples 2 to 18 (glacial-beach) and samples 20 and 21 (offshore lobe) are known. The prime aim was to determine whether samples may be discriminated with a closer inspection of possible misclassifications of offshore grains in onshore Fire Island beach samples.

Factor analysis was necessary in order to uncover those surface feature variables responsible for discrimination in order that they may be related to south shore processes and applied to different sediments from similar environments in different regions.

To return to cluster analysis, a successful clustering of grains into correct samples would have in one sense represented a failure as far as the primary aim of the present study was concerned. As regards sample 1 and the Headlands samples, and the offshore and onshore Fire Island samples, successful results would involve the clustering of these two groups together.

It has been necessary for such a long digression at this stage in the presentation of results because cluster analysis for this study's samples must be interpreted bearing these points in mind.

Owing to the fact that all 550 grains were grouped along the dendrogram base, occupying nine pages of printout, only a portion has been presented for inspection (Fig. 7.3). Interpretations of such dendrograms have already been described under methodology and in the

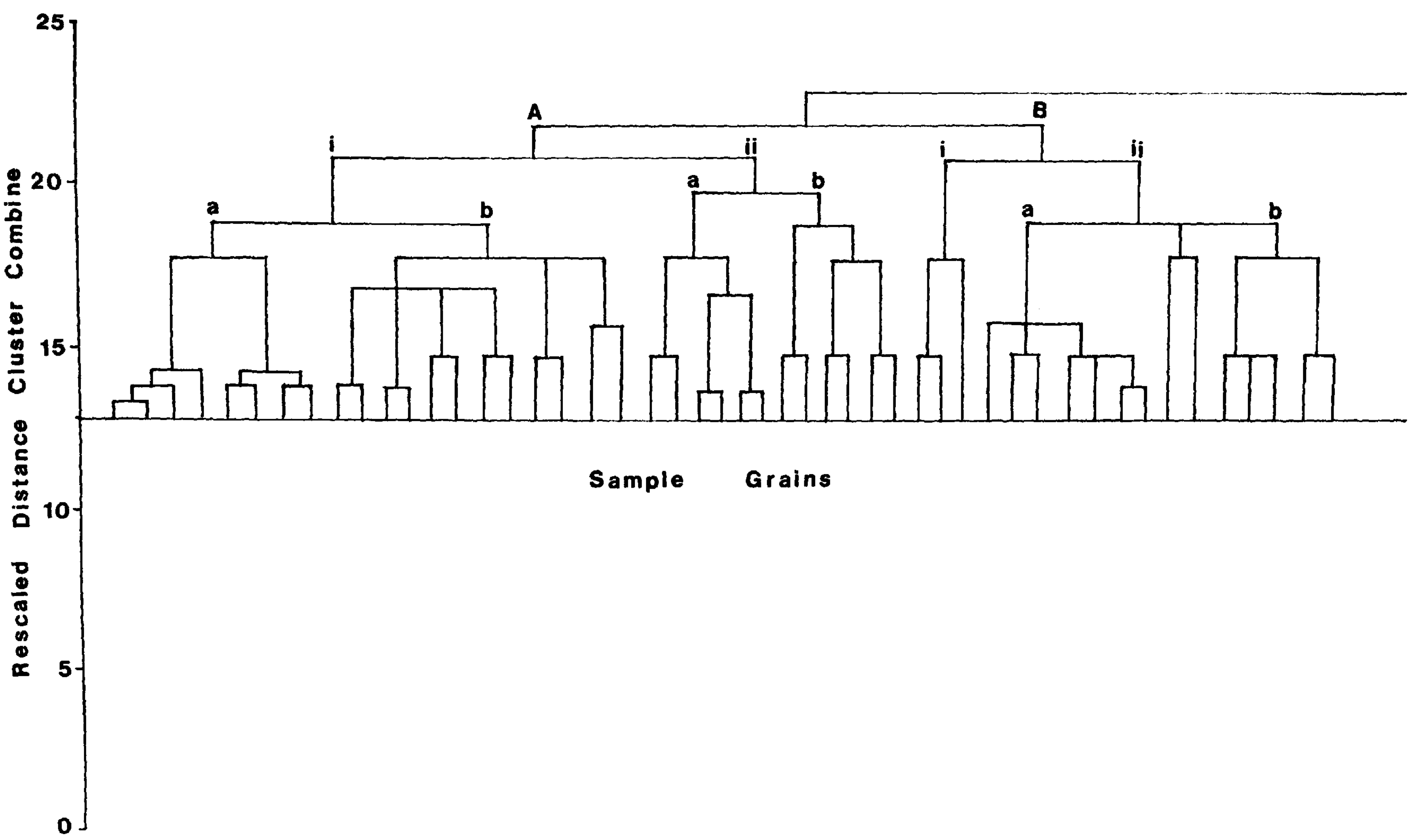


Fig. 7.3. Dendrogram based on cluster analysis 1 using 40 grain surface features.

literature (Bull, 1975; 1978a). The SPSSX package was used for hierarchical clustering with the complete linkage method and Euclidean distance measure.

Initial interpretations of the dendrogram involved colour coding all 22 samples before colour coding vertical linkages. Only those grains from the same sample which were adjacent were allowed to link up at the first similarity coefficient linkage break higher up. Adjacent grains from different samples were left as vertical lines.

Fig. 7.3 represents the left hand portion of the original dendrogram accounting for 186 of the 550 grains. It has been drawn from approximately half way up the similarity scale (here termed the rescaled distance cluster combine) because very few natural groupings extended below this level (12.5) and because of the logistics of presentation below this point when 186 grains with few linkages had to be drawn.

Cluster analysis has clearly failed to group grains into their correct sample locations at lower levels where similarity values are high. However, at higher levels there were more discernible groupings if the rigidity of sample location is relaxed. The method may not be suited for discerning grain groupings using grains from what amounts to the same 'beach' environment for 17 out of the 22 samples.

The completed dendrogram showed three major groupings linked at the highest level. The smallest grouping contained only 27 grains of which 14 were from Headlands samples and 11 from Fire Island, few grains from the same samples being adjacent.

This major grouping was mixed with no overall pattern. However, if for the sake of discussion samples from the Headlands section may be assigned to a single 'Headlands section' source and samples 1 to 7 were considered to be adjacent the second grouping of 46 grains would have formed a significant grouping at much lower levels extending to the top.

This group was labelled 'Headlands and Offshore' as over 20 grains were from the Headlands section and the remainder from samples 19 and 21. Such a manouvre is not permissible or desirable and no significance may be attached to the groupings, yet it serves to illustrate the problems that may encountered when applying a clustering technique to grain samples so closely related generically.

If we apply the same rule of substitution for Fire Island samples, group Aia in Fig. 7.3 represented Fire Island and offshore with 37 of the 57 grains in this group being Fire Island beach samples and 15 being derived from offshore samples. Group Aib consisted of a mixture and would have produced no natural groupings even if substitution were allowed. Similarly Aiia was a mixture of samples. Despite the disappointing but possibly expected results of cluster analysis, they warrant presentation because .... "meaningful analysis of surface textures can only be achieved when the total character of the sample is assessed by relating all surface features to each other" (Bull, 1978a; p.212). Later analyses in the present study used a reduced checklist feature number and may not be strictly comparable with the first analysis.

The SPSSX package also computed F values and their probabilities for analysis of variance. F values test the null hypothesis that cluster means for each variable (surface texture) are equal and are a measure of the statistical significance of the amount of separation as a result of, or what may be attributable to, the inclusion of a specific variable. The F values for surface feature variables were as follows: feature 7 (edge abrasion), 19.5982; feature 10 (subrounded edges), 13.0801; feature 11 (rounded edges), 23.2594; feature 12 (high relief), 16.2074, feature 13 (medium relief), 16.7479; features 26, 27 and 28 (M.V.'s, small straight grooves and small arcuate grooves respectively), 21.5584, 14.0250, 17.9104. All F values were significant with probabilities of less than 0.000.

II.D Reduction of Features

The 40 feature analyses produced results which were considered to be generally less than successful because of the large number of canonical variates and factors needed to account for up to 90% of data variance. In a study of cave sediments Bull (1978a), performed cluster analysis in order to discern sample groupings based on a 22 surface feature checklist which he subsequently reduced to 11 to include only those textures representing mechanical processes. Similar results were obtained for the 11 surface feature analysis as for the 22 surface feature analysis.

In the present study, it was considered appropriate to follow a similar procedure, but in addition to pointers already obtained from canonical variate analysis 1, factor analysis 1 and analysis of variance associated with cluster analysis, a cluster analysis of surface feature variables was carried out.

A more powerful, if more complex, statistical package called ARTHUR was used employing a hierarchical complete link method of clustering using the Mahalanobis distance of order 2 (i.e. - Euclidean distance). Initially, the package set up a training set by means of a computer generated independent variable which may be fitted to an associated test set. Surface feature variables were grouped along the horizontal axis and progressive dendrogram groupings were formed on the basis of feature cluster similarity values (Fig. 7.4).

Those surface textures which linked near the base of the dendrogram were most similar in their ability to account for data variance and their groupings were most significant. Higher groupings formed clusters which were less similar and linkages which were less significant (Fig. 7.4).

Four clusters may be seen with similarity values of between 0.75 and 0.8, shown as i to iv in Fig. 7.4. Each cluster may be further subdivided into two subclusters shown as 'a' and 'b' in each case, with similarity values of between 0.85 and 0.90. Bearing in mind previous surface feature variable significance in discriminating samples a new surface feature checklist was determined using each subcluster.

Bull (1978a), pointed out that for multiple discriminant analysis, surface feature variables should be independent of each other. If they were not the Mahalanobis distance and variable loading factors would be affected. Choice of feature variables from the dendrogram in Fig. 7.4 used separate clusters as much as possible since they combine only at low levels of similarity higher up.

The features chosen from cluster i were 16 (cracks) and 15 (late stage complete grain breakage), and feature 38 (adhering particles). It may be suggested that in terms of energy regime and casual mechanisms, cracks and grain breakage are closely related and may be expected to be dependent. However, as far as their statistical significance in accounting for data variance is concerned they occupy separate smaller clusters which do not combine until a similarity value of 0.85 is reached.

Chemical features in general were avoided if possible because of their notorious independence of discrete environmental modifications and poor discriminating abilities (Bull, 1981a; Bull 1978a). Large solution pits, large smooth flat fractures, meandering ridges and small straight grooves were discarded from subcluster i (features 30, 19, 21 and 27 respectively).

Feature 35 (very fine precipitated particles) and rounded edges (feature 11) were selected from subclusters iia and iib. Edge shape had already been shown to be an important discriminating variable in canonical variate analysis 1 and of the three variables in iia, dulled surfaces (feature 39) and subrounded edges were discarded. Preliminary training scans had already shown feature 35 (v.f.p.p.) to be peculiar to this study's samples representing a form of finely divided adhering particles or amorphous silica precipitation referred to originally as 'snow'.

Subcluster iiia accounted for 9 surface features most of which were linked at high similarity levels so care was taken to choose only one from the first seven with similarities higher than 0.95 on the scale. Large blocks (feature 18) and Edge abrasion (feature 7)

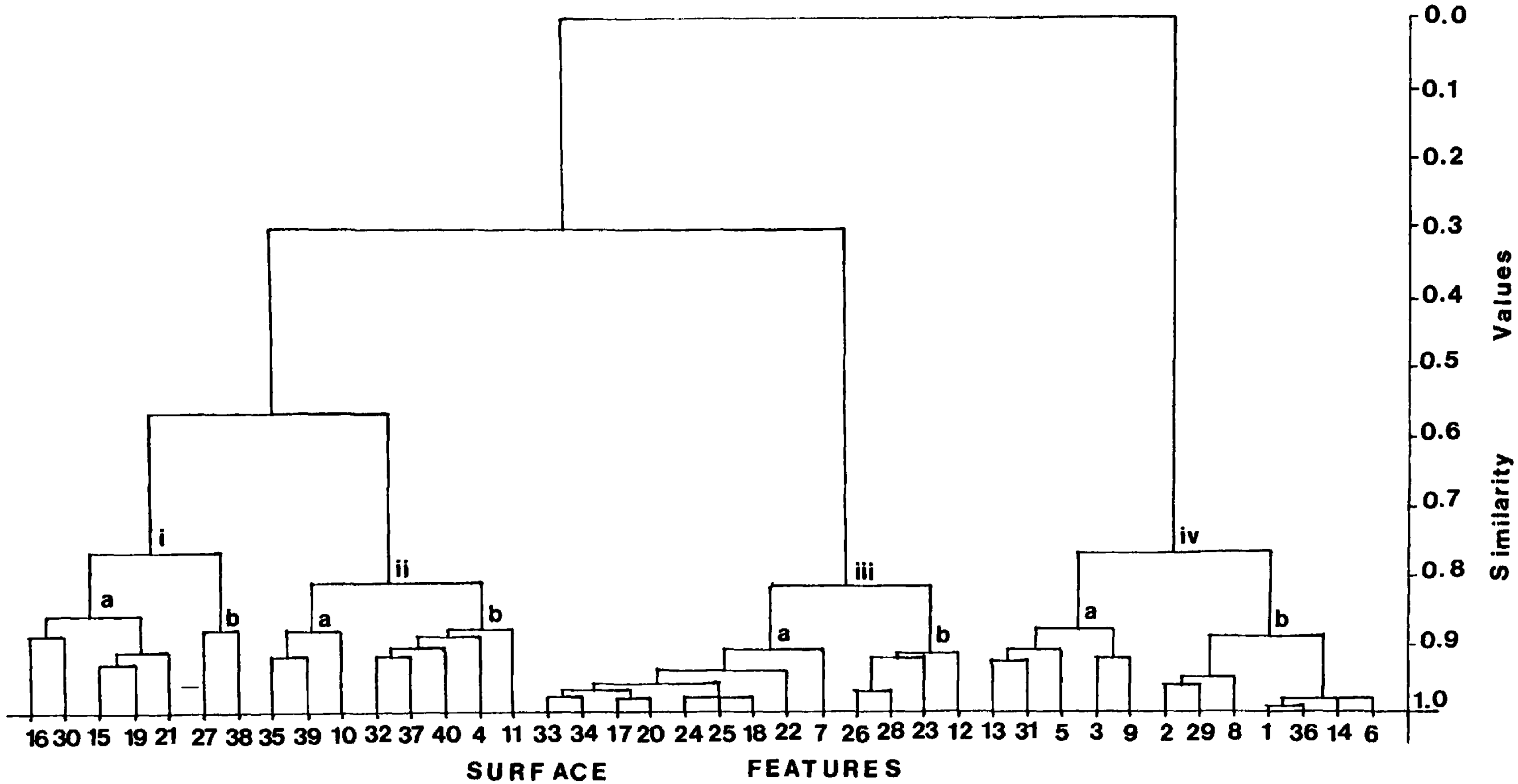


Fig. 7.4. Clustering of surface features.

were chosen because they had already been chosen by a previous canonical variate analysis and factor analysis, especially feature 7. 'Large blocks' was preferred because it was one of the textures depicted by Eyles (1978), as being characteristic of low level glacial transport and would be a better discriminating variable as such compared with large conchoidal fractures (feature 17) which may also be found on source grains.

Subcluster iiib presented a decision whether to choose M.V.'s (feature 26) or high relief (feature 12). Feature 26 was chosen because of its strong links with beach modifications and as such may distinguish samples 1 and offshore (samples 20 and 21) from the others.

Subcluster iva represented grain morphology in general, so rounded grains (feature 5) was chosen in preference to subangular grains (feature 3) and subangular edges (feature 9). Rounded grains varied more alongshore if descriptive results are taken into account, one of the important trends of which was the shift toward more rounded grains westward from Montauk Point.

Finally subcluster ivb presented the most difficult choice, angular edges (feature 8) being chosen because of its links with glacial grains at Montauk Point and edge abrasion alongshore.

The choice of the figure of 10 for the number of surface features was purely arbitrary and partly decided by significant textures already depicted in earlier analyses, but also by the nature of the four subcluster split in Fig. 7.4. The new reduced checklist was as follows:

Feature 16	Cracks
Feature 15	Late Stage Complete Grain Breakage
Feature 38	Adhering Particles
Feature 35	Very Fine Precipitated Particles
Feature 11	Rounded Edges
Feature 18	Large Blocks
Feature 7	Edge Abrasion
Feature 26	M.V's
Feature 5	Rounded Grains
Feature 8	Angular Edges

Bull, (1978a), stressed the importance of the fact that surface features should be independent of one another for discriminant analysis to be valid. In order to provide such a check all ten features were crosstabulated against each other and X^2 tests performed in each case. X^2 tests the null hypothesis that the relationship between two variables is due to chance alone i.e. that they are not dependent. The appropriate formula to use for 2 x 2 X^2 is:

$$\frac{N\,[|a.d - b.c| - N/2]^2}{r_1.r_2.c_1.c_2}$$

Where N = number of observations, in this case 550

a = numbers of grains with zero observations of both variables x and y.

b = numbers of grains with only feature X observations.

c = numbers of grains with only feature Y observations.

d = numbers of grains with observations of both features X and Y.

r_1 = row total (a + b)

r_2 = row total (c + d)

c_1 = column total (a + c)

c_2 = column total (b + d)

Example:- For feature 15 (late stage complete grain breakage) by feature 18 (large blocks).

$$X^2 = \frac{550\ [1(30 \times 279) - (222 \times 19)/ - \frac{550}{2}]^2}{252 \times 298 \times 49 \times 50/}$$

$$= 4.6008$$

Reference to critical values for X^2 with n - 1 = 1 degree of freedom shows that there was >95% probability that the frequency distribution of observations of features 15 and 18 occurred by chance alone. In other words they may be considered to be independent on the basis of the observations made upon them.

The results of crosstabulation of features for independence are presented in Table 7.6. For features 16 (cracks) independence with more than 95% probability was achieved only with features 38 (adhering particles) and 5 (rounded grains), feature 15 (late stage complete grain breakage) achieving >90%. Independence of surface features is calculated on the basis of observations made and observations expected for X^2, actual observations depending on grain

Features	15	38	35	11	18	7	26	5	8
16	2.9	6.8	0.5	2.0	1.7	2.0	0.3	4.7	1.2
15		7.1	1.1	2.4	4.6	1.6	0.6	0.6	0.3
38			2.4	17.3	5.7	15.5	1.0	0.5	4.7
35				7.2	0.2	2.4	0.9	0.8	0.3
11					0.0	0.8	10.7	4.5	-
18						30.8	16.5	0.0	1.6
7							11.0	10.1	8.5
26								7.5	2.2
5									6.7
8									

Table 7.6. A matrix of X^2 values for crosstabulation of surface features 16, 15, 38, 35, 11, 18, 7, 26, 5 and 8.

characteristics. It may be reasonably expected therefore that grain surface textures related to similar casual mechanisms may show a greater degree of dependence.

Apart from the fact that both features may be produced by mechanical breakages there is no reason for cracks to be controlled by or control M.V.'s as shown by the low X^2 value although angular edges and large blocks may be generically related to a common glacial source.

Late stage complete grain breakage (feature 15) also showed correlation with edge abrasion, M.V.'s and angular edges (features 7, 26 and 8) as evidenced by the low X^2 values (Table 7.6). This is not so surprising if the final cycle or late stage age of such features is considered (apart from angular edges).

It is possible that feature dependence is not related to the processes operating on Long Island's south shore which combine to produce family groups or textural assemblages diagnostic of that environment. Examination of X^2 values for rounded grains and angular edges (6.7, >95% probability) produce what may be expected, however edge abrasion (feature 7) is strongly independent of M.V.'s (feature 26) with values of 11.0 equivalent to >99% probability.

The question arises that if operator variance and feature interpretation fall within reasonable bounds for the present study, such grain surface feature dependence would be duplicated in other S.E.M. studies. Although outside the scope of the present study the problem arises as to the inherent dependence of surface features at the outset of any checklist study if subsequent discriminant analyses are to be employed.

The dilemma facing S.E.M. workers may be of choosing statistically independent features which may possibly have little geomorphological creditability as an assemblage, or of choosing features which are dependent but have been linked to grain modifying processes. This question arises only in relation to the significance which may be attached to the results of discriminant analysis and would not influence qualitative results and their interpretation.

Had a different selection of 10 surface features been made, or simply all mechanical as opposed to chemical features (Bull, 1978a), similar problems may have arisen. On the basis of evidence of feature significance in the earlier analyses it was decided to proceed with discriminant analysis 2.

7.III DISCRIMINANT ANALYSIS 2

II.A Canonical Variate Analysis 2

In the second canonical variate analysis using the SPSSX package there were h = 22 groups (samples), and p = 10 variables (surface features). In this case h > p giving only 10 canonical discriminant functions (canonical variates) and 10 eigenvalues. The first two canonical variates had eigenvalues >1 accounting for 69.26% of the variance, which was an improvement on the 53.01% variance accounted for by C.V.1 and C.V.2 in canonical variate analysis 1. Both were highly significant with values of 0.00. The results were as follows:

FUNCTION	EIGENVALUE	% VARIANCE	CUM. %
1	1.51999	36.88	36.88
2	1.33427	32.38	69.26

- - - ; 7.7. The first two eigenvalues with their % variance, Canonical Variate Analysis 2.

Mean canonical variates for the first two variates are presented in Table 7.8. Canonical variate 1 (function 1) contrasts samples 1, 3, 4, 5 and 6 derived from the Headlands section (Fig. 2.4), and sample 18 (western Fire Island) and sample 19 (offshore east of channel H in Fig. 2.3) with the others. This strongly reinforces the discrimination obtained by C.V.1 in canonical variate analysis 1 by largely separating the Headlands off from the others.

Mean canonical variate 2 (function 2) contrasts samples 10, 12, 14, 16, 17, 18, 19, 20 and 21 with the others. In both cases (C.V.1 and C.V.2), offshore samples 20 and 21 have been included within Fire Island beach samples.

The SPSSX package provided a territorial map on which group centroids were plotted along with an areal representation of sample separation for C.V.1 against C.V.2. This is shown in Fig. 7. 5 . Sample codes for canonical variate analysis 2 with 10 features were alphanumerical and the correct sample identification and colour coding is shown in Table 7. 9.

Qualitative interpretation of Fig. 7. 5 show those samples which were most closely grouped in the centre to be the least discriminated. Samples 1, 3, 5 and 6 from the Headlands section were located in the north and west sector (Fig. 7.5). Fire Island samples 8, 9, 11, 13 and 14 occupied the central and east sector. Offshore samples 19, 20 and 21 were distributed in the southern half.

A plot of mean canonical variate 1 against mean canonical variate 2 is shown in Fig. 7. 6. In the same way as for canonical

GROUP	FUNC 1	FUNC 2
1	-3.63162	0.46556
2	0.11954	0.72159
3	-0.96107	1.13232
4	-0.01177	0.80190
5	-0.00363	1.87591
6	-1.24034	0.94333
7	0.05490	1.20510
8	0.65675	0.57092
9	0.30099	0.62825
10	0.60049	-0.07425
11	0.67777	0.50156
12	1.03758	-0.52162
13	0.17279	1.26141
14	0.85782	-1.03186
15	0.53634	0.28079
16	1.01458	-0.42421
17	1.03738	-1.18969
18	-1.26904	-2.11110
19	-2.60051	-2.24040
20	1.18775	-1.60185
21	0.76455	-1.40975
22	0.69876	0.21608

Table 7.8. Mean canonical variates (canonical discriminant functions) for the first three variates. Canonical Variate Analysis 2.

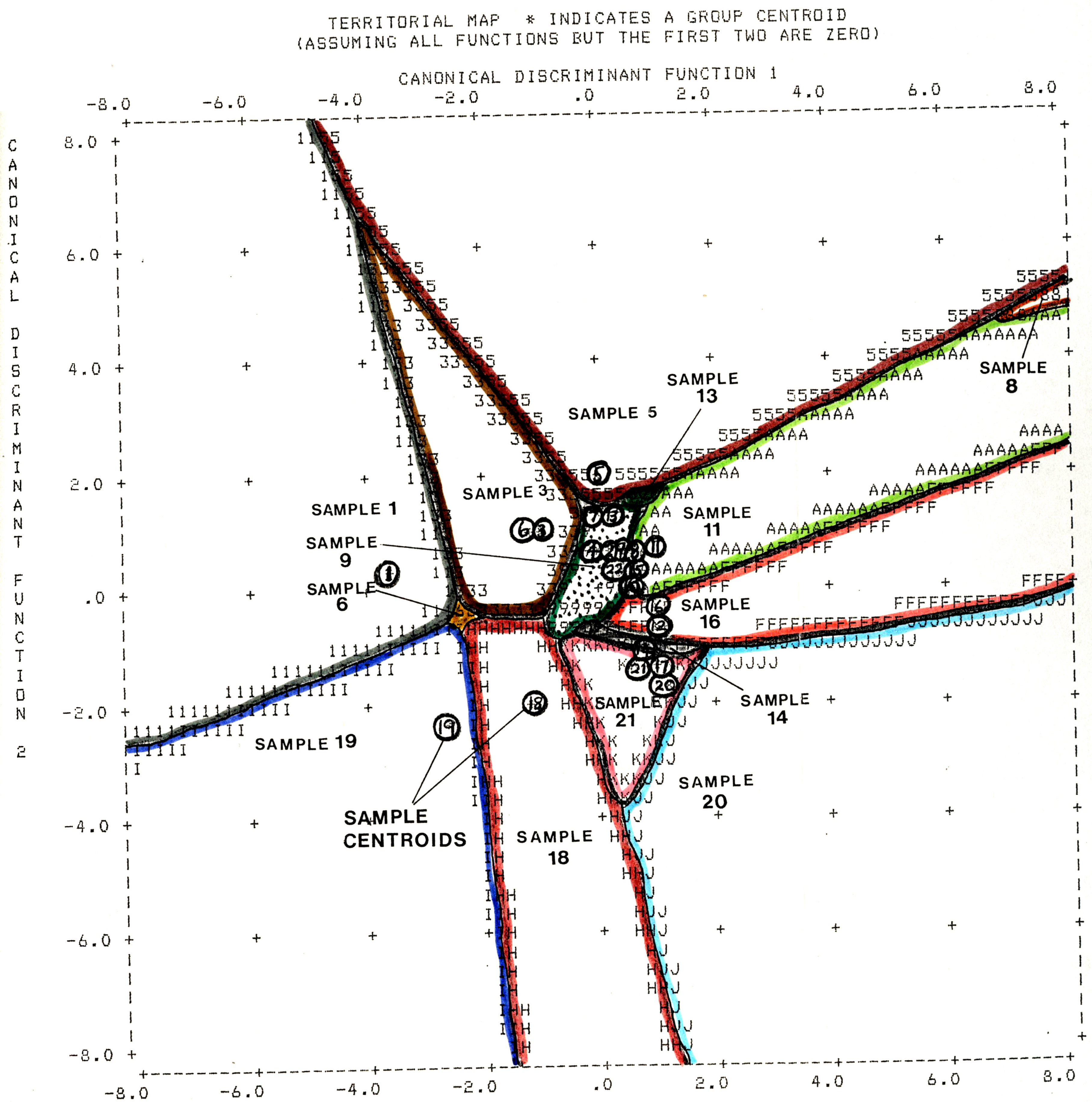


Fig. 7.5 Territorial map of sample separation for C.V.1 against C.V.2.. Canonical Variate Analysis 2.

SAMPLE IDENTITY	CANONICAL VARIATE ANALYSIS 2 CODE	COLOUR CODE
1	1	
2	2	
3	3	
4	4	
5	5	
6	6	
7	7	
8	8	
9	9	
10	0	
11	A	
12	B	
13	C	
14	D	
15	E	
16	F	
17	G	
18	H	
19	I	
20	J	
21	K	
22	L	

Table 7.9. Alphanumeric and colour codes for sample identities for the territorial map and group scatter plots. Canonical Variate Analysis 2.

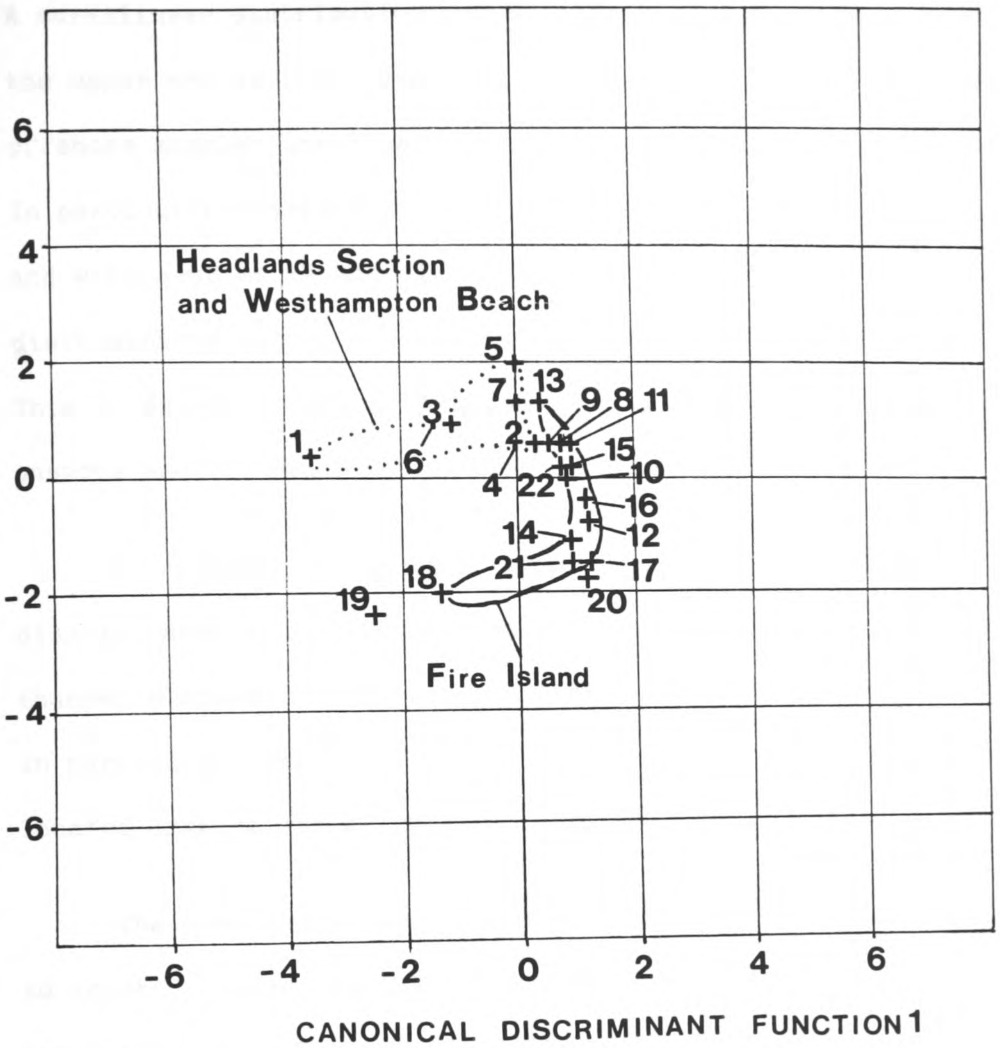


Fig. 7.6. Canonical Variate Analysis 2, Plot of mean C.V.1 against mean C.V.2. Numbers refer to samples 1-22.

variate analysis 1 Headlands samples 1 to 6 (and 7 was included), and Fire Island samples were delineated in a purely arbitrary fashion. A curvilinear distribution may be seen with samples 1 to 7 forming the upper arc of the curve (Fig. 7. 6). Apart from sample 19, other offshore samples are closely associated with Fire Island samples. In particular, samples 20 and 21 are closely linked with eath other and with samples 14 and 17. This suggests that they have not been discriminated very well, perhaps indicating an offshore-onshore link. This is especially important considering that samples 14 and 17 are onshore and downdrift of channel H (Fig. 2.3).

In general, the glacial sample 1 from Montauk Point is clearly discriminated as is offshore sample 19. Offshore sample 22 west of channel H appears to be closely linked to Fire Island beach samples, in particular samples 15 and to a certain extent 16 which are located onshore and slightly updrift (Fig. 7. 6).

The canonical discriminant function coefficients which help to identify those feature variables responsible for discrimination are presented in Table 7.10. All six variables may be related to edge abrading processes to a greater or lesser degree. Canonical variate 1 compares Headlands samples (including sample 1) with

C.V.1	SURFACE FEATURES	C.V.2	SURFACE FEATURE
0.59169	M.V.'s	0.67830	Adhering Particles
0.55639	Edge Abrasion	0.41636	Very Fine Precipitation Particles
0.33937	Rounded Edges	0.38614	Edge Abrasion

Table 7.10. Canonical discriminant function coefficients for C.V.1. and C.V.2. Canonical Variate Analysis 2.

the others (excluding samples 18 and 19) on the basis of Edge abrasion features, with C.V.1 accounting for 36.88% of the variance. Canonical variate 2 compares most of Fire Island beach samples and offshore with the Headlands section using edge abrasion and related comminuted particles, this accounting for 32.38% of the variance.

Pooled within-groups correlations between discriminating variables and canonical variates show edge abrasion (0.68998) and mechanical V's (0.67336) to be reasonably strongly positively correlated with C.V.1. Adhering particles (0.72222) is strongly correlated with C.V.2.

In order to examine in greater detail possible links between offshore samples and onshore Fire Island beaches, individual scatter plots produced by the SPSSX package for all samples for canonical variate 1 against canonical variate 2 were studied. The plots for all samples, except sample 1, and offshore are presented in Fig. 7.7 as a means of reference. Individual contours have been subjectively sketched for each sample. Subsequently, samples 19 to 22 offshore were superimposed on Fire Island beach samples immediately onshore or downdrift slightly. These are presented in Figs. 7.8 , 7.9 , 7.10 and 7.11. The rather more complex superimposition of Headlands samples upon sample 1 is provided for comparison in Fig. 7.12.

In order to decipher alphanumeric codes and the colour code, reference should be made to Table 7. 9, although sample centroids and contours have been pointed out as much as possible. Fig. 7.8 shows good areal coalescence of Fire Island beach samples 10, 11 and 12 with tight groupings. They are not closely linked to Sample 19, the

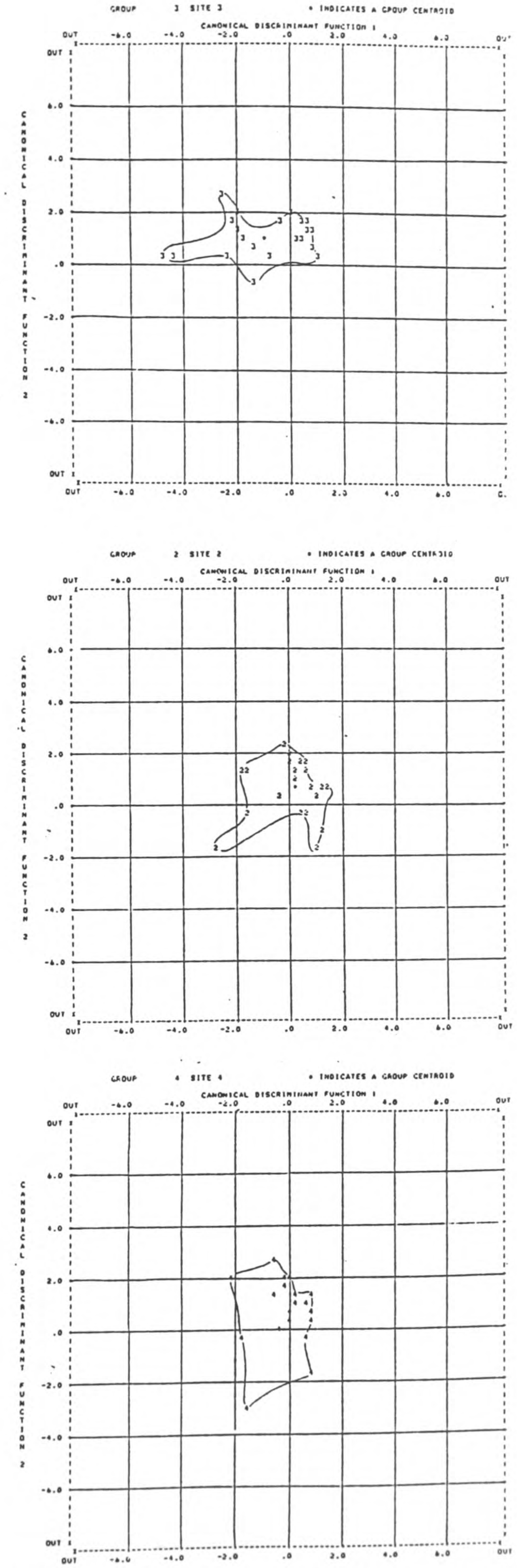
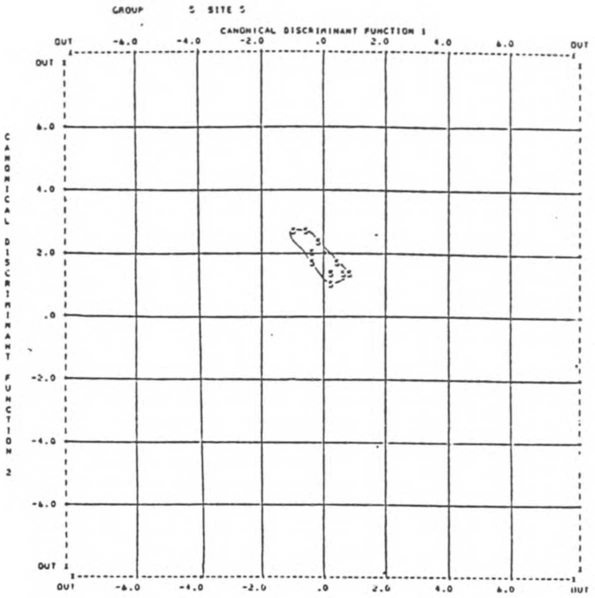
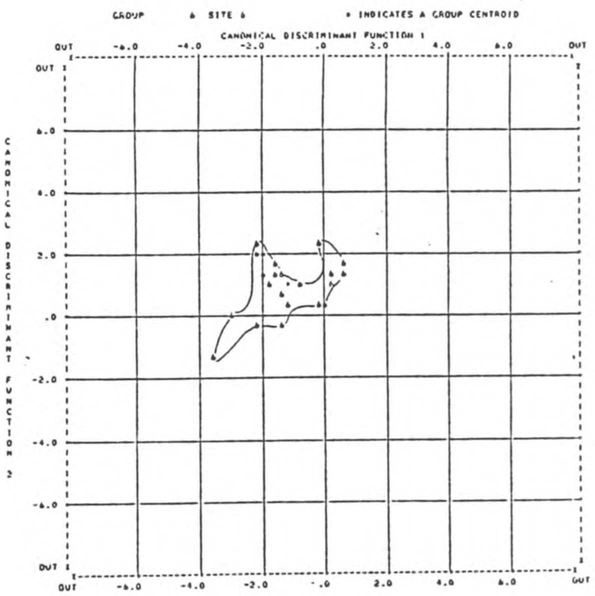


Fig. 7. 7. Scatterplots for samples 2,3 and 4 for C.V.1 against C.V.2. Canonical Variate Analysis 2.





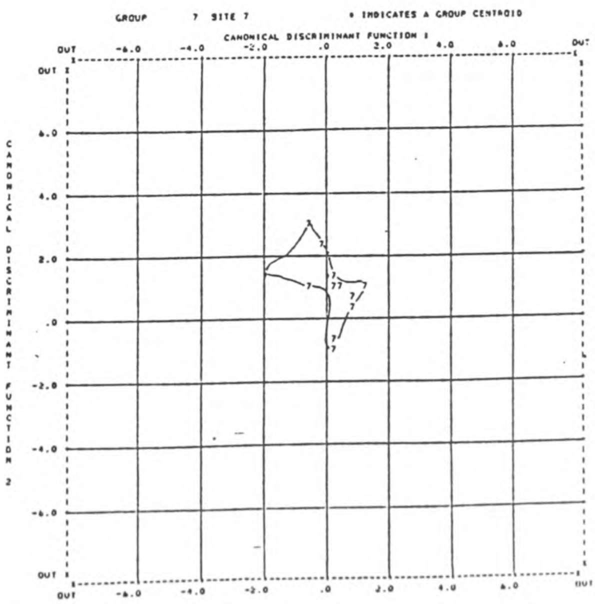


Fig. 7.7 continued for samples 5, 6 and 7.

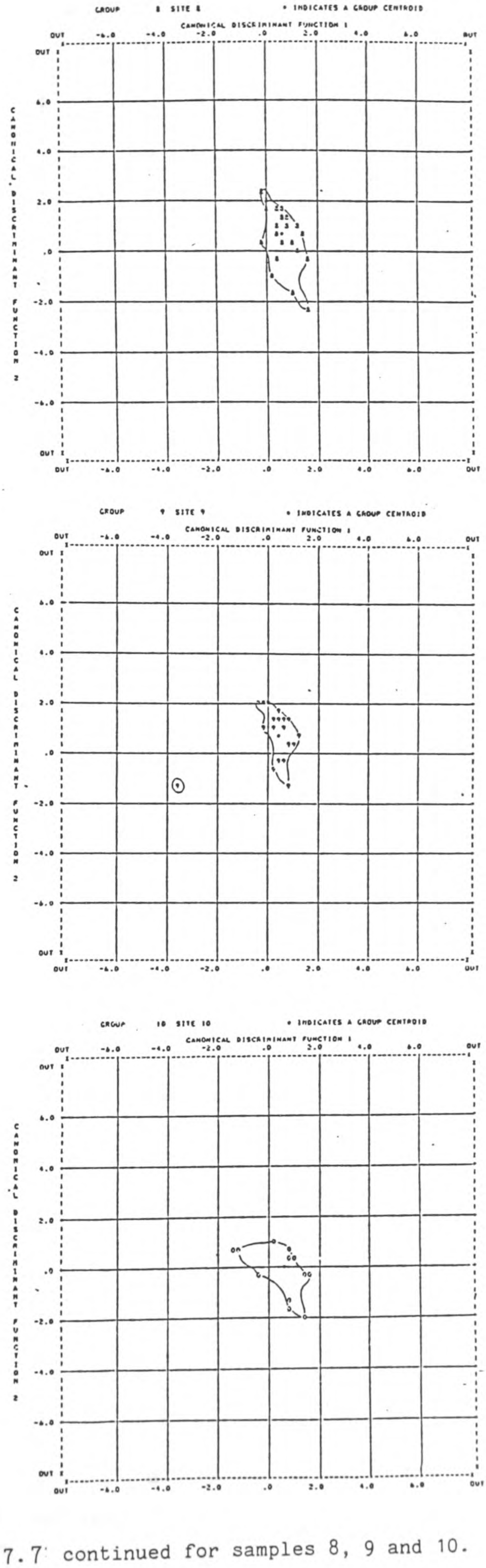
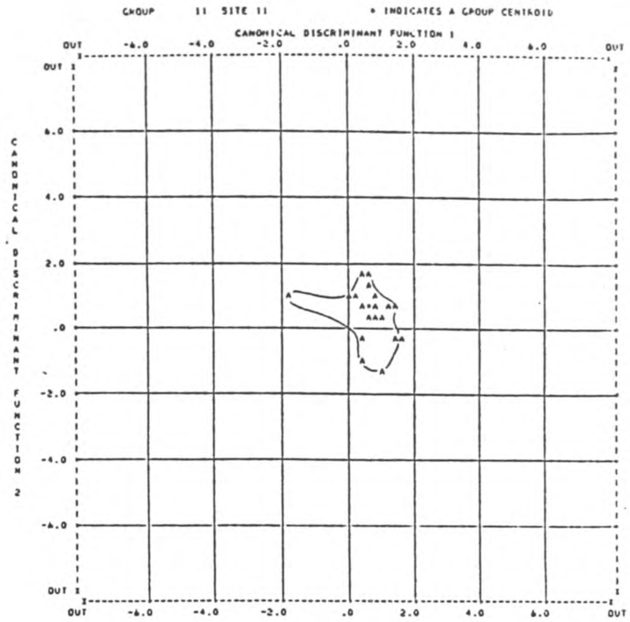
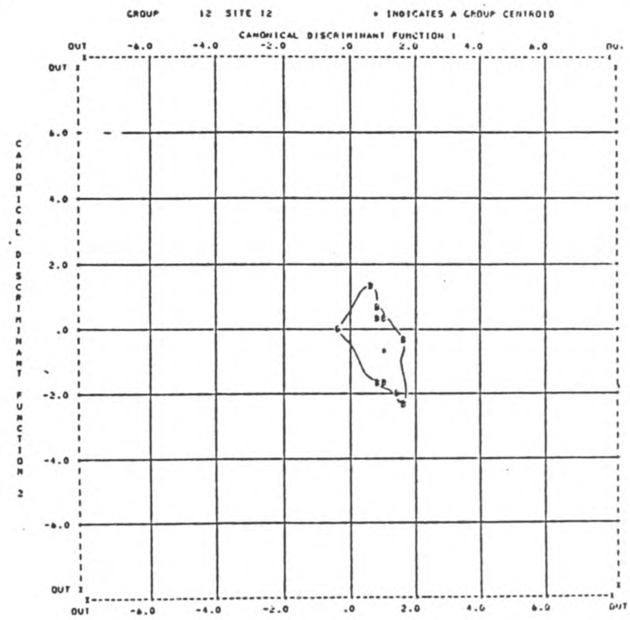


Fig. 7.7 continued for samples 8, 9 and 10.





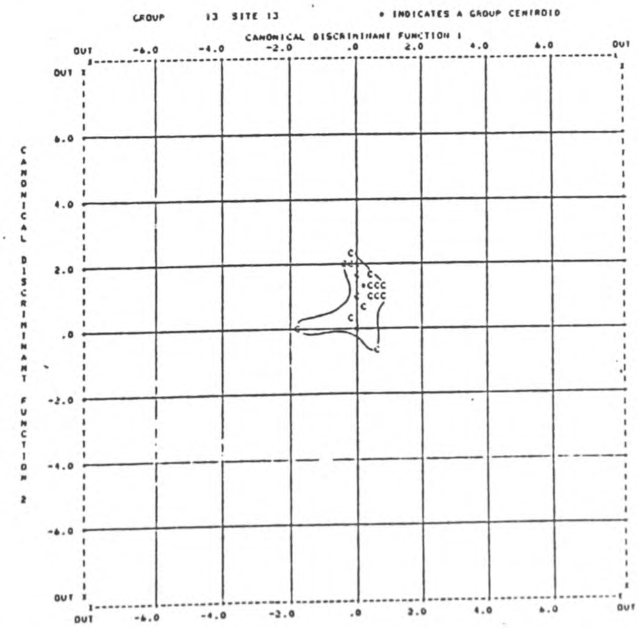


Fig. 7.7 continued for samples 11, 12 and 13.

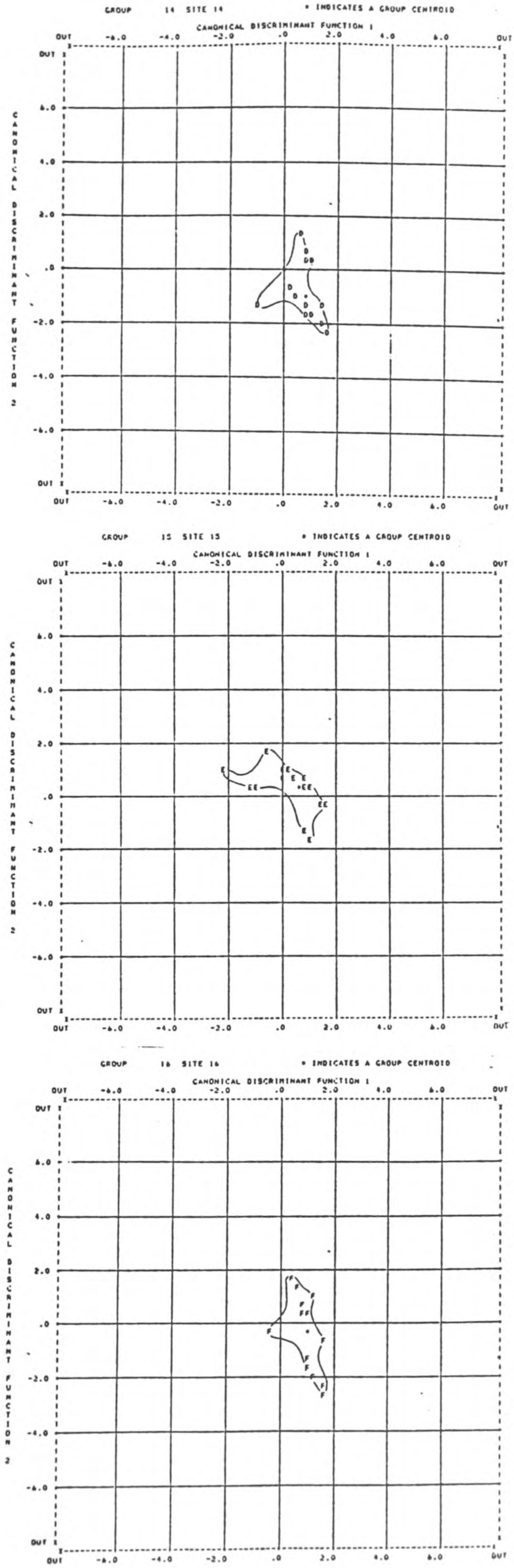
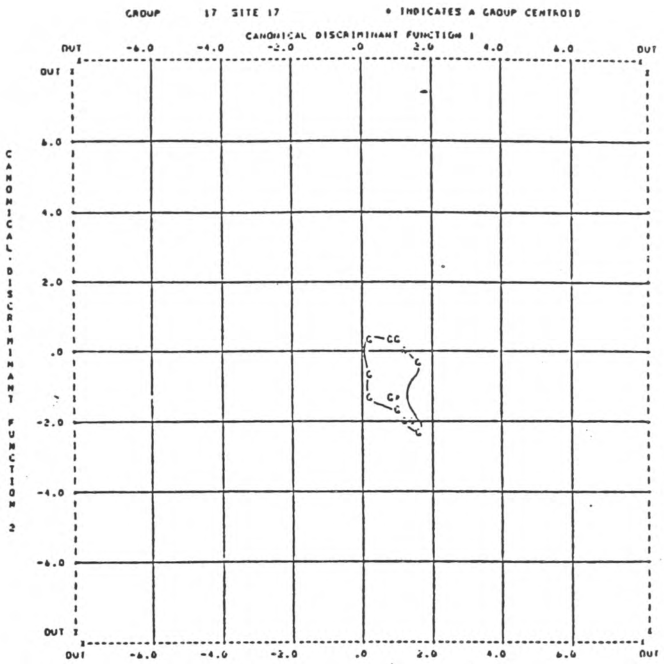


Fig. 7.7 continued for samples 14, 15 and 16.



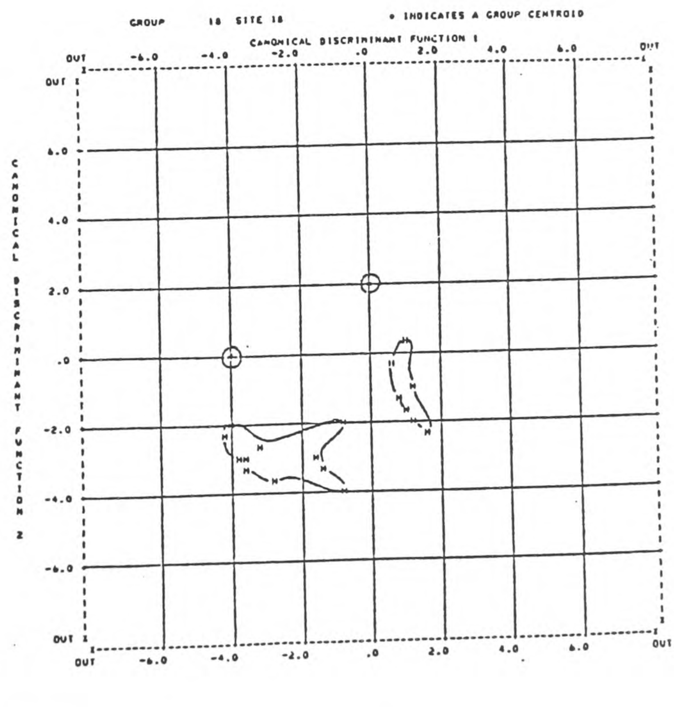


Fig. 7.7 continued for samples 17 and 18.

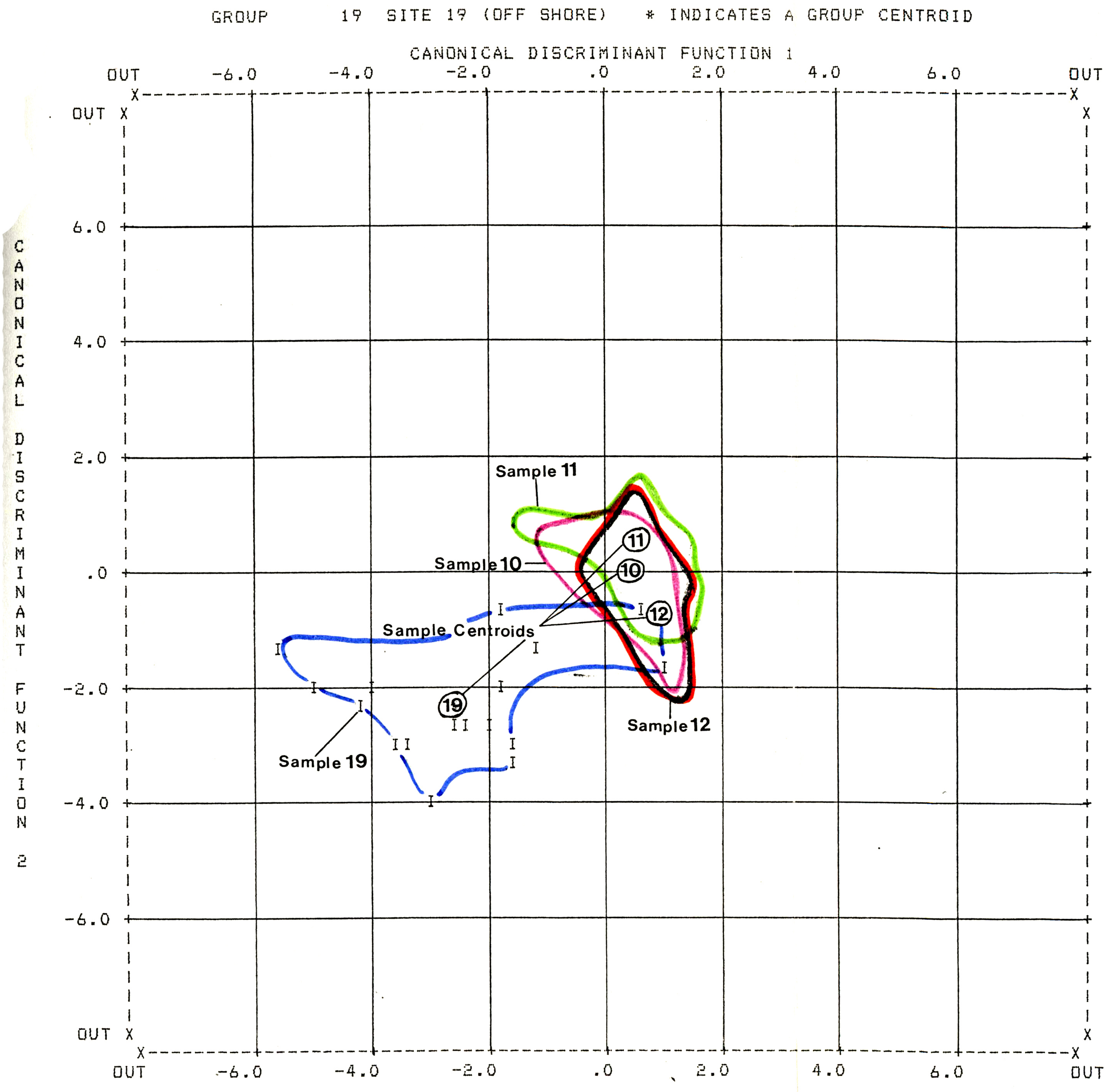
scatter is much greater possibly indicating a less homogenous sample.

Channel H deposits (samples 20 and 21 shown in Figs. 7.9 and 7.10) present a different picture. Onshore Fire Island beach samples are closely related to both samples almost overlying them. Samples 14 and 15 are immediately onshore or downdrift of sample 20 (Fig. 2.3), the latter forming a closely bound group. Samples 14 and 15 and 16 also closely correspond to sample 21 (Fig. 7.10).

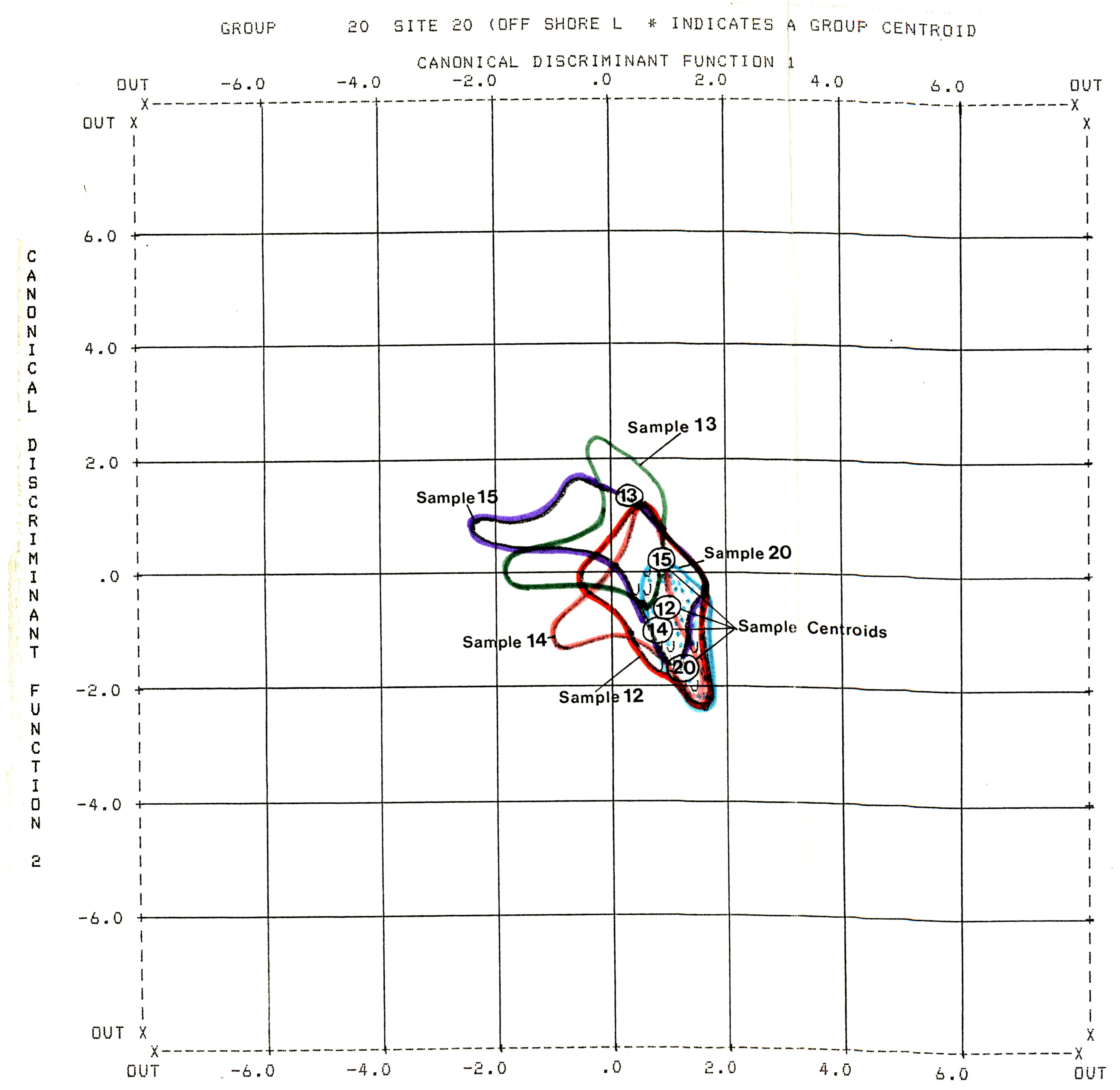
A similarly close fit may be seen for sample 22 west of channel H and onshore samples 16 to 18 (Fig. 7.11). However sample 18 at the western end of Fire Island seems to be discriminated into 4 separate groups. This feature is partially duplicated by samples 22 and 21. It may indicate two groups of grains within these samples, but proximity to Fire Island Inlet to the west may be causing an influx of different grains in the western region of the Island.

In comparison, sample 1 and the Headlands beach samples 2 to 6 and Westhampton beach (sample 7), do not show such close relationships. Their contours show a much greater spread and although samples 2 to 7 in Fig. 7.12 show a reasonably well grouped centroid cluster, sample 1 from Montauk till is discriminated clearly from them.

In other words, samples 20, 21 and 22 offshore show close, tightly knit groups overlying each other compared with sample 1 and the Headlands beaches. This may indicate that discriminant analysis has failed to separate them to any reasonable degree suggesting a



7. 8. Superimposition of samples 10, 11 and 12 scatterplots upon sample 19 for C.V.1 against C.V.2. C.V. analysis 2.



7.9. Superimposition of samples 12, 13, 14 and 15 scatterplots upon sample 20 for C.V.1 against C.V.2. C.V. analysis 2.

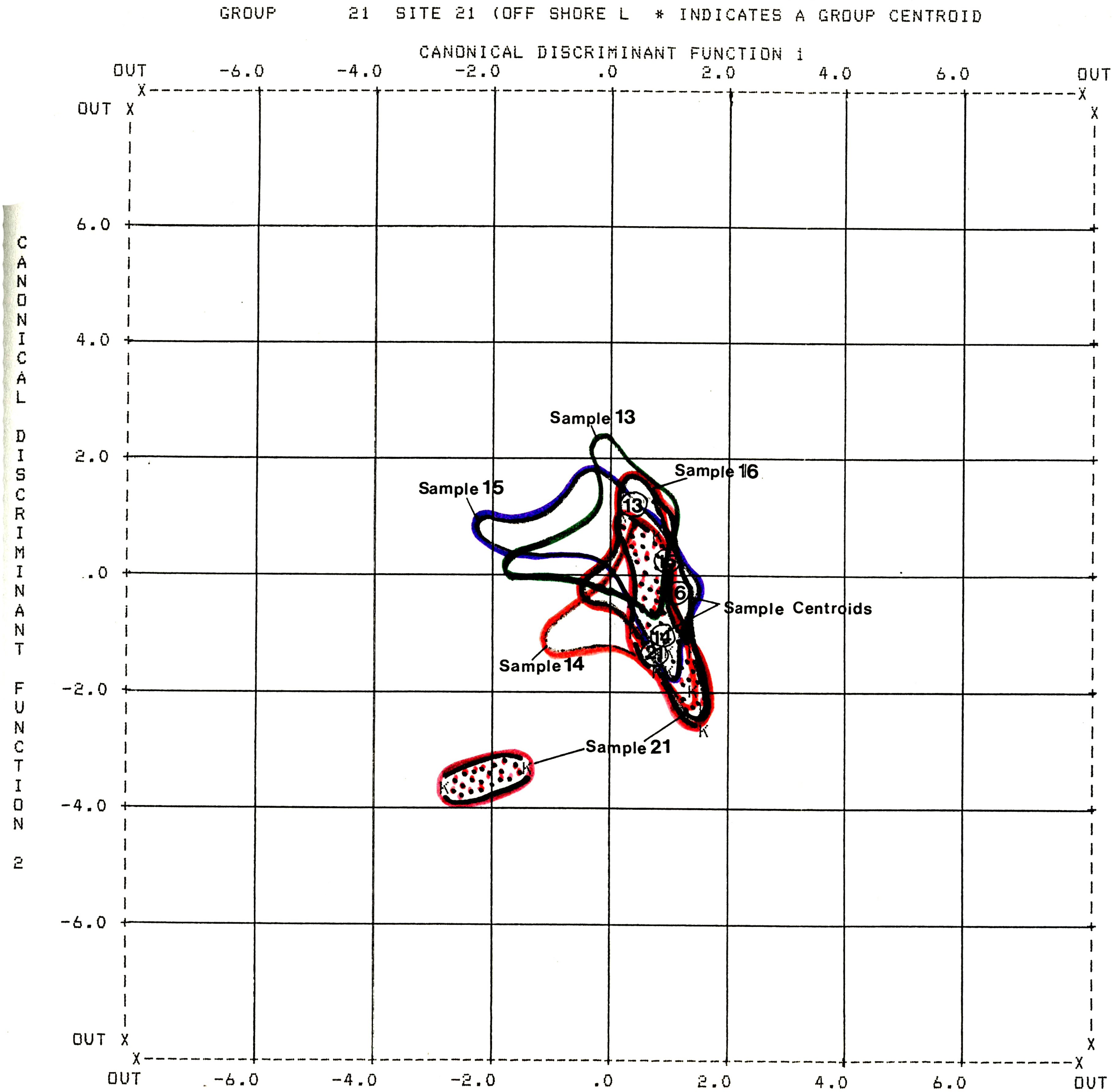


Fig. 7.10. Superimposition of samples 13, 14, 15 and 16 scatterplots upon sample 21 for C.V.1 against C.V.2. C.V. analysis 2.

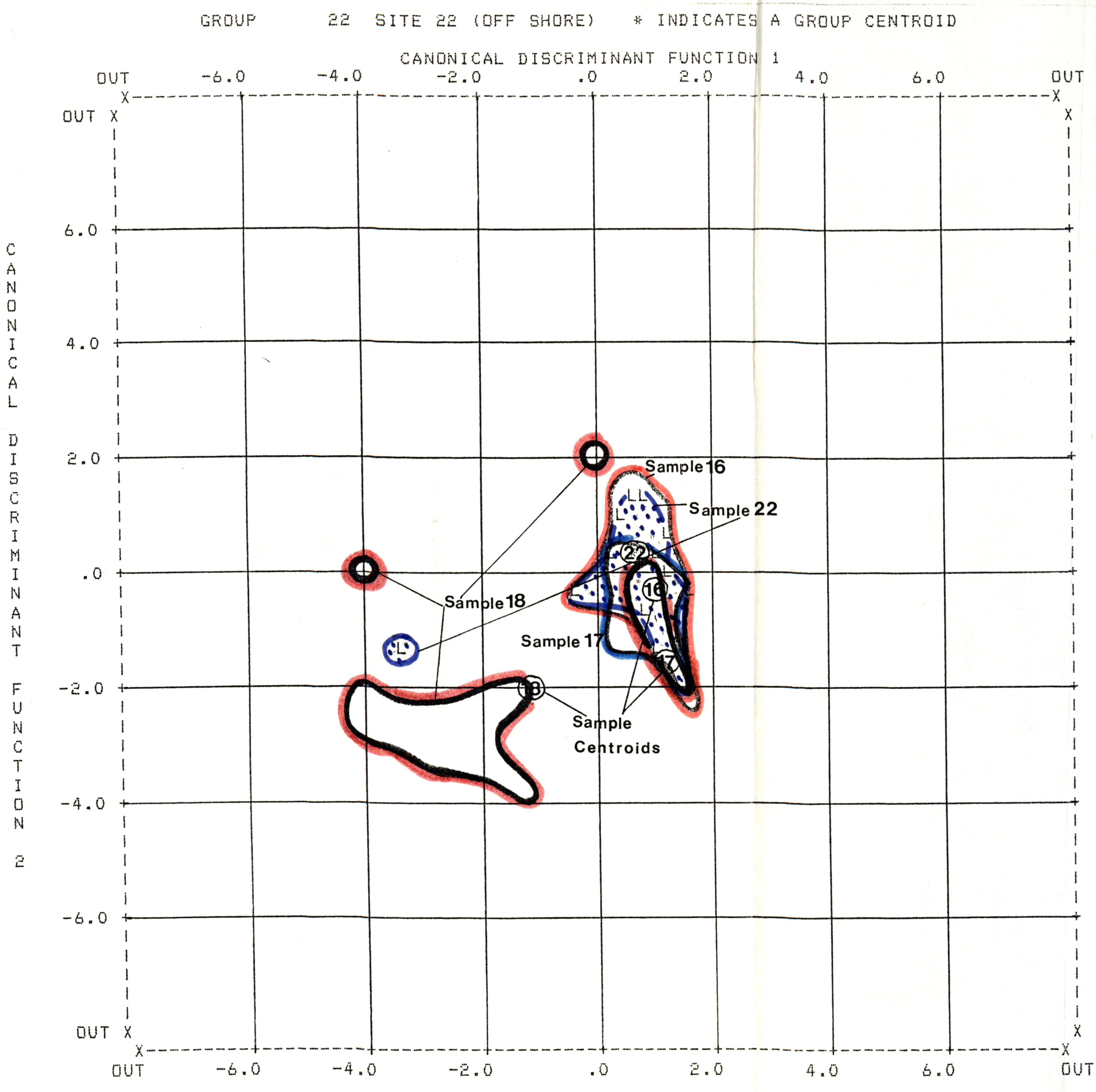


Fig. 7.11. Superimposition of samples 16, 17 and 18 scatterplots upon sample 22 for C.V.1 against C.V.2. C.V. analysis 2.

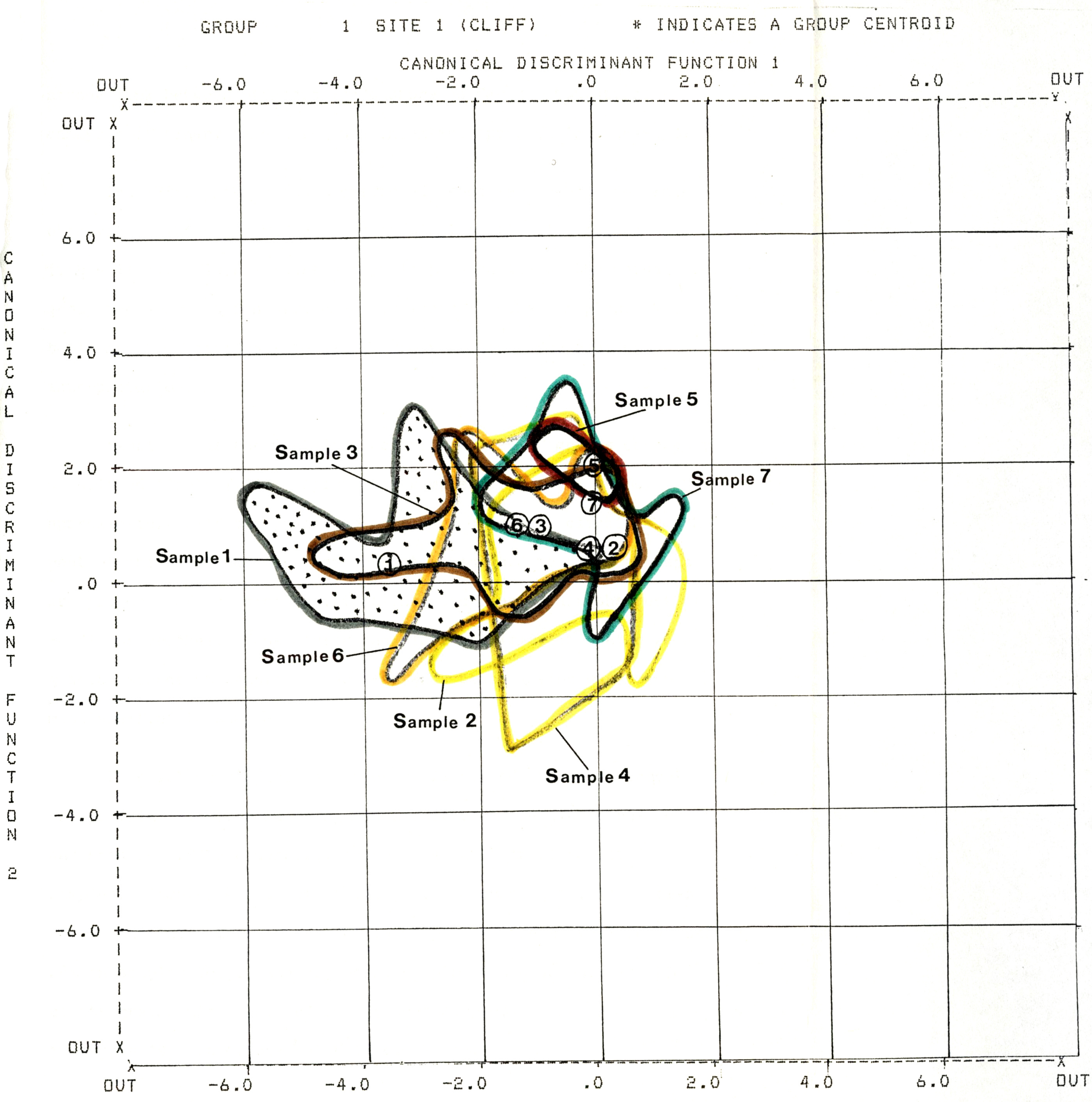


Fig. 7.12 Superimposition of samples 2 to 7 scatterplots upon sample 1 for C.V.1 against C.V.2. C.V. analysis 2.

strong link between offshore and onshore as far as statistical analysis of binary data using the checklist approach is concerned.

The SPSSX package lists predicted group memberships for each observation which are referred to as misclassification tables (Table 7.11). Figures represent grain % belonging to the actual group membership which have been misplaced in other samples. The table has been divided into sample group sections for ease of interpretation.

Sample 1 was the most distinctive with 72% of grains correctly classified (Table 7.11). Apart from samples 5, 6 and 7 where approximately half the grains or more were correctly classified, the rest of the Headlands were not correctly assigned to their correct groups, most of the misclassifications occurring within the rest of Headlands beaches. Considering the close proximity to the known glacial source at sample 1, few Headlands beach grains have been misclassified in sample 1.

Fire island samples were poorly classified in their correct groups (Fig. 7.11), some being misclassified in Headlands beaches and some in offshore samples, but mostly in other Fire Island samples. Sample 14 had 40% of its grains misclassified in samples 20, 21 and 22; sample 16 had 28% in samples 20 and 21; sample 17 had 28% in samples 20, 21 and 22, while sample 18 had as much as 52% of its grains misclassified in offshore samples, although 36% were in sample 19 east of channel H (Table 7.11).

Compound bar graphs were constructed to illustrate misclass-ifications of offshore sample grains for other sample groups

PREDICTED GROUP MEMBERSHIP %

ACTUAL GROUP MEMBERSHIP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	72	-	8	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
2	-	28	4	-	12	8	8	8	-	4	-	-	4	-	-	-	4	-	4	4	-	12
3	4	16	24	8	4	16	8	-	-	4	-	-	8	-	-	-	-	-	4	-	-	4
4	-	8	4	20	8	-	16	-	-	4	-	8	20	-	-	-	-	4	4	-	4	-
5	-	20	-	4	48	-	16	-	-	-	-	-	12	-	-	-	-	-	-	-	-	-
6	4	8	-	-	8	60	8	-	-	-	-	-	4	-	-	-	-	-	8	-	-	-
7	-	-	4	8	20	4	48	-	-	4	4	4	-	4	-	-	-	-	-	-	-	-
8	-	20	-	16	-	-	-	12	-	-	4	4	12	4	8	-	8	-	-	4	-	8
9	-	16	-	4	4	-	12	-	4	8	-	-	12	12	16	-	-	-	4	-	-	8
10	-	-	-	-	-	16	-	-	4	40	-	8	-	16	4	-	-	-	-	4	-	8
11	-	12	-	4	-	4	0	12	-	16	-	12	8	-	8	-	-	-	-	-	8	16
12	-	24	-	12	16	-	-	-	4	24	-	20	-	4	12	-	4	-	-	24	4	-

Table 7.11. Misclassification tables for samples 1 to 22 for Canonical Variate Analysis 2.

PREDICTED GROUP MEMBERSHIP %

ACTUAL GROUP MEMBERSHIP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
13	-	24	-	12	16	-	-	-	4	-	-	-	24	-	8	-	-	4	-	-	-	8
14	-	-	-	4	-	4	-	-	-	8	-	4	-	28	-	-	12	-	-	24	4	12
15	4	-	-	4	4	8	4	-	-	20	-	16	-	4	24	-	4	-	-	-	-	8
16	-	16	-	-	-	4	-	-	-	8	4	8	-	-	12	12	8	-	-	16	12	-
17	-	-	-	-	-	-	-	-	-	-	-	12	-	8	8	-	44	-	-	16	4	8
18	-	4	-	-	4	-	-	-	-	-	-	-	-	4	-	-	12	24	36	12	-	4
19	4	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	4	4	72	-	-	4
20	-	8	-	-	-	-	-	-	-	-	-	4	-	20	-	-	12	-	-	48	4	4
21	-	-	-	-	-	-	4	-	-	8	-	-	-	20	8	-	-	8	-	28	24	-
22	-	4	-	-	-	4	-	-	-	-	-	8	12	-	4	-	4	4	-	4	4	52

Fire Island

Table 7.11. Continued.

(Fig. 7.13). Of the total of 100 grains in the four offshore samples, 51 were misclassified, threequarters of which were misclassified for Fire Island beach groups. More specifically, of the 50 grains in samples 20 and 21 proximal to channel H, 40% were misclassified in Fire Island beach samples, 24% were mispredicted in samples 13 to 16. In contrast only 8% of grains from sample 20 and 4% from sample 21 were misclassified in Headlands groups.

In general, canonical discriminant analysis failed to assign grains correctly, the overall value for correctly predicted grains being 33.9%. However, bearing in mind the close similarity of samples 2 to 18 and a possible onshore link from offshore, it would be unusual if the technique had been 100% correct for all samples.

7.IV DISCRIMINANT ANALYSIS 3

A strong pattern has emerged regarding the success achieved by canonical variate analysis, factor analysis and clustering using all forty surface feature variables, and discriminant analysis employing ten surface features. Factor analysis and cluster analysis was performed on the data using the reduced 10 variables, but results were similar to those in discriminant analysis 1. As a result they are not presented here at the risk of labouring the same point for too long.

However, a technique which had not been used as yet was the employment of discriminant analysis to set up a 'control variable' which splits the data into two parts. A 'training set' of 22 x 13 = 286 grains was used to set up a discriminant model to which the

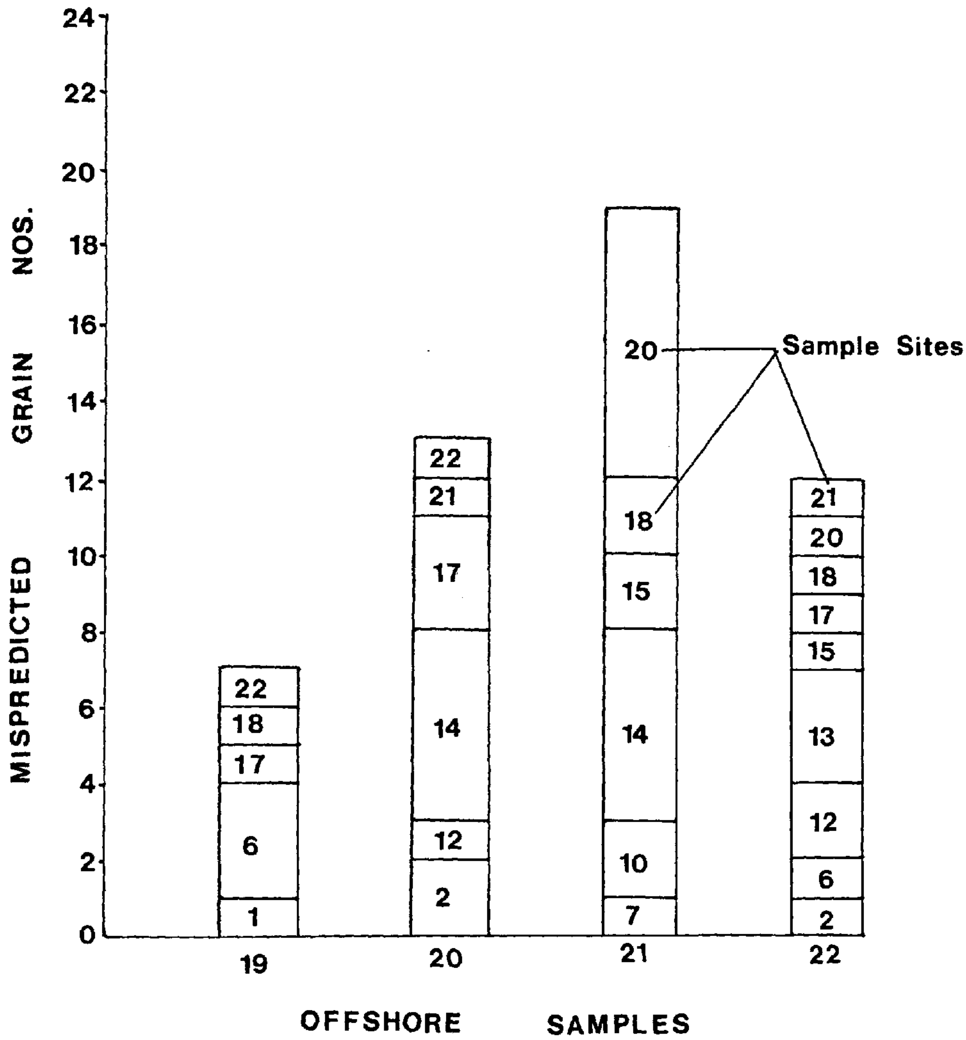


Fig. 7.13 Mispredicted grains from Offshore samples, Canonical Variate Analysis 2.

'test set' of 22 (samples) x 12 (grains) = 264 grains may be fitted. Apparently, the results may remove the initial bias of the initial input of category locations. The 286 grains (unweighted cases) were selected by minimizing Wilks' Lambda and grain surface features were included progressively in the discriminant analysis on the basis of their F values. These are measures of the statistical significance of the amount of separation or discrimination achieved which may be attributed to the inclusion of a specific surface feature variable into the analysis.

Results are presented in Table 7.12. It is not intended to present the results of canonical discriminant analysis 3 in full because apart from ranking the surface feature variables during the setting up of a 'training set' they shed no extra light on the primary aims of the present study. The first two canonical variates had eigenvalues of 1.66410 and 1.21061 accounting for 36.12% and 26.28% of the variance respectively.

Mean canonical discriminant function 1 in fact compared samples 1 to 7 (Headlands section and Westhampton beach), and 9, 13 and 19 with the rest. Mean canonical discriminant function 2 however, compared samples 1, 6, 14 and 17 to 21 with the rest. The separation of Headlands samples from the rest reinforces canonical variate analyses 1 and 2.

Cautionary comments regarding the validity of these statistical results will be made in the section on Discussion. Descriptive and statistical findings will be examined in the light of south shore processes. Initial intentions to carry out a

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS' LAMBDA	SIG.	LABEL
1	FEA26		1	.49587	.0000	MECH.V
2	FEA38		2	.27723	.0000	ADH. PARTS
3	FEA7		3	.18332	.0000	EDGE ABRASION
4	FEA35		4	.13240	.0000	V.F.P.P
5	FEA8		5	.10192	.0000	ANG. EDGES
6	FEA18		6	.07825	.0000	LARGE BLOCKS
7	FEA11		7	.06219	.0000	ROUNDED EDGES
8	FEA15		8	.04856	.0000	L.S.C.G.B
9	FEA16		9	.04193	.0000	CRACKS
10	FEA5		10	.03847	.0000	ROUNDED

Table 7.12. Surface feature variable ranking on the basis of stepwise variable selection, Canonical Discriminant Analysis 3.

detailed study of edge shapes and breakages as a separate and complementary study have not been presented, but will be incorporated into the discussion using the detailed notes made during the main checklist scan.

CHAPTER 8

DISCUSSION

DISCUSSION

8.I INTRODUCTION

Preceding chapters on qualitative and quantitative results have outlined the main features of grain surface textures scanned in the present study, notably their abundance, trends and associated sample groupings. Sample 1 and Headlands section samples have been contrasted with Fire Island and offshore samples. It is not the aim in this chapter to repeat previous assertions, however several comments have already been made pointing to characteristic textural assemblages which are diagnostic of different Long Island's south shore environments. The discussion which follows attempts to consolidate and validate the importance of these textural combinations in terms of geomorphological processes operating in that region.

In particular, an opportunity is afforded to examine the superimposition of glacial, beach and fluvioglacial-glacial marine modifications on grain surfaces to produce the complex multiple cycle textures found on Fire Island beach grains. Quartz grain surface texture combinations described for sample 1 (known glacial source), samples 20 and 21 (offshore fluvioglacial lobe deposits), and samples 2 to 18 (beach) are compared with commonly accepted feature assemblages diagnostic of such environments found in S.E.M. literature.

Finally, the validity of quantitative S.E.M. analysis using a checklist approach and multivariate analysis is examined and its success assessed in terms of the environments and grain samples found along Long Island's south shore.

8.II RONKONKOMA MORAINE - KNOWN GLACIAL SOURCE

Sample 1 proved to be the most distinctive of samples. Its dominantly angular-rounded grain mixture with angular edges and high relief were characteristic. High energy breakages (surface textures 15 to 23) were common or abundant and very varied, but its glacial-source origin was most noticeable in the lack of clean rounded edges produced by seawater solution and small surf induced mechanical breakages (surface features 24 to 28).

It was the most chemically dulled sample and as a result was characterised by a wide variety of solutional and precipitation textures, in particular considerable amorphous precipitation including a smooth capping layer and fine non-oriented etching. The nature of sample 1's grain surface textures is stressed a great deal in the present study because they form the known framework within which subsequent beach modifications are interpreted.

The glacial character of sample 1 from Ronkonkoma terminal moraine as a member of the Montauk till sequence has been accepted by many workers (Colony, 1932; Taney, 1961a, 1961b; Williams, 1976; Rampino, 1978), and its origin is not of direct interest to the present study. However, several references have been made in Chapter 6 to a possible strained metamorphic source in order to account for various geometric breakages and chemical features found on Long Island south shore quartz grains. It is pertinent therefore to enquire into the nature of such a possible origin on the basis of inherited or relict textures preserved on sample 1's grains.

Following on from this it may be possible to identify specific glacial modifications superimposed upon original source textural assemblages.

Grain morphology and high energy breakages probably constitute the most important textural assemblages which can identify original source textures and they have been used to discern subsequent glacial modifications. Mazzullo and Magenheimer (1987, p.479), stated, "The basic underlying assumption of grain shape studies of sediment sources is that the shapes of quartz grains from a given source reflect the genesis or lithology of that source and are distinct from the shapes of quartz grains from other sources." Culver et al (1983), also called for the inclusion of grain shape parameters in S.E.M. studies of sediments on the basis of their diagnostic importance.

Using the findings of Mazzullo and Magenheimer (1987), and Haines and Mazzullo (1988), Ronkonkoma moraine quartz grains may have a mixed provenance on the basis of grain shape. The angular fraction (8% very angular, 16% angular, 36% subangular) may be derived from a weathered granite or gneiss source. Such rocks may produce original first cycle quartz grains with angular outlines and microfractures caused by crystallisation and deformation at high temperatures and pressures (Mazzullo and Magenheimer, 1987). The absence of well rounded grains and well developed large scale secondary quartz overgrowths preclude the possibility of an aeolian or quartz cemented sedimentary rock source.

The 40% of sample 1's grains in subrounded and rounded shape categories may be derived from a different source or sources. Weathered schists and quartzose multicyclic sediments may produce first cycle quartz grains of a more rounded nature (Mazzullo and Magenheimer, 1987). However, the problem of assigning sample 1's quartz grains to any of these three sources with any confidence is compounded by the assertion that water-transported, non quartz-cemented sedimentary rocks can produce grain shapes and morphologies which are inherited from a previous source. In other words, strained crystalline source grains may pass through weathering, transportational and depositional cycles,the latter involving the formation of non quartz-cemented sedimentary rocks, without their original textural assemblages being substantially modified.

Even more problematical is the interpretation of the extent of glacial modifications on such grains. Workers have described textural assemblages common to both first cycle quartz and glacially modified grains, which make it difficult to distinguish between the two. Margolis and Krinsley (1973), found that schist, gneiss and granite regoliths produced a wide variety of chemical solution and overgrowth features with large and small conchoidal fractures,small breakage blocks and semiparallel step-like fractures probably caused by frost action or mineral expansion during hydration.

Krinsley and Doornkamp (1973), and Margolis and Krinsley (1973), both agreed on wide variability of both mechanical and chemical textures as indicative of a grus source. Goudie and Bull (1984), and Bull (1984), used the absence of grinding and scratching textures such as steps, parallel striations, imbricate grinding, adhering particles, meandering ridges and scratches to reject a subglacial origin for colluvium and cave derived quartz sand grains. On this basis Bull (1984), postulated a possible englacial, supraglacial or medial moraine origin for cave sediments.

The difficulties of distinguishing passive high level glacial transport and actively ground low level subglacial transport have been examined (Whalley and Krinsley, 1974; Eyles, 1978), and Mazzullo and Magenheimer (1987), differentiated original source grains from glacial grains only on the presence of blocks and comminuted debris found on the latter's surfaces.

In the present study, many original source textures appear to have been inherited in Ronkonkoma moraine e.g. Plates 6.1, 6.18, 6.25 and 6.26. However, the large scratch or striation along an edge on Plate 6.27 and conchoidal fractures along the left and lower right edges on Plate 6.55 possibly indicate glacial modifications. A large variety of the scratching and grinding textures mentioned by Bull (1984), were present on many sample 1 grains (Table 6.1) although not shown in photographs, confirming the presence of glacial modifications and a probable subglacial origin. Presence of the 'cuboidal projection' type of blocks described by Eyles (1978), as opposed to imbricate blocks (Plates 6.66 and 6.70) was considered important. It may be that statements made by Margolis and Krinsley (1973), in response to criticisms of glacial texture assemblage validity (Brown, 1973), to the effect that glacially derived sands exhibited unique combinations of characteristics when surface feature combinations were observed in statistically significant grain percentages, may be true only for breakage blocks and comminuted debris plus original source textures.

The dulled character of sample 1's grains is assigned to chemical action during their passive standstill in the moraine ridge. It is not proposed to surmise the possible origins and relative ages for the wide variety of chemical features found on sample 1's grains because of their propensity to be diagnostically independent of discrete environmental conditions and their reported presence in a variety of energy regimes (Bull, 1981a). The very coarse-coarse etching on 52% of sample 1's grains would be assigned to late stage surface solution development using the findings of Tankard and Krinsley (1975), suggesting an original source origin and thus relict character.

A source or weathering feature, described by Krinsley and Doornkamp (1973), which does characterise sample 1 is that of contrasting grain surfaces such as those on Plates 6.18 and 6.29, the fresh broken surfaces possibly being protected by a fine matrix like clay from chemical action. On the other hand, the protection may have occurred in Ronkonkoma moraine after deposition. Two chemical features which dominate sample 1 are amorphous precipitation and fine etching, both postdating many large breakages, indeed smooth capping layer often covers breakages mirroring underlying relief (Plate 6.1, upper curved edge).

The possibility of extensive quartz solution and redeposition as irregular small platelets (very fine precipitated particles), upturned plate relief or smooth capping layer in Ronkonkoma moraine since deposition at the close of the Pleistocene is not unreasonable. The notion that quartz goes into solution when the pH is high (9 or more) and groundwater is undersaturated with respect to silica during weathering or pedogenetic processes may not need to be applied in all cases. Bennett and Siegal (1987), found that organic compounds helped the process of quartz dissolution and may occur in marine or freshwater environments during diagenesis at neutral pH and near-surface environmental conditions.

The findings of the present study agree with those of Krinsley and Takahashi (1962c), and Krinsley et al (1964), as far as the nature of surface textures found on sample 1 are concerned. Using T.E.M. analysis they reported conchoidal arc shaped steps, semi-parallel irregular steps and extensive relief on grains from a sample of Montauk till. The 'glacial' origin of such textures was confirmed by comparisons with glacial synthetic textures produced in a glacial simulation experiment.

8.III THE HEADLANDS SECTION AND WESTHAMPTON BEACH

Interpretations of grain morphology variations from sample 2 to sample 7 are problematical (Table 6.1, Figs 6.1 to 6.8). Mazzullo and Magenheimer (1987), maintained that quartz grains derived from a non quartz-cemented sedimentary rock source contained relict textures from previous cycles on the basis that water deposited grains did not exhibit any shape modifications. The findings of the present study do not agree with this tenet (Fig. 6.1). As stated previously, grains become progressively rounder with transport in littoral drift westward from Montauk Point.

Angular and round edge analysis support an increased grain roundness trend alongshore (Fig. 6.3), but the pattern is not as straightforward as one might expect in the Headlands section. It is difficult to account for the resurgence of very angular and angular grain percentages in west Headlands' samples 4 to 6 and samples 7 and 8. In particular, samples 5 to 7 contain no rounded or well rounded grains at all. In addition, a marked reduction in angular edges from sample 1 to sample 2 became an increase in samples 3 and 4. Edge abrasion increases sharply from sample 1 to beaches down-drift and maintains high values so the trend expected would be uniform edge rounding and grain relief reduction.

If we apply a similar approach to that used by Goudie and Bull (1984), and Bull (1984), the presence-absence of other features may support or disprove the validity of such an angular grain resurgence in relation to Headlands' beach processes. Large breakages such as late stage complete grain breakage show a decrease in west Headlands' samples after an increase from sample 1 to sample 2. The same pattern is shown by cracks, meandering ridges and scratches. These seem to relate to angular grain resurgence along this part of the shore (Table 6.1).

Small breakages in this coastal stretch (west Headlands) show mild downturns in abundance for small conchoidal fractures, but Table 6.1 shows that edges are being rounded mechanically in the surf. Some samples do not fit in with the expected model of increased roundness and edge abrasion. Samples 3 and 6 in particular show marked reductions in M.V. pits and arcuate groove abundance.

As pointed out in Chapter 6, Fig. 2.3 shows two major buried channels J and K traversing the eastern Headlands, bifurcating into seven subchannels offshore. One of the notions implicit in this study's design was that of a possible resurgence of glacially modified grains from offshore in onshore beach samples. Although outside the strict terms of reference of this study such a notion may apply equally to the Headlands section as to central Fire Island. On the basis of angular grain increases which may not be explained by progressive surf modifications one might surmise an onshore transfer of buried lobe deposits from offshore. Increased edge abrasion and small breakages would be caused during onshore transport and a short distance of beach transport.

Krinsley et al (1964), carried out one of the earliest attempts to quantify M.V. pit densities and their relationship to energy regimes in the easternmost 20 miles of the Headlands section. A maximum value of 2.3 M.V.'s per μm^2 was recorded and Long Island south shore beach environments were considered to be uniform as regards turbulence. It is the constant turbulence factor which demands a south shore grain abrasion model of gradually increasing intensity downdrift from sample 1 and why minor breakage variations need to be ascribed to some external control such as onshore sediment transport.

Using sample 1 texture assemblages as a starting point, source or glacial modifications which decline in abundance westward and hence reflect the superimposition of beach textures, include large blocks only (Table 6.1). However, the increase in high energy breakages such as complete grain breakage, cracks, large smooth flat fractures and others do not fit the beach relief reducing model one would expect. This may be explained by two additional environmental controls not yet described. The beach from sample 2 at Montauk east to sample 1 consisits of coarse sand, gravel and boulders derived from weathering, undercutting and collapse of Ronkonkoma moraine (Krinsley et al, 1964). Coupled with localised increased turbulence at this point (Krinsley et al, 1964), quartz sand grains may be expected to suffer increased cracking and churning as a result of higher energy pebble-grain impacts.

Further west a more uniform finer grain size distribution (Taney, 1961a, 1961b; Williams, 1976), with a lower energy regime than Montauk Point may be expected to produce a more uniform trend. If sample 1 is derived partly from a strained granitic or gneiss source, internal weaknesses such as microfractures would be exploited to the full in such turbulent conditions shoreward of Montauk Cliff.

In general, all small edge breakages (textures 24 to 28) increase sharply from sample 1 to sample 2 thereafter increasing gradually to maximum percentage abundancies by mid or western Headlands samples. However the findings of this study do not support Krinsley et al's observations that by "20 miles west of Montauk Point ...... glacial textures have been almost entirely obliterated and replaced by beach textures, although the former are still recognizable on certain grains." (Krinsley et al, 1964, p.118).

The 20 mile limit is represented by sample 4 at Easthampton (Fig. 2.4) in the present study. Examination of Table 6.1 percentages and Fig. 6.1 shows dominantly subangular-subrounded grains (72%), high relief (92%), and 48% combined angular-subangular edges. There are very high abundancies of source and glacially modified grain textures, large conchoidal fractures, large smooth flat fractures and steps exceeding 90%.

Plates 6.33 and 6.48 show contrasting surface texture dominance. Grain edges and projections have been rounded off on plate 6.33 with a good example of minor breakage feature combinations consisting of small M.V. pits, curved grooves, small conchoidal fractures and blocks. Also presented are large scratches (right edge, centre), a large crack on the left, and medium conchoidal fractures and blocks (lower grain centre edge and right). Smooth capping layer possibly inherited from sample 1 and extensive solution-precipitation is preserved in depressions.

Plate 6.48 however shows complete grain breakage with large smooth flat and curved fractures, parallel straight steps (harmonic fractures) and extensive coarse edge abrasion (upper right). These are quite fresh and dissociate themselves from the subdued shallow conchoidals and meandering ridges on the upper surface.

Early stages of beach texture superimposition upon inherited glacial textures are presented on plate 6.3 (sample 2). Large unmodified conchoidal fractures (facing, upper and lower right) with a blocky V pit (centre right) and grain embayments are being modified by coarse, blocky edge abrasions.

Only supporting notes and photographic interpretation can provide documentary evidence of surface feature dominance, distribution and relative age. Contrary to the assertion by Mazzullo and Magenheimer (1987), that subaqueous transport cannot extensively alter grain shape, the present study suggests that in what may be considered to be a dual energy regime such as Long Island's south shore washed by lower energy waves for most of the time, and battered by less frequent extra tropical storms, large and medium breakages may occur.

Plate 6.31 illustrates the point well in sample 3 where large fresh conchoidal fractures cut across a more chemically modified and subdued grain background. Similar examples can be seen on plate 6.49 (sample 3) and 6.52 (sample 5).

Reference to supporting notes made during the main scan revealed a more detailed qualitative picture of surface feature assemblages and their dominance. On the basis of crosscutting textures, the sequence of surface textures seen in sample 3 may be interpreted from Table 8.1.

Such a sequence is interpreted as one of original source or glacial textures inherited from sample 1 (stage 1, Table 8.1), which have been modified by a prolonged period of silica dissolution and redeposition resulting in the formation of very extensive amorphous precipitation of the smooth capping layer type (stages 2 and 3, Table 8.1).

Release of sample 1's grains into the south shore beach environment produced both large and small breakages which were subsequently pitted chemically by seawater solution (stage 4, Table 8.1). Further transport alongshore may be creating a two tier system of very fresh breakages ranging from M.V's and straight and arcuate grooves which combine with both O.T's and irregular fine pits rounding edges and a progressively larger higher energy suite of small blocks and conchoidals and their large partners (stage 5,

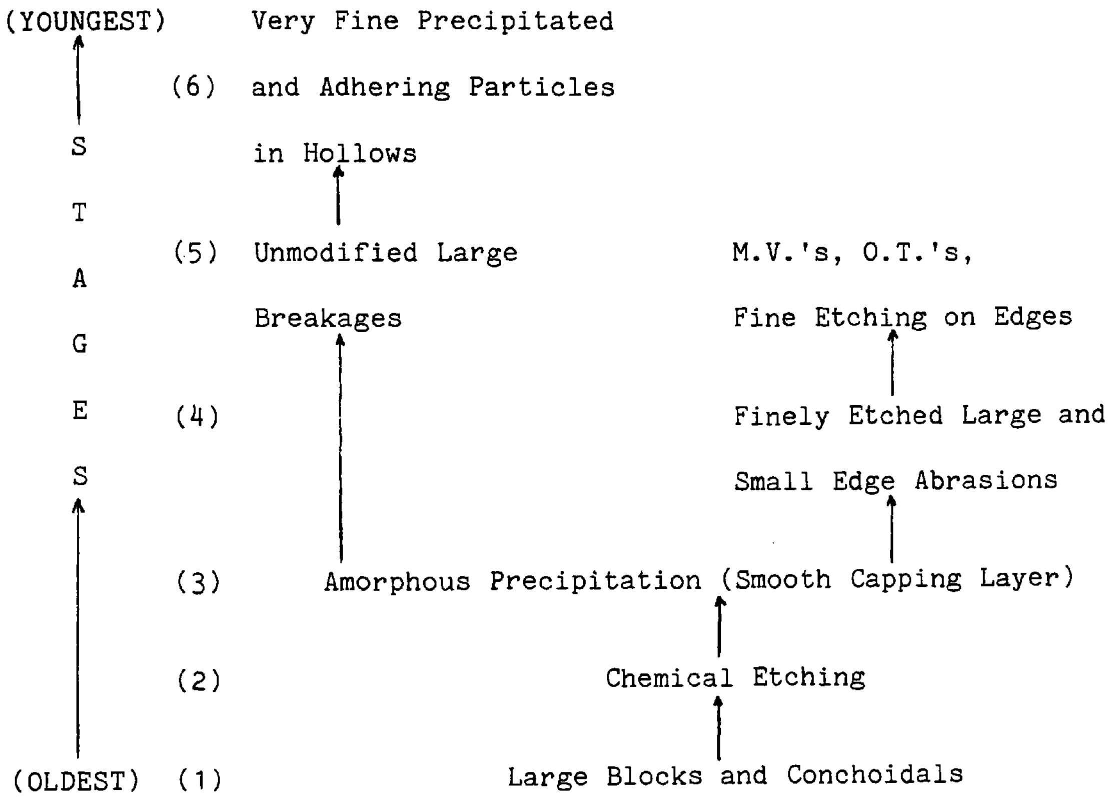


Table 8.1. Suggested stages in texture assemblages sequence, sample 3.

Table 8.1). The youngest surface feature appears to be that of small precipitated particles (snow) and finely comminuted particles inside fresh unmodified small and large breakages (stage 6, Table 8.1).

Examination of many grain edges suggests that minor abrasions go hand in hand with silica solution in the form of oriented triangular etch pits and fine irregular pits. Margolis and Krinsley (1971), studied surface frosting on grains from a variety of environments. Several frosted grains were included in samples for scanning although their locations on stubs were not recorded. They ascribed such frosting in subaqueous environments to seawater solution and abrasion solution. Subaqueous impact V pits were described as defrosting agents. These assertions may be pertinent to edges described from south shore samples.

"Littoral, shelf, fluviatile and deep sea sands occasionally contain frosted grains," ...... caused by "closely spaced oriented etch pits produced by the action of sea water on the abraded surfaces." (Margolis and Krinsley, 1971, p. 3403). Oriented triangular etch pits and their origins have already been described in Chapter 5. Abrasion solution has been described as a chemical process which related directly to continued grain impacts in the surf (Margolis and Krinsley, 1971). Grain-grain impacts may produce disordering and hydrating of grain surface layers generating finely comminuted amorphous silica particles which increases silica concentrations in waters surrounding grains. Whalley (1978b), has stated that such fine particles may go easily into solution.

From these assertions, the suggestion by Krinsley and Margolis (1969),that there may be a continuous gradation from O.T. dominated edges characteristic of low energy beach grains to M.V. dominated higher energy grains may be true. Certainly, most rounded edges on south shore beach grains exhibited small impact pit-fine etch pit combinations whether the latter were geometric in character or not. Often grain edge etching merged imperceptibly with oriented solution-precipitation textures in protected adjacent depressions. Examples of impact pit-etch pit assemblages will be presented in the sub-section on Fire Island beach samples later.

8.IV BURIED GLACIAL LOBE (CHANNEL H) OFFSHORE

Samples 20 and 21 did not resemble sample 1 in several ways (Fig. 6.1, Table 6.1), not least in their increased grain and edge roundness with 84% and 80% subrounded and rounded grains respectively. Mazzullo and Magenheimer (1987), have rejected the ability of sub-aqueous transport to alter grain shape significantly. However, if we accept Williams (1976), findings that samples 20 and 21 represent fluvioglacial or even parent glacial deposits, their increased roundness may be the result of edge abrasion during turbulent melt-water transport, chemical solution-precipitation during their passive cycle offshore or indeed a rounded original source.

The latter may be possible if glacial transport was high level and passive (Eyles, 1978). Examination of high energy and minor breakage abundancies in Table 6.1 support Williams (1976), glacial or fluvioglacial origin for these deposits. Only in the case of large blocks (surface feature 19 in Table 6.1) does sample 1 exhibit a greater abundance of high energy breakages. All the textures considered to be diagnostic of original source or glacial modifications are present in large percentages (surface features 15 to 23 in Fig. 6.1, Table 6.1) in offshore samples 20 and 21.

In order to determine the nature of sample 20 and 21's increased roundness, small edge abrasions (surface features 24 to 28) were examined and found to be ubiquitous. This may support the capacity of meltwater streams to round glacial grains at first sight. However, chemical solution-precipitation was found to have rounded some of sample 1's grains to give a microhummocky dulled surface. Similarly, grain edges may have been rounded chemically offshore. This is supported by the high percentages of amorphous precipitation (surface feature 34), fine etching (feature 33), and to a lesser extent coarse etching and oriented triangular etch pits (features 31, 32 and 40 respectively).

A closer examination of photographic evidence with supporting notes suggested the following texture superimposition sequence for offshore lobe samples as shown in Table 8.2.

Although many of sample 21's plates showed a good degree of rounding, there were many grains that had retained relict high energy breakages such as conchoidal fractures in hollows e.g. Plate 6.15. Such inherited textures may be a faded remnant of original source-glacial textures before emplacement in the palaeodrainage channel. Plate 6.9 (sample 21) shows such a high energy breakage or possibly late stage grain breakage. The strong contrast between sample 1 and offshore can be seen on plates 6.17 (sample 22) and 6.18 (sample 1).

The surface feature sequence presented for offshore lobe deposits above shows at least two major phases of chemical

YOUNGEST ↑	(3)	Fresh Angular Large Conchoidal Fractures ↑	Fresh Angular Small C.F. And Blocks ↑	M.V.-Etch Pit Edge Rounding ↑
STAGES	(2)	Amorphous Precipitation (Smooth Capping Layer) Coarsely Etched in Hollows with Strong Crystallographic Control and Reflecting Grain Relief ↑		
↑ OLDEST	(1)	Older Grain Surface with Conchoidal Fractures in Hollows, Itself Covered with Finely Pitted Smooth Capping Layer		

Table 8.2. Suggested stages in texture assemblage sequence, offshore lobe samples 20 and 21.

modification. The first one involves solution and redeposition of silica over old conchoidal surfaces. This may have occurred at any time between glacial emplacement and subsequent reworking by melt-water streams and deposition in its present offshore location when sea level was lower.

Plates 6.92 to 6.94 and Plate 6.97 show a much thicker more extensive smooth capping layer which overlies stage 1 in the sequence (Table 8.2). Its remarkably uniform nature and unusual geometric characteristics are shown on plates 6.92 to 6.94 for sample 21. Very small euhedral crystals and less well formed geometric solution-precipitation features were a hallmark of samples 20 and 21 and have been described in Chapter 6.

They do not represent gross secondary quartz overgrowths associated with diagenetic recrystallisation but are reminiscent of protocrystals of the silica globule type. In this study they are tentatively assigned to the period after deposition in the lobe and subsequent marine submergence. The reflection in fine detail of underlying relief (plate 6.97) and geometric characteristics have been assigned to slow solution-precipitation activity in low energy conditions (Krinsley and Doornkamp, 1973). An incomplete form of this feature may be represented by the texture seen on plates 6.102 and 6.103.

Superimposed upon stage two (Table 8.2), are mechanical breakages and more irregular pitting. These are more problematical to interpret owing to a lack of wave induced abrasion. Grain shape and edge shape abundancies presented in Table 6.1 would seem to be incompatible with the great variety of high energy breakages.

At the risk of dwelling for too long on offshore lobe sample surface feature characteristics, their relationships or contrasts to sample 1 and onshore beach samples are important for this study's grain surface history interpretation. It is also of intrinsic importance in view of the worldwide distribution of such continental shelf relict sediments.

Plates 8.1 and 8.2 from samples 1 and 21 respectively show clearly the increased edge roundness, cleaned surfaces and lack of dulling with silica plastering on sample 21's grains. Yet high energy original source-glacial features are preserved in sample 21's grain hollows. Plates 8.3 and 6.54 (sample 21) show relatively unmodified large smooth planar and curved fractures with low relief, the steps and meandering ridges providing the high relief. The relict hollow breakages are interpreted as stage 1 (Table 8.2) fluvioglacial-glacial features in the present study.

Proceeding to stage 3 in the sequence presented in Table 8.2, Plates 8.5 and 8.6 show edge rounding to be dominantly chemical in origin with some subordinate M.V.'s and fresh small conchoidals (Plate 8.5) and small V blocks with small hertzian cracks or straight and curved grooves (lower right edge on Plate 8.6).

A difference not brought out in checklist data is the nature of edge pitting (Plates 8.7 and 8.8). This has already been described as a problematical texture in Chapter 6. Many pits on Plate 8.7 are mechanical in origin but extremely fine and dense varying from M.V. to sickle shapes and irregular tiny blocks set in a smooth surface of apparently shallow dipping surfaces overlapping each other to the right. There is a crude orientation as shown in the chemically subdued version on Plate 8.8.

Perhaps lower energy offshore conditions produce slight impacts of low velocity, finely disordering the surface followed by chemical solution-precipitation on grain surfaces which have already been described as having unusually developed crystallographic control.

Therefore, offshore lobe samples are interpreted as glacially modified with superimposed fluvioglacial edge abrasion subsequently rounded in situ offshore. Modern edge abrasions may be the product of intermittent transport on the shelf during extra-tropical storms.

Lavelle et al (1978), observed considerable bottom sediment transport offshore, often influenced by the ridge and swale topography to the west (Fig. 2.3). In a study of palimpsest offshore sediments on California's shelf, Nordstrom and Margolis (1972), described high energy beach textures on such grains which they interpreted as relict features from a previous shore cycle, but considered the possibility of the ability of bottom currents and storm induced wave surges to duplicate such surf abrasions in situ offshore.

Middleton and Kassera (1987), found that grain size as well as turbulence were important controls of M.V. creation and density. In a study of an intertidal sand bar sample they ascribed M.V. abundance and density to current rather than wave regimes. Their rationale was based upon the fact that predominant traction, intermittent suspension and continuous suspension transport mechanisms were strongly dependent upon the relationship between grain size (and therefore settling velocity) and hydraulic characteristics. A good indication of the latter was the shear velocity which was related directly to shear stresses acting close to the bed and indirectly to turbulence strength (Middleton and Kassera, 1987).

Offshore lobe deposits from channel H were studied by Williams and Thomas (1989), and compared to samples from onshore beach, dune, inlet, overwash and flood tidal delta environments. Individual offshore lobe feature abundancies using S.E.M. analysis and a check-list approach were not presented, but on the basis of qualitative evidence their findings agreed in part with those of the present study except for edge abrasion and glacial textures. This may be due simply to operator variance or may represent an example of what may be an inherent problem in a checklist approach, which is how to define 'presence' for subjectively determined textures like edge abrasion.

One M.V. pit does not constitute edge abrasion but larger textures such as conchoidal fractures and blocks are more significant. In the present study a single occurrence of medium-small breakages and impact pits on one edge constitute edge abrasion in that it is representative of a discrete set of processes or even a single event such as a storm. Thus Plates 6.16, 6.17, 6.24, 6.39, 6.47, 6.67, 6.68 and so on are interpreted as forms of edge abrasion.

In the case of glacial textures Williams and Thomas (1989), found that offshore lobe grains either exhibited feature absence or heavy masking by subsequent modifications. Source-glacial textures have already been presented and described on many plates from sample 21 and interpreted as relict features preserved mainly in protected hollows. On these results this study does not wholly agree with Williams and Thomas (1989, p.13), who stated that, "Offshore delta lobe samples did not show distinctive glacial surface patterns."

Returning to the discussion of the capacity of a low energy shelf environment to produce edge abrasions, Bull (1981a), drew attention to the problem of equifinality of form. In other words, prolonged low energy grain-grain impacts offshore may be able to produce an edge abrasion assemblage of M.V. pits resembling higher energy onshore beach environments during shorter time spans. Increased roundness of offshore lobe grains with smoother surfaces may induce greater grain rotation during traction and intermittent suspension bringing only rounded edges into contact: a form of positive feedback loop between grain roundness and edge abrasion and implicit in the elastic impact theory (Kuenen and Perdok, 1962).

Fine M.V.'s and small mechanical breakages found on offshore lobe grains may reflect a subtle interrelationship between grain roundness, surface textural development and grain interactions in flow regimes within grain flows. Certainly, the blocky less mature edge abrasions described in onshore beach samples in Chapter 6 are absent in general on offshore lobe sample grains.

Perhaps grains with more angular outlines and edges onshore collide so that angular projections which may be rotating produce an arced hammer blow effect with more unidirectional stresses causing notches and irregular breakages to form. More rounded grains may be likely to collide so that there is a more uniformly directed stress pattern resulting in small partial Hertzian cracks (straight and curved grooves) and small dish shaped conchoidal fractures. In lower energy regimes such as those present offshore, bottom currents and storm induced wave surges (Lavelle et al, 1978), may produce the textures described on offshore lobe samples. Higher energies onshore in Fire Island would produce deeper M.V. profile blocks which mark the edges of small edge-blocky projections.

Grain-grain collision, either solid-solid contact or near approach deflection may develop during aqueous bedload transport of coarse sands at values four times greater than the critical threshold of shear stress (Leeder, 1979). A scratch on an edge would indicate a superficial prolonged grain-grain contact, whereas blocky topographies would need more prolonged grain-grain contact (Leeder, 1979).

Another factor not mentioned so far is the possibility of an onshore-offshore input (Williams and Thomas, 1989). This may apply to samples 20 and 21 on the basis of the presence of rounded and well rounded grains and their rounded edges. Plate 6.8 and 6.9 show elongated grains from samples 20 and 21 also described by Williams and Thomas (1989), which they ascribed to a different source than the rounded grain population from offshore lobes seen on Plate 8.9 from sample 21. Riester et al (1982), described two distinctive grain types offshore south of the study area, one of which represented immature less abraded forms and the other consisting of more mature abraded types. Williams and Thomas (1989), considered that the more abraded rounder grain types were represented by sediments adjacent to channel H samples.

In the present study these would be represented by samples 19 and 22 (Fig. 2.3). Sample 22 may concur with such an onshore-offshore input on the basis of grain shape, but Fig. 6.1 and Table 6.1 show that sample 19 east of channel H is more angular than samples 20 and 21.

In order to resolve palaeoenvironmental interpretation of offshore lobe and non lobe deposits it would be necessary to analyse grain surface textures along a transect offshore parallel to the present coast, as well as from deeper horizons in lobe deposits. In particular, similar buried channel deposits off eastern Long Island and eastern Fire Island need to be compared. It may be impossible to unravel accurately the sequence of major texture assemblage superimposition because of reworking by the transgressive shoreline as it advanced northwards after the Pleistocene. Williams and Thomas (1989), cited the possible cannibalising of an underlying fluvioglacial substrate as the Flandrian shoreline advanced northwards in order to compensate for material lost offshore to the trailing sand carpet. The need to maintain dynamic equilibrium between sediment supply, energy regime and barrier morphology would have necessitated such a mechanism.

8.V FIRE ISLAND BEACHES

Samples 8 to 18 along Fire Island have been described as showing a continuation of grain modifying trends from the Headlands section as far as grain shape and edge roundness are concerned. An interesting and somewhat unexpected result was that of a Moriches Inlet divide between the Headlands and Barrier beach sections. Fig. 2.4 shows that Taney (1961a) separated these two shore sections between sample 7 and 6 near Shinnecock Inlet, yet sample 7 from

Westhampton beach was usually associated with Headlands' samples on the basis of grain surface textures.

As stated in Chapter 6 very angular grains disappear and angular grain percentages fall sharply west of sample 7. Subangular and subrounded grains diverge markedly, rounded grains appearing for the first time. Fig. 6.5 shows that sample 7 is not associated with Fire Island beach samples at all on the basis of grain shape.

Williams and Thomas (1989), reported surface textures from both Moriches Inlet and Shinnecock Inlet samples which resemble those described for Headlands samples in the present study. Stressing the importance of leading-edge abrasion on inlet grains and accepting the presence of higher flow regimes in shallow inlet channels, they concluded that its dominance on inlet grains was difficult to explain.

Fig. 6.7 confirms the trend shown in Fig. 6.5 using edge roundness as a criterion. Although barrier inlets represent punctuations in the relatively smooth flow of littoral drift alongshore by removing small amounts of sediment landwards to form flood tidal deltas (Leatherman, 1988), no surface texture trend was presented by Williams and Thomas (1989), to suggest a Moriches Inlet divide rather than one for Shinnecock Inlet.

A control which has already been tentatively suggested and not related to south shore processes is that of a second buried channel lying across Fire Island immediately to the east of sample 8 (Fig. 2.3). The Smithtown-Brookhaven channel (channel I) in Fig. 2.3 is in a position to influence eastern Fire Island beach sand grain textures should there be an onshore sediment transfer.

One would expect channel I therefore to contribute to onshore beach grain roundness if this was the case. Sample 19 is east of channel H (Huntington-Islip channel) and represents a non-lobe offshore source. Although its grain shape category abundancies are comparable with onshore beach grains (Table 6.1), its edge abrasion and edge shapes do not. However, it is a non-lobe sample and closer to the shore than samples 20 and 21 (Fig. 2.3). No samples from channel I have been analysed in the present study so no inferences can be drawn, but the possibility of an offshore lobe influence southeast of sample 8 which may account for a Moriches Inlet divide in grain morphology trends alongshore may be borne in mind.

Reference to supporting notes showed several changes in surface texture pattern dominance to be taking place along Fire Island beaches. Edge abrasion became far more pronounced and dominated by small partial hertzian cracks (straight and curved grooves) often associated intimately with clean deep straight edged satellite V blocks. The latter texture may be distinguished from randomly oriented M.V. pits and sickle shaped notches which are smaller and shallower and rarely as regular. During the main scan such small V blocks were noted as small blocks (if larger) and M.V. pits when much smaller and not found in the same fracture as straight and curved grooves.

M.V. pits were associated with irregular and geometric etch pits (often oriented triangular etch pits) to form M.V. pit-etch pit assemblages already described for the Headlands' beaches. Invariably etch pits on grain edges graded into much better developed chemical etching in adjacent hollows.

The complete edge abrasion feature combination was rounding older high energy breakages. Very fine precipitated particles were reduced, and sample 9 was noted as exhibiting the first example of aligned smooth capping layer windows, with large isolated oriented triangular etch pits appearing in sample 10. An interesting development was that of the appearance of chattermarks more and more on rounded grain edges with a strong rucked appearance in this coastal stretch.

By mid-Fire Island a slightly altered texture superimposition sequence could be discerned.

Plate 6.14 (sample 13), and Plates 6.63 to 6.65 from sample 8 illustrate these points.

Figs. 6.1 to 6.13 and Table 8.3 illustrate Fire Island beach grain surface texture variability. Even allowing for a degree of environmental variation alongshore, such fluctuations are difficult to explain in terms of onshore processes. It is possible that Fire Island beaches are the site of offshore lobe site-specific onshore transport of fluvioglacial sediments. Inspection of Figs. 6.1 to 6.13 show that it is virtually impossible to be more specific on the basis of qualitative and subjective analysis. Any onshore links may only be uncovered with more objective statistical analysis presented in Chapter 7.

8.VI SAMPLE DISCRIMINATION

Chapter 7 has decribed in detail the results of canonical discriminant analysis, cluster analysis and factor analysis for the samples under study. Also some of the implications for Long Island's

STAGES			
YOUNGEST	(4)	Straight and Curved Grooves with Deep Satellite V Blocks ($5\ \mu m - 50\ \mu m$)	M.V. Pit-Etch Pit Edge Assemblage
	(3)	Large Fresh Conchoidals and Steps Being Abraded Along Meandering Ridges	
	(2)	Etched Amorphous Precipitation (Smooth Capping Layer)	
OLDEST	(1)	Solution-Precipitation Modified Relict Features in Hollows	

Table 8.3. Suggested stages of texture assemblage sequence on Fire Island beaches.

south shore and offshore environments have been discussed. On the basis of statistical results it was concluded that there is a statistically significant link between samples 20 and 21 and Fire Island beaches. Since sample sources are known in the present study and their grain surface textures described in relation to modern processes related to their environments and possible palaeoenvironments, the findings presented in Chapter 7 are self evident in their implications for Long Island's south shore.

In this section it is proposed to summarise the salient points in readiness for an assessment of the degree of success achieved by the statistical techniques employed for this project's sand grains.

In general, canonical discriminant analyses 1 to 3 were not successful in correctly predicting grain memberships in their appropriate sample locations. Canonical discriminant analysis 1 achieved 53.64% correctly classified while the reduced ten feature C.V. analysis 2 managed only 33.9% correct. Williams and Thomas (1989), managed a 66% correct classification for beach, inlet, washover, dune and flood tidal delta environments using stepwise multiple discriminant analysis in a study of Long Island's south shore environments. In a repeat analysis using two groups the degree of discrimination increased to 80% correctly classified.

Other workers have had variable success in discriminating between environments using discriminant analysis. Bull (1978a), achieved successful discrimination of cave sediments into groups which could be assigned to different sources using cluster, linear and multiple discriminant analyses.

This study concurs with the statement expressed by Williams and Thomas (1989), that the homogenisation of samples and surface features inhibit classification. However, having said this, it is possible to employ a technique in order to use a negative result for a positive purpose, in this case the misclassification of samples 20 and 21 grains for onshore Fire Island beach samples.

The question remains as to whether the failure of discriminant analysis to discriminate between samples at a high level has any repercussions for subsequent statements about the significance of the misclassification values. Qualitative results have shown that samples were very closely related on the basis of their checklist surface texture abundancies. Discussion has shown that surface texture superimposition sequences differ mainly in terms of the reordering of abundancies and crosscutting relationships of the same surface textures. Perhaps the fundamental raw material input for statistical analysis based upon binary data of presence-absence is not subtle enough to discriminate between such closely related samples.

Culver et al (1983), obtained 100% correct classification of reasonably different environmental samples: Aeolian (hot), Millstone Grit regolith, Beach, Glacio-fluvial, Sandstone source rock, Aeolian temperate, Glacial and Grus. In a second reduced feature analysis they achieved 97.5% correct classification. However, it was not stated whether samples were related geographically and generically in the same way as Long Island's south shore samples. Aeolian (hot), Aeolian (temperate) and some others were probably unrelated. Further, Mazzullo and Magenheimer (1987), have stressed the importance of a priori knowledge of the environmental or lithological source in studies of grain morphology.

Given the fact that discriminant analysis was not particularly successful in differentiating between all samples, it is argued for this study that results have achieved the primary aim of examining onshore and offshore links. Figs. 7.1 and 7.6 show a degree of separation of Headlands' samples from Fire Island beaches which may be the best that can be expected in the circumstances. It is not suggested that circles drawn around mean plots represent natural statistically distinct clusters,only that with a priori knowledge of sample sources the Moriches Inlet divide shows up in each diagram.

Subjective inspection of the patterns in Figs. 7.1 and 7.6 by another person may result in a different interpretation without a priori knowledge of sample site locations and the geomorphology of Long Island's south shore. In order to support this distinction, a battery of other diagrams based on statistical results and checklist data were employed. The territorial map shown in Fig. 7.5 tentatively supports the Headlands-Fire Island group distinction.

In each diagram sample 1 is always associated with Headlands samples and is itself distinctive and samples 20 and 21 are associated with Fire Island beach samples. Fig. 7.7 shows each sample's scatterplot for C.V.1 against C.V.2 in C.V. analysis 2 and may be used to interpret the degree of homogeneity of samples by means of inspection of their spread about the sample centroid.

Grid squares have been drawn on plots in Fig. 7.7 in order to better appreciate sample location and spread. Table 7.9 gives the code for the computer lettering assigned to samples and each sample is named at the top of each plot.

Superimposition of such scatterplots upon each other may be used to interpret sample to sample similarity and hence the links between any two may be deduced on the basis of south shore geomorphological processes. Such overlays are presented in Figs. 7.8 to 7.12 and their relationships already discussed. The trends which come out of these overlays include the homogeneity of Fire Island samples and their relationship to samples 20 and 21 and the lack of homogeneity within Headlands samples (Fig. 7.12) and their less well defined relationship to sample 1.

This may be interpreted in terms of the superimposition of one set of environmental modifications upon an older set. Headlands' samples derived from sample 1 type sediments still retain relict textures in abundance. Sample 1 has already been interpreted in this study as being of mixed provenance with a combination of an angular strained granitic source and more rounded grains from other sources. This mixture would be reflected in a lack of homogeneity in Headlands samples.

The tight grouping and superimposed clustering of Fire Island beach samples reflects the degree to which beach modifications have removed initial Montauk Point source relict textures. This may be interpreted as a testament to the efficiency of Long Island's south shore as a grain surface texture modifying environment. This interpretation fits the descriptive results and the known geomorphology of Long Island's south shore beaches. The fact that samples 20 and 21 are so closely related to onshore Fire Island beach samples in Figs. 7.9 and 7.10 also supports earlier qualitative and quantitative interpretations.

In order to clinch the offshore-onshore link Figs. 7.13 and 6.14 are cited. The former graphs proportions of mispredicted grains from offshore samples in canonical variate analysis 2 and those samples in which they were misplaced, while Fig. 6.14 graphs the percentage variations between sample 21 to onshore samples.

Inspection of sample overlays and mean C.V. plots show that sample 19 in particular is not closely related statistically to other offshore samples. This was possibly on the basis of its increased grain angularity and edge angularity compared with samples 20, 21 and 22, as well as reduced minor breakage abundancies (Table 6.1). This suggests that nearshore sediments south of Fire Island are more complex than originally thought. Figs. 7.1, 7.5 and 7.6 show samples 18 and 19 to be less related to Fire island beach samples than the Headlands section. Thus while sample 22 which is a non-lobe offshore sample may be categorised as one of the more mature abraded types described by Riester et al (1982), and Williams and Thomas (1989), sample 19 does not fit this category.

8.VII DIAGNOSTIC SURFACE FEATURE IDENTIFICATION

The results of discriminant analysis in this project support the findings of Margolis and Kennett (1971), Krinsley and Doornkamp (1973), Whalley and Krinsley (1974), and Culver et al (1983). This is that discrimination is extremely complicated and no single feature is able to perform the task. Canonical discriminant analysis 1 identified 16 feature variables for canonical variates 1 and 2, while canonical discriminant analysis 2 listed 6 separate variables out of the 10 used in the reduced feature analysis (Tables 7.3 and 7.10). Culver et al (1983), found that 13 out of a possible 20 features were needed for discrimination. If 90% of variance is taken as the benchmark for the amount of variance which is desirable for discrimination then canonical discriminant analysis 1 would have used a lot more variables.

In canonical discriminant analysis 1 grain shape and edge shape accounted for 5 of the 13 discriminating variables for C.V.1 and C.V.2; edge abrasions for 3; high energy breakages for 2 with the rest being made up of very fine precipitated particles, dulled surfaces, adhering particles and high relief, medium relief and coarse etching. Of these the first 5 with the largest correlation for C.V.1 were subangular edges, M.V.'s, late stage complete grain breakage, angular edges and subrounded edges. For C.V.2 in canonical discriminant analysis 1 subrounded edges, adhering particles, subangular edges, edge abrasion and rounded edges were the first five.

In other words the development of edge rounding alongshore in the surf, or lack of it in sample 1 and edge shape offshore appear to have separated this study's grains into a Headlands group and a Fire Island beach-offshore lobe group. This is supported by C.V. analysis 2 where M.V's, edge abrasion and rounded edges were the first three variables for C.V.1, and adhering particles, very fine precipitated particles and edge abrasion for C.V.2.

Supporting factor analysis results confirmed and amplified discriminant analysis 1 (Table 7.5). Factor 1 was ascribed to edge abrasion features and hence an important control of edge shape as well as grain relief which was the category assigned to factor 2. Factor 3 was assigned the title high energy breakages. The results of surface feature clustering have been described in Chapter 7 and portrayed in Fig. 7.4 and used to generate the reduced 10 feature checklist in canonical discriminant analysis 2.

In order to test the validity of C.V. analysis 2's weighting of discriminating feature variables C.V. analysis 3 was carried out and its results listed in Fig. 7.12 which ranks them in order of significance based on F values.

Culver et al (1983), found that while certain textures were important environmental indicators others served only as cosmetic detail and that the same textures may not be the pre-eminent discriminators in every case. In this study it was considered to be important that discriminating variables should be linked to environmental processes on the basis of discriminated sample groupings. It is inferred from the result of both qualitative and quantitative analysis that edge abrasion and associated edge shapes may reasonably be linked to a Headlands and Fire Island beach-Offshore separation.

8.VIII QUALITATIVE AND QUANTITATIVE ANALYSIS - ASSESSMENT

This study's results support the findings of Bull (1978a), and Culver et al (1983), that a checklist approach supported by statistical analysis is a valid and reliable method of S.E.M. analysis of quartz grain surface textures and their interpretation. During the initial stages of this study it was felt that some feature abundance-dominance should be incorporated into the analysis. A Setlow-Karpovich (1972), approach however proved to be unworkable (Williams et al, 1985). The task of composing a suitable checklist was therefore considered to be of vital importance since it establishes the quality of the net which discerns major grain surface characteristics.

The use of surface textures such as very fine precipitated particles and oriented solution-precipitation surfaces is defended on the grounds that they were noticeable grain surface features observed during the training scan and represented a part of grain surface textural mosaics (Whalley, pers. comm). Bull (1978a), advised that features of unknown or controversial origin should be examined closely in order to draw inferences regarding their environmental conditions of formation, if not the causal factors.

In retrospect, oriented solution-precipitation surfaces proved to be an umbrella term for a variety of geometric chemically modified surfaces and thus give only subsidiary evidence regarding chemical crystallographic control in addition to euhedral precipitation and oriented triangular etch pits. On the other hand very fine precipitated particles represented the youngest cycle of chemical action on Headlands' sample small and large breakages.

Bull (1978a), stressed the importance of the quality of initial data input. It would be of little use if a checklist was 'congested' with surface textures normally used to diagnose environments as distinct from those on Long island's south shore as hot deserts which would introduce too much noise into the data. On this basis one would expect every S.E.M. study to be specific to the geology of its sample sources in terms of checklist composition. It may be some time in the future before a standard surface feature net can be applied across a range of environments.

An area which needs to be clarified is what constitutes 'presence' during surface feature scans. Culver et al (1983), recommended that qualitative features such as roundness and relief should be excluded from statistical analysis on the basis that presence was inevitable for such features within the texture category. This would have implications for subsequent statistical analysis. This study suggests that such duplication may also occur for other surface textures e.g. minor breakages such as M.V. pits, straight and curved grooves and small conchoidal fractures-blocks with edge abrasion; late stage complete grain breakage with large conchoidal fractures etc..

It was observed repeatedly during scanning that there were many textures' subvarieties sometimes lumped under one heading and at other times included as separate textures. Williams and Thomas (1989), were probably correct in their assertion that homogeneity in terms of the causal mechanisms of surface features and the lack of rigorous parameters which may be used for subaqueous grain S.E.M. studies are major stumbling blocks.

The problem of surface feature dependence in statistical analysis was discussed by Bull (1978a). It is possible to relate many checklist textures to each other and some generic control. In an attempt to examine this problem the present study used X^2 analysis to determine surface feature correlations used in canonical variate analysis 2. The results show that some expectedly high correlations occur between members of small surface feature subfamilies such as M.V.'s and edge abrasion, but some less expected apparently generically separate relationships also occur.

It is felt that in order for S.E.M. analysis to advance, the problem of grain surface feature interdependence must be resolved in order that results from multivariate analysis can be interpreted more reliably. The major problem involved in such a task is that mutually independent surface features per se may be difficult to relate to environmental processes within the study area. There may be a danger of sacrificing geological significance for statistical significance.

It is wholeheartedly accepted in the present study that it is essential for qualitative and semiquantitative analysis to be supported by statistical analysis. In this sense it supports the recommendations of Culver et al (1983), that a thorough investigation should contain both qualitative and quantitative elements.

Results presented have attempted to follow these recommendations. Descriptive results supported by photographic evidence confirmed most personal and therefore subjective impressions of sample locations during scanning. They also supported detailed notes made during scanning. This confirmed the present author's opinion that even though sample identity is unknown operators can identify samples on the basis of a visual scan.

Statistical results have been interpreted as less than successful from the point of view of the ability of discriminant analysis to separate samples successfully. However, given the similarity of samples it is doubtful whether any form of statistical analysis could achieve separation of what are essentially beach grains from a single relatively uniform stretch of coast. In the event analysis managed to distinguish between a Headlands group and a Fire Island-offshore group.

C H A P T E R   9

C O N C L U S I O N S

CONCLUSIONS

1. On the basis of photographic, descriptive and statistical evidence presented in this study it is concluded that there is a link between offshore samples 20 and 21 and onshore Fire Island beach samples. This is interpreted as an onshore movement of sediments from site specific locations such as offshore lobe deposits.

2. The S.E.M. methodology of using a checklist to score the presence and absence of a multiplicity of textures is considered to be a valid and reliable approach to S.E.M. analysis of quartz sand surface textures when sample differentiation and sample affinities are sought.

3. The known glacial source derived from Montauk Point consisting of Ronkonkoma terminal moraine is considered to be a distinctive source on the basis of its grain morphology which may be related to a possible mixed provenance of a strained crystalline source and other sources which may include metamorphic schists but exclude non-quartz cemented and aeolian sources.

4. The Headlands section of Long Island's south shore forms a distinct unit on the basis of its close affinity to the known glacial source at Montauk Point. The possible mixed original source-glacially modified characteristics derived from sample 1 are reflected in the heterogeneous nature of Headlands section grain surface feature assemblage cohesiveness.

5. Fire Island beach samples form a separate and distinctive group divided from the Headlands section by Moriches Inlet. This may be ascribed to two controls:

(i) A possible site specific onshore movement of buried channel deposits from the Smithtown-Brookhaven buried lobe channel offshore east of sample 8 in eastern Fire Island and the Huntington Islip Channel, on the basis of marked grain morphology variations.

(ii) An increase in grain and edge roundness induced by increasing distance of transport alongshore which incluences the nature of surface feature impacts. It is inferred that a positive feedback loop may occur between edge and grain roundness and the nature of surf induced edge abrasion.

6. Offshore lobe samples 20 and 21 are distinct from sample 1 on the basis of increased roundness and edge abrasion. This may be ascribed to a previous fluvioglacial transportation cycle and chemical modifications induced during the passive standstill offshore.

7. Sample 19 is not as closely related to lobe samples 20 and 21, as sample 22 which shows greater surface texture affinities. This presents a more complex picture for offshore sediments than that of the two-group mature-abraded and less mature-unabraded grains suggested by Riester et al, (1982).

8. The dominant textural modification alongshore is one of edge rounding caused by a mechanical-chemical process combination which does not substantially erase sample 1 characteristics

until much further west of Moriches Inlet.

9. On this basis the assertion by Mazzullo and Magenheimer (1987), that subaqueous transport is unable to significantly modify grain shape is rejected to a certain degree.

10. Edge abrasion appears to be more complicated than would seem at first sight as far as subaqueous transport is concerned. The existence of fresh M.V. pit-etch pit, partial hertzian crack, small conchoidal-breakage block and large fresh breakage texture assemblages suggest that subaqueous transport may be able to overcome the impact reducing effects of water cushioning suggested as being significant by some earlier workers.

11. There appears to be at least a two-tier edge abrading assemblage consisting of a finer M.V. pit-etch pit combination and block producing small conchoidal fractures (straight and curved grooves with satellite V blocks). Since turbulence is considered to be relatively uniform alongshore this may be a product of increased grain and edge roundness.

12. Surface feature fluctuations in Headlands' samples which may not be ascribed to beach modifications or sample 1 heterogeneity may reflect an onshore input of non beach grains from the bifurcated channel deposits of buried channels J and K in eastern Long Island.

13. Discriminant analysis is as valid a statistical technique for determining sample affinities on the basis of binary data

generated by S.E.M. analysis using a checklist approach as for sample differentiation. This involves a priori knowledge of sample site location and is based upon subjective evaluation of sample grain misclassifications.

14. Cluster analysis is rejected as a valid technique for establishing sample affinity when such similar sediments as those along Long Island's south shore are considered.

15. Both discriminant and factor analysis succeeded in identifying significantly diagnostic grain surface feature variables which could be married to environmental processes considered to be chiefly responsible for grain surface modifications alongshore.

16. Grain surface feature interdependence should be an important area of future research if multivariate statistical analyses are to be more reliably interpreted. This relates to the original composition of checklist features and poses the dilemma of reconciling process-related but dependent families of textures with independent textural assemblages which appear to have less cohesive environmental significance but produce more statistically significant results. In addition, future studies along Long Island's south shore and offshore should include analysis of an offshore-onshore link. In particular, a shore-parallel transect to include all buried palaeodrainage channel deposits would be important, as well as comparisons with their opposite numbers onshore.

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