THE ARCTIC BEACH ENVIRONMENT,

SOUTH-WEST DEVON ISLAND, N.W.T.

THE ARCTIC BEACH ENVIRONMENT, SOUTH-WEST DEVON ISLAND, N.W.T.

By

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A Thesis

Submitted to the Faculty of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

May 1969

MASTER OF SCIENCE (1969)
(Geography)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: The Arctic Beach Environment, South-West Devon Island, N.W.T.

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NUMBER OF PAGES: xi, 152

SCOPE AND CONTENTS:

Investigations have been carried out in the southern Queen Elizabeth Islands, N.W.T., to determine some of the features and characteristics of the beach environment in that area of the Canadian Arctic Archipelago. Analysis of beach material from three locations, mapping, profiling, measurement of tidal cycles, and a study of ice conditions have provided some insight into the processes acting upon these beaches. The period when those wave processes which operate freely at lower latitudes are active in the study area is less than two months in the year. The role of ice in preventing wave generation and restricting wave action in the littoral zone greatly reduces the level of marine processes in this sheltered environment. Numerous ice-push ridges were recorded and mapped, but the characteristics of the beach result primarily from the action of infrequent storms. Comparisons with other arctic areas, Cape Thompson and Point Barrow, Alaska, and the Sverdrup Islands, indicate the variety of conditions which exist within the arctic region. These may be related to exposure, or fetch, and the distribution and movement of sea ice which determines the length of time for which waves processes can operate in the littoral zone.

ACKNOWLEDGEMENTS

The work was carried out under the supervision of Dr. S. B. McCann to whom the author is greatly indebted for advice, assistance, and guidance. The initial opportunity for undertaking field-work in this area was offered by Dr. F. G. Hannell; logistic support was provided by the Arctic Institute of North America and Polar Continental Shelf Project (Department of Energy, Mines, and Resources). In particular, Polar Shelf, through the offices of Dr. E. F. Roots and D. L. Lindsay, have given direct assistance in terms of radio facilities and aircraft. Field-work was carried out with the aid of Dr. McCann, R. L. Cox, and the author's wife, Beti Wyn; much is owed to their help in obtaining the data and in discussion of problems in the field.

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I should pray but my soul is stopt.
This is a bombast world: fig-trees,
Snow, macacos, ocean's hurl
And surf and surge, on applebough
As crag whose cave holds kraken or
With comb of coral mermaid cuddles.
All's mad majesty and squander,
And x and y or zodiac
Excreting wizard mathematics
Like a slew of ebbtide worms
Won't solve it. ....

Ralph Gustafson 1960

CHAPTER I

INTRODUCTION

"The zoning of coastal processes by latitude has been described in general terms, but the matter has not yet advanced beyond a statement of facts" (Zenkovich 1967).

(i) Purpose:

This study was undertaken to provide information concerning the form and sediments of, and the processes operating within, the modern beach zone in an arctic environment. Whereas the analysis of littoral processes in temperate and tropical latitudes proceeds at an ever increasing pace, few detailed studies have been attempted on high latitude beaches. The only systematic contributions to the understanding of beach processes and features in the North American arctic are the studies made in the vicinity of Point Barrow, Alaska by such workers as Rex, Hume, and Schalk, and at Cape Thompson, Alaska, by Moore. Various problems have been touched upon by other authors, notably Horn (1967), in describing sedimentary environments in the Sverdrup Islands, and, Ellis and Wilce (1961), in a discussion on aspects of the littoral ecology of Frobisher Bay. With regard to Eurasia, Zenkovich (1967 p. 169-173) mentions Russian contributions in this field, but these again are few.

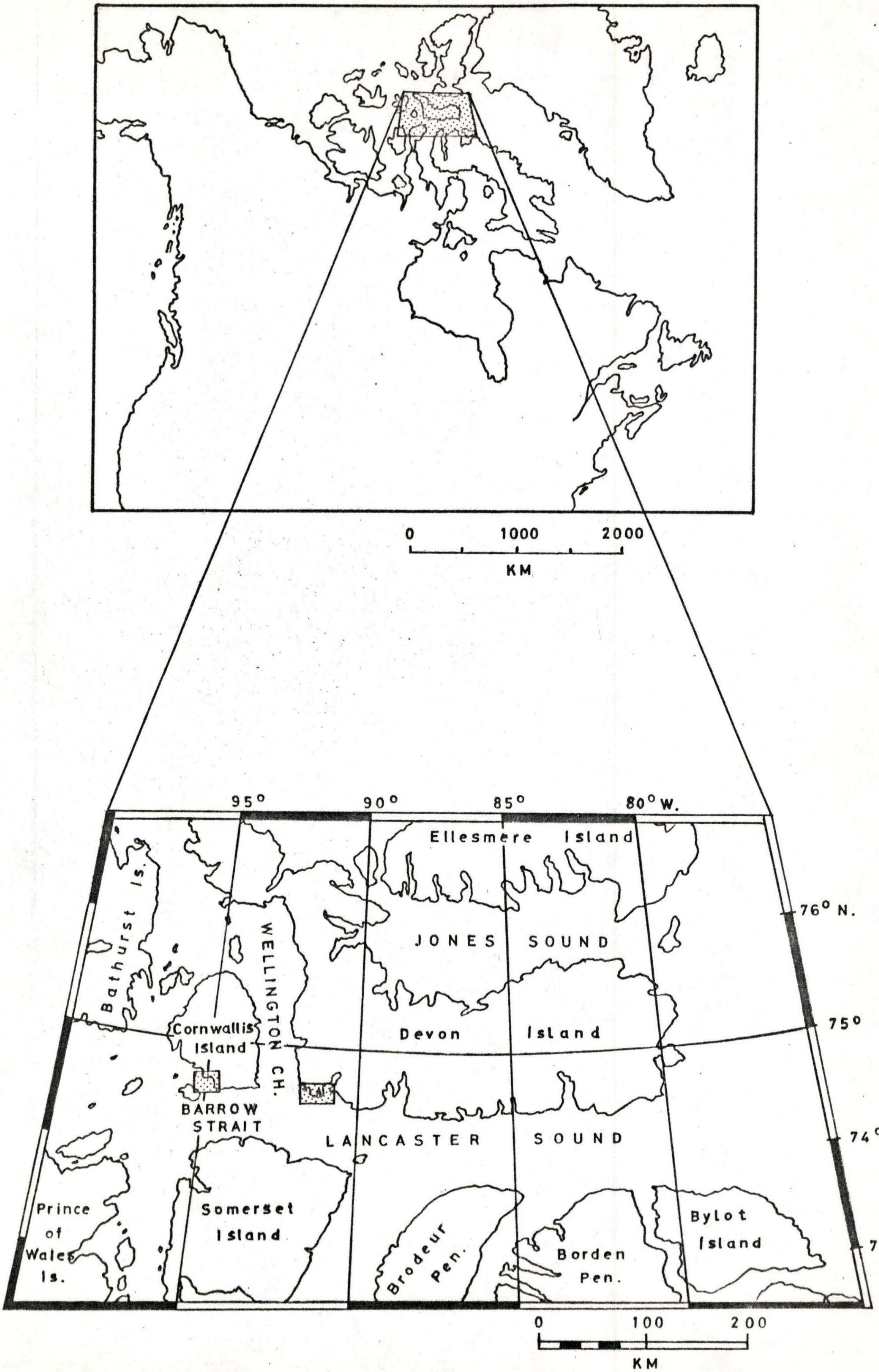
(ii) Location:

Field work was carried out during July 1967 on Allen Bay, near Resolute, Cornwallis Island, N.W.T. (74°41' 95°00'). This area was also visited in the summer of 1968, but due to the interest aroused in the subject matter a more suitable area was selected so that the continued investigations would be more fruitful. Greatest effort was directed towards the Cape Ricketts foreland (74°37' 91°23'); western Radstock Bay (74°43' 91°10'); "Walrus Bay" (74°38' 91°23'); and Beechey Island (74°44' 91°48'); which are on the south-west coast of Devon Island, N.W.T. (Figures 1 and 2).

Part of the value of this enquiry in the eastern Arctic Archipelago is to provide and discuss data from a high latitude area which is similar to Point Barrow, yet possesses a very different type of process environment, being essentially sheltered within the arctic islands. The collection of data was carried out on a systematic basis with particular emphasis on Cape Ricketts, which was occupied as the base camp through a ten week period in the summer of 1968. Reconnaissance studies and sample collections were made in the vicinity and a second camp on Beechey Island enabled the investigations to be extended to that area for one week in August 1968. Work on Allen Bay, Cornwallis Island, in 1967, was undertaken as part of an integrated scheme on the geomorphology of the Resolute area, this was directed by Dr. S. B. McCann, to whom the author was an assistant (see Hannell 1968). Observations at Allen Bay were possible in 1968 during the stop-over periods between Resolute and Devon Island.

FIGURE 1

Location of Study Areas.



0
1000
2000
KM
95°
90°
85°
80° W.
Ellesmere Island
76° N.
75°
74°
73°
JONES SOUND
Bathurst Is.
WELLINGTON CH.
Cornwallis Island
Devon Island
BARROW STRAIT
LANCASTER SOUND
Prince of Wales Is.
Somerset Island
Brodeur Pen.
Borden Pen.
Bylot Island
0
100
200
KM

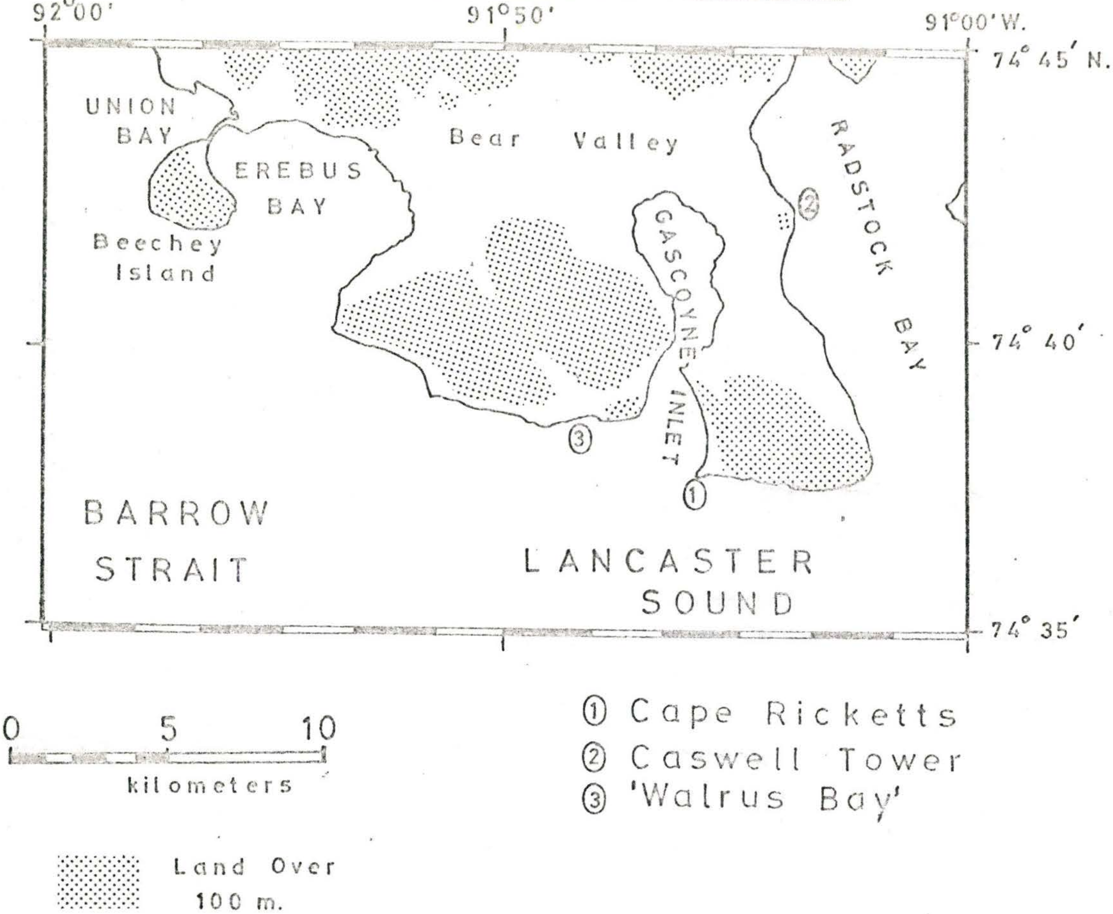
FIGURE 2

South-west Devon Island

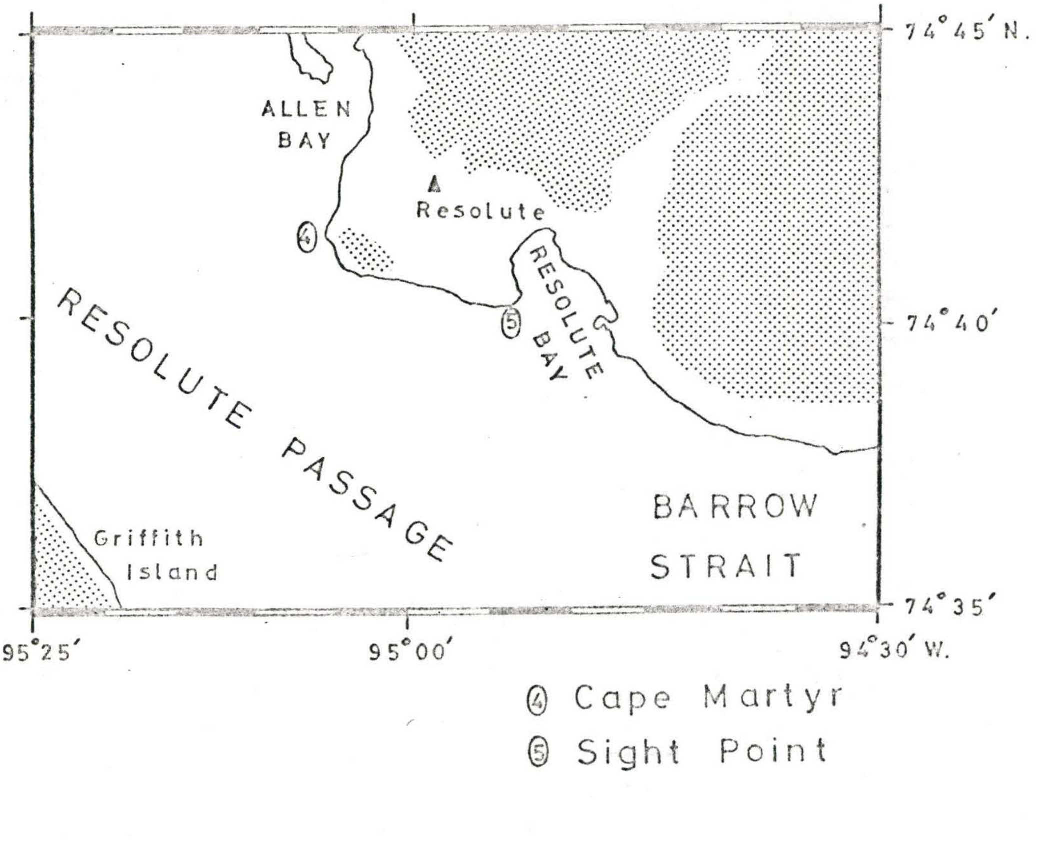
and

Resolute Bay.

SOUTH-WEST DEVON ISLAND



RESOLUTE BAY, CORNWALLIS IS.



(iii) Methods:

In order to obtain an understanding of the beach environment some of the processes were measured directly, whilst others are considered in terms of the features which are produced by their actions. A precise network of survey stations was established by triangulation, from this a series of tidal observations and beach profiles were measured, using levelling techniques, at intervals from ice-locked conditions through to open-water. From the survey network, tacheometric mapping of beach ridges, ice mounds, and ice-push scars was carried out in the modern beach zone. As an indirect measure of wave action, samples of beach material were collected systematically and analysed for size and roundness characteristics. The areal variation of these parameters gives an indication of wave sorting and direction of sediment transport, and allows comparisons to be made with beaches in lower latitudes. Sub-surface profiles of the frost-table in the beach zone were measured with a hand-auger, to estimate changes in the volume of beach material available for reworking at different periods during the summer season.

CHAPTER II

PREVIOUS INVESTIGATIONS

(i) Beach Studies:

Although many early explorers such as Leffingwell (1919) and Stefansson (1921) made notes and observations on beaches and coastal areas in the Arctic, Washburn (1947) was the first to discuss in any detail the processes operating in the beach zone, and his ideas are particularly concerned with observations on ice shove and ice rafting of sediments. Nichols (1953 a, b) made similar note of features produced by ice action in the Resolute Bay area. These forms related to ice were an obvious and interesting topic of discussion, but little emphasis was placed on the relative roles of wave and ice action in the beach zone.

Nichols' initial studies in the arctic, and subsequently in Antarctica, led him to suggest in 1961 that there are certain beach features which are peculiar to polar areas:-

(i) beaches resting on ice

*(ii) pitted beaches

*(iii) ice-pushed and ice-deposited beaches

(iv) truncated beaches resulting from ice-removal

*(v) ice-rafted beach material

*(vi) poorly rounded beach material

(vii) frost cracks and patterned ground features

(viii) striations caused by sea-ice and ice-bergs

*(ix) gaps cut by melt-water streams

(x) features due to ice-contact and glacio-marine deposits

(xi) ventifacts

(xii) presence of cold-water fossils

(xiii) preservation of soft parts of marine organisms.

Each of these features is discussed by Nichols and his account provides a useful view of polar beaches in their own right. The limitation of this work is that criteria normally employed for describing temperate and tropical beaches are not referred to and the emphasis on these somewhat special characteristics, which are due largely to the presence of ice, provides a restricted view of polar beaches. Those features which were observed in Cornwallis and Devon Islands by the author are noted with an asterisk in the above list, and are discussed in Chapter VI(ii).

The work which has been carried out at the Arctic Research Laboratory, Point Barrow, Alaska, is of particular importance in the provision of information and ideas regarding arctic beaches. The first paper on this area was published by MacCarthy (1953), who attempted to consider local erosion in terms of ice and wave processes. This was followed by Rex's work (1955) which looked at the offshore zone and especially the effect of ice grounding in shallow water to form underwater ridges. Rex's main contribution in "a case study of arctic beach processes in an area of minor astronomical tides" (1964 p. 384) was to consider beach changes and sediment transport, and, perhaps more important, to describe the formation of the 'ice-foot'. This is produced by wave spray freezing on the beach during the fall, a glaze of ice, which protects the beach from further wave action, is formed first, and then the ice-foot proper develops, eventually becoming joined to the main pack-ice later in the winter.

Hume and Schalk carried out a long-term systematic study of the Point Barrow beaches from 1954 to 1964. This was the first attempt to investigate the processes on arctic beaches over several seasons and provides much information regarding changes through time. Schalk (1957) was concerned particularly with changes in the beach and near-shore zones, and detailed surveys and wind data were used to comment upon the growth of a submerged bar after a particularly large storm. Whilst Schalk collected samples from the area under investigation, a fuller description of the variation of sediment size in the offshore area is given by Werner (1959). Hume (1963) worked on sedimentation and movement of material, using accumulative samplers, swash samplers, and precise beach profiles. Attempts were made to correlate longshore movement of material with wind, wave, current, and tidal observations which were recorded over a two year period. The conclusions in this respect are summarized in Figure 15 (Hume 1963), and provide an important insight into yearly net transportation of sediments in this area, which is in the order of 10,000 m^3. After comparing processes and physical transport in this area with those of lower latitude beaches Hume concludes that the same processes are in operation, though the actual quantities of material moved and the relative importance of the different processes vary. He also suggests that the protective role of beach and sea ice is important in limiting wave action.

The variation of processes as reflected in beach erosion and accretion is discussed by Hume and Schalk (1964 a), whilst the role of ice as an active process is also considered (Hume and Schalk 1964 b). With regard to ice-push, the authors conclude that, although the volume of ice involved may be large and travel as much as 40 m inland, the amount of beach material affected by such forces is less than 10 per cent of the total volume of sediment available for reworking. Various other results from these stuaies, such as a discussion of the 'flotation' process (Hume 1964) and relative changes of land and sea during the past 2,000 years (Hume 1965), have added to a more complete picture of the beach zone at Point Barrow.

The most important of this series of papers (Hume and Schalk 1967) considers the effect of a major storm in relation to normal processes. This brings to light the importance of the magnitude of infrequent, devastating storms - "a single storm moved more sediment in a few hours than would normally be transported in twenty years" (1967 p. 100). The value of this paper is enhanced by the amount of data collected during the years prior to the storm, and this has enabled the authors to present meaningful comparisons of sediment movements over the long- and short-term periods.

A series of field observations carried out at Ogotoruk Beach, Cape Thompson, north-west Alaska (68°N. 165°W.), are reported by Moore (1961). The results show well sorted beach sediments with a clear variation in material grain size and type of sediment across the beach zone, this is related to the break-point zone of the waves. Use is made of wave data in discussing erosion and deposition in terms of changes in wave characteristics. A broader discussion of the investigations (1966) mentions the development of a beach prism, some 100 m wide and up to 6 m thick, in the active zone. The amount of sediment transport is calculated from a formula developed using the relationship between wave height, surf angle, and rate of longshore movement. The net sediment transport through the study area was of the order of 28,000 m^3 during the four month ice-free period of 1960 (July 1 - October 21).

Although the tidal range in this area is only 0.4 m Moore considers the beach processes to be very similar to those in lower latitudes except for the presence of an ice-foot, or kaimoo, during fall and winter. The exposed position of the beach in relation to the Bering Sea to the south-west, enables sufficient wave generation for normal beach processes to operate, whilst only approximately 1% of the study area was disturbed by the movement of pack-ice during break-up. The role of ice in this area is a purely negative one, acting only to protect the beach rather than producing any features which may be specifically related to the action of ice. Moore concludes - "during the ice-free summer season the arctic beach differs little from beaches in other places", and states that, generally, "a beach deposit formed at a high latitude will be difficult to distinguish by its geologic record from one formed at a lower latitude" (1966 p. 606-7). Although this may hold true for the Cape Thompson area the generalization should not be extended to all arctic beaches. This part of north-west Alaska borders on the northern Pacific Ocean and the presence of sea-ice in summer is not significant in affecting beach processes, as is the case for those shorelines on the periphery of the Arctic Ocean or in the Canadian Archipelago.

The first academic discussion of the beach environment in the Canadian Arctic Archipelago is provided by Horn (1967), based on the evidence of nine beach samples from the Sverdrup Islands (79°N. 100°W.). In this area it was found that the physical energy of processes in the beach zone is very low and that sorting processes operate on a greatly reduced scale. It is an area which is ice-free for less than two months in the year and the presence of pack-ice passing south-east through the Islands imposes further restrictions on wave processes, during most of the summer there is a continuous supply of pack-ice from the polar ice area to the north-west. The effect of ice grounding on the beach appears to be of greater importance here than along the coasts of those islands to the south.

Horn divides beach sediments into two categories which are closely related to the type of coastline. The first of these is associated with beaches in areas of rugged relief, and the sediment is essentially talus with little evidence of sorting once the detritus reaches the water's edge. Samples taken from this type of beach exhibited poor to extremely poor sorting, using Folk and Ward's verbal scale (1957). The second category is associated with beaches in areas of low relief, and here the material is better sorted, but Horn attributes this to the textural properties of the parent rock. Whilst sorting is better, it is still in the poor to very poor range. Using Moment Measures for the statistical interpretation of the sediment characteristics Horn suggests that these beaches "cannot be equated with (those) of ice-free areas of the world. Detritus delivered to the coast remains essentially unaffected by hydrodynamic processes such as waves, surf, and tides" (1967 p. 103).

It is of great importance to note here that the studies carried out at Point Barrow and Cape Thompson, Alaska, and in the Sverdrup Islands, have all been on 'arctic beaches', in the broad sense of the term. The contrast between the results in these areas could not be greater, and the use of the classification is one which requires qualification.

With regard to the remainder of the Canadian arctic, very little work has hitherto been carried out. Robitaille (1959) presents some observations on certain beach forms on south-east Cornwallis Island, and Ellis and Wilce (1961) have undertaken ecological work in the inter-tidal zone of Frobisher Bay, Baffin Island. Some general comments on beaches and coastlines in the Archipelago are given by Roots (in Fortier et al 1963). McCann and Owens (1967) carried out a series of investigations in the Resolute area, and the results from this work will be incorporated in this study. For the rest, most coastal work has been carried out on raised beaches with reference to isostatic-eustatic movements since the Pleistocene (vide Müller and Barr 1967 for an example of this approach on north-east Devon Island).

A summary of Russian studies is given by Zenkovich (1967 p. 169-173). It is noted that no evidence of abrasion by ice has been found, and that the main effect of ice in the beach zone is a protective one. Popov (1959) is quoted - "a fairly thick surface layer of beach shingle froze when temperatures fell below zero", near Gelendzhik on the Black Sea. From the brief discussion of the effects of ice it appears that similar forms to those found in North America have been described on the Eurasian arctic coasts, including shove ridges ('korgi') and hummocks ('stamukhi'). Further analysis of the information collected by Soviet researchers is hampered by language difficulties.

General discussions of world beach types (McGill 1958; Davies 1964) make reference to the arctic region, which is outside the storm-wave environment and sheltered from swell waves. Reference has already been made to the fact that the term 'arctic beach' covers a broad range of environmental conditions from the relatively oceanic beaches of Cape Thompson to the ice-locked coasts of the Sverdrup Islands. Results available from investigations in Alaska and the Sverdrup Islands provide a valuable source of information for comparative purposes, but in terms of the vast literature on beaches in other areas of the world there is a great lack of knowledge concerning arctic beaches. In particular, no work had been undertaken in the sheltered environment of the Canadian Archipelago. The investigations reported here therefore represent an attempt to partially fill this large gap so that more meaningful discussion may take place about the littoral processes of this area which, as Horn points out, - "is at the low end member of the spectrum of energy levels encountered in the beach environments of the world" (1967 p. 98).

(ii) Oceanographic and Ice Distribution Studies:

Studies of the physical and chemical properties of waters of the Arctic Archipelago are few. Other than geological and geophysical works, the most useful contribution in the area of study is that of Collin (1962) on Lancaster Sound, which provides the background for the hydrographic setting (Chapter II (iv)). Reference has been made to the investigations of Horn (1967), which were concerned more with sedimentation than bathymetry and oceanography. Work is still in progress on the North-Water Project in northern Baffin Bay (Dunbar, Dunbar, and Nutt 1967), which is a study of the physical and chemical characteristics of the sea in that area. Whilst these investigations provide information regarding the nature of the water and the offshore zone, a knowledge of the circulation characteristics is particularly valuable in the understanding of ice distribution and movements. As an example of this, the character of the water and the circulation, as mixing takes place between Wellington Channel and Barrow Strait, helps to explain the presence of a 'polynya' in Barrow Strait which is important as an ice disintegration centre (Schule and Whittman 1958).

In a discussion of littoral processes one of the major factors is fetch and in this area of the arctic where fetch varies according to the distribution of ice some knowledge of the ice cover and ice movements throughout the summer is essential. McCann and Owens (1967, table 2) have used aerial observations of ice movements and fetch directions, and related them to wind directions and wind speeds to show that wave generation possibilities are limited, as a result of the low coincidence of winds with long fetches of open water. In terms of wave propagation the distribution of ice is a crucial factor in permitting or inhibiting shoreline processes even during the so-called 'open-water' period.

Basic data concerning the ice cover of the Arctic Archipelago is given by Allen (1964), in the form of break-up and freeze-up dates, and by Swithinbank (1960), who presents a resumé of all the data available until the advent of recent detailed aerial reconnaissance surveys. More valuable is information related to the pattern of break-up and subsequent movement of ice, and work in this field has been carried out by the Geographical Branch, between 1956 and 1963, and later by the Polar Continental Shelf Project, both of these organizations being within the Department of Energy, Mines, and Resources, Canada. Lindsay (1968) references the data available from these surveys (vide Black W. A., Lindsay D. G., and Seifert W. J.). The Department of Transport (Meteorological Branch), Canada, has presented its aerial ice observations and reconnaissance reports in a series of circulars, which are listed by Lindsay (1968 p. 44-45).

A study of the retreat of the ice front and break-up patterns enables an accurate estimation of the duration of the 'open water' period. Markham (1962) points out, for example, the movement of ice westwards along the southern shore of Cornwallis Island during periods of light or south-westerly winds, and also discusses (1963) the importance of frontal depressions, passing over this area of the southern Queen Elizabeth Islands, in relation to the movement of ice to the east. These useful short works by Markham result from a comparison of meteorological data and ice reconnaissance information. Lindsay (1968) similarly uses the aerial reconnaissance data to discuss the annual variations of ice break-up, distribution, and movement, as a means of ascertaining the more general characteristics of the ice conditions in this area. This account is useful in that it is concerned with the duration of the ice-free period and provides an indication of the variety of conditions which may be found in any one season. With regard to Lancaster Sound, Lindsay points out that an ice-front 'retreats' west from Baffin Bay to a position between Prince Leopold Island and Maxwell Bay from May through mid-July, before moving rapidly west to southern Cornwallis Island in late July (this is discussed further in chapter IV (iii)).

It is possible to consider ice conditions in terms of the duration of the ice-free period, of wave generation possibilities, and of the movement of pack-ice, all of which are important in discussing the overall characteristics of sea-ice at any locality in any one season. This knowledge is important and necessary in a process study as fetch varies according to the ice distribution whilst pack-ice or floes dampen existing waves. Even with 'open water' ice may still be present on the beach, protecting it from littoral processes. A full investigation therefore requires a detailed study of local and regional ice conditions over a long period.

CHAPTER III

THE SETTING

(i) The Geologic Environment:

The geological history of the southern Queen Elizabeth Islands has been outlined by Fortier and Morley (1956). Sedimentation occurred over the area, in the Franklin Geosyncline, from the Cambrian through the Devonian. Orogenesis in the early and late Devonian periods interrupted deposition and since the Cretaceous most of the eastern Islands have been subject to sub-aerial agencies. To the north-west the Sverdrup Basin continued to accrete sediments during the Tertiary, these originating from westerly flowing rivers which eroded the area to the south and east as it continued to be uplifted.

The local geology of south-west Devon Island and Cornwallis Island has been discussed by Fortier et al. (1963) and Thorsteinsson (1958) respectively. The Read Bay formation (Middle-Upper Silurian) extends over all of the area under consideration. These beds are mainly a dolomitic limestone with some interbedded conglomerate limestone, argillaceous limestone, and calcareous shale. Cornwallis Island represents one distinct fold zone in the Innuitian Region, whilst south-west Devon is part of the less disturbed Jones-Lancaster Basin (Figure 3). The lower Palaeozoics of this area have been estimated at a minimum thickness of 5,500 m (Thorsteinsson 1958). In west Devon they are

FIGURE 3

Structure of the Arctic Archipelago.

(after Fortier & Morley 1956)

PRECAMBRIAN SHIELD ROCKS

UNFOLDED MIOGEOSYNCLINAL SEDIMENTS: CAMBRIAN - DEVONIAN

CRATONIC BASIN SEDIMENTS: ORDOVICIAN - SILURIAN

MESOZOIC AND CENOZOIC SHELF SEDIMENTS

Innuitian Orogenic Region:

NORTHERN ELLESMERE EUGEOSYNCLINAL FOLD BELT

EUREKA SOUND GEOSYNCLINAL FOLD BELT

MIOGEOSYNCLINAL FOLD BELTS

tilted to the west, in the local Devon Homocline, whilst the folded miogeosyncline of the Cornwallis Fold Belt has beds dipping to the north-west and north.

The region was eroded during the Tertiary uplift and a plateau, the Barrow Surface, between 330 and 400 m in elevation, was formed, which is a dominant feature of the landscape (Bird 1959). Erosion was carried out by north-west flowing streams and it is suggested that these followed graben fault lines (Fortier and Morley 1956), and that downcutting during emergence of the land gave form to the present-day Parry Channel (that is, Lancaster Sound and Barrow Strait). The subsequent development of an easterly flowing drainage pattern, with the watershed to the west of Cornwallis Island, continued this process to give form to the pattern of channels which now separate the islands of this part of the Archipelago. Collin's investigations on the bathymetry of Lancaster Sound support this hypothesis, concluding that - "the present pattern of channels and islands has been formed by a combination of early Tertiary sub-aerial river erosion modified later by differential uplift that determined the original drainage outline at a time when the area was above sea-level, and by glacial erosion during the maximum ice stage of the Pleistocene which widened and deepened the existing valleys" (1962 p. 61).

Opinion varies on the extent of glaciation during the Pleistocene in the Queen Elizabeth Islands, though the consensus is for a series of local ice-caps (Craig and Fyles 1960) which only modified the landscape in detail, the greatest effect being in terms of isostatic recovery rather than erosional or depositional forms.

The marine limit in this area, as indicated by numerous raised beach sequences, may be as much as 130 m (425 ft) (Thorsteinsson 1958). There has been a eustatic rise of sea-level in the order of 67 - 70 m since 14,000 B.P., with relative stability (±6 m) since 6,000 B.P. (Fairbridge 1960; Godwin, Suggate, and Willis 1957). This has given a net isostatic recovery in the range of 150 m.

Although many investigations have been concerned with the limit of marine action and broad patterns of isostatic recovery, little information is available on present rates of recovery. Collins (1951) estimates a continuing emergence of the land relative to sea-level in the order of 0.15 cm per year in the Resolute area, using archaeological evidence, though Robitaille (1959) regards this value as too high. Henoch provides evidence (1964 a, b) from archaeological sites on Melville Island, for a maximum possible emergence of 1.8 m in the last 1,500 years (this would give an annual rise of 0.12 cm). Roots (in Fortier et al. 1963 p. 179) cites evidence for a net downward vertical movement of about 3 m in the last 10,000 years at Cape Sparbo, north-east Devon Island, and suggests a similar trend on Cornwallis Island (ibid p. 178) and on Bathurst Island (ibid p. 582). This may tie in with data published by Hume (1965) for Point Barrow which indicates a lowering of sea-level between 0.6 and 1.0 m since the eleventh century. Moore's work in the Cape Thompson area (1960) leads him to conclude that - "sea-level rose about 3 m during the last 5,000 years, and that the rise was characterized by minor fluctuations with an amplitude of 1 - 2 m. The highest stand of sea-level since the Wisconsin stage was attained in the nineteenth century" (1960 p. B337). It would appear therefore that the trend of net emergence continues but with variations, possibly greater than 1 m, within this trend. Without direct local evidence from the southern Queen Elizabeth Islands firm conclusions must await further investigation, although it may be added here that the results of this study suggest continuing emergence, however slow (see chapter V (iii)).

(ii) The Geomorphic Environment:

A full discussion of the state of knowledge regarding present geomorphic processes in the high arctic is given by Bird (1967). The aspects of the environment which are relevant to this study are concerned with the sub-aerial agencies which supply material to the beach, or directly affect the beach zone. Paramount in this respect is rock weathering.

Evidence of chemical weathering, in the form of a limestone pavement formed by fissure solution, has been observed on the upland plateau of Beechey Island (160 m) but in general mechanical weathering, especially frost shattering, is the dominant process. A particular example of this is a felsenmeer which has developed to the west of the Resolute air-field (McCann and Owens 1967 p. 8).

Due to the prevalence of frost riving nearly all surface material is very angular, this being particularly evident on the talus slopes. As there is no effective agency for the sub-aerial erosion of rock fragments, all material that is derived from the supra-tidal zone is of a very angular nature, even material derived from the erosion of raised beach deposits, which has previously been abraded to some extent, has been subject to frost action and shattering (photograph 1). This type of breakdown is very evident in the Read Bay formation as the dense, fine-grained dolomitic limestones shatter into sharp-edged, irregular-shaped plates (Bird 1967) (photograph 2).

Surface drainage in the areas studied appeared to be ephemeral and not well organized in surface channels. The effect of this is to provide few stream outlets on the beach and consequently there was no area where supply of material in suspension was concentrated. The removal of fines from the slopes above the beach is therefore difficult to measure and an assessment of its importance in supplying material to the beach can only be given from indirect observations. In considering surface drainage an understanding of the frost-table is necessary, as a large volume of melt-water is made available during the thaw period. Most streams were observed to be in flood for only a two or three week period which coincided with the period of maximum temperatures. Cook (1960) shows that 80% of the 1959 flow of the Meecham River, near Resolute, occurred in approximately ten days in June - July.

The depth of the frost-table is a very important aspect of the beach zone, as the depth of the active area conditions the amount of removable or reworkable beach material (chapter V (ii)). It was found from investigations that the frost-table extended beneath the beach to at least the Low Water Mark (Figure 23).

The character of the coastline of south-west Devon Island is essentially that of an upland plateau area truncated by cliffs which were cut back at a time when relative sea-level was about the same as at present. Submergence, possibly as much as 130 m, occurred after the coastline had reached approximately its present position. Little erosion took place during this period but a series of beaches were deposited as the sater receded, giving numerous sequences of raised beaches. The cliffs along the coast of south-west Devon are protected only by narrow beaches at their base, these consisting of talus deposits being reworked in the littoral zone. Roots (in Fortier et al. 1963) discusses many of the features of the coastlines of the Central Arctic Archipelago and stresses the greater importance of deposition features such as spits and deltas in the present process environment, suggesting that wave erosion is negligible because the periods when the beach or sea is free of ice are few and brief. The presence of many deltas in this region of the Central Arctic may be cited as evidence of the inability of waves to remove fluvial sediments from the mouths of rivers. Bird (1967) suggests that longshore drifting is rarely strong in this area, and that spits tend to be simple constructional forms unlike the often complex features in the western arctic and Alaska.

In the area under investigation on south-west Devon Island, vertical cliffs, often greater than 200 m high, exposed at their base to wave action, are found to the east of Cape Ricketts, and 'Walrus Bay', and on the southern half of Beechey Island (see Figure 2). The narrow beaches at the foot of these cliffs are rarely more than a few meters wide, and often below High Water Mark. By contrast, much of the remaining shoreline exhibits sequences of raised beach deposits, with individual ridges less than 1 m high but extending up to 100 m above sea-level. Several large depositional marine features are evident in this area, particularly in Union Bay and Erebus Bay where a series of spits has developed, as well as a tombola linking Beechey Island with the mainland. The foreland of Cape Ricketts is undergoing erosion on the southern edge and the development of beach ridges does not indicate that this is a major constructional feature, but rather results from littoral processes reworking material brought into the beach zone by emergence of inshore deposits (see chapter IV (iv)).

(iii) The Climatic Environment:

A knowledge of wind speeds and directions is necessary for an understanding of sea ice formation and break-up patterns in the Queen Elizabeth Islands. As Dunbar points out (1964), the movement of depressions across the Parry Channel, and the associated wind patterns, is particularly important to a comprehension of ice removal. Also ridging under wind action, during the formation period in winter, allows a greater volume of ice to form compared to a year when winds are light. Even after break-up is completed in any one area floes may be driven onto beaches by wind action. Similar attention to direction and speed of winds over given fetches is required to estimate and understand wave generation possibilities during the open-water season, particularly as this is a region where all waves are formed locally.

Wind data is available from Resolute for the years 1947 to 1967, though Collin (1962) notes that the wind values from this station are subject to topographic influences and may not truly reflect the regional conditions. Rae (1951) points out that winds from the northeast are consistently 7 - 15 km per hour stronger than those from other directions (although this is only applicable to the 1947 - 1950 data, when the anemometer was located at Resolute Bay rather than at the airstrip). Resolute winds, therefore, are affected by local topography as well as the regional constraints also outlined by Collin.

A summary of the Resolute wind data by Thompson (1967) indicates that in the period 1951 - 1960 the prevalent wind direction was from the north-west, for eleven months of the year. This agrees with Rae who shows that ten months in the year had a prevalent direction from the north-west during the 1947 - 1950 period. This means that for most of the year winds are blowing off the land in the area under consideration.

A knowledge of air temperature is of value in understanding the amount of ice formed during the polar winter, the volume being dependent on water and air temperatures, as well as dates of freeze-up and amounts of snow (Lindsay 1968). Similarly, this is important in determining when the ice forms on the beach in the fall, thus protecting it from further wave action. Air temperature and ablation are the factors controlling the speed with which the beach is freed of its protecting snow and ice cover in the early part of the summer. It is the protection afforded by this fast-ice which prevents wave action from being effective after the sea-ice has broken and been removed.

Using Thompson's summary of the Resolute temperature data, only three months of the year have an average above 0°C, whilst six months have an average less than -20°C. The summer period is restricted to June, July, and August, thaw temperatures during the remaining nine months are rare. Of the 541 degree days (with a mean daily temperature above 0°C) between 1951 and 1960, 96 occurred in June, 258 in July, 177 in August, and 10 in September (Thompson 1967).

(iv) <u>The Hydrographic Environment</u>:

The tides of this area are "mixed, mainly semi-diurnal: two high waters and two low waters with inequalities in height and time reaching the greatest values when the declination of the moon has passed its maximum" (Dohler 1966 p. 3). The maximum and mean tidal ranges decrease westerly along the Parry Channel, from a nodal point in Baffin Bay. Values for east Radstock Bay are given as 2.77 m and 1.74 m, those of Beechey Island are 2.71 m and 1.70 m, whilst at Resolute this decrease is even more evident with ranges of 2.07 m and 1.28 m (Canadian Hydrographic Service 1968). Tidal data collected at Cape Ricketts is described and discussed in chapter IV (i).

The general easterly movement of water through Barrow Strait and Lancaster Sound is supplemented by an influx of water from the Wellington Channel moving south through the Islands. This easterly current is particularly strong on the south side of the Parry Channel and its velocity has been estimated at 88 km/day (Gadja 1964). Collin (1962) reports a permanent west flowing current on the north side of Lancaster Sound which may attain a width of thirteen kilometers. This current affects the coast of south-west Devon Island, whilst the coast around Resolute experiences a similar west flowing current which originates from Wellington Channel, causing an opposite movement on the north side of Barrow Strait. A knowledge of the general and local circulation in this area is relevant to the pattern of ice removal after break-up, particularly when winds are too weak to control the movements of ice floes.

With regard to local currents, little is known, however on calm days ice was observed to move west along the southern shore of Cape Ricketts, this was probably an expression of the westerly drift discussed by Collin. As all waves are generated locally and there is no influence of swell, wave-induced currents would be expected to be dependent upon conditions existing at, or shortly before, a given time. The prevalence of winds from the northern sector means that for much of the time when open water exists winds are blowing offshore in this area. Of importance also is the variability of winds during the summer period. Rae (1951) points out that atmospheric pressure conditions are less stable during the summer than in the winter months and this coupled with the eastward passage of depressions does not allow the generation of waves over one fetch for any length of time. Wave-induced currents therefore would be variable.

The infrequent storms must be considered an important element in process studies (see Hume and Schalk 1967), as waves over restricted fetches with variable winds do not produce any consistent pattern of wave and current action. The effect of one large storm may be more important than that of local waves during the open water period, and it is suggested (chapter V (iii)) that this is the case on Cape Ricketts. This concurs with the hypothesis of Wolman and Miller (1960) whose magnitude and frequency concept suggests that maximum magnitude of processes is related to a low frequency. Thus the influence of the rare, large storm, or catastrophic event, is important in the production of major elements of the scenery. This can be seen with reference to storm-beach ridges which are above the level of beach processes, except during the relatively infrequent periods of storm-generated waves.

The short period and length of waves means that refraction can only take place close inshore in the Cape Ricketts area, where the off-shore slope is relatively steep (Figure 4). The wave base in this area is less than 10 m, so that refraction would only occur within approximately 20 - 30 m of the beach. Around Beechey Island this is not the case and the development of the tombola, and some of the spits and bars, is related to the relatively shallow offshore zone (Figure 5). Submarine and littoral processes in Union and Erebus Bays extend over a wide offshore zone, allowing wave action to be more effective in the sorting and transportation of sediments, which leads to the development of the many spits and bars in this area. Shoreline features around Gascoyne Inlet are less affected by deposition, due to the submarine form of the embayment. Sediments are easily transported into the deep offshore zone rather than being redistributed within the littoral zone.

FIGURE 4

Bathymetry of Gascoyne Inlet and

Cape Ricketts Area.

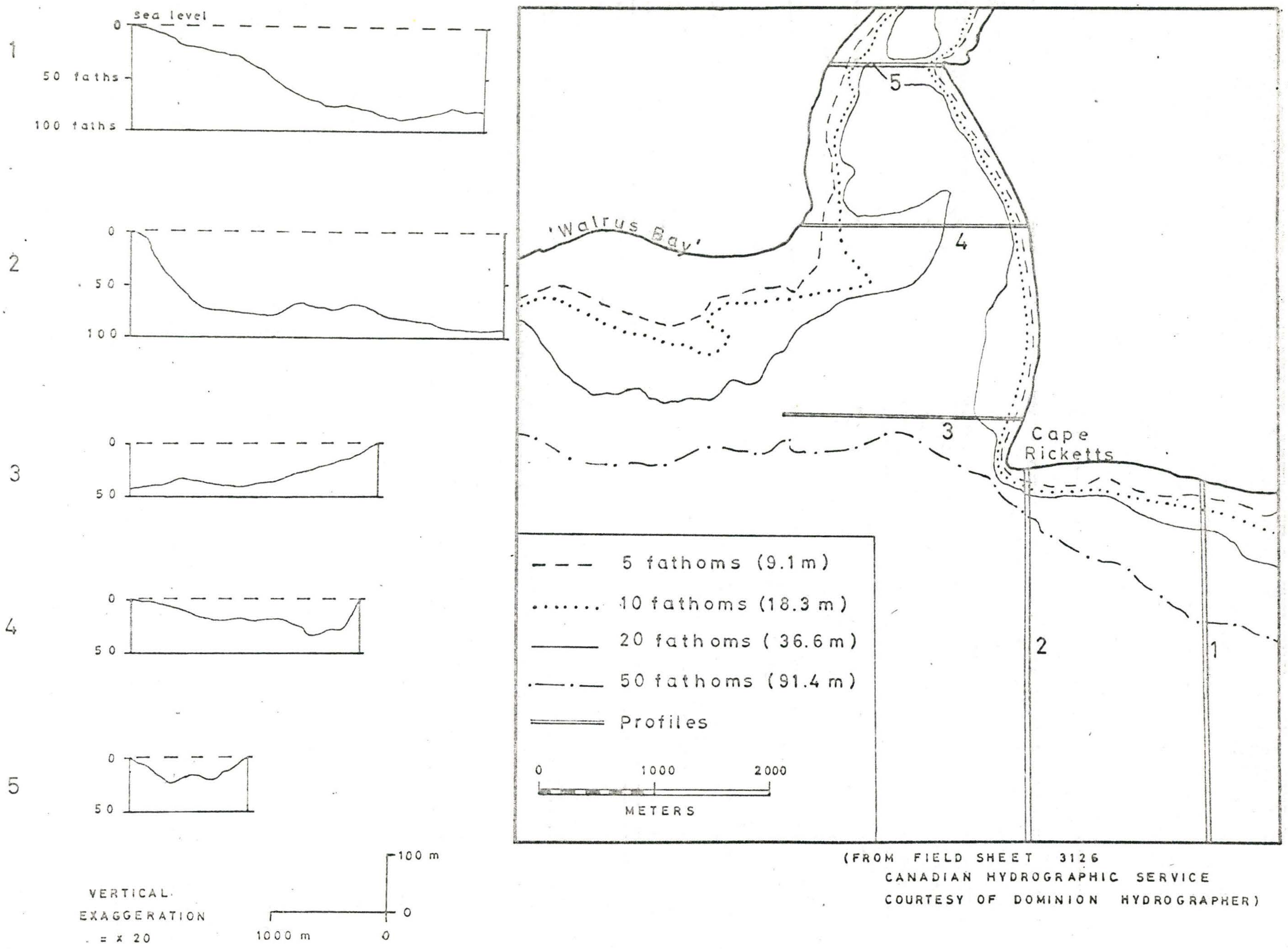
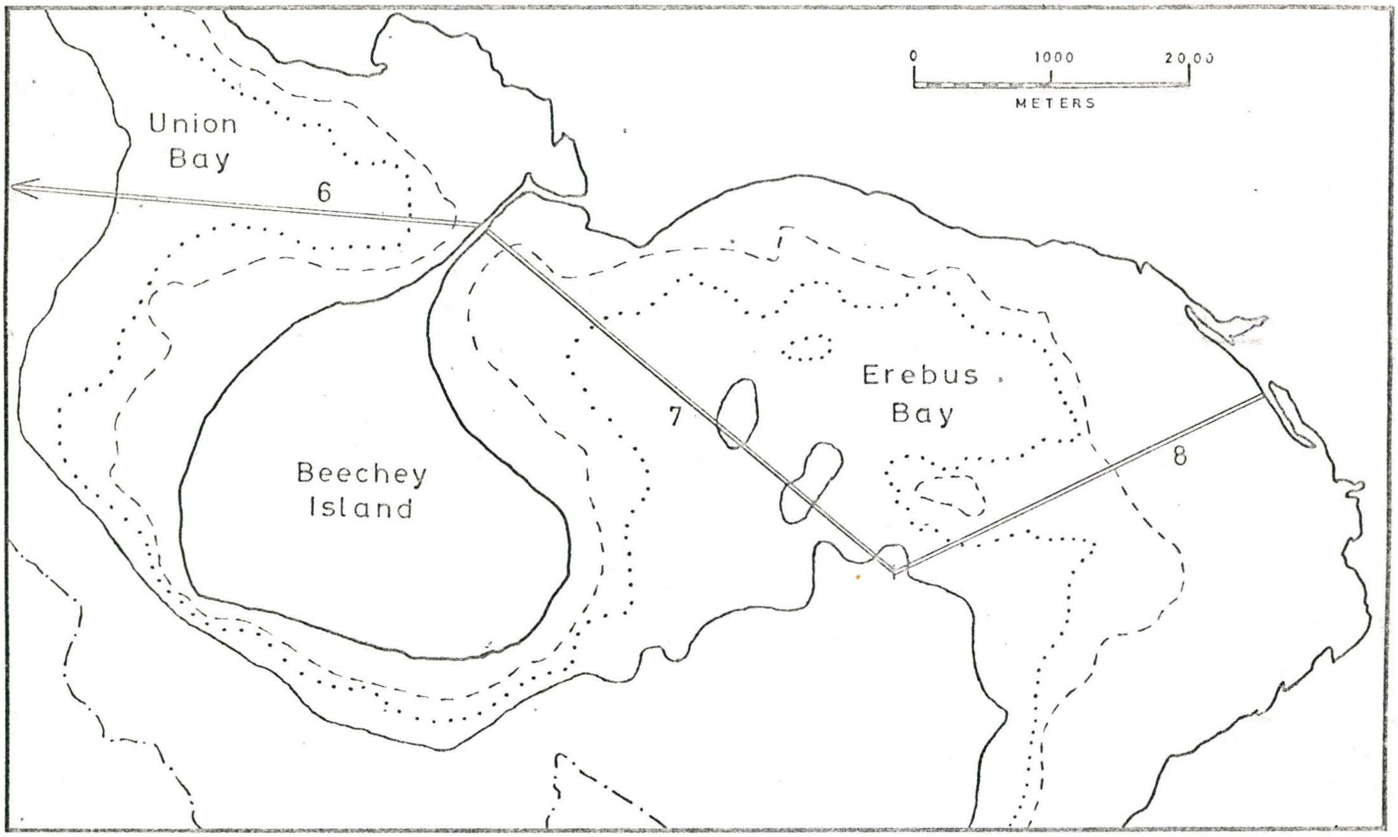
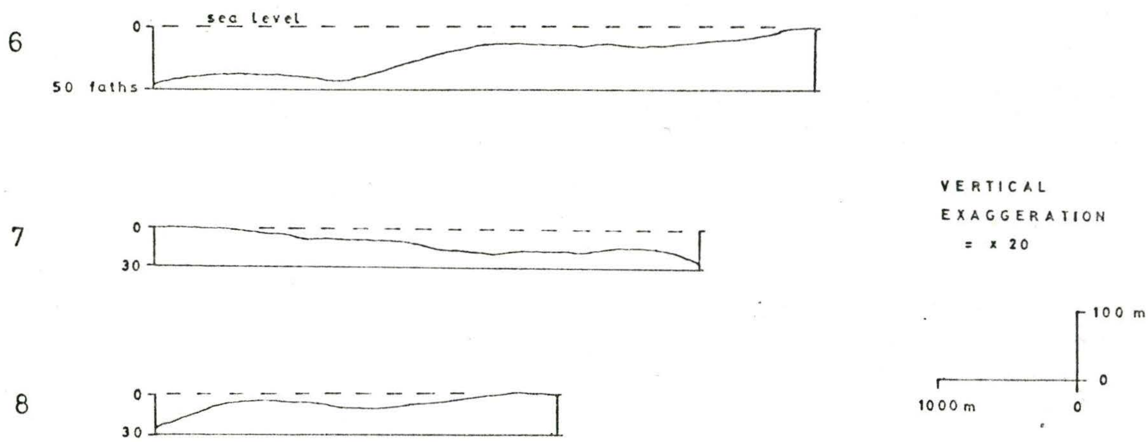

1
2
3
4
5
Sea level
0
50 faths
100 faths
0
50
100
0
50
0
50
0
50
VERTICAL
EXAGGERATION
= x 20
100 m
0
1000 m
0
'Walrus Bay'
Cape
Ricketts
5
4
3
2
1
5 fathoms (9.1 m)
10 fathoms (18.3 m)
20 fathoms (36.6 m)
50 fathoms (91.4 m)
Profiles
0
1000
2000
METERS
(FROM FIELD SHEET 3126
CANADIAN HYDROGRAPHIC SERVICE
COURTESY OF DOMINION HYDROGRAPHER)

FIGURE 5

Bathmetry of Union and Erebus Bays.



Legend as Figure 4.



CHAPTER III

THE PROCESS ENVIRONMENT

(i) Tides:

The broad characteristics of the tidal cycle in the study area were discussed in chapter II (iv). To supplement the published data a series of tidal readings were made in 1968 from a temporary survey station established just inland of the modern beach at Profile 10 (see Figure 19) on the west-facing shore of Cape Ricketts. Mean Sea Level, as deduced from these readings, is used as a datum for the levelled series of beach profiles presented later in this study. In an attempt to tie the local readings at Cape Ricketts into the wider network of survey stations set up by the Hydrographic Service, the temporary tidal station, and the main stations on this small triangulation system used for mapping purposes, were heighted by instrumental levelling in relation to the Hydrographic Service Soil Post ART 4511.

The height of this soil post given in the monument list (Department of Energy, Mines, and Resources 1968) is 10.67 m (35 ft) above chart datum (defined as the plane below which the tide will seldom fall) but this figure cannot be regarded as a meaningful one. If it is regarded as correct then the Mean Sea Level as determined by the author is 3.0 m below chart datum, and the highest recorded high water 1.834 m below this level. This cannot be the case and it is instructive to compare these figures with the ones for east Radstock Bay (Canadian Hydrographic Service 1968) where Mean Sea Level is given at 1.28 m above chart datum.

It would, therefore, appear that there is an error of some 4.28 m (3.0 + 1.28 m) in the recorded height of ART 4511. The survey station is a fixed soil post, which is unlikely to have moved more than a few centimeters, and the author's levelling to the temporary tidal station was checked by an independent survey party.

In recording the tidal rise and fall, the water level at fixed time intervals was levelled to the temporary survey station. The results of this investigation are summarized in Figure 6. Measurements taken during the "day" were at hourly intervals, with more frequent observations at the turn of the tide, whilst "night" recordings were generally every two hours. For the first series of recordings (June 28 - 29) no open water or leads were present and the tidal cycle is represented by the height of the ice surface seaward of the buckled beach-ice zone. To relate the relative movements of ice- and sea-levels, both were measured on the next run (July 16 - 17). No open water was present at this time and the measurements of sea-level were taken at the edge of the water in an offshore lead. It was found, throughout this run, that the height of the ice level was consistently 15 - 19 cm above the height of sea-level, this would indicate that there is a constant relationship between the movement of ice and the water surface during the tidal cycle. On the third run, (July 27 - 28) the level of the sea was taken on the beach, this is nevertheless accurate as the absence of any wave action provided a reliable surface for observations.

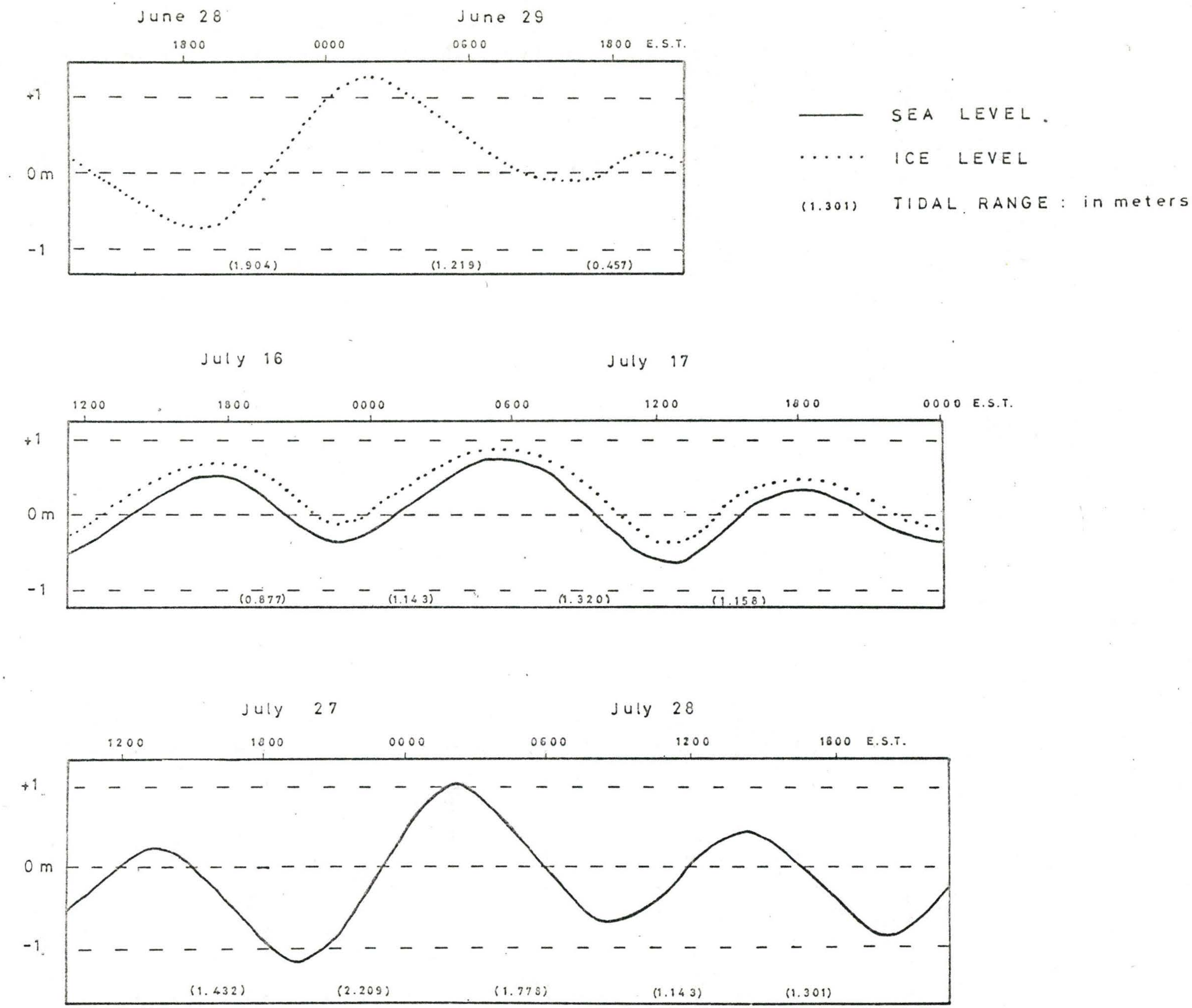
The summary of the first series of recordings, which shows the ice-level changes during one tidal cycle 72 hours after the new moon, indicates a marked inequality in the two high tides (+ 1.222 m and + 0.181 m). A more equal semi-diurnal tide is shown on the second run, this was measured at the last quarter of the moon, and gives high tides of + 0.581 m, + 0.981 m, and + 0.359 m respectively. The effect of the new moon producing inequalities is again shown on the third run, taken 48 hours after the new moon. The high tides in this instance were + 0.295 m, + 1.071 m, and + 0.335 m. Whilst the tidal range is not referred to in detail here, the range for each quarter cycle is given in Figure 6.

The width of the inter-tidal zone is an important characteristic of the beach as this affects the total area over which wave and ice action can take place. The maximum width of the tidal zone at spring tides was found to be in the order of 14 m, this was in the central section of the west-facing Cape Ricketts beach. This zone decreases in width to the north and to the south as the beach slope increases. Photograph 3 shows the width of the inter-tidal zone at Low Tide on August 7, in the area where this zone is widest. Also visible in this photograph are the limits of the two previous High Tides.

Of added importance in an arctic environment is a consideration of ice movement during the tidal cycle. No information has been published on this matter, though Moore (1966) mentions that the height of the sea ice relative to the land varied when measurements were taken at two different times. Precisely levelled heighting carried out in the Cape Ricketts area during June 28 - 29, and July 16 - 17, clearly reveals that the solid ice cover in the offshore zone moves relative to changes in sea-level during the tidal cycle. Fast ice on the beach remains attached and, so far as is known, does not move at all. The effect of having these two conditions, of moving and fast ice, is to produce a

FIGURE 6

Summary of Tidal Observations



DATUM IS MEAN SEA LEVEL (0 m) : 13.67 m BELOW HYDROGRAPHIC STATION ART (4511) zone of cracks and buckling which is subject to considerable pressure at times (photograph 4 shows a series of tidal cracks in the ice, parallel to the beach, at High Tide; see also photograph 8). The ice cover on Gascoyne Inlet was some 4 m thick and, as it responds to tidal variations in sea-level, it is difficult to conceive that this does not exert some force on the beach-fast ice. Further work is necessary during the winter months to determine if any movement of beach-fast ice occurs and if so, the importance of such movements in determining the character of the beach zone.

The movement of beach material by ice-rafting causes the removal and transportation of some sediments in areas where the tidal range is sufficient to carry floes onto the higher parts of the beach, or to refloat those pushed onto the beach by wind. In this area of the Queen Elizabeth Islands such a process may occur frequently, and indeed was observed on numerous occasions, though the volume of beach material involved was, in all cases, very small. When ice grounds on the beach (as is shown for instance in photograph 12), or inshore, sediments are incorporated into the base of the ice, if the floe is then refloated by a subsequent high tide this material will be removed with the ice. The floe may be stranded on another beach, or a different part of the same beach, and may deposit the material there if the ice is not refloated and melts, generally, though, such sediments are carried from the area and deposited in deep water.

(ii) <u>Ice:</u>

The seasonal variation of ice conditions both on the beach and at sea is of vital importance in explaining physical processes which operate in the littoral zone. Considerable attention was focussed during the field investigations on the removal of ice from the beach as this controls the length of time for which wave action is delayed. Although the conditions under which ice forms on the beach during the arctic fall were not observed, the sequence of events can be suggested, so that further discussion can take account of the effect of ice in the beach zone throughout the year.

Personal observations on Lake Ontario, during the winters of 1967-68 and 1968-69, showed that the spray or swash from breaking waves froze on contact with the beach during cold periods (photographs 5 and 6). A similar phenomenum is mentioned by Rex (1964) and Moore (1966) in Alaska, and by Popov (1959 - in Zenkovich 1967) on the Black Sea coast. It would appear that once a glaze, or layer, of ice is formed on the surface of the beach, wave action will cease to be effective unless that ice is ablated (photograph 7). Moore (1966 p. 593) presents a full account of the development of an ice-foot, or "kaimoo", in the Cape Thompson, Alaska, area - "sea water freezes on the exposed part of the beach before the ice begins to form on the sea. A layer of ice is left over the beach gravel by a portion of each wave that runs up the beach". As this ice-foot develops it can incorporate beach material, and these interbedded layers of gravel or pebbles are particularly evident as the ice ablates during the following summer.

Feyling-Hanssen (1953) records the development of a similar ice-foot, which he defines as that part of the sea ice which is frozen to the beach and therefore unaffected by the tidal movement of the water. In this instance the ice-foot is described as a "congealed deposit" which grows faster on the upper parts of the beach. It is this beach fast ice, the ice-foot or kaimoo, which remains after the removal of the tidal sea ice during the summer break-up, and thus prevents wave action in the early part of the open water season. Similarly the growth of the ice-foot before the development of the sea ice cover means that the conventional freeze-up dates (Allen 1964) do not apply to the beach zone, as wave action has already been rendered ineffective.

Callaway (1954) discusses the main factors in the growth of sea ice, suggesting that the controlling variables are air temperature, cloud cover, and wind speed. Data from Resolute, for the years 1947 to 1956, is analysed by Bilello (1960), who finds that for the nine years on record freeze-up occurred between September 12 and 26 (see Table 1). These dates of freeze-up refer to the date of formation of the first sea ice, and it may be safely assumed that by, or at the latest on, this date there is a protective covering of ice on the beach. Again from observations on Lake Ontario beaches, the transition from ice-free conditions to the development of an ice-foot over a meter thick took only four days. On the sea coast of the study area there is the added effect of tidal variations which would allow a wide zone of the beach to be covered by ice during a short period of low air and water temperatures. Once this has occurred the beach is essentially inactive until the removal of beach ice during the following summer. The possible movement of this fast ice due to pressure from the sea ice, or the displacement of beach material by ice action during the winter, are completely unknown factors, but intuitively such action would not cause any major changes due to the rigidity of the enclosing ice cover.

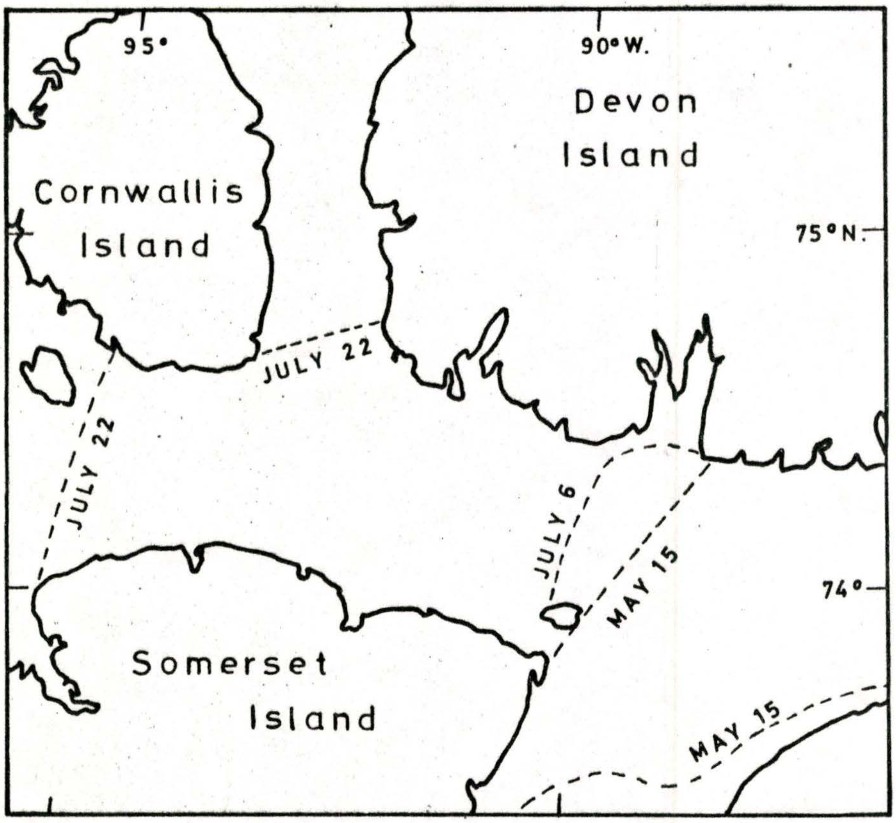
This static condition may be expected to persist, in the Cape Ricketts area, until late July, after this the break-up of the sea ice allows wave action to attack and erode the beach ice. The pattern of ice removal and break-up for Lancaster Sound is discussed in detail by Lindsay (1968) and the retreat of the ice during the 1966 season, which Lindsay regards as an 'average year', is summarized in Figure 7. The local pattern of ice removal for the Cape Ricketts area is shown in Figure 8, and results from observations made during the 1968 field investigation (photographs 8, 9, and 10). The retreat of the 'ice-front' was a sporadic and rapid process, the removal of the ice cover at the head of Gascoyne Inlet from position A to position B took place over a five hour period on the morning of July 27, several million cubic meters of ice floating away in a solid sheet. Leads corresponding to the lines of fracture on July 22 and July 27 were first observed, from the top of the cliff above Cape Ricketts, as early as June 26, attention was drawn to these because of the large number of seal holes along their length. At each of the lines of break given in Figure 8, a fracture developed into a lead about a meter wide before the removal of the ice sheet took place, occasionally several days before the event.

The removal of ice from the Cape Ricketts-Gascoyne Inlet area must not be taken as representative of the removal of ice from other bays and inlets on this coastal area. Erebus Bay, only fifteen kilometers to the west, was still covered with a solid ice sheet when the party left Beechey Island on August 15. Union Bay, to the west of

FIGURE 7

Progression of Break-up in Lancaster

Sound and Barrow Strait, 1966.

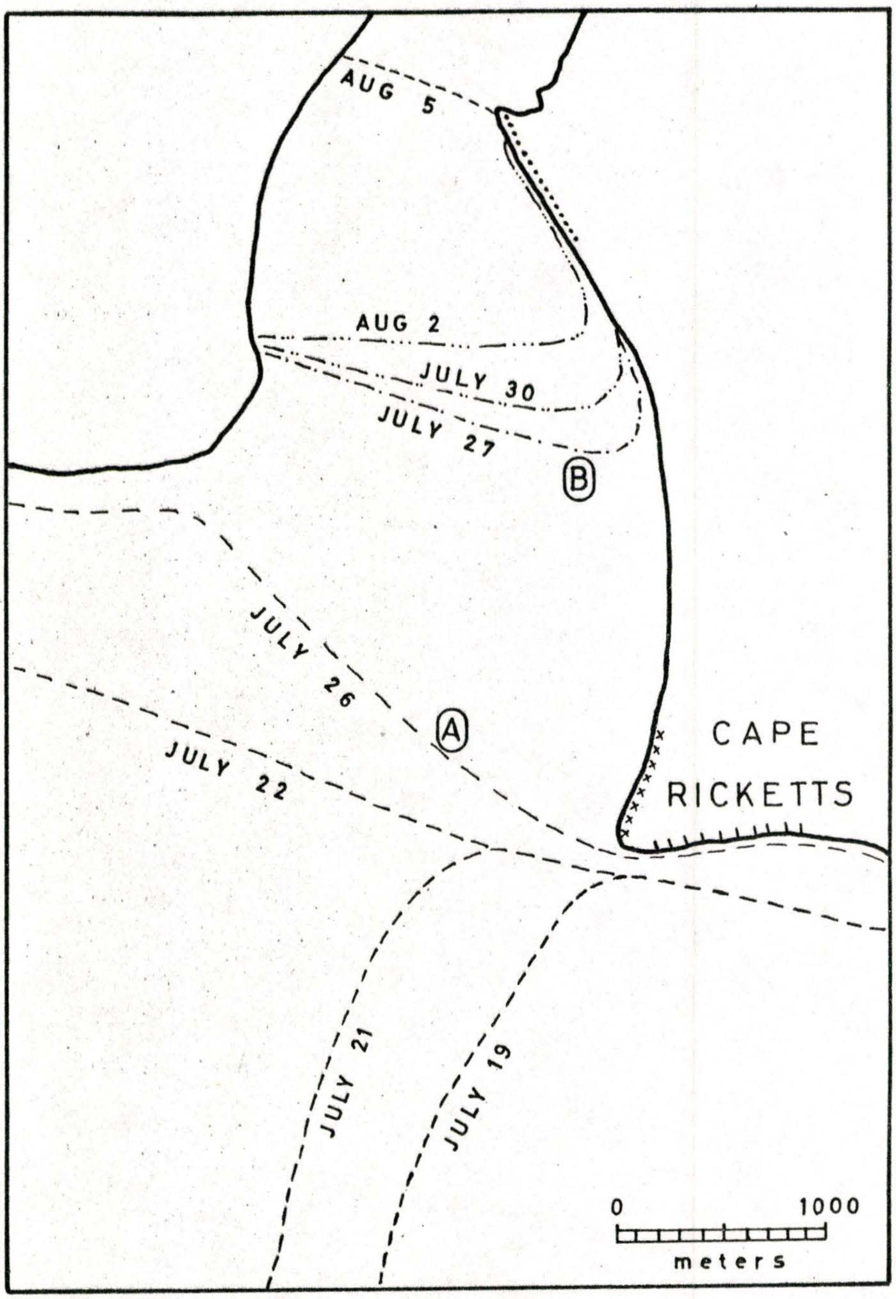


(after Lindsay 1968)

FIGURE 8

Pattern of Break-up in the Cape Ricketts

Area, 1968.



Zones of beach-fast ice
after August 5, 1968:

(a)

(b)

(c)

Beechey Island, was clear of ice on August 12, but had been refilled with pack ice from Wellington Channel by August 14.

Although the absence of the ice cover in Lancaster Sound at the end of July meant that the 'open water' season had commenced, there were considerable influxes of ice floes which were continually moving eastwards through Barrow Strait and Lancaster Sound as break-up continued in areas to the north and west. The occurrence of winds from the southern sector would cause this ice to drift against the southern coast of Devon Island. At other periods complete open water conditions may exist and maximum fetch conditions would allow wave generation over an area which varies from 70 km to an optimum of 150 km. Even when wind direction may coincide with open fetch, ice floes present a dampening effect on waves, and with ice distribution conditions varying almost hourly this is a relevant factor in discussing the role of waves. Hume (1963) notes that for the Point Barrow area - "Even when the ice was out of sight of land it was probably still close enough to shore to limit fetch and prevent the formation of large waves. The quantitive effect of this influence is unknown, but it must be important. Barrow's waves are far smaller than would be found in most ocean areas". The open water season in this area is approximately 2½ months, from mid-July to early October (Hume and Schalk 1967).

The ice which is fast on the beach remains for some time after the sea ice has been removed, this delays the time when waves can become active on the beach. Where material on the surface on the fast ice protected it from ablation, the ineffectiveness of waves to erode the beach ice was demonstrated by the fact that this ice remained for over three weeks after the rest of the beach had become clear of ice. Three areas on which ice remained until after August 5 are shown on Figure 8. The first of these (a) is the west part of the southern Cape Ricketts beach, this was protected by a large snow bank and ice-foot initially (photograph 11), and the ice-foot persisted until after the party departed. This prohibited sample collection and profile measurement on the western half of the southern beach. It would appear that the snow bank and ice-foot are annual features and offer considerable protection to the beach zone, again weak wave action is indicated by the inability to erode the ice-foot.

The second zone of protected beach (b) is an area which was covered by large ice mounds, some 7 m thick. This ice was protected from ablation by material on the surface and it was not until August 6 that the first of these mounds was undercut by waves (photograph 24), at which time the other, and larger, mounds still covered a large section of the beach. The presence of such mounds is discussed fully in chapter V (iii), and they are not annual features at this location, though they may well be formed again if similar conditions were to prevail as outlined in the discussion of these forms.

The third zone (c) is the north part of the Cape Ricketts beach, which was not freed of sea ice until August 2, and possessed a considerable amount of beach ice for several days thereafter. Once the spell of cold temperatures which existed for that period had ended the ice was removed rapidly by ablation.

These three ways in which ice prevented waves from acting upon the beach zone are of considerable importance in reducing the already short period of wave activity. The two factors of removal of sea-ice and beach-ice must be allowed for, as the latter can be present for some time after 'open water' conditions exist. Beach-ice, in particular, is important as it forms before the sea is frozen in the arctic fall. The dates provided by Allen (1964), Gajda (1964), and Bilello (1960) indicate a longer period of open water than must be allowed for when investigating the role of waves on beaches. The dates given for break-up (Table I) refer to the first indication of ice removal, and the sea would not be expected to be clear for several days after this date. This does not allow for any delay in the removal of beach-ice. The freeze-up dates report the initiation of the freeze-up of sea-ice, which again does not take into account the freezing of wave swash and spray, which may provide the beach with a protective covering before the growth of an ice-foot or the sea-ice cover. With this in mind the maximum period of wave action for beaches in this area is less than two months in the year and may be as little as four or five weeks in some years.

(iii) Waves:

From the preceding section it is clear that a consideration of the beach zone must involve different criteria than would be employed in temperate or tropical latitudes. Wave action is confined to a period of less than two months in the year on these coasts of South-west Devon Island. Investigations at Point Barrow and Cape Thompson, Alaska, measured wave heights and wave periods, the results in both cases indicated that conditions in those areas are basically

TABLE 1

Break-up and Freeze-up Dates

Date of Commencement of Break-up for Resolute			Time Interval (in days)	Date of Commencement of Freeze-up for Resolute		
Source / Year	ALLEN (1964)	GAJDA (1964)		ALLEN (1964)	GAJDA (1964)	BILELLO (1960)
1947	-	-	-	Sept 11	Sept 11 to 20	Sept 20
1948	-	Aug 2	47	-	Sept 18	Sept 18
1949	-	Aug 6	40	Sept 13	Sept 13 to 23	Sept 15
1950	-	July 26	57	-	Sept 21	Sept 21
1951	-	Aug 4	-	-	-	-
1952	-	Aug 7	41	-	Oct 6	Sept 17
1953	-	-	-	-	Sept 21	Sept 20
1954	-	Aug 1 to 6	48	Sept 17	Sept 17 to 26	Sept 26
1955	-	Aug 10 to 11	42	Sept 21	Sept 21 to 24	Sept 23
1956	-	-	-	-	Sept 21	Sept 12
1957	-	-	-	-	Oct 6	-
1958	-	-	-	-	-	-
1959	-	-	-	-	-	-
1960	-	-	-	-	-	-
1961	Aug 5	-	42	Sept 20	Sept 16	-
1962	-	-	-	Oct 4	-	-
1963	July 12	July 9	64	Sept 14	-	-
	Earliest - July 9 Latest - Aug 11			Earliest - Sept 11 Latest - Oct 6		

similar to those found in other oceanic areas. Wave recordings made by Leschack (1965) on an ice-island to the north of Point Barrow show that wave motion and wave generation do not cease beneath the "thin, elastic ice-cover", though the amplitude of swell is considerably limited.

In the sheltered areas of the arctic archipelago wave generation is limited by short fetches and for the study region the maximum fetch is to the south-west for approximately 150 km. As noted above, fetch conditions vary daily, according to the movement of ice through this area as controlled by the factors of break-up and wind conditions. The role of ice in protecting the beach is of major importance in assessing the contribution of wave action to littoral processes. Effective wave action is therefore dependent on the beach being clear of ice, open water conditions over a suitably long fetch, and winds over that fetch being of sufficient strength and duration to generate waves. It is not possible to suggest a significant level of wave period or wave height which may be considered as "effective" as any waves cause change, but only certain waves produce lasting changes, such as the development of a storm ridge.

All incoming waves on the beaches of south-west Devon Island are of local origin. Although it may be possible to detect the presence of some swell from analysis using wave recording equipment, these would be relics and have little influence on the overall wave pattern. Personal observations during the open water period indicated the presence of several wave trains at any one time, the dominant direction of approach being dependent on wind direction. The lack of wave refraction except in the immediate inshore zone would evidence the fact that waves are small. Photograph 12 shows a wave train striking the west Cape Ricketts beach from the north-west, the wave crests are almost perpendicular to the shore showing how little they have been affected by refraction due to the low wave height.

During the field study one storm was experienced, August 9 - 10, which generated waves large enough to break over the main beach ridge and move material and ice up to a height of one meter above the highest spring tide limit. Ice was deposited in this zone and much coarse material was combed down the beach at the south-west tip of Cape Ricketts. Beach samples taken before and after this storm show a marked decrease in the mean grain size of the material at the two locations -

Date	Mean High Water Mark Sample (133)	Mean Sea Level Sample (134)
Aug 2 68	-3.37 ϕ	-3.77 ϕ
Aug 10 68	-2.18 ϕ	-0.95 ϕ

As it was not possible to measure wave properties directly, a series of samples were collected of the beach material on three shorelines and these were analysed for their size frequency distribution and shape characteristics. The interpretation of this analysis provides an indirect gauge of the effectiveness of wave action, particularly when the results are compared with those from other areas, this analysis and discussion is presented in chapter V (i). The conclusions which may be drawn from this part of the study confirm the relative minor role of wave action when compared to beaches in more southerly latitudes.

(iv) Supply of Material:

In this area which has undergone coastal emergence since the Pleistocene it would be expected that the source of much of the material in the beach zone could be attributed to formerly submarine deposits which are now subject to littoral processes. The major supply of beach material, therefore, would be the reworking of these recently emerged deposits, and this is in common with many areas which are undergoing isostatic recovery (vide Kidson 1964).

Evidence for the emergence of the shoreline can be seen with reference to the zones into which the beach can be divided on the basis of the colour of material. The lowest of these zones, between Lowest Low Water Mark and Mean High Water Mark, is subject to all beach processes and covered by water or ice for the greater part of the year, the material is dark grey in colour (photograph 13). The zone between Mean High Water Mark and the Highest High Water Mark is only affected during spring tides and periods of storm waves, material here is light grey. The third zone extends above Highest High Water Mark as far as the change in colour from grey/yellow to light brown. This last zone is a transition area between grey active and brown raised beach material, which would suggest that it has only recently been raised above the highest level of wave action, and that this period has been too short for it to have been affected by those processes which have given the raised beach deposits their colour characteristics. The three zones outlined above are represented in Figure 20 on the Cape Ricketts beach profiles as zones (i), (ii), and (iii), and are further discussed in chapter V (ii).

The yellow/brown colour of pebbles in the raised beach zone results from the precipitation of limonite which is produced by weathering. These pebbles are also characterised by solution-facetting, as pits, grooves, and rims are evident on the upper sides, whilst a deposit of travertine is found on the underside. These features denote solution in arid areas (Bryan 1929) and, as Nichols (1953 b) notes, these solution-facetted pebbles are found only in the surface layer of the raised beach deposits, below this the deposits are unmodified. It is this surface layer which gives this zone its distinctive colour and enables differentiation between active and raised beach material.

The width and height range of the three modern beach zones varies according to the beach gradient and, even allowing for minor fluctuations in sea level, the overall picture is one of an emerging shoreline.

No rivers were sufficiently large, in the area under investigation, to transport a great deal of material into the littoral zone. During periods of flood it would be expected that some material is introduced into the littoral by stream and river transport, but these periods are infrequent and brief. Cook (1960) notes that during 1959 the Meecham River, which drains into Resolute Bay, discharged 80% of its annual flow in ten days. Another possible source of supply is from material being washed down into the beach zone by subsurface drainage above the frost-table. It is likely that such material would be small in size and volume, and again this process would be confined to a relatively short period in the year. No data is available for either of these sources of material, but for rivers the contribution may be related to the discharge characteristics. The Meecham River enters Resolute Bay through a small delta, implying a large amount of bed-load deposition, despite the short period of high flow. A similar delta is found in Allen Bay to the west of Resolute (74°45' N. 95°03' W.), both rivers having large drainage basins. Some 800 m along the cliff to the east of Cape Ricketts a small stream which drops down the cliff has built up a small but wide beach of debris (74°37' N. 91°15' W.), this has presumably been transported during a continuous upper flow regime throughout the stream's existence for the summer period. The supply of material by rivers does not necessarily depend upon total discharge, rather on the character of flow.

Little is known of the movement of material onshore from deep water. Personal observation, on August 10, indicated the movement of a large volume of material in suspension from east to west along the southern shore of Cape Ricketts. This was evident because of the distinct milky colour of the water, as compared to its normal clear, blue nature. This sediment-laden zone of water extended seawards for approximately 100 m, and was terminated to the west at the tip of Cape Ricketts by an abrupt change from the milky to clear, blue water. No material was transported past this point possibly because of the presence of a current moving down the east side of Gascoyne Inlet at this time. Whether the material in suspension was derived from the beach or offshore zone could not be determined, but the fact that this occurred after the storm on August 9, and the night of August 10, would suggest that it resulted from the competency of storm waves to bring material from the inshore zone into suspension.

The analysis and interpretation of samples of beach material in the eastern part of 'Walrus Bay' clearly indicates a transportation of material from the base of the cliffs to the east. Talus from the free-face accretes in the littoral zone (photograph 14) and is transported westwards into an area of wide modern and raised beaches (photograph 15). The evidence for this is taken from size and roundness data of the samples collected in this area by Dr. McCann. These show a marked decrease in mean grain size and an increase in roundness (Figure 9). Similar evidence is presented in chapter V (i) for the supply and transportation of material on the western beaches of Radstock Bay. In both instances material is supplied from the reworking of material at the base of the eroding free-faces of cliffs, (see also photograph 34), and the subsequent transportation of this sediment within the littoral zone. The most northerly parts of the Cape Ricketts beach are also supplied with talus, at the base of a retreating face, which here extends into the beach zone, and this material is then subject to beach processes. From the samples collected in this area it was not possible to show any littoral transport of material.

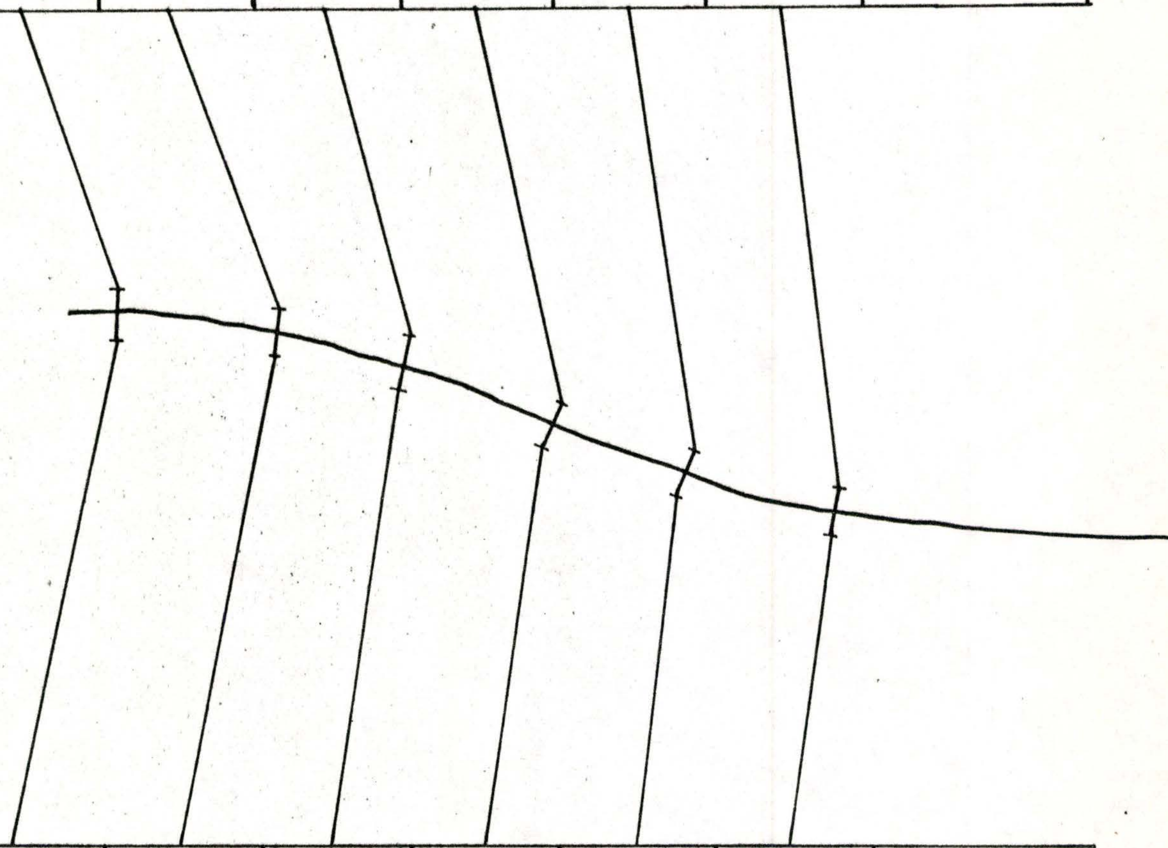
Another aspect of the supply of beach material is the varying amounts which are available for reworking during the year. This involves a consideration of the depth of the frost-table which was found to vary, in 1968, from a minimum of 15 cm on June 24 to a measured maximum of 60 cm on August 8. Further analysis and discussion of the

FIGURE 9

Supply of Material to eastern 'Walrus Bay'

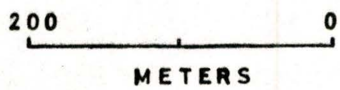
Samples from above HHWM

—	-4.91	-4.64	-5.15	-5.15	-5.43	MEAN SAMPLE SIZE (ø)
185	141	149	145	97	147	MEAN SAMPLE ROUNDNESS



—	-3.51	-3.84	-4.00	-4.10	-4.78	MEAN SAMPLE SIZE (ø)
191	221	173	149	201	153	MEAN SAMPLE ROUNDNESS

Samples from HHWM



frost-table profiles shown in Figure 23 is given in chapter V (ii). It is clear that there is a marked increase in the supply of material for reworking by wave action as the summer progresses.

The overall lack of data regarding the topic of supply and source of material does not permit conclusions regarding the origin of the beach sediments, but the three agencies of river mouth deposition, gravity deposition below free-faces, and provision from emerging off-shore zones are factors to be considered, although their relative contributions are not clear.

(iv) Aeolian Effects:

Most of the material in the beach zone is larger than 1 mm in diameter, and thus not susceptible to movement by wind action. In addition, where fine and medium sands do exist they are on the lowest parts of the beach, near Low Water Mark, and are exposed for only short periods which are seldom long enough for the material to dry out. It appears that wind has little direct influence on the beach zone other than its role in wave generation and ice movement.

Hume (1964) discusses the 'flotation' process, by which sand and pebbles may be transported by rafting on the surface of the sea, because of an increase in surface tension due to cold water temperatures. Such transport of material was observed on several occasions whilst travelling on the sea ice in the Cape Ricketts area. Fines had been carried out from the shore by wind, and deposited on the surface of pools of melt-water on the ice. Often this formed a thick scum where accumulations were concentrated at one end of such a pool by small waves.

The source of this material is from the sub-aerial zone, and eventually will be deposited in the sea, or possibly on the beach if the ice should ground and melt. The total volume involved in this process is very small, but, as Hume points out, it is unique to polar areas. Although the examples cited by Hume did not involve wind-blown material this certainly must be included in this process. No examples of flotation were observed after break-up, whereas Hume actually recorded the movement of material, up to 10 mm in length, on open water.

CHAPTER V

THE ELEMENTS OF THE BEACH ZONE

Discussion of the data and information which refers to the beach zone will be divided into three sections - the material, the beach in profile, and the beach in plan. Each of these aspects is closely related to the others, but for the purposes of clarity and analysis they will be considered individually before looking at the overall characteristics of the beaches of this area in the following chapter.

(i) The Nature of the Beach Material:

In order to provide meaningful information concerning the size and roundness properties of material on the three beaches in the area of study, the collection of samples was based on a systematic procedure. One composite sample was taken at each of the locations indicated below, along surveyed profile lines. Greatest emphasis was directed towards Cape Ricketts where seven sample profiles were used, with four samples of each profile taken from above the Highest High Water Mark, at this High Water Mark, from Mean High Water Level, and at Mean Sea Level. The precise location for this set of samples, in terms of the beach profile, is shown in Figure 20, whilst the sample pattern for Cape Ricketts is given in Figure 10. The sample layouts for the other two beaches were similar (Figures 11 and 12), but as collection took place before break-up of the sea ice on these beaches none were taken from Mean Sea Level on Radstock Bay and none from Mean High Water Mark or Mean Sea Level at 'Walrus Bay'.

To facilitate reference to individual samples a three figure code will be used. The first figure refers to the beach, 1 - Cape Ricketts, 2 - west Radstock Bay, and 3 - 'Walrus Bay': the second figure is the profile number as shown in Figures 10, 11 and 12, and the last figure is the position of the sample site on the profile, numbered 1 to 4 down the beach. For example, 1 7 3 refers to the sample taken at High Water Mark on the most northerly profile at Cape Ricketts.

In the instances where the same sites were sampled more than once the notation (i), (ii), and (iii), refers to the date of collection as given in Appendix B. Therefore 1 7 3 (i) is the sample noted above which was collected on August 2, 1968, the first in that series of samples.

The roundness properties of the samples will be discussed first, as this presents a measure of the effectiveness of littoral processes in abrading material supplied into the beach zone. In the light of this the more sensitive parameters related to the size frequency distribution may be analysed and interpreted.

a. Roundness

Analysis of the shape characteristics was carried out following the procedure outlined by Cailleux and Tricart (1963). This involves the measurement of three axes and the least radius of curvature, in the plane of the two longest axes, for each pebble, and the calculation of a series of shape indices. The shape samples were taken from the material used in the size analysis, as each sample of material was sieved for its size characteristics 25 pebbles greater than 4 mm and less than 120 mm in length were measured using a transparent rule and a Cailleux roundness target.

FIGURE 10

Sample Profiles on Cape Ricketts

(Beach No. 1)

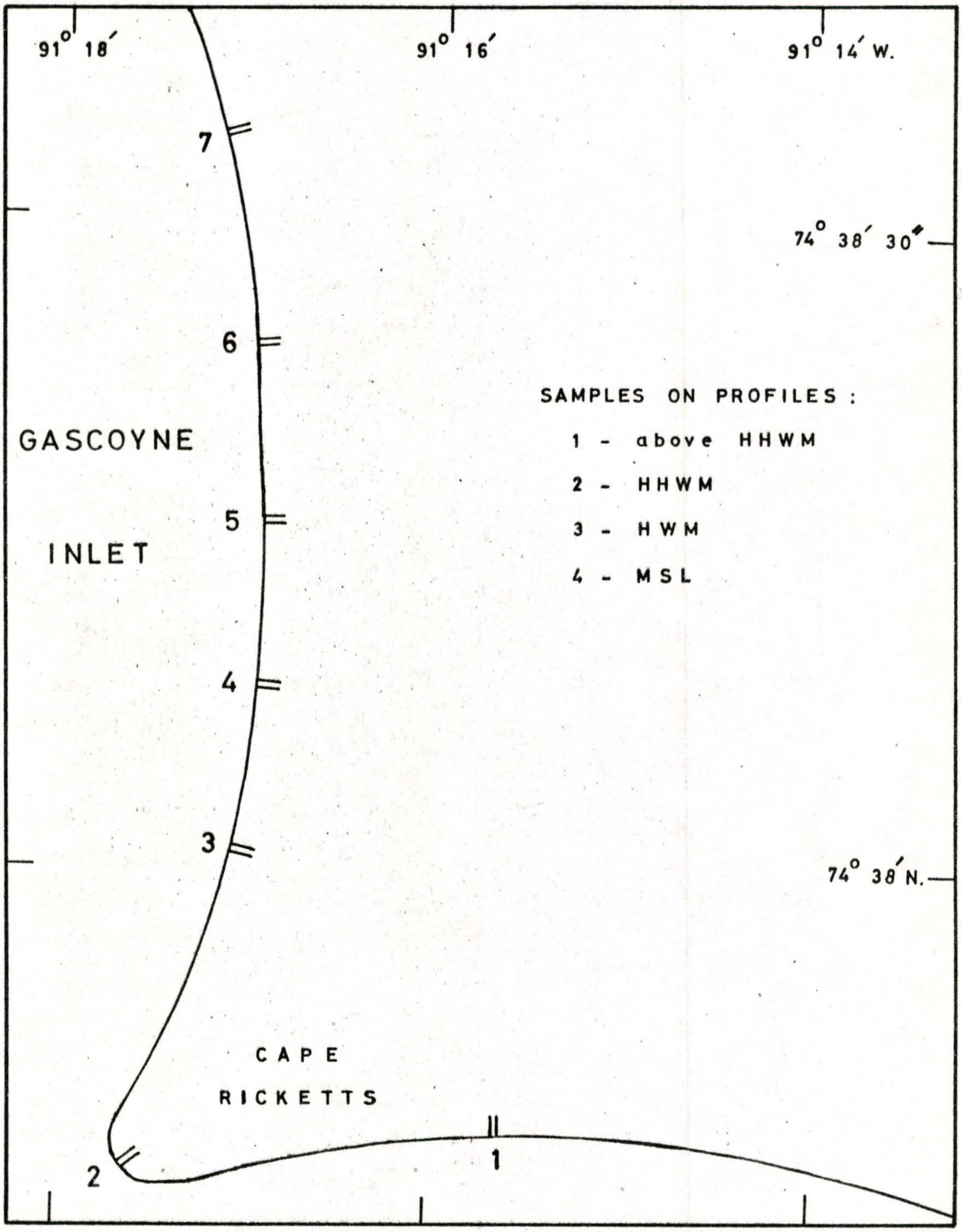

91° 18′
91° 16′
91° 14′ W.
74° 38′ 30″
74° 38′ N.
GASCOYNE
INLET
CAPE
RICKETTS
7
6
5
4
3
2
1
SAMPLES ON PROFILES :
1 - above HHWM
2 - HHWM
3 - HWM
4 - MSL

FIGURE 11

Sample Profiles on west Radstock Bay

(Beach No. 2)

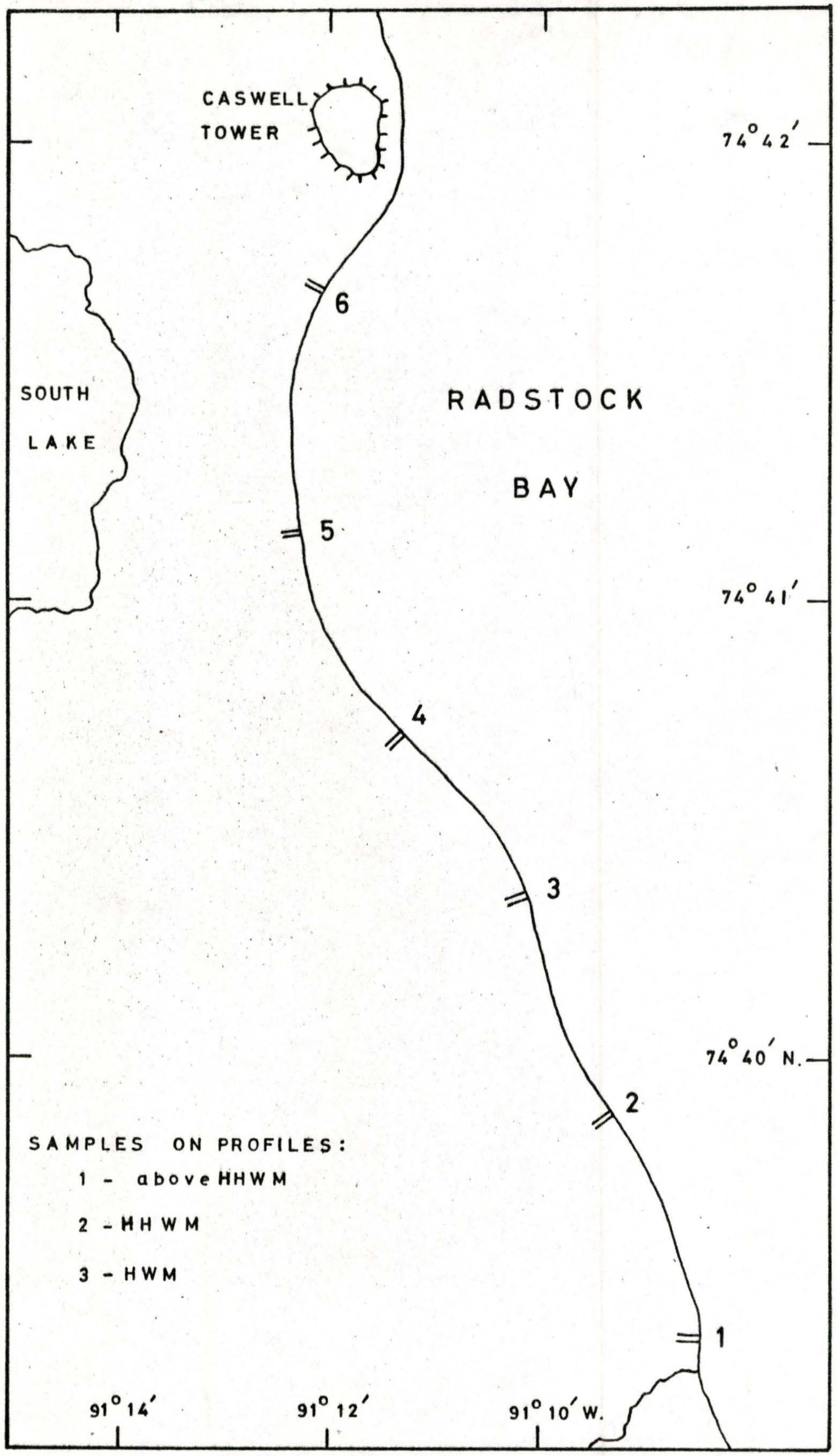
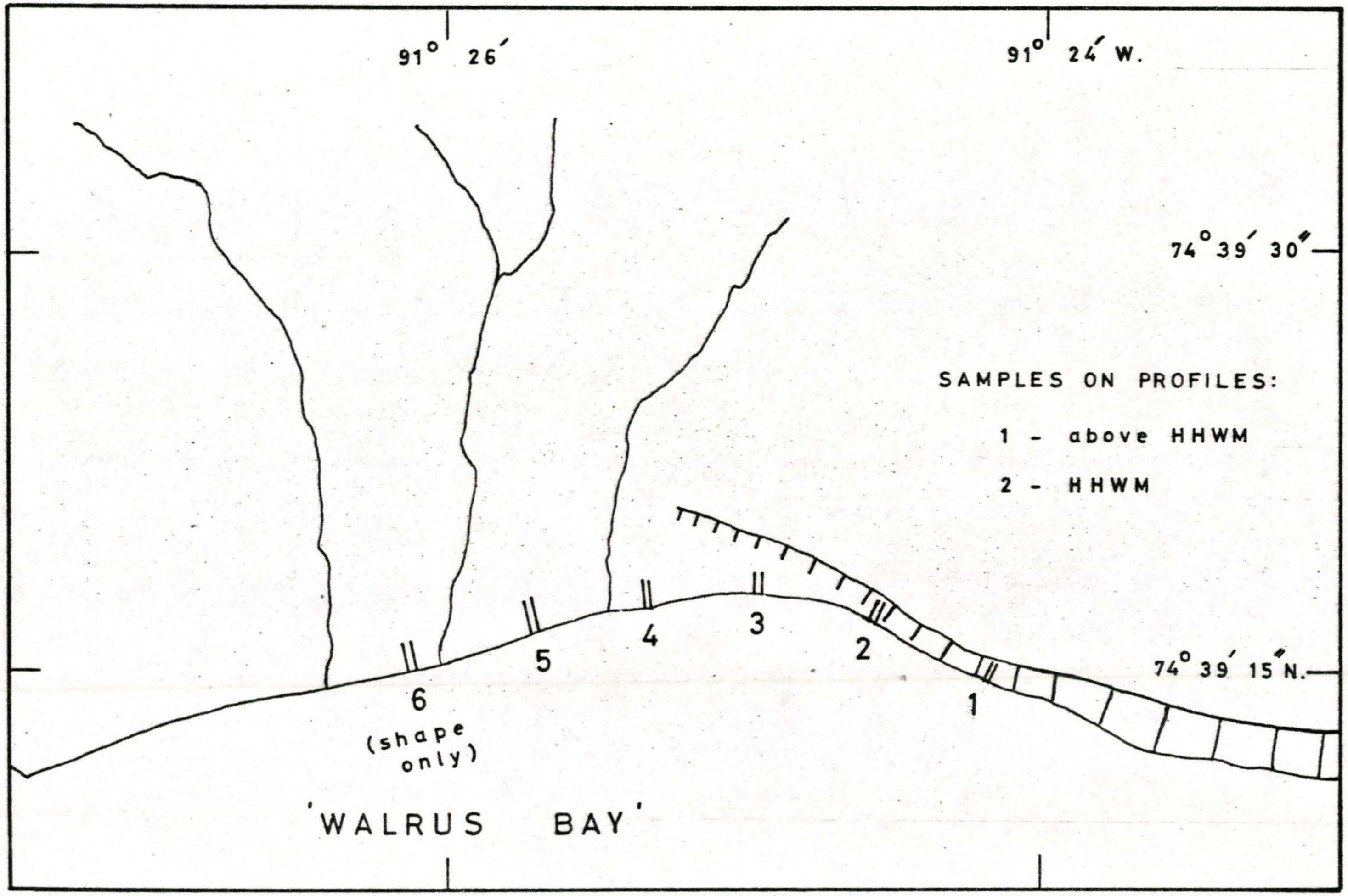

CASWELL
TOWER
74° 42′
SOUTH
LAKE
RADSTOCK
BAY
6
5
4
3
2
1
74° 41′
74° 40′ N.
SAMPLES ON PROFILES:
1 - above HHWM
2 - HHWM
3 - HWM
91° 14′
91° 12′
91° 10′ W.

FIGURE 12

Sample Profiles on 'Walrus Bay'

(Beach No. 3)


91° 26′
91° 24′ W.
74° 39′ 30″
SAMPLES ON PROFILES:
1 - above HHWM
2 - HHWM
74° 39′ 15″ N.
6
(shape only)
5
4
3
2
1
'WALRUS BAY'

The calculations of individual roundness, flatness, and sphericity values for each pebble, and of mean values and standard deviations for each sample of 25 pebbles were made using a computer programme developed by the former Geographical Branch (Department of Energy, Mines and Resources, Canada). Sphericity and flatness values are more applicable to comparative studies of different rock types and were found to add little to the description of shape for the purposes of this study once roundness had been considered. This index is the most useful and the one which will be discussed.

The roundness index of Cailleux is calculated from -

$$\frac{2r}{a} \times 1{,}000$$

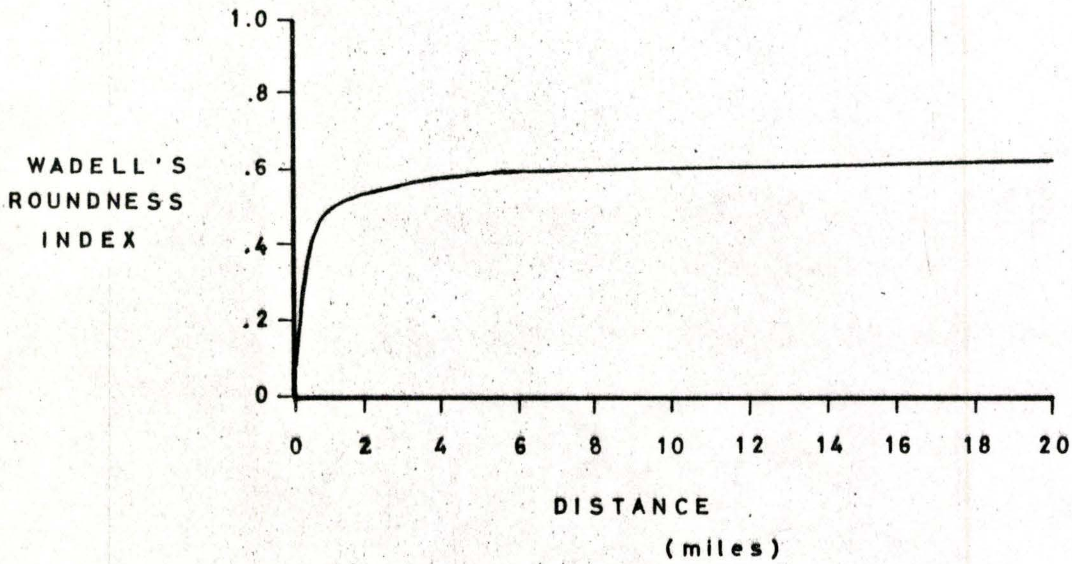
where a is the longest axis of the pebble, and r is the least radius of curvature in the a/b plane (b is the second longest axis of the pebble at right angles to a). The measurement of least radius of curvature uses a target made up of a series of concentric circles, each pebble is fitted to an arc, thus providing an exact measure of angularity, which is preferred to the eye-ball method of Zingg. Values may range from 0, which indicates no rounding at all but a sharp edge, to 1,000, a perfect sphere. This method of measurement and calculation, using only the least radius of curvature and one axis, takes no account of the shape of the individual pebbles as do the methods described by Wadell and Wentworth (Müller (1967) discusses the various methods in detail). The purpose of sampling the beach for shape characteristics was to provide some indirect measure of wave action, to this end the Cailleux index is well suited, as abrasion of the individual pebbles is simply shown by a value which is not complicated by some measure of overall shape.

Krumbein and Sloss (1963) refer to the purpose of measuring roundness - "as particles roll and slide along the bottom (or beach) edges are knocked off or abraded and particle roundness increases rapidly in the early stages of transportation" (p. 208). Krumbein (1941) quotes Daubrée - "The rate of wear or abrasion is a function of the rigour of the process". By the use of a roundness as an index of abrasion it is possible to assess the effectiveness of wave action in terms of the movement of material. Krumbein was able to demonstrate (1941), using Wadell's formula to provide a measure of the roundness of limestone fragments which were abraded in a tumbling barrel, how roundness varied with time, or distance transported, and to show that roundness increased very rapidly in the early stages of transportation (Figure 13). As the values in this experiment were obtained using the formula given by Wadell, they are not directly comparable with those of Cailleux, but this does not preclude from the implications which are relevant to both sets of values. A wide range of roundness values derived according to the Cailleux method, from natural beaches in different environments, are available for comparison with the Devon Island samples, these will be discussed following the presentation of the data for each of the three beaches.

A process alluded to earlier (p. 21-2), the frost-shattering of beach material, is discussed by Taber (1950) who concludes that this only occurs when pebbles are embedded in finer material, as this allows water to be drawn up and ice crystals to develop. The important factors in frost-splitting are pore space size, material size, permeability, and availability of water. "On beaches with thick gravel deposits

FIGURE 13

Increase of Roundness Values with Abrasion (Transport)



(after: Krumbein 1941)

conditions are unfavourable for frost-splitting and, therefore, cobbles ...... become well-rounded" (1950 p. 793). It would appear from this account that frost-shattering should not be an important process in the modern beach zone of south-west Devon Island, and this was found to hold true even though a few isolated examples were found. The shape of the material in the beach zone results primarily from the abrasion of rock fragments and is little affected by frost action.

As a visual indicator of the type of beach material under donsideration photograph 16 shows part of sample 1 2 1, taken from the Highest High Water Mark at Cape Ricketts. Photographs 17, 18, 19, and 20 indicate the size and roundness characteristics of the material sampled on profile 7 of Cape Ricketts.

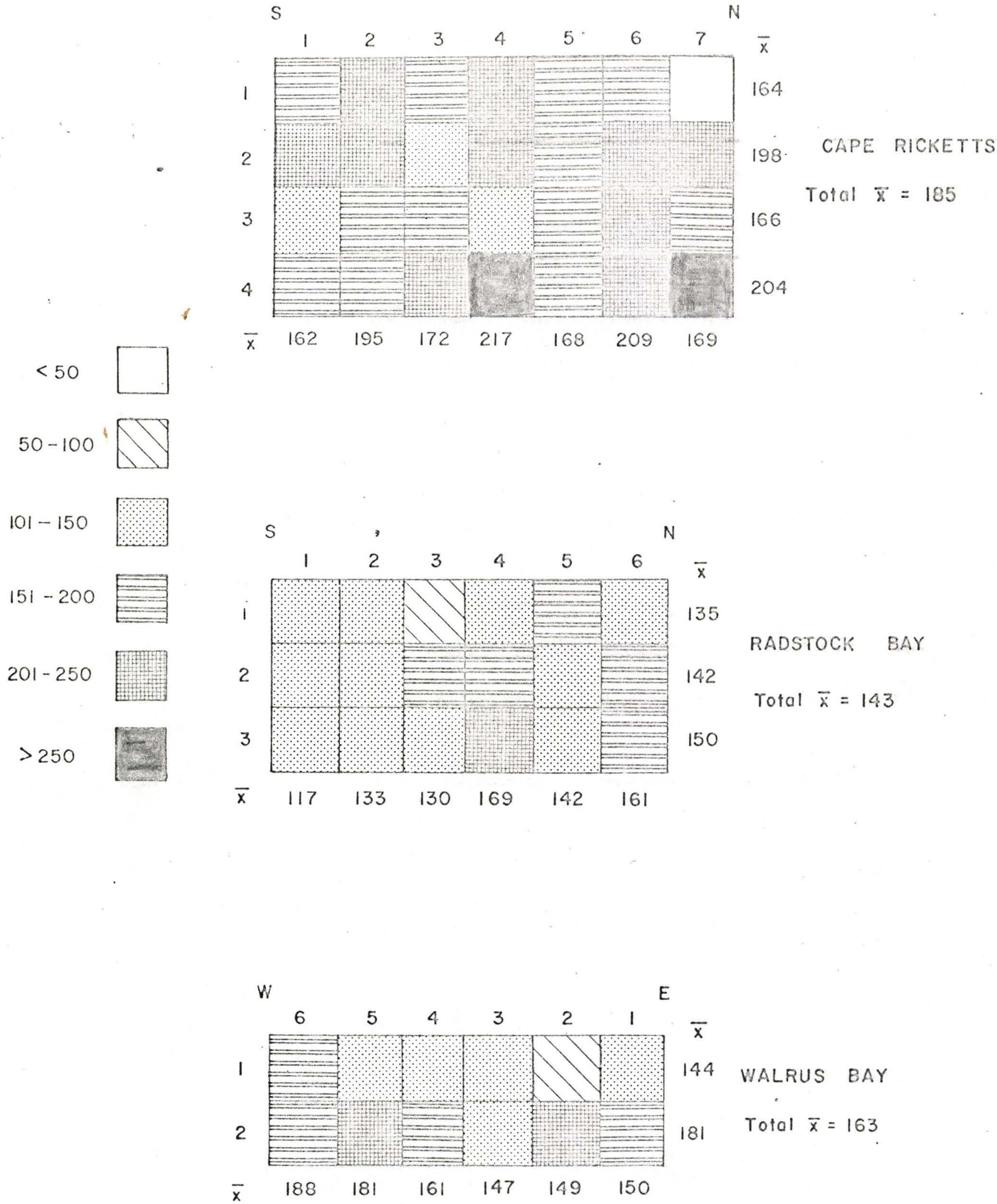
The results of the analysis are given in Appendix A and shown diagrammatically in Figure 14 which also gives the mean roundness value for each beach, each profile and each row of samples. Each sample location is represented by a square on the series of diagrams. Profile numbers are given along the top of the diagrams and the horizontal rows are arranged so that the samples taken from above Highest High Water Mark occupy the top row, etc.

Standard deviation values for most samples are high and this must necessarily detract from the significance which can be attached to the values. However, where trends are obvious either along or across the beaches these may be taken as indicative of real changes and are of value in discussing beach processes.

<u>Cape Ricketts</u>: The roundness values for Cape Ricketts do not show any clear trends along the beach, though there is some suggestion of

FIGURE 14

Mean Values for Roundness Samples



S
N
1 2 3 4 5 6 7
x̄
1 164
2 198
3 166
4 204
x̄ 162 195 172 217 168 209 169
CAPE RICKETTS
Total x̄ = 185
< 50
50 - 100
101 - 150
151 - 200
201 - 250
> 250
S
N
1 2 3 4 5 6
x̄
1 135
2 142
3 150
x̄ 117 133 130 169 142 161
RADSTOCK BAY
Total x̄ = 143
W
E
6 5 4 3 2 1
x̄
1 144
2 181
x̄ 188 181 161 147 149 150
WALRUS BAY
Total x̄ = 163

a slight increase in values from south to north, that is, there is an increase in roundness in this direction. The only exception to this trend is sample 7 1, which is taken from above the Highest High Water Mark and is in fact part of the talus which is over-riding the beach in this area. Variations in roundness across the beach also do not conform to any regular progression, though the values for Mean Sea Level samples tend to be high and the overall mean roundness for row 1 is the highest of any of the beaches, including the only two values greater than 250. This can be attributed to the greater intensity of wave action in this zone. The overall mean for the beach (195) is higher than that for Radstock Bay or 'Walrus Bay', this may be attributed in part to the fact that some of the modern beach material is derived from the offshore zone and from the erosion of raised marine material along the south-facing section of the Cape Ricketts foreland, and therefore sugject to abrasion before reworking in the modern beach zone. Neither the Radstock Bay, nor the 'Walrus Bay' samples would appear to derive any appreciable amount of material from raised marine deposits, and the roundness values from these beaches are thus a more reliable guide to the extent of abrasion due to wave action.

Radstock Bay: The samples from this east-facing beach show a clear increase in values from south to north, this is explained as the result of abrasion of pebbles as they are moved northwards by wave action. The mean value for profile 1 (117) is the lowest for any profile on the three beaches and supports the suggestion that the source area lies at the foot of the cliffs to the south, that is at Cape Liddon. A roundness value of 169 is achieved at profile 4, less than four kilometers to the north, which would agree with the assumption of a rapid increase in roundness during the early stages of transportation.

'Walrus Bay': The values for this beach again infer transportation, from east to west. There is also a noticeable difference between the upper and lower parts of the beach, samples taken from below High Water Mark having a higher roundness value in each case, which reflects greater abrasion due to more prolonged wave action at this level. The mean roundness value for the beach (163) is greater than that for Radstock Bay (143) despite the fact that the material on the former beach has not travelled as far alongshore, this may be considered to reflect the degree of exposure of the 'Walrus Bay' beach which is open to the waves from the south-east, south, and south-west.

Table II presents, for comparative purposes, a summary of some of the available data for roundness values of beach material derived according to the Cailleux formula. A large number of values for a variety of environments and rock types are given by Cailleux and Tricart (1965) and only a selection which is directly relevant is given here. Whilst the values from other areas may not in every case represent the true measure of marine abrasion, for some of the beach materials may have been derived from material previously abraded by other agents, certain general points can be made. The roundness values for the south-west Devon beaches and for the sample from Hall Beach (King and Buckley 1968) are much lower than the values for limestone pebbles from the western Mediterranean (Cailleux and

TABLE II

A Selection of Cailleux Roundness Values for Beach Sediments in Different Environments.

Source	Area	Rock	Environment	No. of Samples	Values
Owens	S.W. Devon N.W.T.	limestone	arctic sheltered	58	25 - 267 mean: 184
King and Buckley (1968)	Hall Beach Baffin Is., N.W.T.	limestone	arctic sheltered	1	216
Cailleux & Tricart (1965)	Western Mediterranean (Various sites)	limestone	mid latitude enclosed sea	559*	170 - 610 mean: 355
Owens	Mexico Bay, Lake Ontario	gneiss	mid latitude enclosed sea	1	388
Berthois (1950)	Finnestere, N.W. France	breccia & schist	Atlantic storm, swell waves	? many	200 - 500
Cailleux & Tricart (1965)	Jakobshavn, West Greenland 68 N. 51 W.	quartz	arctic sheltered ice-jammed bay	50*	90 - 105
- ' -	Kugssa Delta, West Greenland 70 N. 55 W.	quartz	arctic exposed	82*	135 - 160
- ' -	Sarqaq, West Greenland 70 N. 52 W.	quartz	arctic sheltered fjord	42*	227 - 250
- ' -	Godthaab, West Greenland 64 N. 52 W.	quartz	arctic exposed	85*	270-388
- ' -	Finnestere, N.W. France	quartz	Atlantic storm, swell waves	67*	400-460

* the total number of measurements.

Tricart (1965) or for gneiss pebbles from Lake Ontario, both mid-latitude enclosed seas with little or no tidal range and no major wave trains related to open ocean swell. The low nature of the values for the arctic beaches are particularly evident when compared to the results presented by Berthois (1950) and Cailleux and Tricart (1965) from Finnestère, North-west France, an Atlantic storm and swell wave environment. There is, as might be expected, a difference in roundness values, representing degree of abrasion, which accords with a subjective assessment of the degree and amount of wave action on the various beaches. The effect of sea ice, in protecting the beach for as much as 10 months of the year and inhibiting wave development during the open water period, is to decrease abrasion. Thus arctic beaches, in particular those reported here, exhibit low roundness values. The series of values for West Greenland (Cailleux and Tricart 1965) illustrate this point and also show a progressive increase in roundness as the inhibiting effects of ice on wave action become less important.

<u>Summary</u>:

1. The roundness values suggest that there is alongshore transportation of newly supplied beach material from south to north on the western side of Radstock Bay, and from east to west along 'Walrus Bay'. This conclusion rests on the assumption that the material becomes more abraded with transportation and, if the source areas are local as seems evident here, the samples represent the initial phase of rapid abrasion. The orientation of the Radstock Bay beach is such that any waves from the south or east would generate a

north-flowing longshore current, so this set of results would be acceptable as indirect evidence for such a littoral drift.

2. The overall values for the beaches indicate that the material from Cape Ricketts is more rounded than that of the other two beaches, this is probably due to the fact that some of the modern beach material is derived from the erosion of already rounded raised beach material or from the emerging offshore zone. The differences in roundness between 'Walrus Bay' and Radstock Bay may be due to greater exposure to wave action, the latter occupying a more sheltered location, or due to the fact that wave generation from the west is more important in terms of energy transmitted to the beach zone.
3. All the roundness values from south-west Devon are low. The poor degree of rounding can be attributed to the sheltered wave environment and the fact that ice is a major factor in limiting wave generation and wave action.

b. Size and Sorting:

The size distribution analysis of beach sediments was carried out in the field using Tyler sieves and a spring balance. At the designated locations (Figures 10, 11, and 12) three surface samples of approximately 300 gm each were collected within a 30 cm radius. These were then mixed and the composite sample hand-sieved and the various fractions weighed. A sieve gradient of whole phi (ϕ) intervals was employed and all material that passed through the + 1.0 ϕ sieve was later resieved and weighed in the laboratory. The data was transferred to I.B.M. cards and Moment Measures of the sediment size distribution calculated using a computer program adapted by D. R. Ingram from that devised by Schlee and Webster (1965). This program seeks to improve estimation of the statistical parameters used to describe grain size data by use of interpolated values and is described fully in Appendix B. The use of interpolated values in the statistical analysis is no substitute for more original data, but allows an approximation to be made of the continuous distribution which provides a more accurate estimate of the size frequency characteristics.

The analysis of the size distribution was performed to determine certain features of the beach sediments, which are expressed concisely by the Moment Measures. The predominant material size is given by the Mean ($\bar{X}$). Standard Deviation (σ) reflects the effectiveness of sorting processes, and Skewness (Sk) and Kurtosis (K) are used to describe the bias and spread of the distribution (Folk 1962; Baker 1968). Bimodality of the distribution is evident from the frequency curve, which is produced by the program. The last two Moment Measures (Sk, K) have proved to be important discriminatory aids in the comparison of different depositional environments (Folk and Ward 1957; Horn 1967), but when only one environment such as the beach zone is under investigation their relevance decreases, though they are still useful for the description of the distribution.

The data presented in Appendix B consists of values for the four Moment Measures for each sample calculated using interpolated values plus the original data. As a second indicator of the predominant material size the percentage sand fraction is given in column 7, this figure being the percentage by weight of that sample which is finer than - 1.0 ø. If the sample exhibits a bimodal distribution this is indicated in column 8 by an asterisk.

To demonstrate the effect of the use of interpolated values in the computations four examples are given in Table III which have been calculated with and without the interpolated values. The frequency curves of these four examples are given in Figure 15, to indicate the effect of employing the interpolated values when describing the tails of the sediment distributions. Very little difference can be detected in the Mean values, if there is any change the Mean is slightly larger when interpolated values are used. Similarly, the Standard Deviation values are greater with more data points, suggesting an increase in the spread of the distribution because of interpolation. In neither of these cases is the difference significant in the descriptive analysis. The parameters of Skewness and Kurtosis are affected closely, for these rely on the accuracy of the data at either end of the distribution. The use of more values enables more accurate representation of the distribution, but it must be stressed that the values are interpolated and not actual, also the use of whole phi intervals in the original seiving does not lend itself to the calculation of accurate K values. Kurtosis is the most sensitive of the Moments and therefore the one which is treated with most caution even under favourable conditions, in this instance its usefulness is small because of the gradient of data points in which often only seven original values are available to describe the distribution. The merits of interpolation are more evident in the graphic presentation of the size frequency where the curve

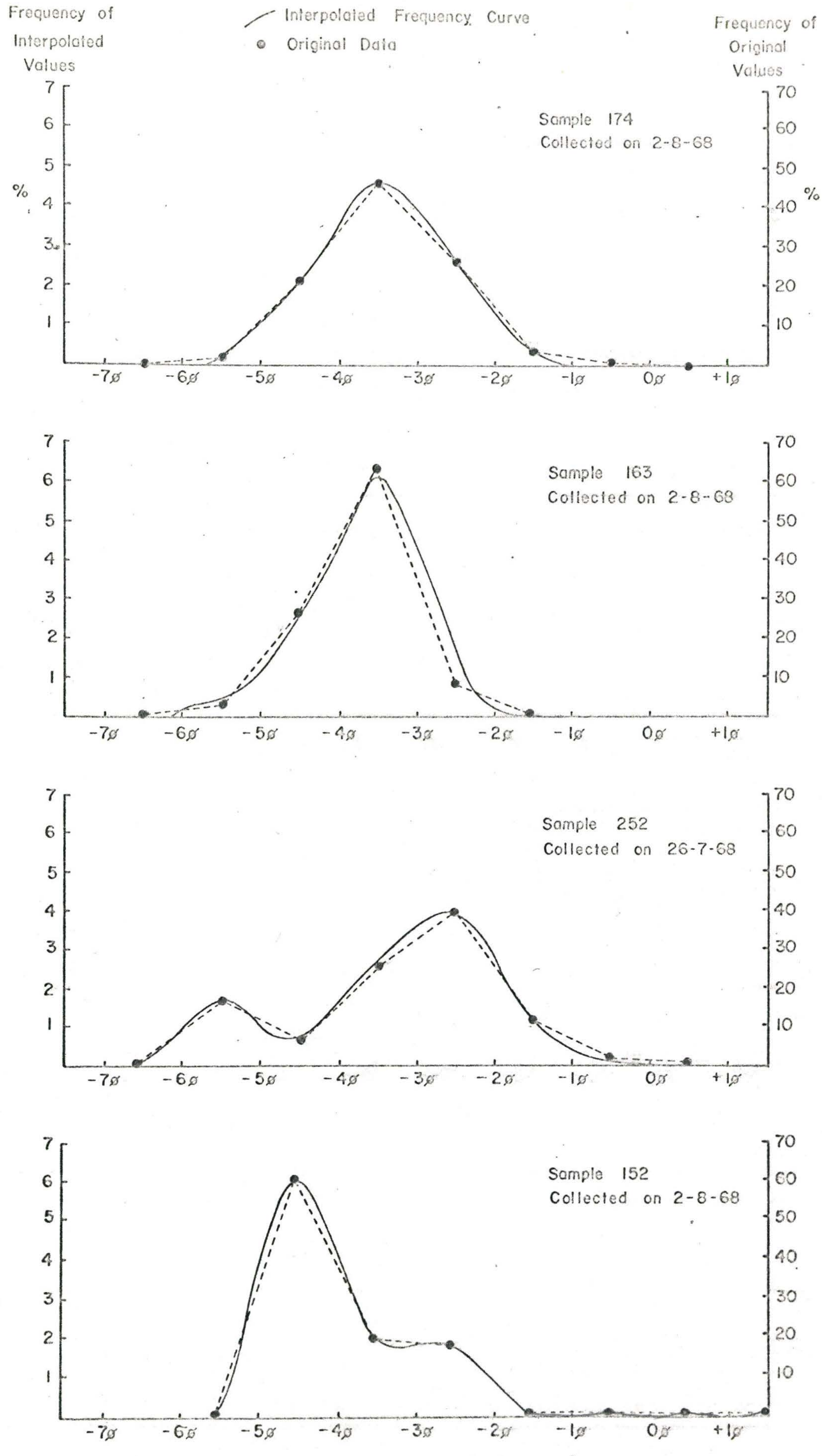
TABLE III

Comparison of values for the Moment Measures of Four Samples, calculated with and without the Interpolated Values used in the Computer Program

Sample		with interpolated data	original data only
	$\bar{X}$		
1 7 4		-3.41 ϕ	-3.41 ϕ
1 6 3		-3.76 ϕ	-3.75 ϕ
2 5 2		-3.26 ϕ	-3.24 ϕ
1 5 2		-4.93 ϕ	-4.89 ϕ
	σ		
1 7 4		0.84	0.78
1 6 3		0.69	0.61
2 5 2		1.30	1.24
1 5 2		0.90	0.80
	Sk		
1 7 4		0.03	0.09
1 6 3		-0.07	0.07
2 5 2		-0.27	0.26
1 5 2		0.43	0.76
	K		
1 7 4		-0.33	0.09
1 6 3		0.80	3.52
2 5 2		-0.47	-0.58
1 5 2		-0.43	2.32

FIGURE 15

Size Frequency Distribution of the Four Samples Calculated with and without the Interpolated Values


Frequency of Interpolated Values
Interpolated Frequency Curve
Original Data
Frequency of Original Values
%
Sample 174
Collected on 2-8-68
Sample 163
Collected on 2-8-68
Sample 252
Collected on 26-7-68
Sample 152
Collected on 2-8-68
-7ø -6ø -5ø -4ø -3ø -2ø -1ø 0ø +1ø

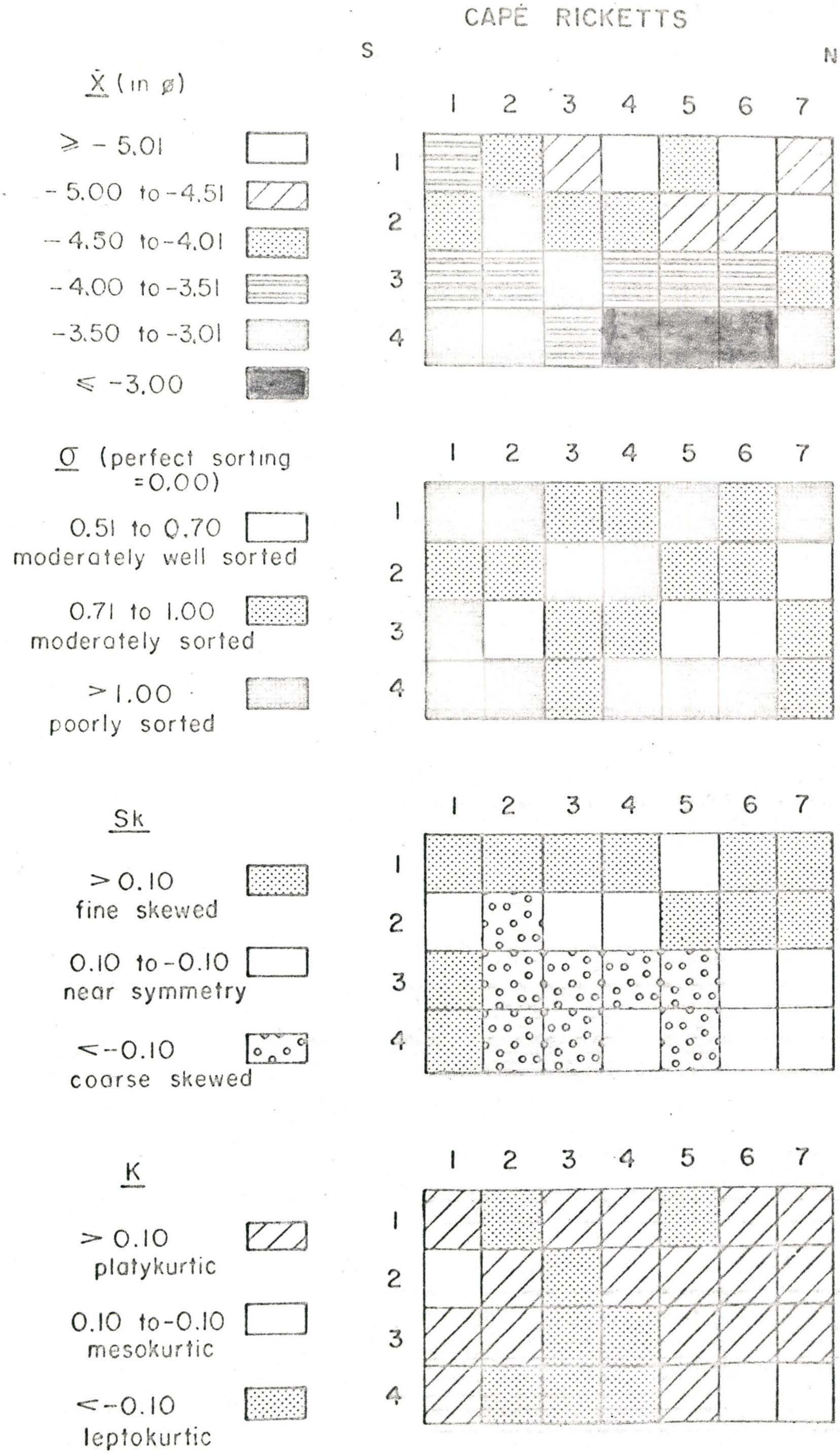
is reproduced with more precision by the inclusion of more values. Again, this is no substitute for more original data but within the framework of the values being analysed its benefit is in providing a better description of that data.

The analysis and interpretation of the four Moment Measures along and across the three beaches is made with reference to Figures 16, 17, and 18, which present diagrammatically the values for each sample location in their relative positions on the beach, as outlined below for the roundness values (p. 62).

Cape Ricketts: All the mean grain size values of the samples from the Cape Ricketts beaches, collected on August 2, 1968, fall between -2.78 ϕ and -5.33 ϕ, that is within the pebble grade of the Wentworth Scale (Table IV). Only seven of the 28 samples show more than 1% sand by weight. A sample (1 3 1 (ii)) taken from the tip of the Cape after a storm was the only one to exhibit a significant sand percentage, 49.34%. There is no apparent regular change in the size of the material along the beach but there is a distinct coarsening of the material upwards across the beach from Mean Sea Level, this is particularly clear on sample profiles 6 and 7 but is evident also on the remainder of the profiles. It may be noted that in six of the profiles the lowest mean values occur at Mean Sea Level. This tendency for coarser material to be at the top of the beach occurs on pebble and cobble beaches in more temperate latitudes and results from the sorting action of breaking waves which move the larger material to the upper part of the intertidal zone. Deposition above this zone results from storm waves which are

FIGURE 16

Moment Measure Values for Cape Ricketts



CAPE RICKETTS
S
N
X̄ (in ø)
≥ -5.01
-5.00 to -4.51
-4.50 to -4.01
-4.00 to -3.51
-3.50 to -3.01
≤ -3.00
σ (perfect sorting =0.00)
0.51 to 0.70
moderately well sorted
0.71 to 1.00
moderately sorted
>1.00
poorly sorted
Sk
>0.10
fine skewed
0.10 to -0.10
near symmetry
<-0.10
coarse skewed
K
>0.10
platykurtic
0.10 to -0.10
mesokurtic
<-0.10
leptokurtic
1 2 3 4 5 6 7
1 2 3 4

TABLE IV

Phi Scale, Material Size, and Wentworth Size Classes

ϕ	mm	Wentworth size class
-6.0	64.0	
-5.0	32.0	
-4.0	16.0	pebble
-3.0	8.0	
-2.0	4.0	
		granule
-1.0	2.0	
		very coarse sand
0.0	1.0	
		coarse sand
1.0	0.50	
		medium sand
2.0	0.250	

(C.E.R.C. 1966

& Inman 1952)

capable of moving the largest particles into the highest parts of the modern beach.

It should be mentioned that it was not possible to sample the southern beach of Cape Ricketts adequately to establish changes along this beach as the presence of a snow bank and ice-foot protected the inter- and supra-tidal zones until after the party left the area (photograph 11).

It may be assumed, from the evidence of the regular variation of the mean size of the material across the beach that wave action, and possibly storm-wave action, is important in the reworking of the Cape Ricketts beach sediments, but the standard deviation (σ) values for the individual samples indicate that the sorting action of waves is not particularly effective. Folk and Ward (1957) suggest that when standard deviation is used as a measure of sorting the following verbal limits may be applied:- standard deviation below 0.50 ϕ, well sorted; 0.51 ϕ to 0.70 ϕ, moderately well sorted; 0.71 ϕ to 1.00 ϕ, moderately sorted; and greater than 1.00 ϕ, poorly sorted. Although these categories were suggested for moment measures calculated graphically they are equally applicable to computed moments. On this basis none of the samples collected from Cape Ricketts are well sorted, and 12 of the 28 are poorly sorted. There is no regular variation in sorting along or across the beach, but the better sorted material tends to occur in the lower part of the intertidal zone.

Skewness values show that the material on the upper parts of the beach has a positive skewed sediment size distribution, that is, an excess of finer particles, and that the opposite is true on the lower parts of the beach. This reinforces the information about sorting across the beach provided by the mean and standard deviation values. The Kurtosis values show no significant trends in any direction, though it may be noted that the Kurtosis value for sample 7 1 refers to a sample from the talus slope immediately above the beach, and this would be expected to exhibit a very peaked distribution.

The Mean High Water Mark and Mean Sea Level sites on profiles 6 and 7 were sampled on three occasions to see if any changes in the characteristics of the distribution had taken place as a result of the beach becoming more open to wave action. The mean size and percentage sand values for this time series are given in Table V. The samples of August 2 were taken when the beach had already been clear of ice for 14 tidal cycles but ice lying some 20 - 30 m offshore provided a complete protection from all waves during this period (as shown on photograph 9, taken on July 31). The material on this section of beach was, therefore, only affected by the movement of water across the intertidal zone by the tidal rise and fall. By August 6, when the second sample was taken, the ice had left this part of Gascoyne Inlet (see Figure 8 and photograph 10) and the beach had been open to wave action, by small waves from the west and south, for two tidal cycles. A further four tidal cycles with small waves were allowed to elapse before the last samples were collected on August 8. There is no systematic change in the characteristics between the three sets of samples.

The second set of samples taken at Mean High Water Mark and at Mean Sea Level on profile 3 (Table V) on August 10 are quite different from the earlier August 2 samples. There is a marked decrease in

TABLE V

Mean Size and Percentage Sand for the Time Sequence Samples from Cake Ricketts

Sample	Date 1968	$\bar{X}$ ϕ	% Sand
1 3 3 (i)	2 Aug.	-3.37	0.14
(ii)	10 Aug.	-2.18	10.84
1 3 4 (i)	2 Aug.	-3.77	0.15
(ii)	10 Aug.	-0.95	49.34
1 6 3 (i)	2 Aug.	-3.76	0.22
(ii)	6 Aug.	-3.60	0.00
(iii)	8 Aug.	-3.57	0.08
1 6 4 (i)	2 Aug.	-2.83	8.55
(ii)	6 Aug.	-3.29	0.08
(iii)	8 Aug.	-3.31	0.08
1 7 3 (i)	2 Aug.	-4.10	0.21
(ii)	6 Aug.	-3.37	0.06
(iii)	8 Aug.	-3.09	0.18
1 7 4 (i)	2 Aug.	-3.41	0.21
(ii)	6 Aug.	-2.96	0.29
(iii)	8 Aug.	-3.18	0.03

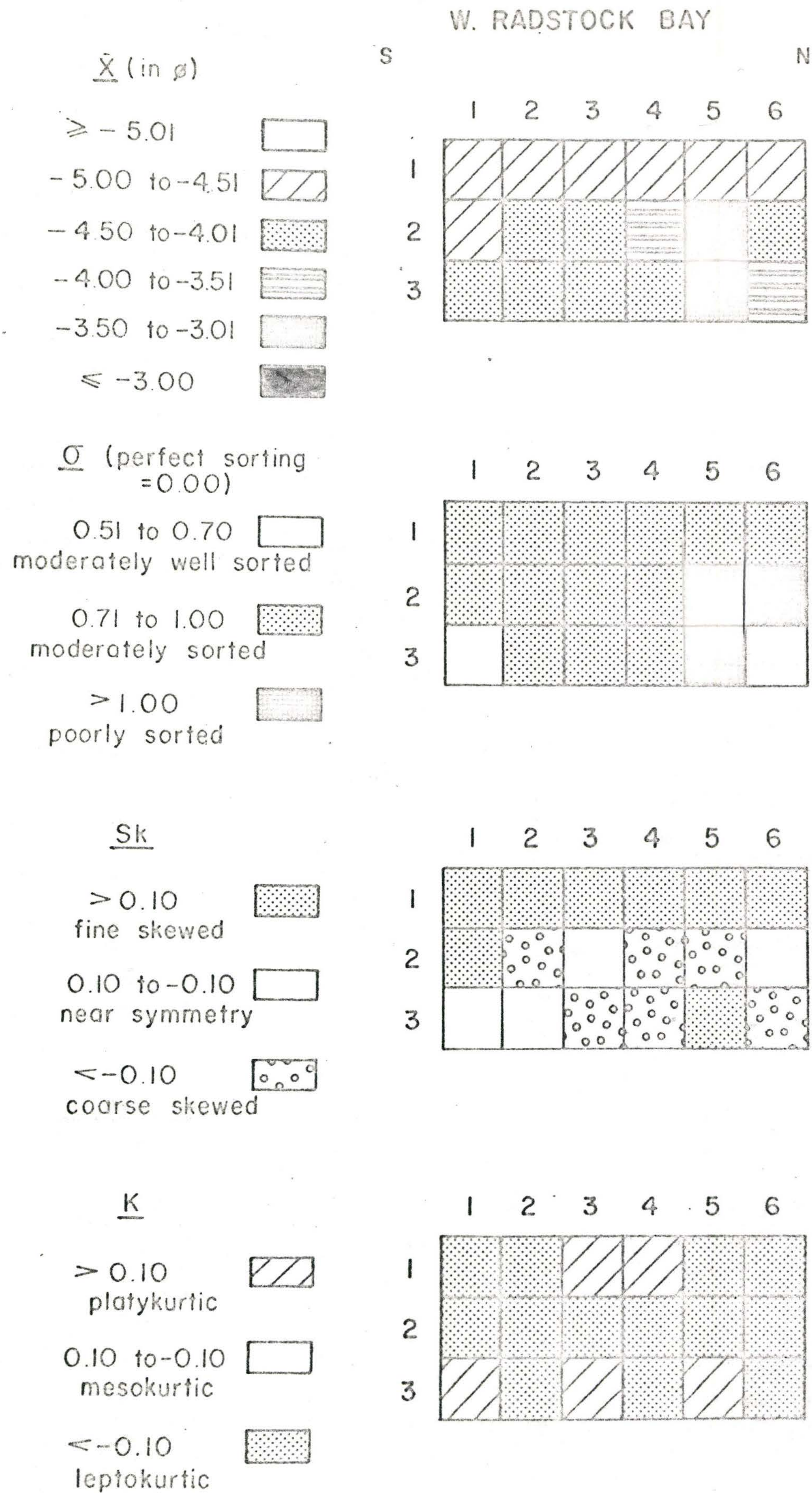
mean grain size coupled with an increase in the percentage sand in the later samples, although the standard deviation values remained more or less constant (0.83 ø to 0.93 ø, and 0.96 ø to 0.93 ø for MHWM and MSL respectively). This change in mean size and percentage sand may be attributed to the action of somewhat larger waves which were generated during the storm experienced on August 9 - 10. This would suggest that the storm, although it was not particularly severe, was able to bring about greater changes than could be effected by normal wave action.

Radstock Bay: The mean grain size data for this beach (Figure 17) again shows the dominance of pebble grade material, with the coarsest fractions occurring on the upper parts of the beach. This may be attributed once more to the cross beach sorting due to wave action. In addition to this change across the beach there is an evident regular decrease in mean grain size along the beach between profiles 1 and 6, that is from south to north. This is taken to indicate alongshore movement of material from a source area at the foot of the cliffs in the south (Figure 2) and shows that as material is transported the smaller particles are carried farther whilst the material is also broken and worn down during movement. These samples were collected before the removal of ice from the lower parts of the beach, and therefore this trend is one which is inherited from the previous open water period.

Only two samples from this beach are moderately well sorted, the majority are moderately sorted. No marked variation occurs and

FIGURE 17

Moment Measure Values for Radstock Bay


W. RADSTOCK BAY
S
N
X̄ (in ø)
≥ − 5.01
− 5.00 to − 4.51
− 4.50 to − 4.01
− 4.00 to − 3.51
− 3.50 to − 3.01
≤ − 3.00
σ (perfect sorting = 0.00)
0.51 to 0.70
moderately well sorted
0.71 to 1.00
moderately sorted
> 1.00
poorly sorted
Sk
> 0.10
fine skewed
0.10 to − 0.10
near symmetry
< − 0.10
coarse skewed
K
> 0.10
platykurtic
0.10 to − 0.10
mesokurtic
< − 0.10
leptokurtic
1 2 3 4 5 6
1
2
3

it is the uniformity rather than the diversity which is most evident. As a general comparison, these samples are better sorted than those from Cape Ricketts, which could suggest more efficient wave action from the south-east, such waves would not affect the west-facing beach at Cape Ricketts.

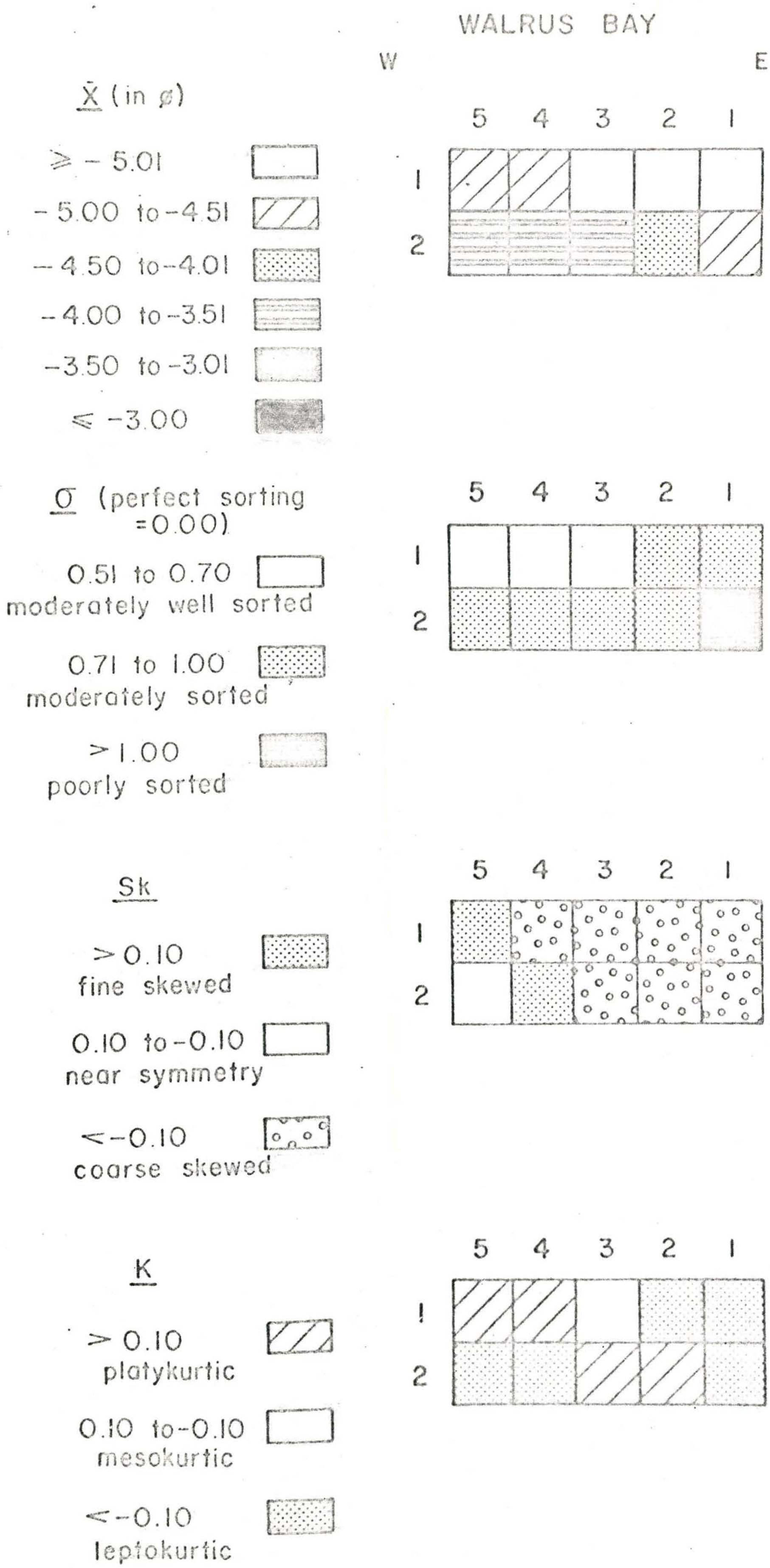
The plot of Skewness values is similar to that of Cape Ricketts with a fine skewed distribution on the upper part of the beach and coarse skewed on the lower parts. Little inference can be drawn from the Kurtosis values which show neither uniformity nor systematic trends.

'Walrus Bay': The mean size values for this beach (Figure 18) suggest a movement from east to west by littoral drift. There is a readily available source area in the east to provide material which is selectively transported as well as abraded and broken (see chapter IV (iv) and photographs 14 and 15). It is also evident that on the upper part of the beach this decrease in mean grain size takes place at a much slower rate as this is an area of lesser wave action, sorting, and abrasion.

This longshore transport is also indicated from the standard deviation values which show an increase in sorting to the west. Selective transportation of the source material leads to the movement of a particular range of particle sizes, thus giving a smaller deviation around the mean than in areas local to the source. "The fréquent generalization that sorting increases with transport is ...... due to the fact that mean size of the sediment changes with transport and the improvement of sorting is dependent on the decreasing mean size not the distance" (Folk and Ward 1957 p. 14).

FIGURE 18

Moment Measure Values for 'Walrus Bay'


WALRUS BAY
W
E
X̄ (in ø)
≥ -5.01
-5.00 to -4.51
-4.50 to -4.01
-4.00 to -3.51
-3.50 to -3.01
≤ -3.00
σ (perfect sorting =0.00)
0.51 to 0.70 moderately well sorted
0.71 to 1.00 moderately sorted
>1.00 poorly sorted
Sk
>0.10 fine skewed
0.10 to -0.10 near symmetry
<-0.10 coarse skewed
K
>0.10 platykurtic
0.10 to -0.10 mesokurtic
<-0.10 leptokurtic
5 4 3 2 1
1
2

The Skewness values of the samples taken near the source show a coarse skewed distribution, whilst those farther along the beach are fine skewed, which again illustrates the selective nature of longshore transportation. Kurtosis values show no variation which can be related to the trends outlined above, either along or across the beach.

Summary:

1. There is very little sand present on any of the beaches, the majority of material falls within the pebble category, greater than 4 mm in diameter.
2. All three beaches show variation of mean grain size across the beach, this is due to wave sorting and results in an increase in mean size on the higher parts of the beach.
3. Samples from Radstock Bay and 'Walrus Bay' suggest that alongshore movement takes place on these beaches, this is evidenced by mean grain size, sorting, and Skewness parameters.
4. No sample falls into the 'well sorted' category when standard deviation is examined. The majority of values indicate moderate or poor sorting of the beach sediments. This is to be expected considering the nature of the material and the absence of wave action for ten months in the year.
5. The Kurtosis values contribute very little to the description of the distribution of the samples. This may be attributed to the sieve gradient employed for the size analysis.
6. The patterns of across and along the beach variation shown by

the interpretation of the size distribution frequencies of the samples agree with the trends indicated by the mean roundness values discussed above.

Horn (1967) collected 9 beach samples on Ellef Ringes Island (78°N. 105°W.), all of which contained greater than 50% by weight of sand, whilst 5 contained greater than 75% sand. Mean size of these samples varied between 3.23 ϕ and -2.12 ϕ, and the lowest value for standard deviation was given as 1.07 ϕ. The material is therefore finer and better sorted than in those samples collected from south-west Devon. Horn suggests that these sand/gravel mixed beach deposits are 'immature' - "the presence of clay in the beach deposits indicates that the physical energy exerted on the sediments by water agitation is so small that even the first steps towards textural maturity is not achieved" (1967 p. 143). To explain the size distribution characteristics of the samples Horn suggests that these are entirely dependent upon the parent material and the local physiography - "detritus delivered to the coast remains essentially unaffected by hydrodynamic processes such as waves, surf, and tides" (1967 p. 103). Skewness and Kurtosis values are regarded as being a function of the availability of particles of certain size grades in the parent material and not a function of sorting and abrasion, noting that in general Kurtosis is of limited value in studying sediments from polar desert environments.

These conclusions drawn from Horn's samples show similarities with the results from south-west Devon, the major difference being that wave processes are even more limited in that area, which is in the north-west of the Archipelago adjacent to the polar basin. As a measure of the ice conditions, the weather station of Isaachsen on Ellef Ringes is supplied completely by air, whereas the coasts of Lancaster Sound and Barrow Strait are open to ships and/or ice-breakers for at least a short period every year. With a high proportion of sand in the samples from Ellef Ringes beach deposits some expression of sorting would be expected, but this may be hidden by the mixed nature of the sediments giving two or more modes, that is silt, sand, and gravel each contribute to the size frequency distribution.

(ii) The Beach in Profile:

a. Across the Beach Variation:

A series of twenty beach profiles were accurately surveyed on three occasions at Cape Ricketts (June 21 - 23; July 16 - 18; and August 5 - 6). This set of measurements was taken to determine any changes which might occur as the beach became free of ice and open to wave action. The location of the surveyed profiles is given in Figure 19, the sequence of the profiles at each site is shown in Figure 20, and the techniques employed are discussed in Appendix C. The limits of the three zones of the modern beach area, as defined on page 47 , are indicated on the profile diagram, Figure 20 and in photograph 13.

All the profiles, except for 1, 2, 19, and 20, give way to an area of raised beaches above zone (iii). In the case of profiles 1 and 2 the beach lies below an eroding free-face of unconsolidated raised beach material (photograph 11), whilst the beaches of profiles 19 and 20 are being overridden by talus deposits (this is visible towards the bottom of photograph 10).

FIGURE 19

Location of Survey Stations and Beach Profiles

on Cape Ricketts

LOCATION OF BEACH PROFILES

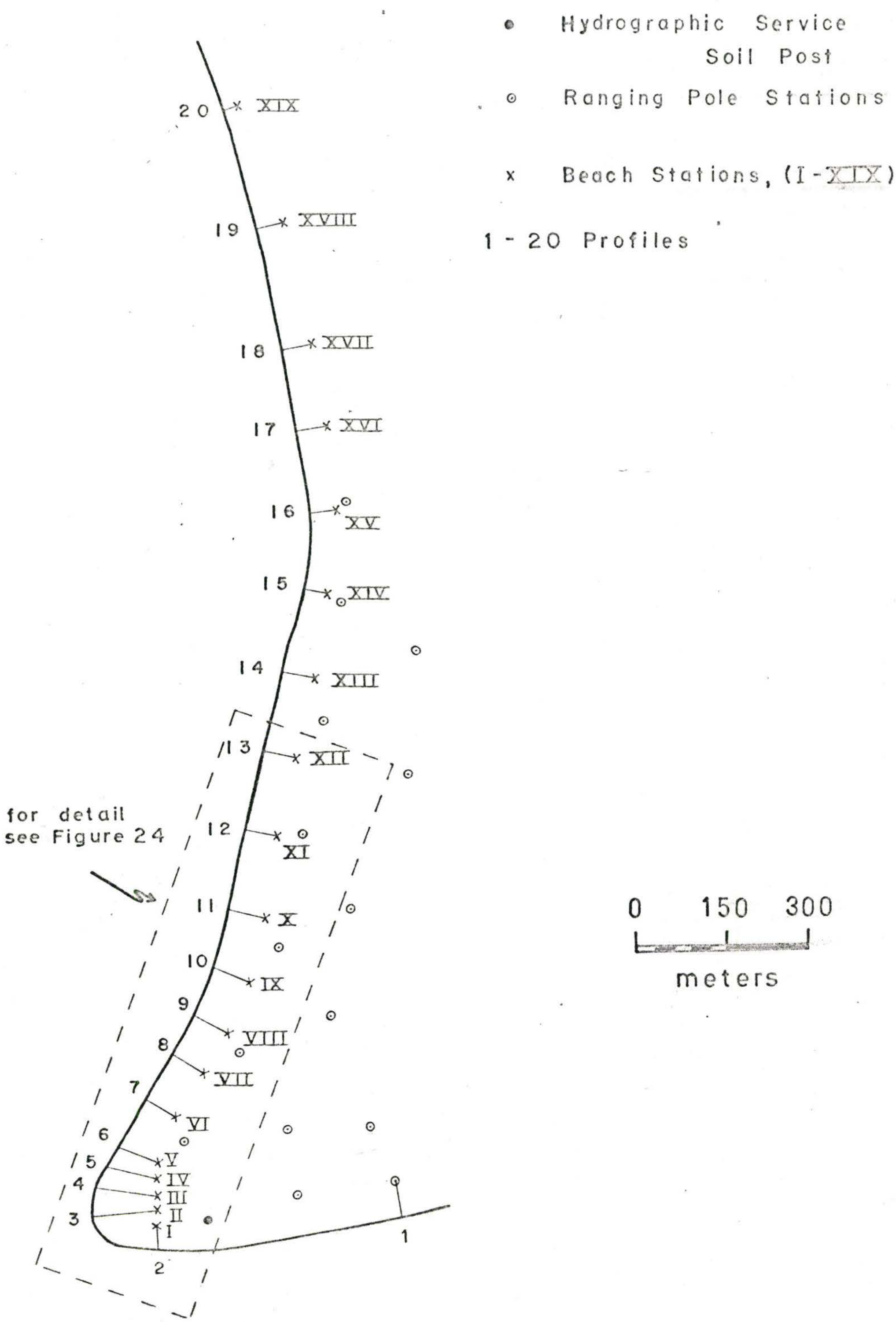
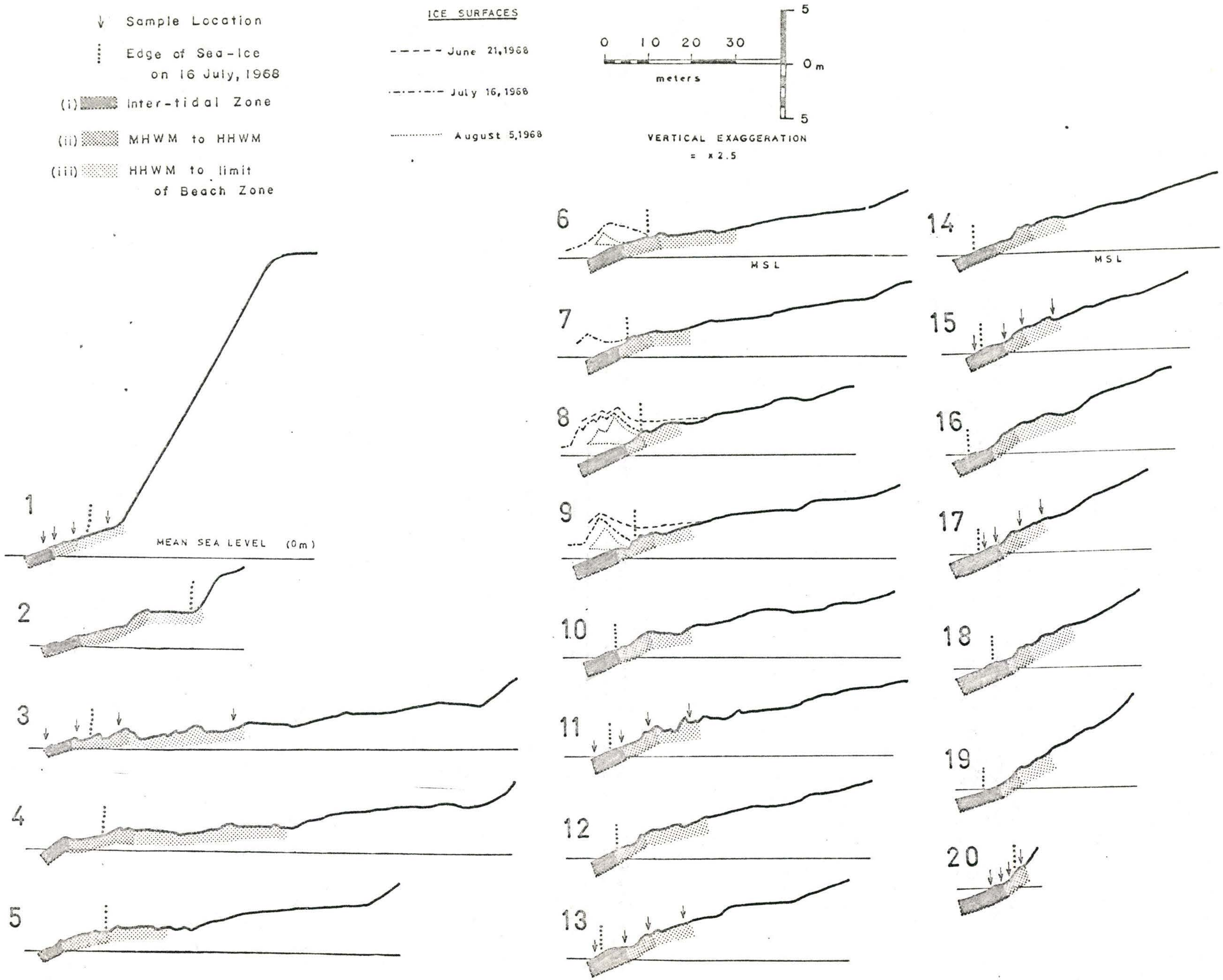


FIGURE 20

Cape Ricketts Beach Profiles



Sample Location
Edge of Sea-Ice on 16 July, 1968
(i) Inter-tidal Zone
(ii) MHWM to HHWM
(iii) HHWM to limit of Beach Zone
ICE SURFACES
June 21, 1968
July 16, 1968
August 5, 1968
0 10 20 30
meters
5
0 m
5
VERTICAL EXAGGERATION = x 2.5
MEAN SEA LEVEL (0m)
MSL
MSL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

In terms of the process environment, the lowest part of the beach, zone (i), represents the most active part of the shore as it is subject to constant wave action in the periods allowed by ice conditions. The area between Mean High Water Mark and Highest High Water Mark, zone (ii), is subject to wave action on infrequent occasions, this is often restricted to periods of storm conditions during times of open water. The effects of such wave action as may occur over this zone are probably intense though for very limited periods, and considering the length of the open water season it is possible that such conditions may not be experienced in any one season. The highest zone of the modern beach, (iii), is free of wave action except during the most severe storms (such as reported by Hume and Schalk 1967). This is essentially a transition zone, being the most recently elevated part of the modern beach and only slightly above the active wave zone, nevertheless it is not readily incorporated into the raised beach sequence.

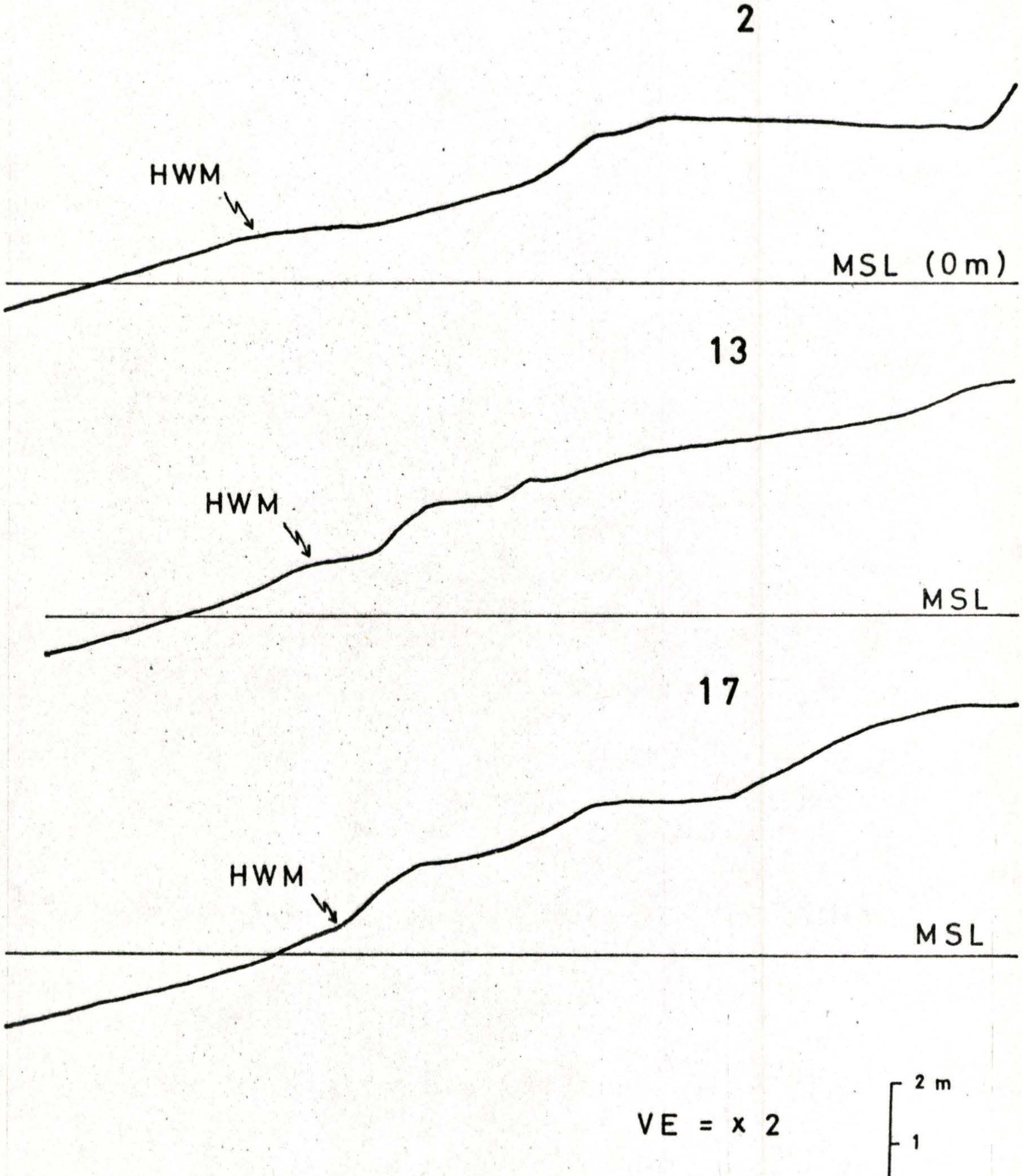
The width of the modern beach, including zones (i), (ii), and (iii), as shown on profiles 3 through 20, decreases northwards with an increase in the slope of the foreshore. The zone affected by wave action is relatively narrow and the decrease in width can be seen as a function of the change in steepness of the foreshore, which varies from 5° on profile 3 to over 25° on the most northerly profiles. Foreshore slope is a restricting factor on wave action but the actual controlling agent is the tidal range. Measurements of the tidal cycle on Cape Ricketts (chapter IV (i)) indicate a maximum range of approximately 2.2 m and that the mean tidal range is in the order of 1.3 m.

The width of the tidal zone and accordingly the area in which normal wave action takes place, during the period of maximum tidal range, was never greater than 14 m (photograph 3), and on the northern and southern sections of the foreland was as low as 4 m. The action of waves under normal conditions is limited, therefore, to a narrow strip of the overall beach zone. The topographic effect of foreshore slope is important as this causes variation in the width of the inter-tidal zone, tidal range being constant over the length of beach under discussion.

One of the major features of the beach in profile is the steepness of that part of the beach about Mean High Water Mark. On the whole length of the western Cape Ricketts beach there is a steep section, up to 2 m high, which gives a low, sharp ridge backed by a shallow swale. In photograph 3 the figure is standing on this low ridge. Figure 21 shows profiles 2, 13, and 17 on a larger scale than presented earlier, as these examples are particularly suited to illustrate the steep character of the beach-face slope above MHWM. This section of beach appears to have been combed down by wave action. At no time were any ridges seen to be built by waves that could reasonably be expected to be preserved except during a period of storm conditions on August 9 - 10. During this short period the main beach ridge at the south-west tip of the Cape was built up slightly by the pushing and throwing of material onto the highest parts of the beach. Changes in detail at this time were too small to be picked out by the profiling techniques and were only in the range of a few centimeters, though the effect of a large storm would certainly bring about measurable changes

FIGURE 21

Enlargement of Three Cape Ricketts Beach Profiles


2
HWM
MSL (0m)
13
HWM
MSL
17
HWM
MSL
VE = x 2
2 m
1
0
10 m
5
0

in the beach profile. The action of storm waves during this period illustrated the type of conditions indicated by the beach sampling study, with coarser material pushed onto the upper parts of the beach and finer particles washed down the beach (see also the time series samples on profile 3, Table V and p. 77-9). In this environment, which is essentially one of low energy conditions, it may be suggested that the storm wave plays a dominant role in littoral processes. These possibly may be of greater importance, relatively, than in the so-called storm-wave environments of the North Atlantic, due to the ineffectiveness of those waves acting on the beach during the remainder of the open water season.

The build-up of small ridges, with a maximum height of 20 cm, such as the one picked out on profiles 2 and 13 (Figure 21) and on profile P1 (Figure 23), at the high tide limits, was observed on several occasions. These are short-lived and present no permanent addition to the character of the modern beach zone.

A possible explanation for the character of the beach in the intertidal zone is that this is an emerging foreshore upon which wave action is attempting to flatten the beach, whilst the action of storm waves builds a ridge above tidal zone which will eventually become a feature of the raised beach sequence. In this manner it is possible to envisage the sorting and transportation of material under normal wave conditions, without a change in the character of the beach, presenting a smooth, gently sloping intertidal zone. The development of a permanent ridge at the top of the beach slope takes place during periods of exceptional wave action at infrequent intervals.

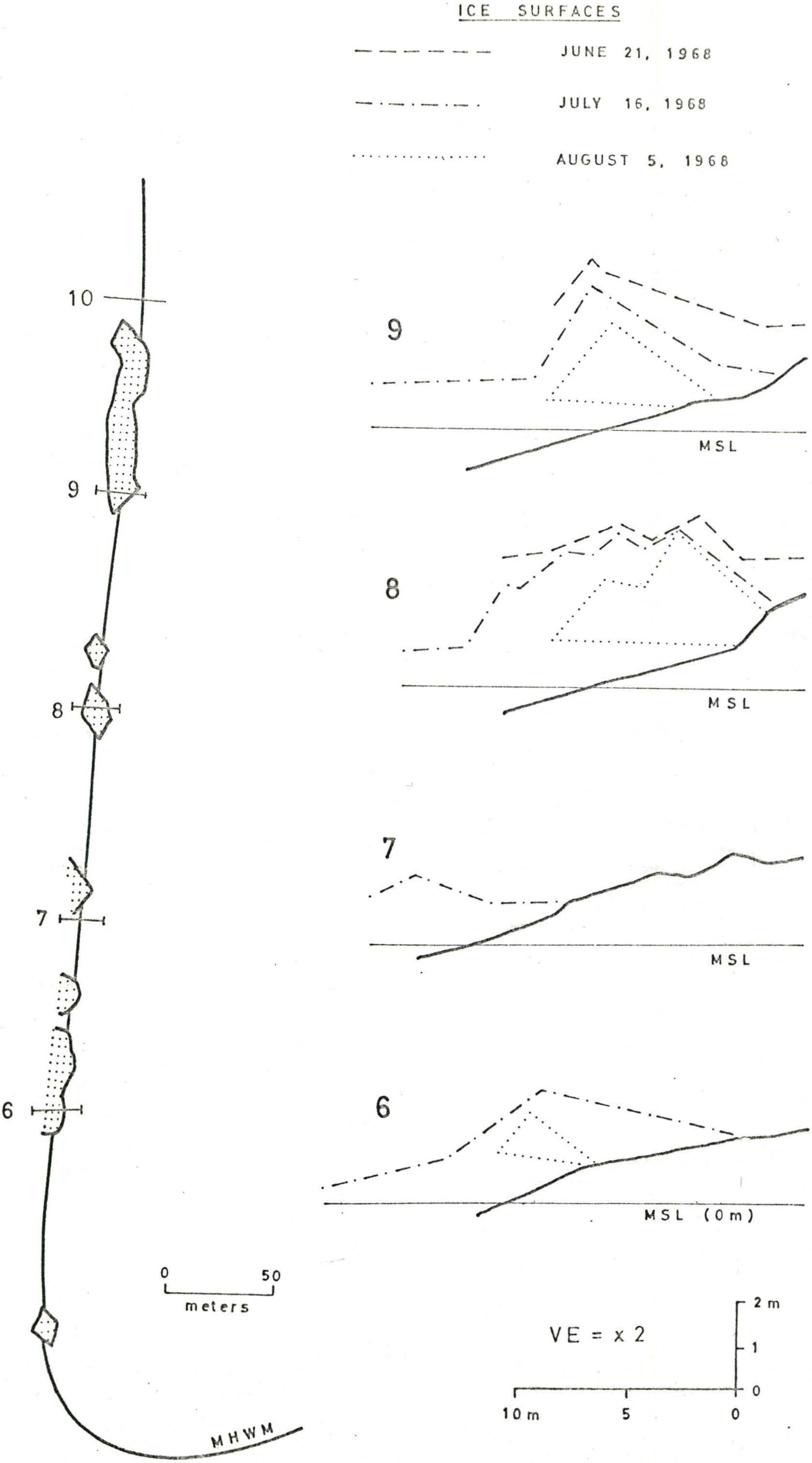
b. Ice Features of the Beach in Profile:

The presence of ice on the beach after the removal of sea-ice has been referred to in chapter IV (ii). In particular the ice mounds mentioned on page 42 were a major characteristic on the beach. The plan shape of these features on July 29, 1968 is presented in Figure 22 along with enlarged sections of profiles 6, 7, 8, and 9, which were taken through this area on June 21, July 16, and August 5. Photographs 21 through 25 show the decay and reduction of these features from June 21 through August 6, and extensive remnants of these forms were still present on the beach when the party left the area on August 10.

The largest of these ice mounds was that found between profiles 9 and 10 which, at the end of July, extended some 80 m along the beach, and had a height up to 7 m above Mean Sea Level. By mid-July some seven separate mounds were visible on the beach, though on arrival in early June these could not be distinguished as individual features. These were rather part of a section of buckled ice which covered this southern section of the west-facing Cape Ricketts beach, landwards of the tidal cracks (photograph 21 was taken on June 21 looking towards the beach along profile 4). With the ablation of snow and ice during late June and early July gravel and coarse sand within the ice became exposed and rested on the surface of the buckled ice, this then protected the ice beneath it from further ablation (photograph 22). On profile 7 (Figure 22) the buckled ice on that section of beach disappeared between July 16 and August 6, however, where material rested upon the ice surface the protective role became evident, (profiles 6, 8, and 9) and the development of the seven separate mounds can be related to the distribution of

FIGURE 22

Ice Mounds on Cape Ricketts Beach


ICE SURFACES
JUNE 21, 1968
JULY 16, 1968
AUGUST 5, 1968
10
9
8
7
6
9
MSL
8
MSL
7
MSL
6
MSL (0m)
0
50
meters
MHWM
VE = x 2
2 m
1
0
10 m
5
0

material on the ice surface. The thickness of material may account in part for the degree of protection afforded to the ice, as the reduction of the ice by ablation appears to have been more rapid on the mound crossed by profile 6 than in the cases of profiles 8 and 9. In the latter two instances the height of the mound is reduced by less than 2 m at the highest points. The mounds were ice-centered (photograph 23) and the maximum depth of material, except for swales and hollows, was 0.3 m.

The preservation of the mounds may be explained in terms of the theory used by Wilson (1953) to account for dirt cones on glaciers. The material on the surface of the ice acts to protect the ice from further reduction by ablation. Although this accounts for the form of the features during the thaw period, it is also necessary to explain how the ice and material came to be on the beach during the early summer.

Rex (1964) discusses the formation of a storm ice-foot in the area of Point Barrow, Alaska, and accounts for the presence of large volumes of buckled ice in the beach zone. He suggests that pack ice moves into the littoral zone during storm conditions at a time when shore ice is forming. If this fast ice is rigid then buckling will take place at the seaward edge of the beach ice, if, on the other hand it is not sufficiently fixed to the beach this will lead to a piling up of shore and pack ice on the beach itself. Rex reports that this buckled ice may reach as much as 9 m (30') in height. This ice may contain large amounts of beach material which, as ablation takes place during the following thaw season, will become exposed and cover the surface of the ice-foot. This explanation involves storm conditions at the time of freeze-up and the presence of pack ice to exert pressure on the shore ice. Such storms are common in the Point Barrow area during the fall and, though they are less frequent in the area under consideration, if one had occurred during the previous freeze-up period it would adequately explain the presence of a large mass of buckled ice on the beach. As parts of the mounds became exposed during July 1968, layered ice in this zone was observed to dip at 45°, showing that the feature had resulted from some form of fracturing rather than the growth of ice due to freezing wave spray. The buckling of the ice appears to result from pressure at the seaward edge, and some rigidity of this ice, due to its fixed position on the beach, would prevent it from being pushed in advance of the pack ice and cause it to buckle and fracture in situ. Photograph 26 shows a zone of pressure ice ridges around the south-west tip of Cape Ricketts in early June 1968 and this may be an expression of the pressure which led to the buckling of ice in the beach zone.

The effect of this set of processes during the fall would become particularly apparent as thaw takes place in the following summer. Beach material incorporated in the ice is exposed as the surface snow and ice is ablated. Where this material is present in sufficiently large quantities it acts as a protecting cover and prevents the ablation of ice beneath it at the rate which the surrounding debris-free ice is removed. This leads to the presence of mounds, which in this instance were more susceptible to wave erosion than ablation (photographs 23, 24, and 25). The irregular profile of these ice-cored mounds (Figure 22) may be a result of cracks in the buckled ice or to differential ablation. The latter can be related to certain parts of the ice having only a thin cover of debris which would not inhibit ablation but would in fact accelerate it, by the material absorbing heat and transferring it to the ice beneath. The formation of such depressions would be short-lived as further debris would fall into the hollow and provide a sufficiently thick cover to prevent further ablation, however, the form of the depression would remain. Greater melting took place at the edges of the debris carpet because of this indirect ablation and often the ice mounds were rimmed by a small 'moat' as the rate of ablation at the ice edges was greater than that of the surrounding debris-free ice.

These ice features are not permanent, probably not surviving the summer, and have not been reported elsewhere in the Canadian Arctic, though this does not preclude their existence in other areas of the Arctic Archipelago. The development of such mounds would depend upon a particular set of conditions existing at the time of ice-foot development, the combination of a storm occurring during the freeze-up of wave spray may not permit such a development in many seasons. It is of value to note that the location of the mounds, as shown on Figure 24, is on the most southerly section of the west-facing beach, that area most affected by the storm of August 9 - 10. This zone is probably the one most generally affected in storms and where the development of a large ice-foot could well take place in the conditions outlined above.

c. Frost Table Profiles:

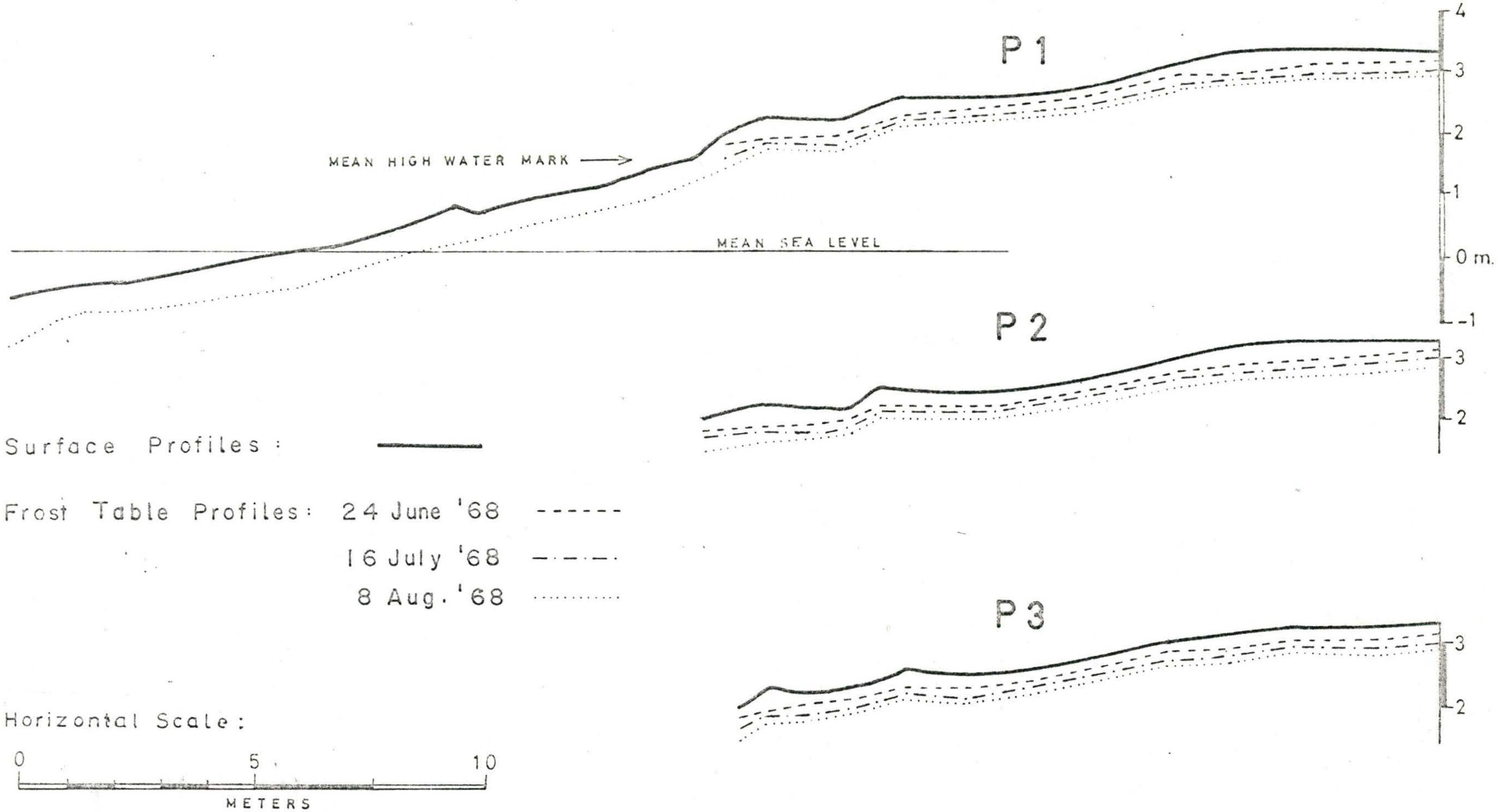
A series of subsurface frost table profiles were augered during the summer field season of 1967 on Allen Bay, near Resolute, and these are discussed in McCann and Owens (1967). On Cape Ricketts a similar programme was carried out to determine the depth of the active zone over a seven week period, as this indicates the amount of material which is available for reworking by ice or wave processes (Figure 23). A hand auger was inserted along the three profiles at 0.5 m intervals (profiles P1, P2, and P3 on Figure 24). The depth at which resistence was met and ice chippings were present on the tip of the auger when brought up indicated the limit of the unfrozen, active zone.

Early in the thaw season, June 24, 1968, the depth of the active zone was generally less than 0.25 m, but by August 8 the depth had increased to a maximum of 0.60 m. This agrees with the results obtained in 1967 from the Resolute area, where a maximum depth of 0.53 m was recorded on July 31. From a comparison of the subsurface and surface profiles it is interesting to note that the surface topography is closely reflected by the frost table.

In order to determine the limit of the frost table in the inter-tidal zone a series of measurements were taken along profile P1 on August 8 as far as the sea edge at low tide. This sequence of augerings was carried out at 0.25 m intervals. It was found that the depth of the active zone increased slowly towards Low Water Mark, but was not greatly deeper than the active zone above High Water Mark. The last two measurements, those nearest low water, failed to produce ice chippings although firm resistence was found at the depths indicated. Despite this the results clearly show that the frost table extends into the

FIGURE 23

Frost Table Profiles on Cape Ricketts


P 1
P 2
P 3
MEAN HIGH WATER MARK
MEAN SEA LEVEL
4
3
2
1
0 m.
-1
3
2
3
2
Surface Profiles :
Frost Table Profiles: 24 June '68
16 July '68
8 Aug. '68
Horizontal Scale :
0
5
10
METERS

intertidal zone such that it could prevent the reworking of large amounts of beach material either by ice-push or storm wave action. At Mean Sea Level the depth of the active zone was 0.45 m on August 8, during the later part of the summer this value would be somewhat larger, but the frost table would nevertheless exist as a lower limit for beach processes in the vertical direction and could inhibit major changes in the form of the beach. By the same argument ridges, which are mirrored by the frost table, may have their basic form preserved even if ice were to be pushed across the upper parts of the beach. This may be discerned in photograph 27 where ice has pushed over a series of ridges and swales above the modern beach zone without destroying their form.

(iii) The Beach in Plan:

a. Beach Ridges:

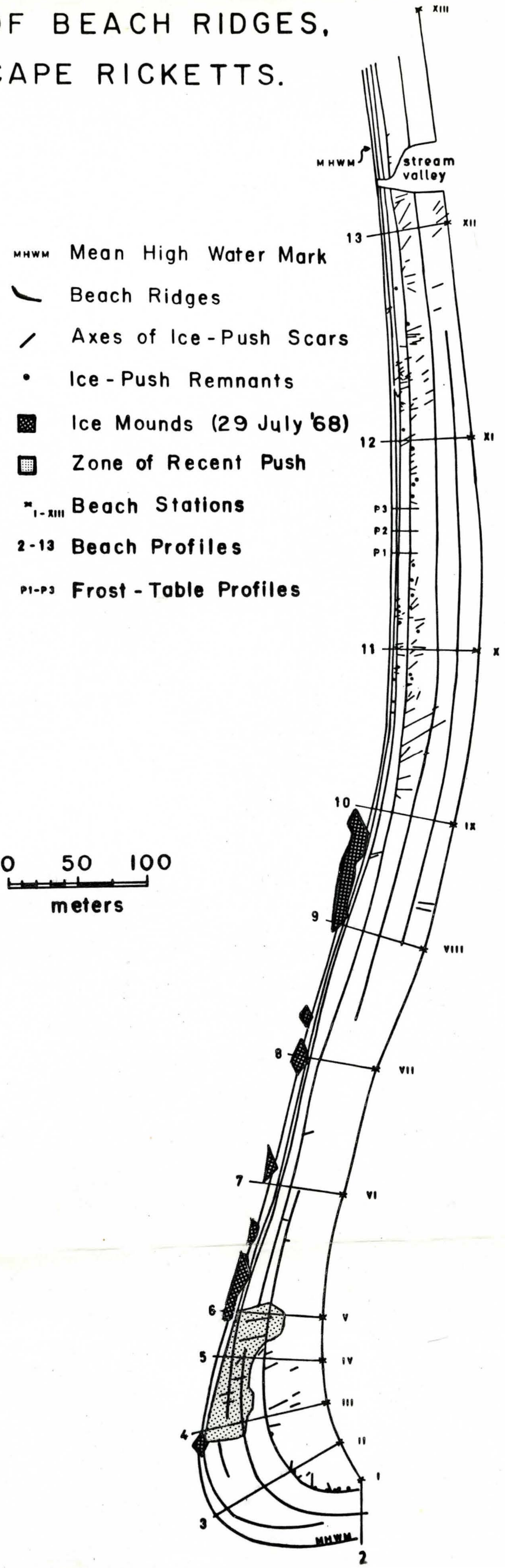
A map produced from the tacheometric work carried out on Cape Ricketts is presented in Figure 24, a discussion of the preparation of this map is given in Appendix C. Whilst it is often possible to obtain the plan shape of a beach and beach ridges from aerial photographs this could not be applied to the area under investigation, particularly in view of the many small-scale features present in the modern beach zone.

The parallel or sub-parallel nature of the beach ridges in the mapped area would suggest that these have been formed by a similar agency with no variation in their orientation as emergence took place. The south-westerly tip of the Cape is a zone in which most change would be expected, being the most exposed section, but here the curved sections of the ridges show no great diversions from the trend expressed by the adjacent raised beach ridges.

FIGURE 24

Tacheometric Map of Cape Ricketts

TACHEOMETRIC MAP OF BEACH RIDGES, CAPE RICKETTS.



A consideration of the beach ridges in profile and plan (Figures 20 and 24) indicates that those found in the active zone have a greater relief and are more closely spaced than those present in the raised beach series. This can be seen as a result of consolidation and compaction of the beach sediments which leads to the preservation of a set of wide, low ridges separated by shallow swales. These raised beach ridges may represent several former active zone ridges which have coalesced during a long period of consolidation and compaction. It would therefore be expected that as emergence continues those ridges now above Highest High Water Mark will be subjected to similar changes and will perhaps lead to the formation of another wide, low raised ridge.

b. Ice-formed Ridges:

The effect of ice or ice-floes driving onto the beach area has been described by several authors (for example: Washburn 1947; Nichols 1953 a; Hume and Schalk 1964 b; and Horn 1967). Pack ice or ice-floes may be carried over open water by wind action and allowed to ground on the beach where there is a relatively deep inshore zone. In areas of shallow water the ice will ground offshore and produce micro-relief features such as those described by Rex (1955). Bird (1967) suggests that often floes are shunted onto higher parts of the beach by further pressure from other floes or pack ice, and it is only these ridges, formed in the zone above the highest wave action, which will survive subsequent wave erosion. The major characteristic of the Cape Ricketts beach, when seen in plan, is the presence of a large number of ice-push scars or remnant mounds, particularly in the southern section of the west-facing beach. Although no scars were seen in formation during the summer field seasons, a comparison of photographs taken in 1967 and 1968 around Cape Martyr, near Resolute, indicated a noticeable increase in the number of ice-push ridges in that area. These had formed during the late summer and fall of 1967.

A zone of recent ice-push at the southern end of Cape Ricketts (outlined in Figure 24) represents a single event during which ice had been forced inland some 40 m. This presumably had occurred in the previous summer or fall. The feature was not visible until late June after the ablation of snow on the beach, it then became apparent that remnants of sea ice were present some 40 m inland of the modern beach zone. These pieces of ice were less than 2 m high and only present at the extreme eastern, or landward, end of the zone (photograph 27). Further ablation of snow led to the exposure of straie in the beach material, indicating the direction in which the ice had travelled. The volume of ice and beach material involved in this particular push event appears to have been small, little transfer of beach material from the lower beach zones occurred and no scar or ridge was formed at the terminus section after ablation had removed all the ice (photograph 28). The amount of ice in the push may have been greater than is shown in photograph 27 as ablation may have occurred after push had taken place during the previous summer or fall.

This type of push feature has been recorded by Hume and Schalk (1964 b) in the Point Barrow area. These authors suggest that, generally, only 1% of the local beach material is involved in this process. Such a value is reasonable for the example discussed from Cape Ricketts where the ice appears to have overridden the beach and little material has been moved inland (photograph 28). The more visible push scars to the north (Figure 24) are different, in that they represent small floes ploughing into the beach and usually travelling only short distances. Any occurrence of the type of overriding push described above would not produce a lasting feature, whilst the smaller and less dramatic lunate scars present a form which will remain unless removed by wave action or further ice push (photographs 29 and 30).

The presence of a large number of ice push features in the small area of the map summarized in Figure 24 often presented a confused pattern of coalescing ridges. In most cases it was possible to record the direction of push, as evidenced by a scar which represents that part of the beach over which the ice floe had been driven (photograph 30). If no direction of push was evident the feature was recorded as a remnant. The maximum length of ice push scars in this area was approximately 50 m, from the truncated end of the scar to the edge of the proximal lunate ridge. In no instance was this ridge greater than 1 m in height. No features of ice push were visible in the intertidal zone as the snow and ice retreated from the beach, suggesting that all the push ridges are older than freeze-up 1967. Many of the scars in zones (ii) and (iii) are truncated by small ridges (photograph 29), which may indicate that following the formation of a series of scars wave action combed down the upper part of the then modern beach, truncating these features. Emergence would then raise them above the limit of all wave processes.

The distribution of scars on Cape Ricketts (Figure 24) suggests that there is a higher frequency in the lower, or more modern, parts of the beach. For the same reason that raised beaches undergo consolidation and compaction it would be expected that the small-scale forms on the beach would be levelled and possibly disappear. The lack of such features in the higher raised beach sequences does not necessarily indicate that ice push was absent at the time when that part of the beach was being formed, as they are forms which are unlikely to be found in the geological record unless particular circumstances should favour their preservation.

The high concentration of ice push scars and ridges on the southern section of Cape Ricketts is itself interesting. Reconnaissance of other beaches in this area of south-west Devon and around Resolute, as well as a low level aerial survey of beaches along the west coast of Prince of Wales Island (due to the generosity of Dr. D. Dinely), indicated that although ice push features are not uncommon, the presence of so many in such a small area was peculiar to Cape Ricketts. The region of ice push around Cape Martyr, near Resolute, is the only area which had any similarity, though the number of scars was but a fraction of those recorded on Figure 24. An explanation for this concentration is that Cape Ricketts is a favourable location for ice floes to ground on the beach. The offshore zone presents no obstacle to floes reaching the beach (Figure 4) and the west-facing shore projects south from the generally straight trend of the coastline on this part of Devon Island. As such the beach is exposed to floes and pack ice moving eastwards through Barrow Strait from Viscount Melville Sound and Wellington

Channel. Ice is moving past this area throughout the summer and fall, as it is removed from areas to the north and west, and only requires strong winds from the south or west to drive floes onto the Cape Ricketts beach. The northern sections of this beach exhibit only a half dozen push scars, a possible result of the protection afforded by the headland on the opposite side of Gascoyne Inlet.

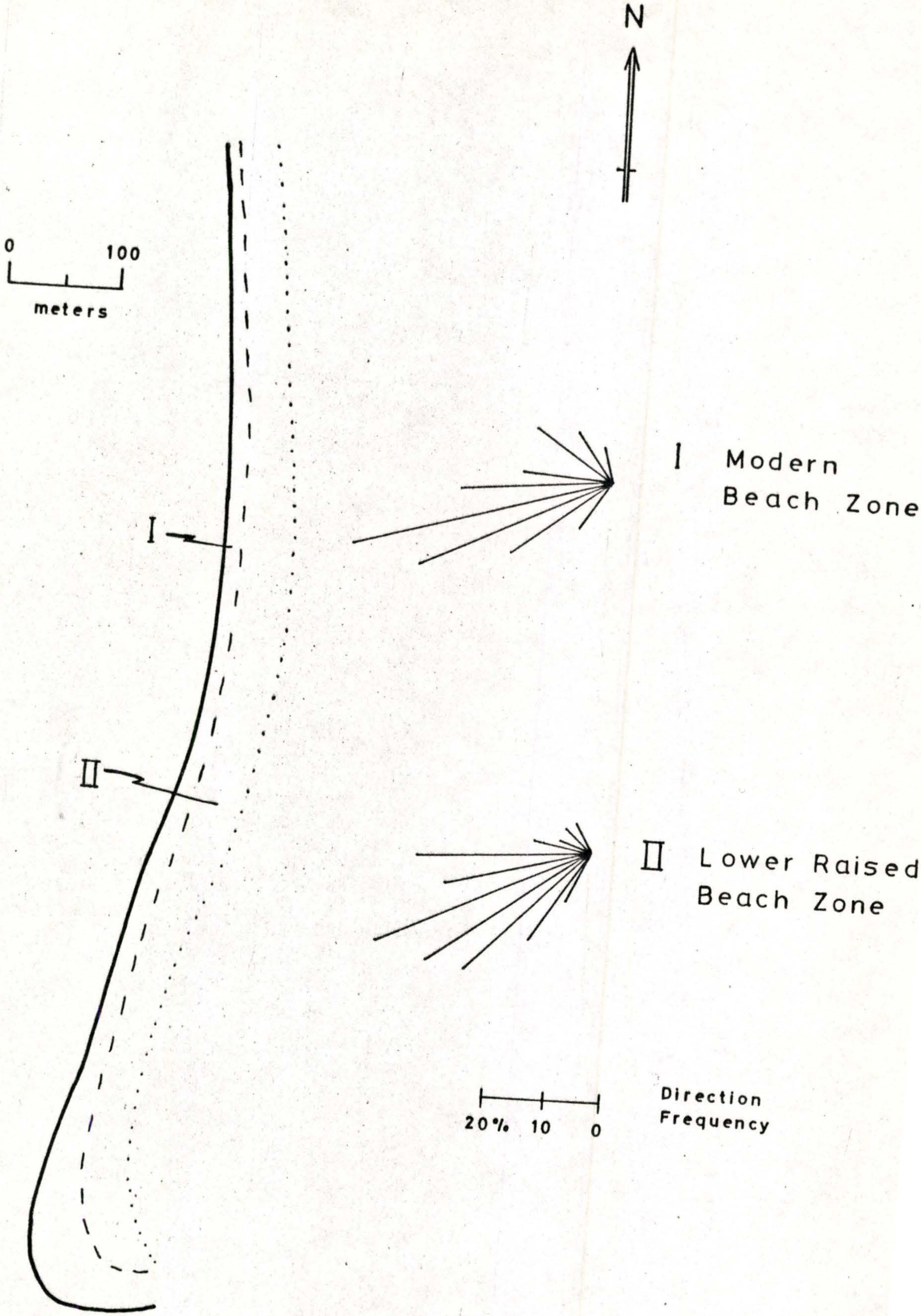
As a measure of the orientation of these beach features the direction of push is given in two rose diagrams on Figure 25. The upper rose (I) represents all those push scars present on the beach below the ridge marked on photograph 29, which includes only the most recent scars, whilst the second, and lower rose (II) is for those measured in the upper part of the modern beach zone and on the lower raised ridges. The two frequency diagrams show that there is a dominant push orientation from the south-west, that is, at an angle to the beach rather than perpendicular to it. A few floes have come from the north-west quarter, which involves a movement down the limited fetch within the southern section of Gascoyne Inlet. There appears to be no major difference between the orientation of those scars formed in more recent times, with those on the higher parts of the beach which have now been raised above the level of all wave action, though there is a slightly greater variation in the direction of push on the upper parts of the beach.

c. <u>Summary of the Beach in Profile and Plan</u>:

1. The zone over which wave processes can act is narrow, and reaches a maximum of 14 m in certain areas at spring tides. This is a result of the foreshore slope and tidal range.

FIGURE 25

Orientation of Push Scars on Cape Ricketts


N
0
100
meters
I
II
I Modern Beach Zone
II Lower Raised Beach Zone
20% 10 0
Direction Frequency

2. The beach face slope is steep, which suggests that normal wave action has a very limited effect and that it is the infrequent but relatively energetic storm waves which produce the High Water Mark ridge and beach face slope, the main characteristics of the modern beach zone.
3. A series of ice-cored and debris covered mounds resulted from the buckling of beach-fast ice in the fall of 1967. Subsequent protection from ablation by exposure of a material incorporated in the ice preserved these features after the disappearance of the sea ice, during the summer of 1968.
4. The frost table extends below Mean Sea Level and may reach beyond Low Water Mark. The depth of the active zone increases during the thaw season, but may nevertheless inhibit form changes in the beach zone.
5. The beach ridges of Cape Ricketts show no variation in their alignment, which suggests that the conditions leading to their formation have not changed greatly, in terms of fetch and orientation.
6. Ice-push features were present in two forms, in one instance a floe, or floes, was driven inland some 40 m, but less than 1% of the beach material was involved and no ridge was formed. Smaller floes bulldozing into the beach have produced lunate ridges and scars which, if they extended above the Highest High Water Mark, could be preserved in lower raised beach zone.
7. Ice-formed features are rarely found on the higher parts of the raised beach sequence, due to compaction and consolidation of the sediments.

8. The direction of ice-push appears not to have changed in recent times. The major orientation of ice push scars is towards the south-west.

CHAPTER VI

SYNOPSIS AND PERSPECTIVE

The implications of the body of data and information presented and discussed in chapters III, IV, and V, are now related to the beach complex, at the local and regional levels. The character of the littoral zone, in terms of process and form, will be discussed for this area of South-west Devon Island initially. From this, an understanding of the beach environment will enable reference to other studies undertaken within the arctic, as well as to world beaches in general, so that the content of this investigation may be seen in its correct perspective.

(i) Synopsis:

The study of beach processes in low- and mid-latitude areas is concerned, primarily, with the effects of wave action, which involves consideration of tides as well as storm and swell waves. The form of these beaches is seen in profile, plan, and in terms of exposure, that is, fetch. A similar approach and similar methods of investigation are applicable for high-latitude beaches, except that these must include a close study of the role of sea ice. In order to compare the characteristics of the beach environment of South-west Devon with other areas, the beach complex will be summarized using 'normal' criteria for littoral studies. The introduction of the ice factor into the complex will then allow an assessment of the relative roles of ice and waves in this area.

The source of material from the offshore area for reworking in the littoral zone is made possible by the continuing isostatic readjustment. This is evidenced by the numerous raised beach sequences in the study area. Although this source must be viewed over the long term, emergent zones do contribute to the supply of sediments. The movement of material from the offshore zone into the littoral area by present processes is not well understood, even in more southerly latitudes, though this was observed on one occasion, after a storm during August 1968, and involved the movement of material in suspension. Further material is supplied by gravity deposition from the weathering of free-faces above the beaches, numerous talus cones above and over-riding the intertidal zone are evident beneath most cliffs in this area. In the Cape Ricketts location there is also the supply of material which is exposed on the south-facing section of the foreland. The supply of material by rivers is a relatively unimportant factor in the study area, but its importance in other areas is not to be overlooked.

The tides on the south-west corner of Devon Island are 'mixed, semi-diurnal', and measurements revealed a mean range of 1.3 m, with a maximum recorded range of 2.2 m. The intertidal zone of Cape Ricketts is relatively narrow, reaching a maximum width in the most favourable locations at spring tides of approximately 14 m. This is seen as a function of the foreshore slope, as well as the tidal range, and limits the littoral area over which wave action can take place.

The position of the study area in the Arctic Archipelago is sheltered and unaffected by swell waves, all waves are locally generated. The maximum fetch for Cape Ricketts is 150 km to the south-west, though if this were an ice-free region waves generated in the western Parry Channel, Viscount Melville Sound, would be an integral part of the wave pattern of south-west Devon. The prevalent wind direction, for Resolute, is from the north-west, that is, offshore. During the summer the passage of numerous pressure systems through this area gives a great variety of wind directions for this period. Storms are also associated with these depressions and this leads to the formation of short-lived but energetic wave patterns. Wave-induced currents, such as longshore drift, are hampered by the limitations of offshore and variable winds on wave generation. The interpretation of the sediment size and roundness analyses carried out for beach samples collected along west Radstock Bay and 'Walrus Bay' does show, however, that transportation of material, by longshore movement, occurs on these two beaches. The deposition of sediments and plan shape of beaches is closely affected by wave refraction, but for the Cape Ricketts area this is minimised by the relatively deep offshore areas. This is in contrast to the hydrography of Union and Erebus Bays, as well as Resolute Bay. In these areas the effect of the offshore zone as an influence on the pattern of wave approach is shown by the numerous spits and bars which parallel submarine contours. This is particularly evident in the Beechey Island tombola which links the island to the mainland.

The role of ice in this system is important in three ways which are related to the types of ice involved; the frost table, beach ice, and sea ice. In the first instance, the depth of the active zone in the beach area, as determined by the frost table, limits the amount of material which can be reworked by littoral processes. Although the depth of the active zone in the latter part of the summer is sufficient for it to have little influence on impeding wave action it nevertheless exists as a lower limit for reworking processes and may inhibit major changes within the beach zone.

The presence of ice on the beach due to the freezing of wave spray or swash, as well as the development of an ice-foot, leads to the premature cessation of wave action during the fall, a period when wave generation is still occurring before the development of the sea ice cover. Beach-fast ice remaining on the beach after break-up delays the commencement of wave action in the spring and summer, again during a period when wave generation is possible offshore. The maximum length of the open water season, at Resolute, from the scanty data available, is approximately 64 days and may be as little as 40 days. The season is slightly longer in the Cape Ricketts area, but, as this period refers to the sea ice cover, this is offset by the presence of ice on the beach before freeze-up and after break-up, which reduces the already short open water period. The maximum period for which waves are active in the littoral zone may be taken as two months.

The effect of sea ice in the fall and winter is to prevent wave generation and, although this ice cover is removed during the following fall and spring, pack ice inhibits wave generation, as well as dampening existing waves. The major impediment in this respect is that the ice distribution pattern controls the available fetch for any given beach at any one time. The two month period available for possible wave processes to operate on the beaches is therefore not representative of the amount of time during a season when such wave action may occur. Similarly the removal of ice from the sea precedes that of the ice cover in bays and inlets. The southern section of Gascoyne Inlet was not clear until August 5, whilst in Erebus Bay break-up had not commenced on August 15.

All the roles of ice so far discussed have been negative. The more positive aspects, those which bring about change rather than merely preventing it, can be seen in terms of floes and pack ice which are driven onto the beach. The effects of this ice push vary, as ice may override the beach and move considerable distances inland without displacing much beach material, or it may plough into the beach and produce a scar and lunate ridge. Although these push features are important aspects of the character of the beach zone at Cape Ricketts it is unlikely that these forms will be preserved in the geological record.

The other positive role of ice is in the rafting of sediments, either between different sections of beach or from the littoral zone into deeper water. The amounts of material involved in this method of transport are small and do not significantly alter the character of the beach sediments.

The area of investigation is a sheltered wave environment, which does not lend itself to the generation of large waves, and the role of ice severly reduces wave generation to only a few weeks in the year. To this must be added the necessity for the fetch to be free of ice, and for winds blowing over that fetch to be of sufficient strength to generate waves, as well as the beach being free of ice so that wave action is able to take place in the littoral zone. The necessity for the coincidence of these favourable factors restricts wave processes considerably during the short 'open water' season, and it is suggested that the dominant waves in this environment are generated during periods of storm, as these waves appear to be the only ones capable of causing any significant changes within the littoral zone.

The relative roles of ice and wave action can be seen in terms of the character of the elements of the beach zone. The low abrasion, or roundness, values of the beach material sampled on the three beaches, as well as the general low sorting values given by the size frequency distributions of the samples, indicate the ineffectiveness of littoral processes to rework material supplied into the beach zone. This is strikingly evident when comparisons are made with lower latitude beaches, though this does not deny that wave processes operate at all, as along and across the beach variations show that reworking and transportation does take place. The role of ice is the dominant feature of the environment although its function is largely negative. Normal wave generation and wave processes within the littoral zone are minimal, so that the major active role is played by storm waves. The form characteristics of the beach result almost entirely from storm waves and ice push.

(ii) Perspective:

In order to draw comparisons between the results of this investigation and conclusions of authors working on other arctic beaches it is proposed to discuss each of these major contributions separately, before remarking upon the place of this investigation in terms of arctic and world beach environments in general.

The work of Nichols (1961) refers to those characteristics which are considered to be unique to polar beaches (p. 6-7). As some of the features described belong to the elevated beach zone or to areas of ice-shelves and ice-cliffs, only a few of the forms were observed in this area of South-west Devon Island. Nichols discusses various types of pitted beaches, and similar features were found on Cape Ricketts. Although on a different scale and formed by different processes the term pitted beach is still applicable. Photograph 31 shows a pit, about 1 m in diameter, which has been formed as a stranded ice floe melted through ablation and wave wash. The pit can be ascribed to a burrowing action, as the floe was shoved about by waves, and to the inability of wave action to fill in the hole as the remnants of the ice floe melted. A series of pits near the south-west tip of Cape Ricketts are shown in photograph 32. These had formed where beach material overlay ice and resulted from differential melting of this ice as the thickness of the material cover varied, in a manner similar to that outlined by Nichols.

Push ridges formed by ice floes have already been described for the Cape Ricketts area, but the presence of ice-deposited beaches was not observed. With the complete ablation of the ice-mounds on Cape Ricketts the deposition of several cubic meters of material would add a significant amount of sediment to the beach zone, though this may not give any particular depositional feature but rather a carpet of material. Ice-rafted sediments have been referred to and are not thought to play an important role in the transport of beach sediments in this area. Nichols' qualitative observations on the poor rounding of beach stones were substantiated by the shape analysis carried out on the beach samples from the three beaches studied. The final feature ((ix) on p. 7) to be described is a gap cut into a beach ridge by a stream on the south section of the west Radstock Bay beach (photograph 33). The streams of this area are short-lived, as their only source is ice and snow melt, so that in the latter part of the 'open water' season, when stream flow is small at non-existant, it is possible for a beach ridge to form which will dam a stream exit. In the following spring the stream may then cut through this ridge. The example shown in photograph 33 has several former stream exits to the left of the present one which may well have been cut during that summer.

In addition to the features described by Nichols, the ice mounds found on Cape Ricketts are the only new items which may be suggested as being unique to polar areas. The other characteristics of the beach, as seen in profile and plan, are similar to those found in lower latitudes. It is valuable, therefore, to look at the beaches in terms of normal wave processes as well as discussing those features unique to polar areas. As an example of this the presence of wave-cut notches at the base of several cliffs in this area (photograph 34), when seen in relation to present processes, is difficult to explain. The answer, in this instance, invokes the idea that they were formed at a time when sea level was relatively the same but wave action was more effective.

The work of Moore in the area of Cape Thompson, Alaska, (p.9-10) was undertaken in an arctic area adjacent to the Pacific Ocean, via the Bering Straits. Although ice plays an important inhibitive role for 8 months of the year, Moore's conclusions (1966) are that the beach environment is basically similar to that of lower latitudes and that ice does not have an important positive role. This area may be considered in a transition zone between non-polar and polar beach types. The investigations reported by the various authors working at Point Barrow, Alaska, (p.7-9) show that, in this region on the north coast of the mainland, ice has an important effect on littoral processes throughout the year. In addition ice plays a positive role forming beach ridges.

When the results from these localities in Alaska are related to the environment on the south-west coast of Devon Island there is a noticeable difference in the scale of processes. The work of Hume and Schalk over several seasons indicates that this coast is more 'open' than that studied in this investigation. The net sediment transport of approximately 10,000 m^3 reported (1967) by these authors implies a considerable amount of reworking and movement of beach material, although this is less than the value of 28,000 m^3 given by Moore for Cape Thompson (1966). One result of this is the formation of quite complex spits and depositional features, as opposed to the more simple forms which develop in the more sheltered parts of the Archipelago.

It would appear that the type of environment investigated in South-west Devon falls somewhere between that described for Point Barrow and the one outlined by Horn in the Sverdrup Islands. The results of Horn's work (1967) indicate that these beaches cannot be equated with those of ice-free areas, and it would appear that wave action on the beaches of this region can be considered in days rather than weeks.

The contrast between this conclusion and equally valid opinions of Moore, who was also working within the broad category of 'arctic beaches', reveals the variety of conditions which may be expected within polar areas. The transition from Cape Thompson, through Point Barrow, South-west Devon, to the Sverdrup Islands, the only areas for which information is available, can be related to a differing scale of the influence of ice in the littoral and offshore areas. This change does not necessarily depend on latitude, for in the instance of the Canadian Arctic Archipelago the increase in the length of the open water season is from west to east, rather than north to south.

The comparison of arctic beaches with those of lower latitudes can be considered largely in terms of the role of ice. Wave processes vary according to location and exposure (cf Point Barrow and South-west Devon) as well as being affected by the distribution and movements of ice throughout the year. The use of criteria normally employed for the study of more southerly beaches is valid in the arctic environment, particularly as this allows meaningful comparisons with results between, and within, regions. The only important difference with littoral studies in the arctic is the need to consider ice action, whether it be negative or positive, and to make sufficient allowance for annual variations in the length of the period during which wave processes may be effective (see Lindsay 1968). The study carried out by Davies (1964), which compared world beach environments with particular emphasis on storm and swell wave conditions, could be usefully extended to include a greater consideration of arctic regions as more information is now available for this area. The beaches of this region are not unique or 'special', but possess many of the features found in other latitudes and, as such, should take their place in any consideration of beaches on a global scale.

CHAPTER VI

CONCLUSIONS

1. Techniques normally applied in temperate and tropical latitude littoral studies are valid for the investigation of similar processes in the arctic environment. These techniques were applied in the area of South-west Devon Island, N.W.T., and provided meaningful results which enable comparison with work carried out in other arctic and non-arctic regions.
2. Certain ice formed features, such as push ridges, are unique to polar beaches and the roles of beach ice, sea ice, and the frost table are important factors in the consideration of littoral processes. Apart from this the processes which operate are the same as elsewhere in the world, although the scale and relative importance of these processes may vary.
3. Different environments within the arctic region may be discerned on the basis of the length of the open water season, which can be related to ice distribution and movements, as well as exposure of the shore in terms of fetch distances. In the study area, South-west Devon Island, the period of possible wave generation is not expected to be greater than two months in the year. The presence of beach ice during this period may reduce the already brief season for which wave processes may be active. The removal of sea ice from inlets and embayments, and of beach fast ice from

the littoral zone, varys considerably over small areas and must be taken into account when discussing the length of the active period.

4. The analysis of the size frequency distribution and roundness characteristics of samples of material collected from three beaches in the study area indicates that normal wave processes are operating in this environment, although their ability to re-work and abrade material is severely reduced. Along and across the beach variations were evident and used to infer the longshore movement of beach material from local sources on two of the beaches.
5. The interpretation of the form of the beach suggests that storm waves are important, as they give the littoral zone of Cape Ricketts its characteristic features. In particular, the beach zone has a steep beach face slope topped by a small storm ridge. The beach appears to have been combed down by storm waves rather than built up by constructional wave action.
6. In terms of the process environment, ice plays a dominant, albeit negative, role in giving the beaches of this area their particular character.

APPENDIX A

Mean Roundness Values for Beach Samples

Sample Number	Mean Roundness
111	177.5
12	202.5
13	105.0
14	165.0
121	202.5
22	227.5
23	187.5
24	172.5
131	180.0
32	130.0
33	155.0
34	222.5
141	225.0
42	227.0
43	150.0
44	267.0
151	152.5
52	152.5
53	182.5
54	185.0
161	182.5
62	222.5
63	217.5
64	212.5
171	25.0
72	225.0
73	165.0
74	260.0

Sample Number	Mean Roundness
211	120.0
12	122.5
13	107.5
221	145.0
22	115.0
23	140.0
231	100.0
32	160.0
33	130.0
241	145.0
42	152.0
43	210.0
251	152.5
52	132.5
53	142.5
261	145.0
62	177.5
63	170.0
311	147.0
12	153.0
321	97.0
22	201.0
331	145.0
32	149.0
341	149.0
42	173.0
351	141.0
52	221.0
361	185.0
62	191.0

APPENDIX B

Sediment Size Analysis and Moment Measures for

Beach Samples

Analysis of Size Data.

The Woods Hole SEDANL Programme.

To analyse grain-size data, moment measures were calculated using a computer programme devised by Schlee & Webster (1965). This was modified by D. R. Ingram for these investigations. The advantage of this particular programme, as there are several which could have been employed, lies in the attempt to "improve the estimation of statistical parameters for grain-size data by use of interpolated values .... (these are computed by) fitting a series of overlapping parabolas to the data". (1965 p. 2)

The use of computation techniques was preferred over graphic methods, such as those proposed by Inman (1952), and Folk & Ward (1957). The graphic moments are an approximation rather than a precise value, and cannot allow for the extremes of the distribution, which are vital to the calculation of skewness and kurtosis (see Fox, Ladd, and Martin 1966). This is particularly important to the high positive values of kurtosis, the computed moment is able to accurately indicate the fullness of the peak and the thinness of the tails. The exponential function used for the interpreted data points allows for negative values which may be produced as a result of the parabolic interpolation. Again this is important to kurtosis which is extremely sensitive to the position of data points, and would be affected by any attempt to omit or transfer negative values. The use of interpolated values plus the original values gives a better and more accurate representation of the characteristics than do the original values alone. A continuous interpretation is obtained by the linear transformation of the polynomials which describe one parabola, to those which describe the next overlapping parabola, and extracts values from these at a designated interval.

SEDANL Programme Output.

(i) Mode(s)

The phi value is given of points where the difference between that value and the preceding one is greater than five class intervals. This indicates a peak or peaks in the distribution; minor modes being eliminated by using five class intervals for differentiation.

(ii) Median.

This is the phi value which corresponds to 50% on the cumulative frequency curve; that is the geometric median.

(iii) Moment Measures.

A moment can be defined as the product of a frequency distribution from an origin or fulcrum. The programme transforms the moments (n) computed around the assumed mean to moments (m) around the true mean; then Sheppard's Correction for grouped data is applied to m_2 and m_4.

For moments around the assumed mean:

(1) $$n_r = \frac{\sum (X-\bar{X})^r}{N}$$

where; r = the rth moment

if r = 1 ; n_1 = difference between the true and assumed means

if r = 2 ; $n_2 = \frac{\sum (X-\bar{X})^2}{N}$ = variance

The assumed mean is taken as the midpoint of the class which contains the greatest frequency. The true mean ($\bar{X} + n_1$) is used as the first moment and from this origin, which is given the value 0, the uncorrected moments around the true mean are computed.

(2) $$m_1 = 0$$

(3) $$m_2 = n_2 - n_1$$

(4) $$m_3 = n_3 - 3n_2n_1 + 2n_1^3$$

(5) $$m_4 = n_4 - 4n_1n_3 + 6n_1^2n_2 - 3n_1^4$$

The moments are referred to the mean as the centre of gravity of the distribution, this value is used as the basis for the calculations and "each succeeding moment can be assigned an analagous physical significance" (Griffiths 1967).

Sheppard's Correction is applied because of an error which arises due to the assumption that "each value within a phi class is centered at the midpoint of each class". The first and third moments require no correction.

(6) $$m_2 \text{ corrected} = m_2 - \frac{1}{12^c}{}^2$$

(7) $$m_4 \text{ corrected} = m_4 - \tfrac{1}{2}c^2m^2 + \frac{7}{240}c^4$$

where; c = the class interval

From these corrected moments around the true mean the last three moments are used for computations in the formulae:-

(8) $$\text{Standard Deviation} = \sqrt{m_2 \text{ corrected}}$$

(9) $$\text{Skewness} = \frac{m_3}{2\sigma(m_2 \text{ corrected})}$$

(10) $$\text{Kurtosis} = \left(\frac{m_4 \text{ corrected}}{(m_2 \text{ corrected})^2}\right) - 3$$

In a normal distribution (mesokurtic) the kurtosis value would be equal to 3; this value is subtracted for convenience so that all positive values indicate a leptokurtic distribution, whilst all negative values refer to platykurtosis.

(iv) Frequency Curve.

The computer is programmed to print out a frequency curve, with or without the interpolated values as directed. Whilst this curve cannot be regarded as accurate it is useful in providing a visual impression of the data, this is particularly helpful in showing bimodal distributions.

Sample Number	Date 1968	$\overline{X}$	σ	Sk	K	% sand	Bi
1 1 1	2 Aug.	-3.81	1.42	0.51	2.04	4.11	*
1 2	2 Aug.	-4.32	0.87	0.06	0.10	0.23	
1 3	2 Aug.	-3.53	1.17	0.55	2.08	4.11	
1 4	2 Aug.	-3.24	1.73	0.45	0.19	14.42	
1 2 1	2 Aug.	-4.05	1.16	0.12	-0.61	0.24	
2 2	2 Aug.	-3.44	0.76	-0.10	0.62	0.24	
2 3	2 Aug.	-3.73	0.42	-0.26	0.66	0.05	
2 4	2 Aug.	-3.28	1.16	-0.14	-0.58	0.02	
1 3 1	2 Aug.	-4.77	0.91	0.19	0.38	0.26	
3 2	2 Aug.	-4.36	1.27	-0.04	-0.84	0.43	
3 3 (i)	2 Aug.	-3.37	0.83	-0.14	-0.13	0.14	
3 3 (ii)	10 Aug.	-2.18	0.93	0.10	-0.21	10.84	
3 4 (i)	2 Aug.	-3.77	0.96	-0.12	-0.30	0.15	
3 4 (ii)	10 Aug.	-0.95	0.93	0.47	2.78	49.34	
1 4 1	2 Aug.	-5.33	0.84	0.52	1.28	0.10	
4 2	2 Aug.	-4.26	1.03	0.07	0.18	0.54	*
4 3	2 Aug.	-3.76	0.89	-0.13	-0.15	0.08	
4 4	2 Aug.	-2.78	1.57	0.06	-0.58	16.59	
1 5 1	2 Aug.	-4.35	1.12	0.06	-0.71	0.20	
5 2	2 Aug.	-4.93	0.90	0.43	0.43	0.19	
5 3	2 Aug.	-3.72	0.62	-0.49	1.50	0.00	
5 4	2 Aug.	-2.93	1.09	-0.12	0.15	2.58	
1 6 1	2 Aug.	-5.12	0.85	0.43	1.46	0.24	
6 2	2 Aug.	-4.82	0.79	0.38	2.09	0.30	
6 3 (i)	2 Aug.	-3.76	0.69	-0.07	0.80	0.22	
6 3 (ii)	6 Aug.	-3.60	0.63	-0.05	0.03	0.00	
6 3 (iii)	8 Aug.	-3.57	0.66	-0.49	2.75	0.08	
6 4 (i)	2 Aug.	-2.83	1.29	-0.06	-0.08	8.55	
6 4 (ii)	6 Aug.	-3.29	0.87	-0.38	0.83	0.08	
6 4 (iii)	8 Aug.	-3.31	0.68	0.02	-0.08	0.08	
1 7 1	2 Aug.	-4.73	1.34	0.83	6.06	2.62	
7 2	2 Aug.	-5.16	0.67	0.47	2.14	0.08	
7 3 (i)	2 Aug.	-4.10	0.77	0.07	0.19	0.21	
7 3 (ii)	6 Aug.	-3.37	0.61	0.09	0.29	0.06	
7 3 (iii)	8 Aug.	-3.09	0.74	-0.11	0.39	0.18	
7 4 (i)	2 Aug.	-3.41	0.84	0.03	-0.33	0.21	
7 4 (ii)	6 Aug.	-2.96	1.20	-0.34	-0.13	0.29	
7 4 (iii)	8 Aug.	-3.18	0.78	-0.29	0.43	0.03	

2 1 1	26 July	-4.72	0.84	0.18	-0.26	0.08	
1 2	26 July	-4.65	0.91	0.16	-0.49	0.12	
1 3	26 July	-4.06	0.70	-0.03	0.38	0.15	
2 2 1	26 July	-4.85	0.87	0.28	-0.32	0.06	
2 2	26 July	-4.18	0.85	-0.11	-0.49	0.06	
2 3	26 July	-4.41	0.85	-0.04	-0.82	0.00	
2 3 1	26 July	-5.00	0.77	0.37	0.65	0.08	
3 2	26 July	-4.36	0.82	0.00	-0.28	0.08	
3 3	26 July	-4.02	0.95	-0.32	0.19	0.16	
2 4 1	26 July	-4.89	0.99	0.48	0.18	0.09	
4 2	26 July	-3.87	0.99	-0.15	-0.47	0.05	
4 3	26 July	-4.16	0.91	-0.19	-0.63	0.10	
2 5 1	26 July	-4.72	0.88	0.18	-0.59	0.50	
5 2	26 July	-3.26	1.30	-0.27	-0.47	1.40	*
5 3	26 July	-3.24	1.18	0.26	0.23	5.79	
2 6 1	26 July	-4.61	0.94	0.19	-0.58	0.03	
6 2	26 July	-4.13	1.17	-0.03	-1.12	0.05	*
6 3	26 July	-3.89	0.67	-0.20	-0.30	0.00	
3 1 1	20 July	-5.43	0.46	-0.26	0.79	0.00	
1 2	20 July	-4.78	0.71	0.05	-0.41	0.00	
3 2 1	20 July	-5.15	0.69	0.41	0.50	0.00	
2 2	20 July	-4.10	0.79	-0.23	-0.44	0.00	
3 3 1	20 July	-5.15	0.65	0.31	0.07	0.00	
3 2	20 July	-4.00	0.92	0.63	3.49	2.11	
3 4 1	20 July	-4.64	0.89	0.11	-0.90	0.00	
4 2	20 July	-3.84	0.99	0.18	1.01	1.41	
3 5 1	20 July	-4.91	0.83	0.29	-0.47	0.00	
5 2	20 July	-3.51	1.47	0.31	-0.16	9.27	

APPENDIX C

Surveying Techniques

In order to measure certain physical characteristics of the beach zone at Cape Ricketts, by means of tacheometric mapping and profiling, it was necessary to establish a precise network of survey stations. Fifteen ranging pole stations were set up and fixed by triangulation with reference to the Hydrographic Service Soil Post ART 4511 (Figure 19). The height of each station was then established by precise levelling. Nineteen beach stations were positioned along a major ridge in the lower raised beach zone, using a tape, and these were later incorporated into the network by tacheometry and the heights of the stations accurately levelled. The beach stations were erected as semipermanent cairns, with the precise location and height given by a painted spot on a flat stone.

All surveyed heights were taken with reference to the Soil Post ART 4511 located at the southern end of Cape Ricketts. The given height of this post is 10.67 m (35 ft) above High Water Mark (Monument list, Dept. of Energy, Mines and Resources, Canada). However, for the practical purposes of this investigation all heights were corrected to a local datum of Mean Sea Level as determined by the author from the tide level recordings discussed on page 31 . This requires that the height of the Soil Post be 13.67 m above Mean Sea Level, and suggests that the height assigned to the soil post is not in agreement with the observed situation.

The area covered by the tacheometric work concerned with the beach features is given in Figure 19, and the results are shown in Figure 24. The purpose of this mapping was to provide an accurate picture of beach ridges and small-scale beach features. The use of a tacheometer enabled relatively rapid and detailed recording, whilst retaining accuracy, and this method is greatly preferred over plane tabling. The area, of approximately 2 sq km, was mapped in less than 30 working hours, with a Wild RDS Tacheometer. This model gives an accuracy of ± 7 cm in the horizontal plane for distance measurements made within a radius of 120 m. Beyond this range the error in staff reading considerably reduced the precision of measurement. Yates (1968 p. 134) notes that "tacheometric work and heighting using a theodolite are both too time consuming at the reconnaissance stage", but under the field conditions experienced during the 1968 summer season the tacheometer proved to be very efficient for the mapping of a small area, particularly for the mapping of detail within a triangulation network.

Profiling of the beach zone was carried out at the twenty sites shown on Figure 19. These profiles were levelled shortly after arrival at Cape Ricketts (June 21 - 23), at the same time levelling was extended across the snow covering the beach wherever possible, and repeated on July 16 - 18 and August 5 - 6. The work was undertaken with a Kern GKI level, which allows an accuracy of ± 0.12 cm, which in view of the field conditions is more than adequate.

The use of a tacheometer for mapping and a level for profiling proved to be an efficient and precise method of combining surveying techniques for recording various features of the beach in plan and profile. The only limitations on the use of these instruments resulted from high winds or cold temperatures, the former affecting the staff-holder and the latter the ability of the operator to carry out fine adjustments on the instrument.

APPENDIX D

Photographs

1

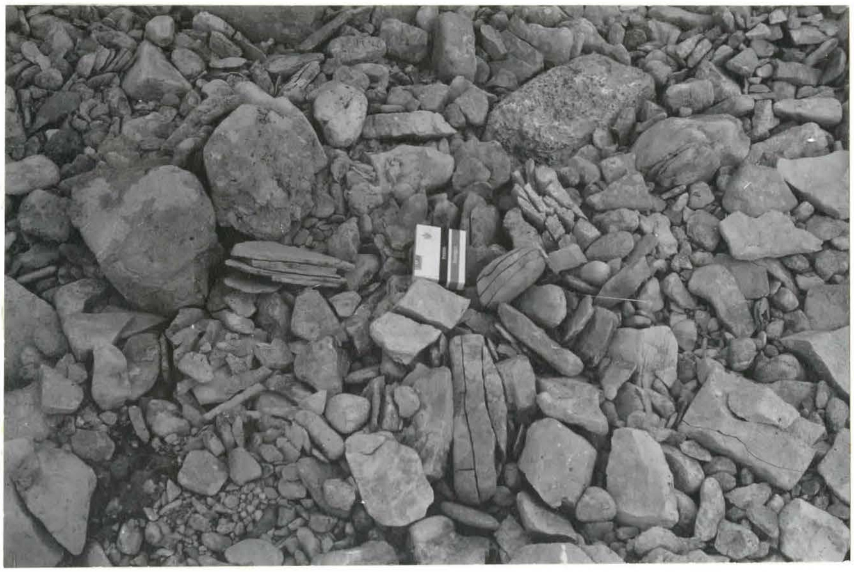
Frost-shattered raised beach pebbles; east Resolute Bay

July, 1967

2

Broken, angular talus deposit; north Cape Ricketts

July 4, 1968



1

2

3

Intertidal zone, at low tide, on west-facing Cape Ricketts beach; near profile 14, August 7, 1968.

- limit of previous high tide indicated by arrow
- high tide before that shown by double arrow
- figure is standing at top of beach face slope, on small storm ridge

4

Tidal cracks between beach fast ice and sea ice, at high tide; near profile 17, Cape Ricketts, July 21, 1968.

- note material within, and on surface of, beach and sea ice

3

4

5

Frozen wave swash; Burlington Bay Bar, Lake Ontario, November 1968

- ice has formed a protective layer over the beach material
- scale given by staff graduations, 0.1 m

6

Frozen wave spray on rocks and rubble; Burlington Bay Bar, Lake Ontario, November 1968

7

Small ice foot at lake level; Burlington Bay Bar, Lake Ontario, November 1968

- ice foot approximately 40 cm high, and 70 cm wide

5

6

7

8

View of Cape Ricketts foreland, looking south, July 4, 1968

- ice cover complete in Gascoyne Inlet and Lancaster Sound
- zone of tidal cracks parallel to beach at landward edge of sea ice

9

Cape Ricketts, July 31, 1968

- ice still present in most of Gascoyne Inlet, but Lancaster Sound open except for some offshore pack ice moving east
- note lead between sea ice and beach, as well as numerous grounded floes
- ice mounds just visible on southern section of foreland

10

Cape Ricketts, August 7, 1968

- sea and Inlet free of solid ice cover
- floes on beach and ice mounds still visible
- talus deposit overriding northern section of beach can be seen in bottom right of photograph

8

9

10

11

South-facing beach of Cape Ricketts foreland, protected by beach fast ice; July 21, 1968

- erosion of unconsolidated raised beach material also delayed because of protection afforded by snow-bank

12

Cape Ricketts beach at low tide, near profile 13, looking south, to show wave train running almost parallel to beach; July 30, 1968

- note larger number of floes on beach, stranded as tide fell
- seaward edge of ice mounds visible in background

11

12

13

Cape Ricketts beach at low tide, near profile 12; August 6, 1968

- three zones shown: (i) up to MHWM
  (ii) MHWM to HHWM
  (iii) above HHWM to raised beach zone
- figure standing on storm ridge, above Mean High Water Mark
- area of ice push visible in middle background

13

14

Talus slopes and littoral zone beneath cliffs to east of 'Walrus Bay',

the source area for longshore transport of material

to the west; July 23, 1968

- material may be removed by ice rafting as talus material is deposited on ice during winter, after break-up floes then carry material from immediate locality

15

'Walrus Bay' beach, looking east towards source of transported material;

July 23, 1968

16

Part of sample 1 2 1 used for roundness analysis; taken from above

Highest High Water Mark on Cape Ricketts

- mean size of complete sample -4.05 ϕ
- mean roundness value of sample 202.5

14

15

16

17

Sample 1 7 1 (above Highest High Water Mark), August 2, 1968

mean size -4.73 ϕ

mean roundness 25

18

Sample 1 7 2 (at Highest High Water Mark), August 2, 1968

mean size -5.16 ϕ

mean roundness 225

19

Sample 1 7 3 (ii) (at Mean High Water Mark), August 6, 1968

mean size -3.37 ϕ

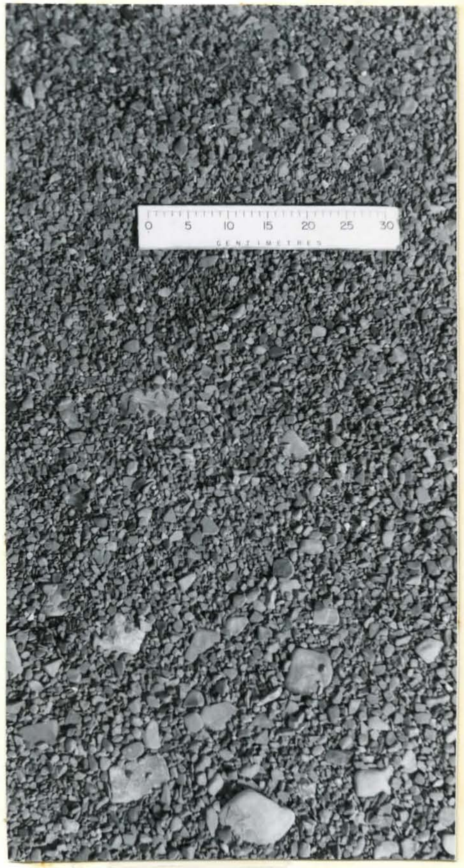
mean roundness 165

20

Sample 1 7 4 (ii) (at Mean Sea Level), August 6, 1968

mean size -2.96 ϕ

mean roundness 260


0 5 10 15 20 25 30
CENTIMETRES

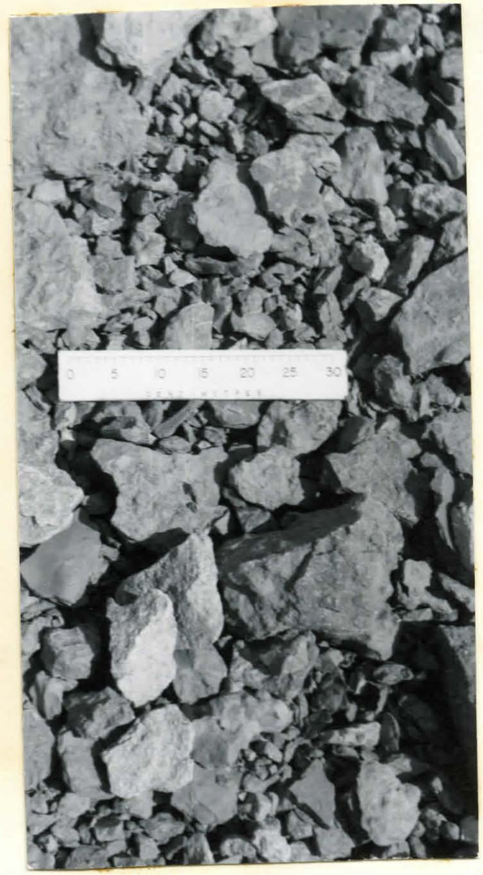
20


0 5 10 15 20 25 30

19


0 5 10 15 20 25 30

18


0 5 10 15 20 25 30

17

21

Zone of buckled beach fast ice, near profile 6, Cape Ricketts:

June 21, 1968

- material can be seen within, and on the surface of, the buckled ice

22

Ice mounds as seen looking north along Cape Ricketts Beach;

July 21, 1968

- shows ablation of most of buckled ice except where protected by a debris carpet, this has led to the development of a series of ice-cored mounds

23

Vies of seaward edge of ice mounds, at low tide, after removal of sea ice cover; July 29, 1968

- lower limit of debris carpet marks highest tide level
- waves have notched the base of the mounds, but rate of 'erosion' is slow

21

22

23

24

Most southerly of ice mounds, at tip of Cape Ricketts foreland;

August 4, 1968

- ice protected from ablation by surface material, ice removal primarily results from action of waves

25

Undercut ice mound shown in photograph 24 on August 6, 1968

- sea ice cover absent since July 26, it has taken 12 days for waves to erode through the base of the smallest of the ice mounds

26

South-west tip of Cape Ricketts; June 16, 1968

- pressure ridges in littoral zone and in offshore sea ice cover
- location of mound in photos 24 and 25 shown by arrow

24

25

26

27

Zone of recent ice push on profile 6, southern section of Cape Ricketts;

June 28, 1968

- note small amount of ice involved in this push
- striations in beach material run from camera position inland towards ice remnants, as shown by arrow

28

Same view; July 21, 1968

- colour differences show that ice has pushed into raised beach zone, but has transported little modern beach material (grey coloured pebbles) from lower parts of the beach
- striations again visible in foreground

27

28

29

Zone of ice push ridges and ice push remnants between profiles 12 & 13,

at low tide; July 30, 1968

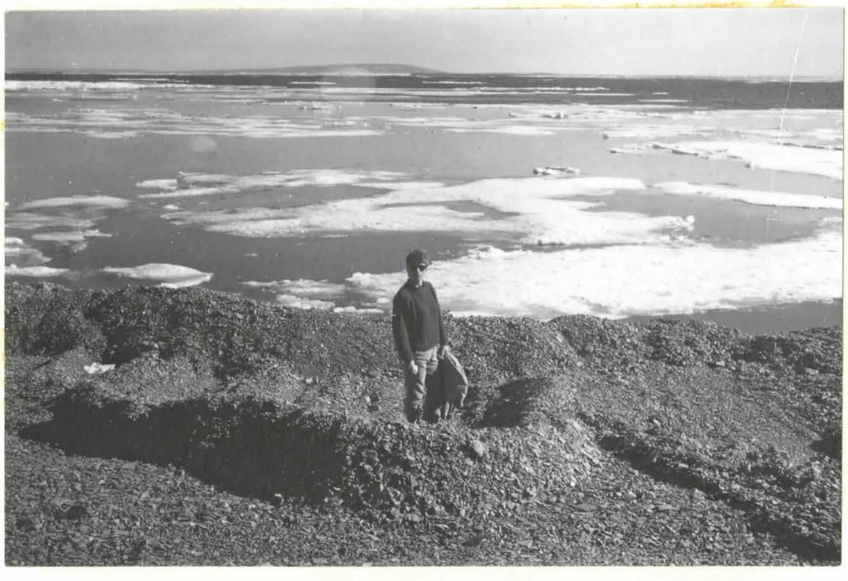
- truncation of scars at the edge of a ridge is marked with an arrow
- note number of grounded floes and ice mounds in background

30

Single ice push scar, Cape Martyr near Resolute; August 17, 1968

- shows the bulldozing effect of one floe ploughing into the beach to produce a lunate ridge and excavated scar area

29



30

31

Ice pit on Cape Ricketts beach, after much of the ice floe has melted; July 21, 1968

32

Pitted section of Cape Ricketts, resulting from differential melting of subsurface ice, near profile 1; July 21, 1968

31

32

33

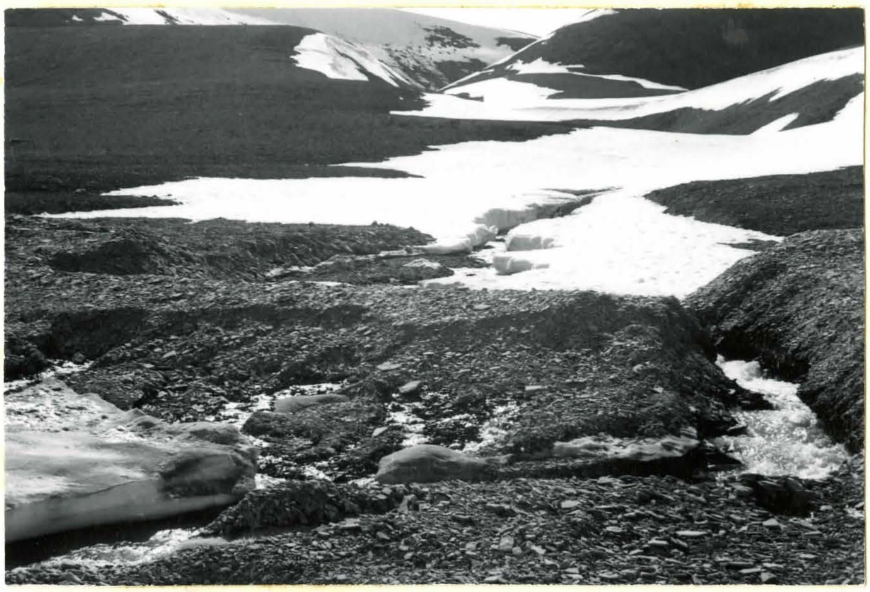
Stream exit on southern section of west Radstock Bay; July 15, 1968

- stream has cut through main beach face slope ridge
- photograph taken from sea ice

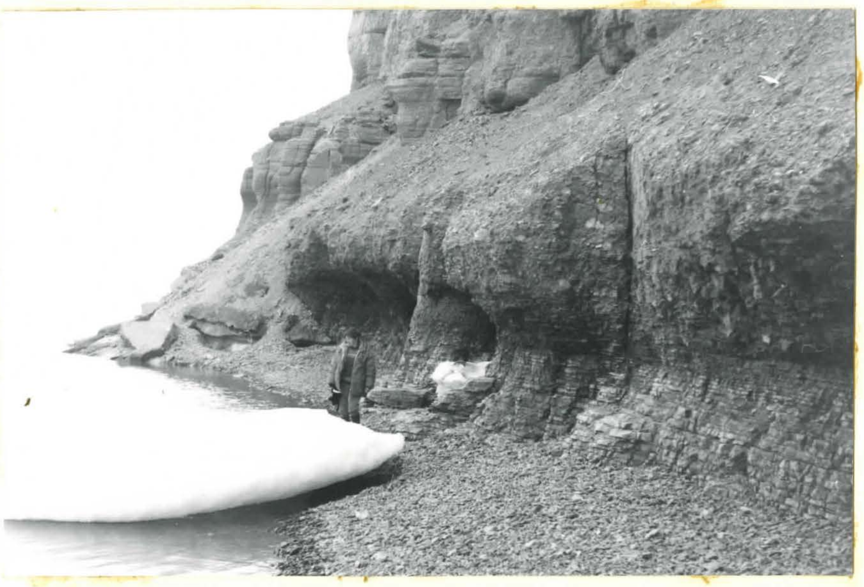
34

Wave-cut notch in cliffs at east end of Beechey Island; August 11, 1968

- note the talus deposit extending into the water in the middle background, and the size of material in this deposit



33



34

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