RECENT SHORELINES BETWEEN BANKS PENINSULA AND COOPERS LAGOON

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John W. Armon
1970

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ABSTRACT

The landforms and sediments in the lakemarginal and coastal area southwest of Banks Peninsula to Coopers Lagoon were studied to ascertain coastal developments in this area during the last 15,000 years. All surficial evidence indicates shorelines following 7,000 years B.P., when sealevels have been close to that of the present. A sequence of shorelines is developed which differs from the conclusions of some recent writers. This sequence is placed within an absolute time-scale by comparing former sealevels with known curves of post-glacial sealevel rise.

The present shoreline of the Northern Canterbury Bight indicates a receeding shoreline on the western Kaitorete Barrier as well as further west. The shoreline for much of the rest of the Barrier appears to be stable at present, but evidence is in conflict about possible stability or equilibrium for the eastern 2 miles of the beach. These recent directions of movement on the coast give an indication of longer-term coastal actions: progradation and retrogradation. The greater eastward extent of dunes on the coast, compared with dunes on the inner Kaitorete Barrier, suggests that more sand has been transported along recent Barrier shores. This may relate to an eastward movement in the sediment source.

A series of curving shingle ridges on the inner margins of the Kaitorete Barrier indicate the form of an initial spit which developed from a western

shoreline, towards Banks Peninsula. Probable relations between the heights of these ridges and sealevel (when they were formed) suggest that this spit formed towards the end of the postglacial rise in sealevel, nearly 7,000 years ago. Beach ridges on the seaward portion of the Kaitorete Barrier indicate that shorelines along the Kaitorete Barrier prograded following the joining of the Spit to the Peninsula. An increase in ridge levels in the east suggests a rise in sealevel associated with the progradation of the shoreline in this area.

Wave action on a former, higher Lake Ellesmere is demonstrated as forming prominent shingle ridges on the inner Kaitorete Barrier and western lake-margins. Various lines of evidence suggest higher lakelevels, and theoretical calculations of wave heights for this lake indicate that waves would have been of sufficient magnitude to move the sediments present in most ridges.

Loess is found to overlie relic shore platforms that are present on the spur-ends of Banks Peninsula. This relationship suggests that the shore platforms, and other associated marine-formed features, were formed at some preglacial high sealevel. Waves formed on the Lake at higher lakelevels are indicated to have recently exposed the platforms and cliffs.

A sequence of shoreline positions is proposed from 'glacial' times, 15,000 years ago, to the present. Shorelines earlier than 10,000 years B.P. are suggested to be seawards of Ellesmere. The positions and forms of shorelines in the Ellesmere area between 10,000 and 7,000 years B.P.

are uncertain. Tentative shorelines, based on deductions from coastline dynamics, are suggested. South of Ellesmere the shorelines existed several miles seawards of the present coast at Rakaia. Shorelines following the presence of the Spit indicate that progradation was active along the whole of the Barrier. An opposite movement, coastal recession, continued west of the Barrier and eventually brought changes from progradation to recession on the western Barrier. Former shorelines, trending to the southwest, have thus been trimmed by recent shorelines of the Western Kaitorete Barrier. Future changes may lead to some recession over more of the Barrier but the extent of these possible changes is suggested to be minor.

INTRODUCTION

General

The geomorphology of the coastal area southwest of Banks Peninsula is of considerable interest in the study of recent coastline changes in New Zealand. Accumulation landforms between the Peninsula and Coopers Lagoon record shoreline changes related to postglacial sea-levels near the present level. Several writers have referred to this area in studies of larger areas but only two detailed investigations have been undertaken. Conflicting opinions have been expressed by different writers about the positions of recent shorelines in the area. Thus a fresh study of the area, on the basis of recent advances in coastal geomorphology in New Zealand, is felt justified. Also, increases in the documentation of recent sealevel variations and of the Canterbury Plains fan surfaces allow a sequence of coastal events to be ordered in absolute time.

The study is concerned with the area southwest of Banks Peninsula to Coopers Lagoon. Progradation has occurred in this portion of the Canterbury Bight while coastal recession has removed evidence of former shorelines elsewhere. There is sufficient evidence in the depositional forms east of Coopers Lagoon to reconstruct past coastal positions and to obtain a picture of recent coastal development. This investigation provides a good opportunity to study coastal dynamics on a steadying sealevel in recent times. It also provides a basis for assessing the extent of future changes in the area.

Purposes

An attempt will be made in this investigation to satisfy six aims. These aims are:-

1. To describe and explain the landforms and sediments between Banks Peninsula and Coopers Lagoon. This permits a better understanding of the relative importance of recent processes which have been active in this area south of Christchurch.

2. To investigate the direction of present coastal movements in Northern Canterbury Bight. Knowledge of erosion, accretion, and stability, allows some extrapolation to longer term coastal movements such as progradation and retrogradation.

3. To describe the sequence of coastal changes northeast of Coopers Lagoon consequent with the postglacial rise in sea-level. Such an account would add to the knowledge of recent shorelines in Canterbury. In addition to this it would allow a greater understanding of the general dynamics of this coastline.

4. To evaluate the extent of the marine influence on the landforms in the area surrounding Lake Ellesmere. Different writers have ascribed certain lakemarginal landforms to formation either on a lakeshore or on a seashore.

5. To account for the eastwards increase in width of the Kaitorete Spit. This Spit exhibits an increase in width away from its sediment source in the west. Spits generally narrow away from their sources.

6. To ascertain the effect of Lake Ellesmere on the landforms at the lakemargins. Prior to man's interference a lake of larger magnitude may have exerted a greater influence on this area than at present.

The realisation of these aims would contribute significantly to the recent geomorphic history of the Canterbury Plains margins. This is because the study area links the well-known coastal areas north of Banks Peninsula with the lesser-known Canterbury Bight to the south.

Description of Study Area.

The study area illustrated in Fig. 1 , is a low-lying area dominated by Lake Ellesmere and Kaitorete Spit. Banks Peninsula, on the north-eastern margins of the area, provides the only major relief form. Landforms are otherwise subdued, with local relief variations in the order of 5 ft to 10 ft. To the north and east the surface grades from lake-level to alluvial fans with no evident change.

The study area is approximately 190 square miles in extent, two-fifths of which is Lake Ellesmere. The area has physical boundaries on two sides: the sea on the south and the hills of Banks Peninsula on the east. The northern and western boundaries show no distinct physical changes. A line from Taitapu to Springston marks the northern boundary and one from Springston to Coopers Lagoon marks the western boundary.

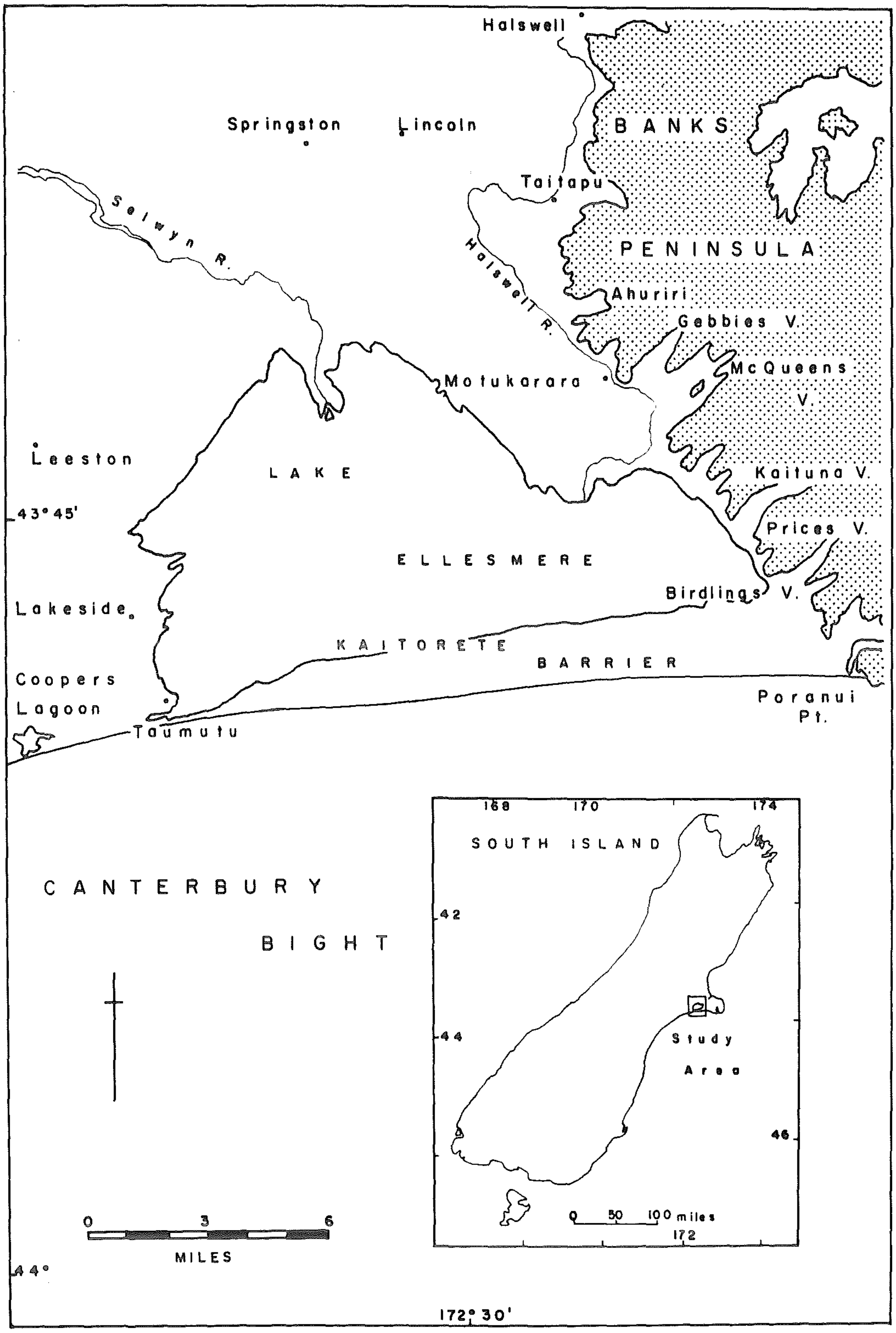


Figure 1. Location of the Study Area.

The Kaitorete Spit is a shingle barrier 17 miles long, joining the outer fan-margins near the Rakaia River Mouth to Banks Peninsula in a continuously trending coastline. Lakes Forsyth and Ellesmere are contained in depressions landwards of the Spit. It is a low marine-formed feature 22.5 square miles in area, lying mostly between 10 and 25 ft above mean sealevel (+). The coastal margin is composed of a mixed sand-shingle beach backed by dunes up to 25 ft high. The lakeward margins of the Spit are lost beneath lakesilts.

Lake Ellesmere is a large brackish water-body landwards of the Kaitorete Spit. The Lake is 77 square miles in area and has a maximum depth of -7 ft. The Lake has a catchment area of 750 square miles, two-thirds of which is Canterbury Plains and the Lake itself. The Selwyn River is the main river entering the Lake. It drains part of the foothills and enters the Lake from the northwest. Burrows (1969) notes that water entering the Lake from the Selwyn and other rivers averages 320 cusecs.

Present lakelevels are controlled by the North Canterbury Catchment Board to maximum levels between +3.7 and +3.25 ft. When the Lake reaches such levels an opening is created in the narrow shingle barrier at the western end of the Kaitorete Spit. The Lake drains into the sea until storm-waves close the outlet with shingle. Saltwater can enter the Lake through an open outlet at high tides and low lakelevels, and the Lake is generally about 20% seawater.

(+) Levels will be expressed as + for levels above mean sealevel and - for levels below mean sealevel. The 'mean sealevel' term will be omitted.

The areas marginal to Lake Ellesmere are low-lying and flat to slightly undulating. Low shingle ridges are present on much of the western margins of Lake Ellesmere. They have their best expression in the series of 'spits' which project into the Lake near Lakeside. From these ridges the surface grades westwards imperceptibly into the surface of the youngest alluvial deposits on the Canterbury Plains. There is a similar northwards transition at the northern end of the Lake. Between the hills and the Lake, on the northeastern lakemargins, there are areas of partly stabilised dunes and sand-ridges. For 12 miles west of the present coastal cliffs, the spurends of the Banks Peninsula hills have been cut to form old shoreplatforms, stacks, and cliffs.

Nomenclature

Placenames are taken from the New Zealand Topographic Map Series 1:63360; Sheets S83, S84, S93, and S94. In this respect Poranui Point refers to the seacoast at the eastern end of the Kaitorete Spit. The name 'Birdlings Flat' has been commonly applied to this area but the usage of the current Topographic series will be followed. Birdlings Flat will be restricted to the area landwards of the present coast.

Geomorphic features are named, were placenames are absent, by some distinguishing aspect. The name 'Speight Ridge' is used for the significant ridge which trends east-west along the middle of Kaitorete

Spit. This usage is retained from Thompson (1964). Other names applied by Thompson to features on the Spit have been changed. Thompson's nomenclature together with that used in this study are presented in Table 1. No distinction is made in name between Thompson's Truncated and Main Spit Ridges. The naming of these features as the Barrier Ridges will be clarified below. Thompson's Arcuate Ridges are divided into the Railway Cutting Ridges and the Birdlings Valley Ridges. What Thompson referred to as Hooked Spits are termed Hooked Ridges in this study. The use of the term 'spit' for these ridges would lead to confusion later in the study.

Table 1. Nomenclature for Geomorphic Features on Kaitorete Spit: Thompson's usage and that of this study.

This Study	Thompson's Study
Speight Ridge	Speight Ridge
Barrier Ridges	Truncated Ridges
Barrier Ridges	Main Spit ridges
Railway cutting and Birdlings Valley Ridges	Arcuate Ridges
Hooked Ridges	Hooked Spits.

USAGE OF 'BARRIER' AND 'SPIT'.

This subsection seeks to clarify the naming of Kaitorete Spit, and it will set forward the usage to be followed in this study. The word 'spit' is defined in the Glossary of Geology (American Geological Institute, 1962, p 276) as "A small point of land or narrow shoal projecting into a body of water from the shore" while Zenkovich (1967, p 384) notes that "Spits and arrows are attached to the land at one end. The other end is free." Both definitions indicate that a spit is fixed at one end with the other end free. Kaitorete Spit does not satisfy this condition because both ends are tied to the land.

The writer feels that the term 'barrier' would be a more accurate description of Kaitorete Spit. Price, in the Encyclopedia of Geomorphology (Fairbridge, 1968, p 51) defines a barrier as "a partly emergent bar-like ridge of sand or coarser sediment lying off a shore or shoal and usually subparallel to the shore, projecting from the flank of a headland or connecting two headlands." Zenkovich describes features such as Kaitorete Spit as 'beach barriers' (beaches connecting two headlands.) Both writers include features connecting two headlands in their ideas of what a barrier can be.

This writer feels that the term 'spit' should not be applied to the present feature; 'barrier' describes it better. For the rest of this study the feature will be referred to as Kaitorete Barrier. The term 'spit' will be used when discussing early forms in the development of Kaitorete Barrier, which satisfy the definitions given above.

Geological History

This brief account will discuss both the study area and adjacent areas. Knowledge of the associated areas is important because they set the limiting conditions for the geomorphic development of the study area. Fig. 2 indicates the position of the Ellesmere area between the two major landform units: Banks Peninsula and the Canterbury Plains. It is important to realise that the sequence of recent shorelines in the study area has been a response to the special position of the area between these two land-units.

BANKS PENINSULA.

Banks Peninsula consists of the erosion calderas of two volcanoes whose central areas were situated where Lyttelton and Akaroa Harbours are now (fig 2). The volcanoes overlie a basement of Torlesse group sedimentary rocks of possible Triassic age, exposed in Gebbies Pass. This basement probably underlies the Canterbury Plains at a varying depth. Where exposed in Gebbies Pass, the basement is overlain by andesite, sandstone, and rhyolite with tentative ages from Cretaceous to Miocene (Liggett and Gregg, 1965).

Stipp and McDougall (1968) date thepresence of the Lyttelton volcano as between 12 and 10 million years before present (B.P.). Most activity from the main Akaroa volcano was from 9.5 to 7.5 million years B.P. The volcanoes are of similar composition; rocks in lava flows are either basalt or andesite. Both volcanoes have a similar history. The Diamond Harbour group ranges from 8.2 to 5.8 million years in age. These lavas were erupted into the centre of the partly eroded Lyttelton Volcano.

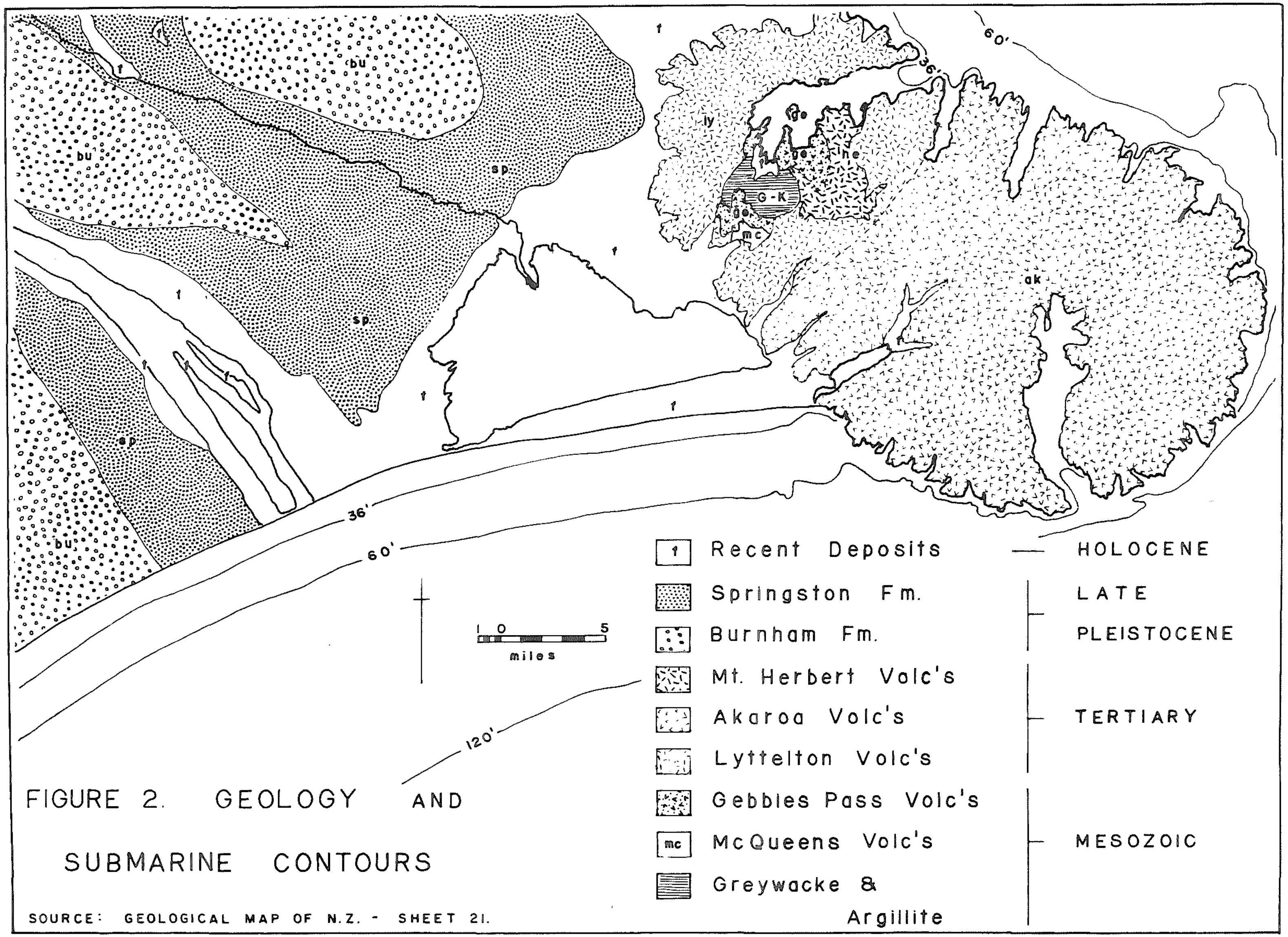


FIGURE 2. GEOLOGY AND SUBMARINE CONTOURS

SOURCE: GEOLOGICAL MAP OF N.Z. - SHEET 21.

Both volcanoes have been extensively eroded on the margins and in their central areas. Drowning by the sea has lead to deposition in the eroded valleys and the formation of erosion calderas.

CANTERBURY PLAINS ALLUVIAL FANS.

The Kaikoura Orogeny began in the Tertiary and reached its climax in the middle Pleistocene (Soons, 1968). This series of earth movements thrust up the Paleozoic and Mesozoic sediments which now form the Southern Alps. Much of New Zealand was of similar relief to that of the present in the middle Pleistocene, but in Canterbury Banks Peninsula was an island at most sealevels.

Late Pleistocene glaciations lead tothe deposition of fluvio-glacial outwash gravels from coalescing fans at the outer margins of the foothills. A succession of glacial and interglacial periods lead to a sequence of alluvial and marine deposits. These sediments have gradually formed the Canterbury Plains. The alluvial deposits and their related surfaces form the present plain-surface. Fig.2 indicates the extent of the Burnham formation (22,000 years B.P., Soons, 1968), the youngest surface of the recent Otiran Glaciation. The Windwhistle formation (greater than 45,000 years B.P. Gage, 1958) and older formations are of limited extent at the surface; they dip beneath the younger gravels and their horizontal extents are unknown.

The Springston formation is the youngest outwash surface and is either wholly or partly of postglacial age (Suggate, 1963). It can be seen on Fig.2 to approach within 1 mile of the Lake's western edge. This surface approximates the study area's western margin. Suggate (1963) suggested that the Springston formation was related to aggradation in the lower reaches of rivers caused by changing baselevels as sealevel rose. Degradation in the headwaters ensured a continuing sediment supply to the lower reaches.

ELLESMERE AREA.

Holocene sediments were deposited during the last 10,000 years mainly near present rivers and the coast. On the northern coastal plain, fringing Pegasus Bay, sands and swamp deposits record a maximum western shoreline position about 5,000 years ago. Progradation since that time has brought about an eastwards movement to the present shore position. The Geological Map of New Zealand 1:250000, Sheet 21 - Christchurch (Suggate and Oborn, 1959) places all of the study area within this category.

Between Lake Ellesmere and the Peninsula the sediments are predominantly silts to medium sands. On the western side of the Lake shingle is present in a hummocky ridge series. The Kaitorete Barrier is composed of sand and well rounded shingle in a complex series of ridges. Towards the Lake, silts overlie the shingle.

Sediments on the Barrier and beach are similar in composition to those in the outwash gravels of Canterbury Plains and different to those from Banks Peninsula. Pebbles are dominantly of 'greywacke' composition: they are slightly metamorphosed sandstones and mudstones. Minor quantities of igneous and siliceous rocks are also present. The composition of the pebbles on the Barrier precludes any possibility of its forming from materials derived from the rocks of Banks Peninsula. Thus the peculiar shape of the Barrier: a westwards decrease in width, cannot be explained by spit development from Banks Peninsula. The formation is necessarily related to sediments from the fan gravels and rivers southwest of Coopers Lagoon. Therefore this shape must be connected with coastal changes during the Barrier's development from the west.

The important time-period for this study is the last 15,000 years. This period follows the deposition of the Burnham formation and includes that of the Springston formation. The important factor, related to coasts in this period, is the glacio-eustatic rise in sealevel. Shoreline changes in Northern Canterbury Bight have been related firstly to the rising sealevel, and secondly to processes of coastal rectification following sealevel stabilisation about 5,000 years ago.

STABILITY OF THE AREA.

It is not known how stable the study area has been tectonically. This is because there is no direct evidence of recent tectonic movement. There is no evidence of recently active faulting on Banks Peninsula or the surrounding Plains, and earthquake activity has so far been minor. Also, the region is situated 35 miles from the tectonically active Southern Alps. However, Suggate (1958) notes that oxidation has been active in the gravels beneath Christchurch to depths of -550 ft, and could suggest subsidence if sealevel curves for the late Pleistocene did not reach this depth.

Suggate (1968) noted that any vertical movement which has occurred in the area would need to be equal over the whole area because the symmetrical form of the calderas indicates that tilting has been absent. In the absence of any positive evidence for tectonic movements in the last 15,000 years the region will be assumed to be stable. Thus, changes in the vertical relations between land and sea will be attributed to sealevel fluctuations.

Sealevel Variations.

Recent writers generally accept that sealevel has risen from between 200 and 300 feet below mean sealevel to its present level, during the last 15,000 years. This is in response to the glacio-eustatic adjustment to climatic amelioration and widespread glacial recession during this time. The curve of glacioeustatic sealevel rise is important to this study because of the very small number of Carbon 14 dates in this area. The sealevel curve offers an indirect way of dating events which were related to sealevel. The accuracy of such inference is related firstly to the accuracy of the sealevel curve and secondly to knowledge of the precise relationship of the landform with sealevel.

The envelopes of dated sealevel positions in Figs. 3A and 3B indicate why there are differences of opinion as to the precise curve of sealevel rise. The differences in opinion among workers in this field is related to differing evidence in different areas. This variance in evidence is related to three factors. They are:-

1. Sealevel curves may be derived from areas which have undergone some vertical movement.

2. Samples which are dated may give an inaccurate sealevel indication because of misinterpretation of their relationships with sealevel.

3. Samples may give inaccurate ages through sample contamination.

The most likely reasons for discrepancies are vertical movements of the areas involved and misinterpretation of samples' relationships with sealevel.

In Fig 3A Curray's generalised curve of sealevel rise indicates a sealevel approximately -260 ft 15,000 years ago (Curray, 1965). The envelope of sealevel dates in Fig 3A suggests that considerable reliance can be placed on Curray's curve of sealevel rise until 7,000 years B.P. This part of his curve suggests a rise in sealevel to a level near that of the present in 8,000 years, a rate of 3 ft per century. This rapid rise would tend to bring about shorewards movement of the shoreline in coastal areas. In Canterbury Bight this landwards movement may have been of the order of 25 miles.

For the period covering the last 7,000 years three broad types of curve have been advanced. These types are:

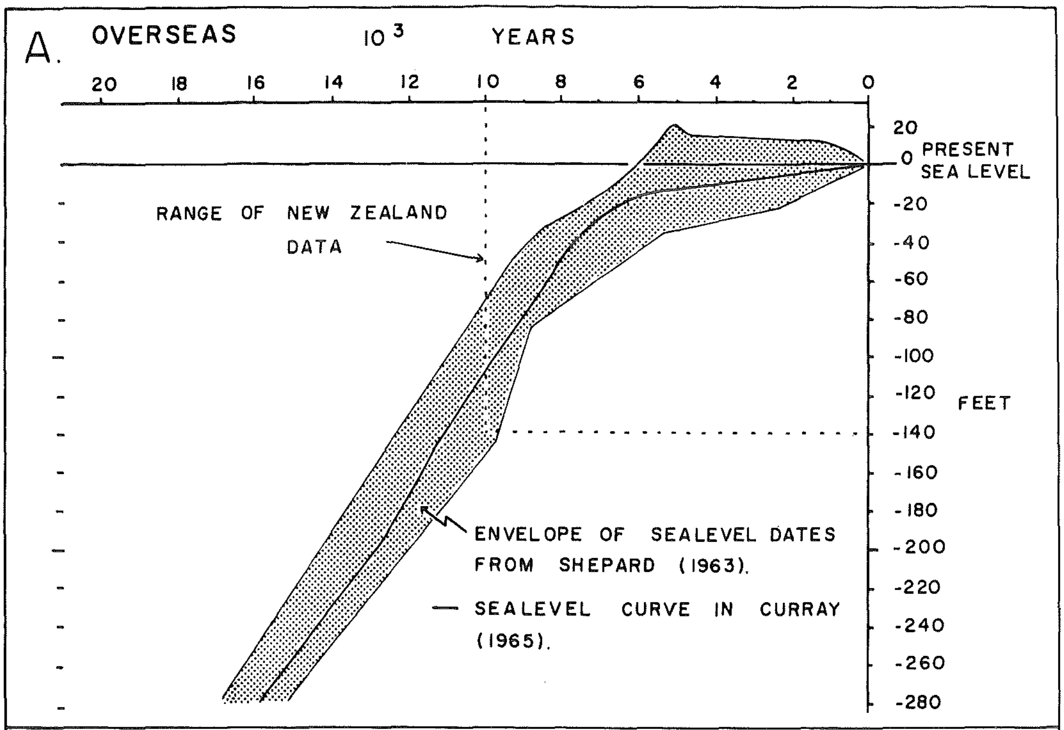


Figure 3A. Overseas data indicating sealevel variations over the last 10,000 years.

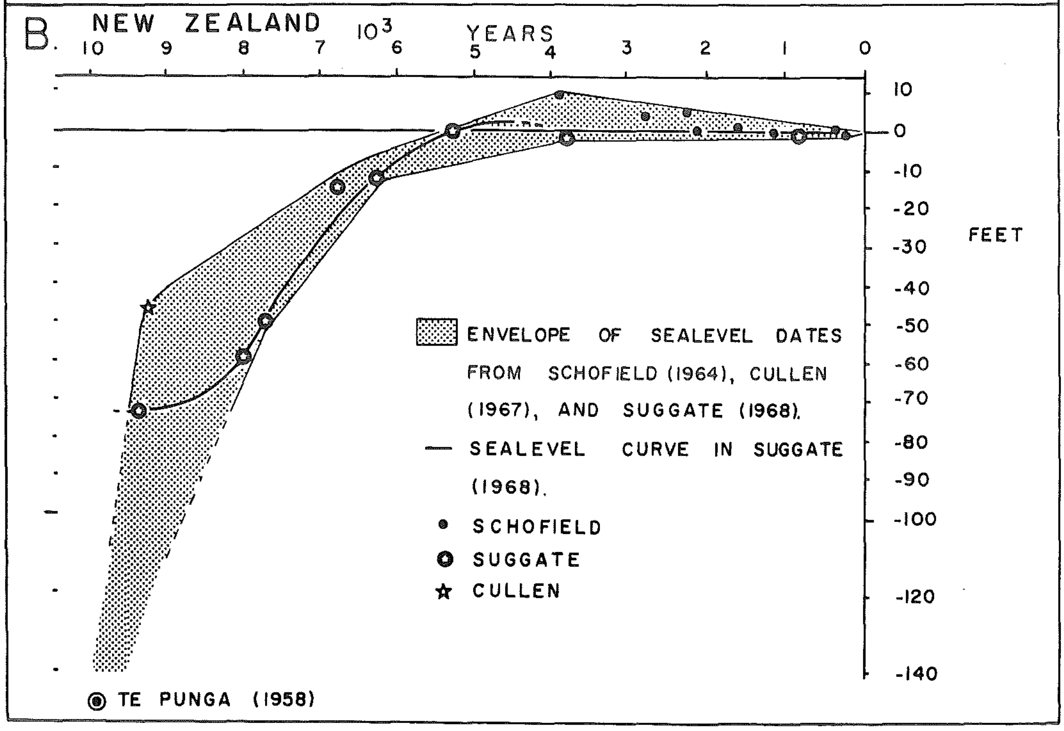


Figure 3B. New Zealand data indicating sealevel variations over the last 10,000 years.

1. An oscillating sealevel about that of the present (Fairbridge, 1961; Schofield, 1964).

2. A sealevel reaching the present level 5,000 years ago, and remaining approximately constant since that time (Shepard, 1963; Suggate, 1968).

3. A slowing rate of sealevel rise which did not reach its maximum until the present (Curray, 1965; Jelgersma, 1961.)

Whateven the nature of the real curve of sealevel the envelopes suggest a sealevel within ± 15 ft for the last 7,000 years. During this time it can be expected that transgressive shoreline movements would have been replaced by movements related to the development of equilibrium coastlines. Thus progradation has been recorded during this time on some shores in many parts of the world.

Curray's curve of sealevel rise will be used to broadly date sealevels prior to 8,000 years B.P. Between 8,000 years and 5,000 years B.P. Suggate's curve of sealevel rise will be used for broadly dating sealevels (Suggate, 1968). This is because the curve is local, being derived from the Christchurch area which is 15 miles north of the study area. It shows the relationship of land and sea in the Banks Peninsula region in recent time, even if the area has been subject to vertical movement.

Following 5,000 years B.P. no attempt has been made to date shoreline events by analogy with sealevels, because of the considerable variation in dated sealevels.

The broad dating of events in the area prior to 5,000 years B.P. will introduce the time factor into this study. Earlier writers have not had the means with which to place events in the area into a time-scale. This has lead to differences of opinion as to the actual sequence of events and shorelines in the Ellesmere area.

Previous Investigations of Study Area.

Carruthers (1877) was the first writer who recognised the importance of wave action on littoral drift and in forming spits. He realised that the Kaitorete Barrier was formed by longshore drifting of sediment from the south. The area did not receive attention again until Speight published articles about the Canterbury area in the early 20th Century. Speight (1910) wrote that the Barrier was formed by shingle moved north by coastal currents. Marshall (1912) mentioned Kaitorete Barrier in connection with the position of outlets of barriers. He wrote that the opening in a barrier is always at the updrift end, and cited the Kaitorete Barrier as an example. He gave no reasons for his conclusions however, Jobberns (1927) repeated Speight's (Speight, 1910) explanation for the presence of the Barrier, and attributed its origin to a northerly current.

Speight (1930) published the most authoritative work on the Barrier to date. He accepted wave action, rather than coastal currents as earlier, as being the action moving sediment northwards to form the Barrier. In this study Speight gave a good descriptive account of the sediments and landforms on Kaitorete Barrier. Writing prior to the development and acceptance of the hypothesis of glacio-eustatic sealevel variations, Speight attributed changes in land-sea relationships to movements of the land. He attempted to explain the formation of certain ridges on the inner Barrier and the western lakemargin in terms of waves from the sea after the Barrier had formed, suggesting that the land was lower and the Barrier was 'awash'. The sea could enter the area of the present Lake and waves formed the following features:

1. A 'Barrier beach' on the inner Barrier (Speight Ridge in this study.)
2. Ridges at the western end of the Lake.
3. Shoreplatforms, stacks, and cliffs on the spurs of Banks Peninsula.

Thompson (1964) however arrived at some different conclusions to Speight (1930). Thompson suggested that the Speight's 'barrier beach' and the ridges at the western end of the Lake were formed by waves on a former higher Lake Ellesmere. He further correlated the levels of the shoreplatforms with the Princess Anne sealevel of 85,000 to 90,000 years B.P., thus implying a preglacial period of formation.

Suggate (1968, p 292) on the other hand, argued for a more recent origin of the shoreplatforms. He wrote:

> "and the fresh appearance (of the shoreplatforms) indicates a postglacial age. All the spur ends are modified to substantially similar extents, which would be unexpected if the beaches were of interglacial age, uncovered along a postglacial lakeshore." (p 292).

He also advanced evidence from the western margins of Lake Ellesmere for recent shorelines in the Ellesmere area. He wrote:

> "A seashore is also indicated by the straightness of the north-west shore of Lake Ellesmere. In the south-west spits developed but failed to extend to Banks Peninsula ..." (p 292).

Suggate mapped approximate shoreline positions for 10,000, 7,500, and 5,000 years B.P. in the Ellesmere area. The shorelines are illustrated on Fig. 4. They indicate the sea to have been recently within the Ellesmere area and the Barrier to have been formed within the last 5,000 years.

Burrows (1969) drew similar conclusions to Suggate for the shore-platforms and the ridges on the western lakeshore. Like Thompson (1964) he ascribed the formation of Speight Ridge to waves on a higher Lake Ellesmere. Burrows tentatively suggested an age of 2,000 years for the Barrier.

From this brief review of previous investigations of the area there appear differences among writers on several points. Included among the more important questions which arise are those related to the age of shore-platform cutting, to the mode of formation of the ridges on the lake margins and inner Barrier, and to the actual shoreline sequence in Ellesmere.

Part of the answers to some of these questions lie in understanding what is presently happening on the coast. Kirk (1967, 1969) undertook a detailed study on the coastal processes and beach responses in Canterbury Bight. He gave new evidence about the present coastal processes and the present coastal development in, and adjacent to, the study area.

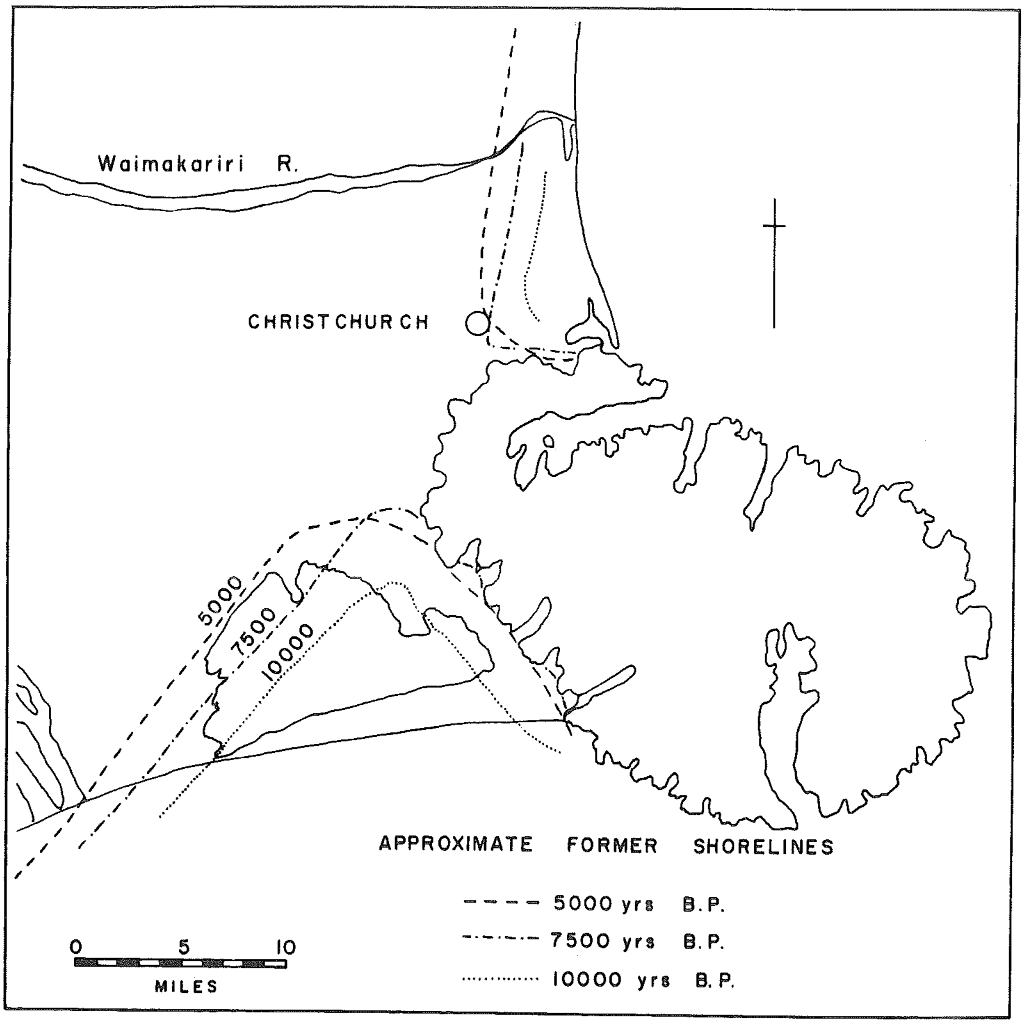


Figure 4. Approximate shore positions suggested by Suggate (1968) south and north of Banks Peninsula.
Source: Suggate (1968, p 294)

Kirk (1969, p 35) concluded that the present "net longshore transport into this sector from the south is small." He wrote that dominant sediment movement in present storms is shorenormal: sediment is moved offshore during a storm and returned to the beach following it. He further suggested that sediment released to the beach system through erosion of the coastal cliffs between the Rakaia and Rangitata Rivers is largely lost offshore.

Kirk's conclusions are surprising in view of the established origin of the Kaitorete Barrier by longshore sediment movement from the west. If these conclusions are confirmed, it will mean that the conditions which formed the Barrier have since ended. It could also mean that present processes are seeking to modify or destroy Kaitorete Barrier.

Summary

This section has been concerned with indicating the study's purposes and providing the background necessary for this investigation.

In the following two sections the basis for this investigation will be fully laid. Methods of data collection and analysis will be described. Following this the major landform groups of the Ellesmere area will be briefly described and discussed. This will allow some understanding of the interrelationships of landforms in different areas and also indicate the spatial nature of the problems to be studied. These sections will provide the basis for the results and conclusions reached in the successive sections.

PROCEDURE

General

A large portion of this investigation involved fieldwork but a significant part was concerned with other methods of data collection. Fieldwork was necessary to gain an understanding of the complex evidence for former coastal and lacustrine environments in the study area. Knowledge of processes acting on the present beach is necessary to test and evaluate the conclusions arrived at by a study of the landforms. Fieldwork was undertaken to investigate marine processes. Also, theory was employed to study some effects of wind on the coastal dunes and on a higher Lake Ellesmere. Analysis of aerial photographs, maps, and well records served to provide further information about landforms, processes, and former shorelines.

Landforms were studied in several ways. Interpretation and mapping of features was undertaken from aerial photographs. Relationships could be discerned in this way which were not apparent in the field. Profiles were surveyed and transects were taken, across prominent features on Kaitorete Barrier. These gave information about levels of ridges, swales, and other significant landforms. Also detailed investigation of landforms was carried out in the field. Sediments, bedding, and stratigraphic relations gave further information about the modes of formation of various landforms. Particle size and shape analyses also allowed a few inferences to be drawn about processes forming some features.

Marine processes were studied by collecting information on various wave parameters and on some beach responses. The wave parameters gave an indication of the wave environment. The beach responses: volumetric beach changes and various sediment characteristics, gave some indication of the actions of the present beach. Wind data was analysed from records taken at Taumutu between 1951 and 1956. One year of wind records was analysed in detail to gain theoretical information about wave heights on a higher, more extensive Lake Ellesmere.

Information about recent shorelines within Ellesmere was obtained from wellhole records. Early workers wrote conflicting remarks about the outlets of Lakes Ellesmere and Forsyth. Unfortunately these different opinions cannot be tested because old maps lack the precision necessary to allow for valid inferences about coastal changes over the last 100 years.

This section will describe the methods of investigation used in this study. Methods involved in landform and sediment study will be discussed first. This will be followed by a description of ways that information about processes was gathered. The use of wellhole records will finally be discussed.

Landforms

AERIAL PHOTOGRAPHS

Aerial photographs were valuable in studying Kaitorete Barrier because the flat nature of the area often precluded the recognition of groups of ridges on the ground. Aerial photographs allowed groups of ridges with distinct plan-form characteristics to be identified. This enabled a more precise study of ridge groups and relationships between groups than has hitherto been undertaken. Aerial photographs also allowed for the investigation of ridge patterns as reflected in the vegetation on the inner margins of the eastern Barrier. These ridges are buried beneath lakesilts and cannot be easily discerned in the field.

The 1952 aerial survey, with a photograph scale of approximately 20 chains to the inch, allowed individual ridge-axes to be mapped. The aerial photographs used in this study are listed in Appendix I. Field investigation was carried out where questions arose from studying the ridge-axes.

FIELD STUDY OF LANDFORMS.

Certain landforms, or groups of landforms, identified on aerial photographs were studied further in the field. Evidence of their depositional history was sort in the form of the surface, in the sediments and bedding, and in the relationships of the landform with associated landforms.

Exposures of sections through depositional landforms were limited because of the low-lying nature of the study area. In most of the northeastern and western lakemarginal areas they were restricted to shallow drains. On the Barrier there were only two sections through ridges and both of these were at the eastern end. The absence of many significant exposures means that conclusions must be derived from the surface form and apparent relationships between features, and also from their sediments. Conclusions thus often lack the certainty which good exposures would give.

RIDGE PROFILES.

Profiles were surveyed across significant features on Kaitorete Barrier and at Taumutu. Their general locations are shown on fig 5, while the more precise position of each profile is described in Appendix II. Two profiles cross some inner ridges at the eastern end, five cross the Barrier, and one crosses the barrier beach separating Lake Ellesmere from the sea. An additional profile crosses the lakemarginal ridges at Taumutu. Heights of ridges, swales, and other significant features were noted.

A Hilger and Watts 'Dumpy' level and staff graded in hundredths of a foot was used to survey the profiles. Accuracy of this instrument was maintained to ± 0.01 ft in 150 ft by M. Reay, University of Canterbury Geography Department Technician. The instrumental error, when compounded for 40 changes of station over an 11,000 ft profile, could produce a total error of ± 0.8 ft. Unfortunately no benchmarks were present in the areas surveyed to check the accuracy of the levelling.

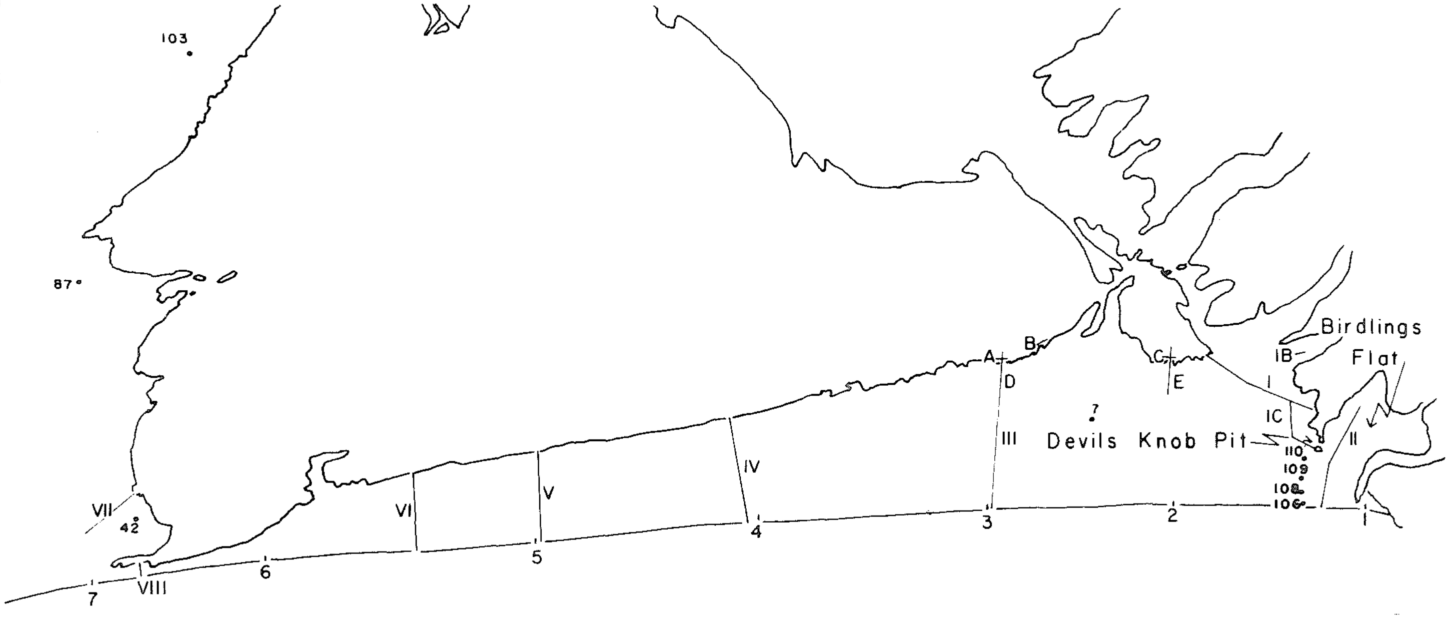


FIGURE 5. LOCATION OF PROFILES, TRANSECTS, AND SEDIMENT SAMPLES ON KAITORETE BARRIER AND WESTERN LAKESIDE.

Profiles were connected with a datum by surveying from the level of Lake Ellesmere. A continuous lakelevel recorder at Taumutu records levels, with mean sealevel in Christchurch as the datum. Thus heights above mean sealevel were obtained for all profiles. Errors may be incurred when lakelevels are used because of fluctuations in the level of the water produced by wind 'piling up' water at the downwind end. Lakelevels were thus used at times when conditions were calm and the Lake was low. Water-levels obtained for the various profiles show a variation of 0.35 ft while recording a slight increase in lakelevel.

SUBSURFACE TRANSECTS.

Vegetation growing on lakesilts on the eastern portion of the inner Barrier exhibits a pattern of lines and curves. To investigate whether the vegetation pattern is a response to subsurface shingle ridge and swale patterns, the form of the underlying shingle was noted along three east-west transects and two north-south transects. The location of these transects is given in fig 5 and Appendix IIIA.

Depths to the shingle surface were measured by forcing a thin steel rod vertically into the soft silt until it reached shingle. On the east-west transects the near-level lakeflat surface was estimated to vary by about ±0.25 ft. A surveyed difference of 0.10 ft in 180 ft on Transect C confirmed this. The north-south transects were tied with surveyed profiles which proceeded from the water-edge. These profiles cross Transects A and C. Thus all transects except Transect B are tied with mean sealevel.

SEDIMENT ANALYSIS.

Samples were collected from locations on the Barrier and lakemargins for particle size and shape analysis. These parameters allowed some distinction to be drawn between certain environments of deposition. Particle size showed differences between dunes on the coast and on the lakemargins. Shape parameters indicated possible differences in selective processes between sediments on the northwestern lakemargins and Kaitorete Barrier. The precise locations for sediments used in this study are recorded in Appendix IV.

Sediment analyses were performed at the University of Canterbury Geography Department Physical Laboratory.

Dry Sieving.

Samples were washed and dried. They were then shaken on an 'Endrock' shaker for 15 mintues in sieves, with half phi divisions, which conformed to the British Standard Code of Practice, Number 410. Weighing of the sediment on each sieve was carried out using a 'Mettler H6' balance. Proportions, by weight, in each sieve size were calculated. These were converted to cumulative percentages and plotted on logarithmic paper. Percentile values were read off and the grain size parameters of Folk and Ward (1957) were calculated. Formulae used in the calculation of these parameters are given in Appendix V.

Pipette Analysis.

Fine sediment samples of approximately 15 gms were weighed and placed in a beaker with some distilled water. Organic matter was removed with 10% Hydrogen Peroxide solution and the sample was heated in a 70°C oven until the reaction was completed. The sample was then washed into a metal mixing flask and a dispersing agent (Calgon) was added; the sample was violently stirred using a soft-drink mixer. When no flocculation occurred the solution was wet-sieved into a litre measuring cylinder.

After wet-sieving was completed the residue, contained on the 4ø sieve (0.063 mm mesh), was dried and analysed according to procedure described above. Pipette analysis was carried out on the silt and clay fraction in the litre jar. The solution in the jar was agitated with a stirring rod and then allowed to stand. Samples of 20ml solution were withdrawn at selected time intervals and depths which gave half phi divisions up to 6ø and whole phi divisions between 6 and 10ø. The 20ml withdrawals were placed in beakers of known weights and dried in an oven. The weight of the sediment in each beaker was calculated. The total sample weight in the jar was calculated from the initial withdrawal. The dry-sieved and wet-sieved fractions were combined and the proportions in each size class were derived. Particle size distributions were plotted as described above, and particle size parameters were calculated.

All particle size names used in this study relate to sizes defined in Folk (1965).

Roundness and form analyses were carried out on 3 samples from the Selwyn River, 4 samples from the western ridge area, 4 samples from a transect across the Barrier, and 12 beach samples. Locations of these samples are given in Appendix VI. Roundness was derived using Power's Visual Roundness Scale. Form was related to measurement of the three main axes of 50 greywacke pebbles contained on a -3 phi ∅ sieve. For each pebble the ratios of short to long axis (S/L) and long minus intermediate axis divided by long minus short axis ((L-I)/(L-S)) were calculated. Folk's (Folk, 1965) 'Effective Settling Sphericity' index was also calculated using the formula given in Appendix V. The ratios were plotted for each particle on Folk's Sphericity-Form diagram and the proportion in each form class was derived.

Weathering Modification.

Samples which were collected on the transect across the Barrier at Birdlings Flat were also studied for weathering modification. The thickness of a zone of staining by iron was measured on coarse-grained greywacke pebbles from each sample.

Processes

WAVES

Wave data were recorded on trips into the area by the writer and also on 41 consecutive days by Mr. Bob Neale, a semi-permanent resident of Birdlings Flat Settlement. The data was of wave height, wave period, and deep-water wave direction.

The writer recorded wave data at various points on the coast, on 24 occasions between late December 1969 and March 1970. Mr. Neale recorded daily wave data at Poranui Pt. from 7th April to 17th May 1970. Two checks were made by the writer of his data and the records compared well.

VOLUMETRIC BEACH CHANGES.

Seven beach profiles were surveyed in December 1969 between Poranui Pt. and Taumutu. The general positions of these profiles are also indicated in fig 5. The profiles were shorenormal lines which ran from datums on the backshore to wave break point. Exact locations of the datums are described in Appendix VII.

Profiles were surveyed using the same level and staff as for the Barrier profiles. Errors using the instrument over a distance of 400 ft and changing station up to three times give a cumulative survey-error of ± 0.07 ft.

Points 50 ft apart on each profile were resurveyed in February, March, May, and July, 1970. The vertical level-changes were calculated and converted to volumetric beach changes by considering a 1 ft wide strip of beach and comparing successive surveys with the December 1969 survey. Profile 1 was omitted from the analysis because considerable errors were involved if the survey line was not shorenormal.

BEACH SEDIMENTS.

Beach samples were collected from surveyed profiles and from three additional beach transects during the surveying of the March, 1970 profiles. The precise locations of these samples are recorded in Appendix IV. Particle size and shape parameters were used to investigate the possibility of longshore sediment trends. Such sediment trends could indicate the action of longshore sediment movement at the present.

The samples were collected on a stratified-random sample plan. Four zones were delineated on the beach on the basis of beach morphology and sediments. These were:

1. backbeach, a low sloping zone of sand and large pebbles.
2. upper foreshore, a steep sloping zone of granules and pebbles.
3. lower foreshore, a level or low sloping zone forming the backslope of the active beach, and composed largely of cobbles with smaller sizes beneath.
4. lower swash zone, granules and sand sizes sloping to wave break point.

One sample was randomly selected from each zone. Samples of one kilogram were collected where pebbles and cobbles were significant. Otherwise samples of 300 grams were collected. The samples were analysed according to techniques described earlier in this section.

Wellholes

Wellhole records, kept at the Geological Survey, University of Canterbury, were studied to obtain information on recent shorelines in the Ellesmere area. Two well records also offered information about the vertical extent of Kaitorete Barrier. The use of wellhole data was severely limited by the paucity of good well records. However a small number of wellholes between Lakeside and Taumutu, and between Greenpark Huts and Lincoln, offer some information. Wellholes from these areas are referred to in the text.

Relevant wellhole data to the purpose of this study is sediment size and sediment colour. Size gives some indication of the environment of deposition; in this area coarse sediment suggests a fluvial or coastal situation, while finer sediment suggests a lagoonal, offshore, or near-shore situation. A brown sediment colour indicates an oxidising location (above the water-table) while a blue colour reflects a situation where reduction has been prevalent (marine or, if on land, below the water-table.)

While a dense network of adequate well records tied to significant dates may allow the tracing of shorelines, the sporadic network in Ellesmere allows few conclusions to be drawn. However the information added is significant and cannot be ignored.

Summary

In these initial sections much of the basis for the present study has been developed. The relevant basic information has been given and the aims stated. Description of the procedure that has been followed, both in collecting and in analysing data, has indicated the varied bases of this investigation. Three main lines of study have been discussed: landforms, sediments, and processes. However, the study does not follow this format but instead follows a broad framework related to the main processes which have been active: Marine, lacustrine, and aeolian processes. In the Ellesmere area this follows certain areal divisions. Thus landforms, sediments, and processes are studied together for the different areas. Before dealing with these areas separately it is necessary to gain a more distinct view of the relationships of the various landform groups in space. The following section will seek to fulfill this purpose. In addition to this it will further define and clarify questions which have been asked in the first section.

MAJOR LANDFORMS AND SEDIMENTS IN STUDY AREA.

General

This section serves as an introduction to the remainder of the study. In it the major landforms and the sediments are briefly described. A treatment of the whole area at this point enables landform groups, discussed separately in following sections, to be understood in the context of the whole area. Also a fuller description of the major landforms than has already been given, permits the full implications of the conclusions reached later to be realised. Thus, this introduction to the landforms and sediments is of considerable importance to the analysis which will follow.

Landforms

The location and extent of the major landforms, referred to in this section, is indicated in Fig. 6. These landforms will be discussed under five major areal headings. These are:

1. Beach
2. Kaitorete Barrier
3. Western Lakemargins
4. Northeastern Lakemargins
5. Spur-ends of Banks Peninsula.

It should be noted that certain points expressed in the following discussion are based on conclusions reached in the succeeding sections.

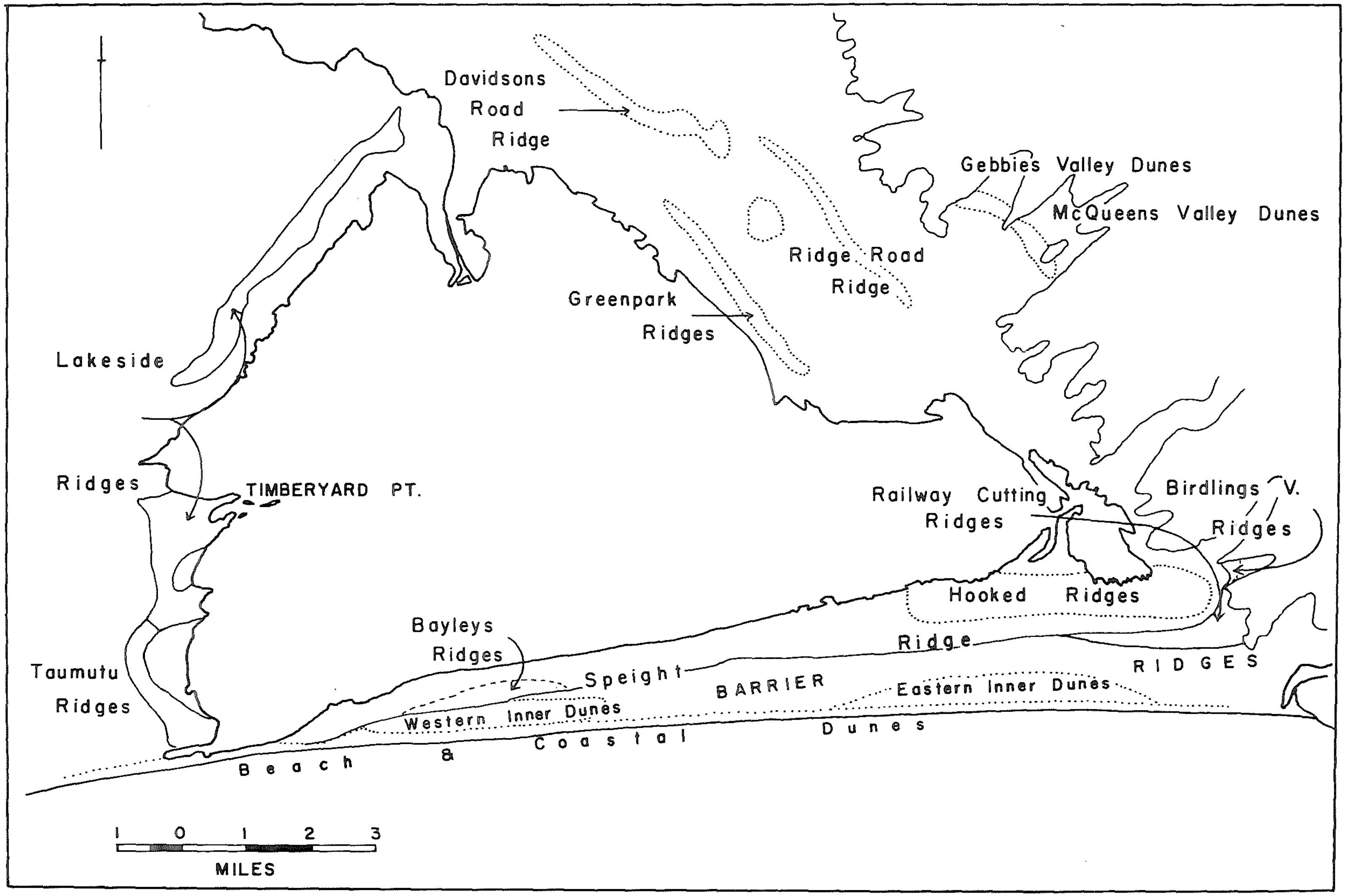


Figure 6. Locations of localities referred to in this study.

BEACH.

The present beach is a narrow zone between 300 and 400 ft wide. It is a sand-shingle beach sloping between 5 and 10° from the break point to the backshore area. A step at the break point marks a sudden increase in depth from the foreshore to the nearshore zones. For the easternmost 2 miles the beach has the characteristics of other shingle beaches; three wave-formed berms are often present at successively lower levels between the backshore beach ridge and the low energy wave zone. Further west, the beach deposit is of mixed sand and shingle, and such features are less noticeable.

For most of the Kaitorete Barrier dunes are present landwards of a narrow backshore area. In other beach situations backshore areas are more extensive and form an important part of the beach system.

The beach forms the 20 mile southern boundary of the study area, and comprises the northern segment of the beach fringing the Canterbury Bight between Banks Peninsula and Dashing Rocks, Timaru. It is important to understand that the beach in the study area is part of a much larger continuous beach. Thus, landward or seaward movement of the coast in the northern sector is related to the attempts of the whole beach to form an equilibrium with the wave regime.

KAITORETE BARRIER.

Barrier Ridges.

Marine-formed ridges are present landwards of the beach on Kaitorete Barrier. This ridge area extends approximately 15 miles in an east-west direction. It narrows westwards from 1.5 miles wide at Birdlings Flat, to 100 yards wide in the extreme west where it is covered by dunes. Speight Ridge forms the northern limit of the Barrier Ridges.

Axial trends of the Barrier Ridges are illustrated in Fig. 7. (see foldout map inside back cover.) The trends of the ridge-axes in the extreme west of the Barrier run obliquely to the shore and suggest that former shorelines crossed the present coast. The implications of the positions of earlier western shorelines are important when considering the present shape of the Barrier. A 9,000 ft profile across the ridges in the east shows an irregular increase in ridge heights from +9 ft to +30 ft over the inner 5,000 ft. A levelling out of ridge heights around +30 ft was noted over the subsequent 4,000 ft to the sea. The seaward increase in ridge-levels is important when considering the age of the Barrier.

Coastal dunes are present along most of the area's seaward margins. Dunes landwards of the coastal dunes are restricted to two areas. An area of Western Inner Dunes is indicated in Fig. 6. to be in the extreme west of the Barrier Ridges. The dunes are low dunes, less than 5 ft high, which were formed before the coastal dunes. The Eastern Inner Dunes are present east of the middle Barrier. They are low dunes with very irregular plan-forms, situated landwards of blowouts in the Coastal Dunes. Two questions related to the dunes on the Barrier need to be asked. It is important to ask why the dunes on the coast decrease in extent to the east, and also, why dunes are largely absent from the inner Barrier eastwards of the Western Inner Dunes. The solution to both of these questions allows for a better understanding of the sediment budget on the present, and earlier, coasts.

Lake-formed Ridges.

Conclusions arrived at in later sections suggest that Speight Ridge and other related ridges were formed by waves from the Lake. The lake-formed ridges on the Barrier include (from east to west): Birdlings Valley Ridges, Railway-Cutting Ridges, Speight Ridge, and Bayleys Ridges. The relations of these ridges to the marine-formed ridges can be seen better on Fig. 7. (inside back cover). The ridges form the lakewards margin of the Barrier Ridges. The main ridge (Speight Ridge) truncates the inner Barrier Ridges; those in the east have been deposited within a re-entrant angle between Barrier Ridges and spur-ends. Bayleys Ridges appear as a complex depositional ridge series in the west adjacent to the Western Inner Dunes.

With one exception lakewaves have removed evidence of the marine ridges on this inner portion of the Barrier. The exception is a series of hooked shingle ridges (Hooked Ridges), preserved beneath lakesilts on the inner margins of the eastern Barrier.

Hooked Ridges.

The Hooked Ridges occupy an area, 4 miles in east-west extent and half a mile wide, on the eastern inner Barrier. Traces of the ridge-axes in Fig. 7. (inside back cover) indicate a series of linear east-west orientated axes; curved hooks branch from them and trend northward towards a north-south orientation. The level of the ridges is between -5 ft and +5 ft. The plan-form and level of these ridges raise important questions. It is necessary to ask how these ridges were formed and furthermore, why they were formed at this level. Answers to these questions have an important bearing on early coastal development in this area.

WESTERN LAKEMARGINS.

Ridges are present on the western lakemargins and have been related by various writers to former shorelines. The absence of any direct relationship between these ridges and the Barrier raises the important question of their age of formation: are these ridges evidence of former marine shorelines or are they related to a former lakeshore?

The Taumutu Ridges fringe the lakeshore for the southern 2 miles of the western lakemargins. They are 2,000 ft wide at their widest point near Taumutu, but they narrow northwards to less than 500 ft. This ridge series has a regular ridge and swale form, similar to the ridges on the Barrier. Fig. 7. indicates that near Taumutu they are orientated facing the northeast.

The Lakeside Ridges are present south of Hart Creek as four low projections extending into the Lake. For 8 miles north of Hart Creek these ridges are present as a hummocky shingle deposit of varying dimensions, situated about two-fifths of a mile from the present lakeshore. The surface form of this ridge area differs to other ridge areas in that there is no ridge and swale form. The level of these 'ridges' varies; the projections have surfaces less than +8 ft but the area north of Hart Creek has a surface up to +15 ft.

NORTHEASTERN LAKEMARGINS.

The northeastern lakemargins differ to the areas mentioned so far in that the features in this area are formed of fine sand. In this area it is difficult to distinguish between ridges and dunes, so both terms are used somewhat freely .

The Davidsons Road Ridge forms the most distinct feature in the whole area; this is an undulating area which rises 10 ft from the near-flat lakemarginal area. The Greenpark Ridges are a low set of distinct ridges less than 4 ft high that parallel the present lakeshore. Towards Motukarara a shallow lakeward-facing slope indicates a ridge feature (Ridge Road Ridge). In Gebbies and McQueens Valleys low dunes less than 5 ft, are present in a broad belt 250 yards wide. They cross the mouths of both valleys.

The base of most of these dune and ridge features is +6 ft but that of the dunes in Gebbies and McQueens Valleys is approximately +10 ft.

These dune and ridge features are in an area which separates the present lakemargins from the spur-ends of the Peninsula. They raise an important question for this study: were they formed adjacent to former marine shorelines or were they formed adjacent to earlier more extensive lakeshores? The distance of this area from the present Barrier makes it difficult to answer this question because stratigraphic associations are absent.

SPUR-ENDS OF BANKS PENINSULA

Various relic marine abrasional features are present on the spur-ends of the Peninsula for a considerable distance from the present coast. They extend for 12 miles west of the present coastal cliffs at Poranui Pt. Shoreplatforms are common west of Kaituna. In some locations the platforms are backed by cliffs in the basalt, but more often cliffs are absent and the platforms have an uncertain relationship with the associated loess. Cliffs with shoreplatforms reduced or absent, are present east of Kaituna. Stacks are located at Kaituna, Motukarara, and Ahuriri.

The presence of these definite marine-formed features at this location landwards of the Kaitorete Barrier, and at this height above mean sealevel, poses the problem mentioned earlier: were these features formed by a recent shoreline adjacent to the Peninsula or were they formed at some time earlier than this postglacial period? The answer to this question has consequences for postglacial sealevels in this area. If these landforms were formed on a postglacial sealevel they indicate a sealevel possibly between +10 and +15 ft.

It is clear from the foregoing discussion that similar questions are being asked in several separate areas. It is necessary to know whether former shorelines were within the Ellesmere area at a sealevel near, or above, that of the present. Interrelated with this is the question of the influence that a former more extensive Lake Ellesmere had on the landforms of the lakemargins. Thus, general problems have appeared which are not limited to one area; they have a general significance for all lakemarginal situations. A few of the problems involved in answering these questions are indicated in the following discussion of the sediments.

Sediments

The sediments present in the depositional landforms were described in a previous section as having one immediate source: the alluvial gravels of the Plains. The provenance of sediments in this part of the Plains area is similar. Thus, particle composition is little help in differentiating environments or sediment movements.

PARTICLE SIZE.

Sediments with mean sizes between silt and large pebbles are present within the area. Silts and fine sands are found in lakemarginal situations while the various dunes are formed of sands. Landforms on the western lakemargins and on most of the Barrier are largely coarser sediments: granules and pebbles. Thus, a considerable range of particle sizes were encountered in this study.

Particle size parameters allow two distinctions to be drawn between sediments from different environments. These distinctions are:

1. among sediments in different dune situations in the study area.

2. between sediments in dunes and those in Ridge and Beach situations.

These arise when comparing mean grain size and sorting. Envelopes of samples from various situations, illustrated in Fig. 8, show these distinctions. Dunes in Gebbies and McQueens Valleys have finer means than those from between Greenpark Huts and Lincoln. These dunes from the northeastern lakemargins have finer means than the dunes on the Kaitorete Barrier. The poorer sorting and coarser mean grain sizes of Western Inner Dune samples often results from the addition of a pebble mode to the sediment. The various dune-sediments can be broadly distinguished from the sediments on the present beach and those in the various shingle ridges.

The distinction between the lakemarginal and coastal dunes allows some conclusions to be drawn about the dunes on the northeastern lakemargins. Otherwise grain size parameters offer little differentiation between depositional landforms that can solve problems in this study. Sediments from the Barrier Ridges, Barrier lakeformed ridges, and Lakeside Ridges mostly fall within the envelope of Beach samples in Fig. 8.

This important method of investigation is thus of limited use in providing answers to major questions arising in this study. However, in contrast to this, particle form analyses allow some distinguishing of certain landforms.

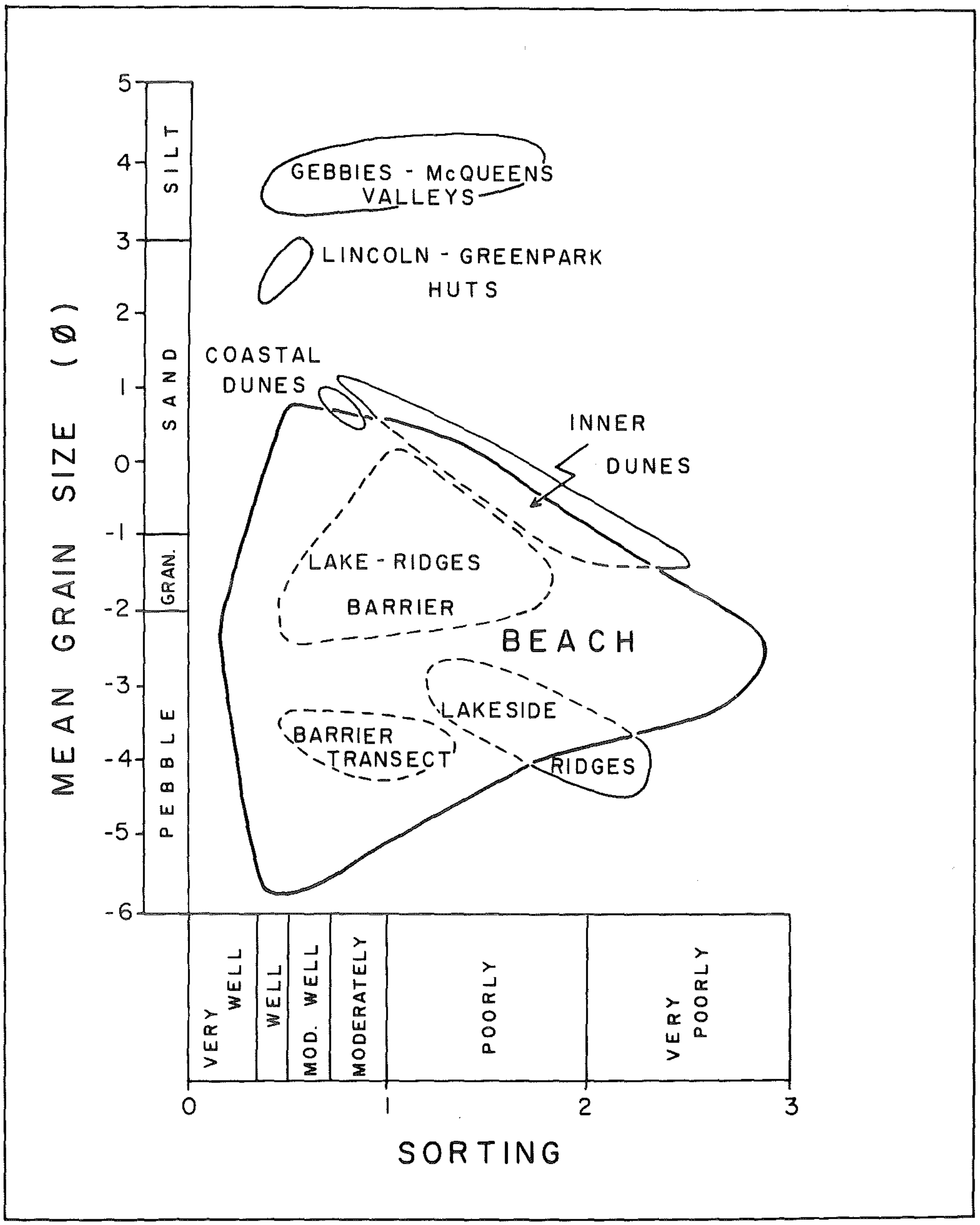


Figure 8. Mean grain size and sorting relationship of samples from different situations.

PARTICLE FORM.

Two measures of particle form are mentioned in this study; they are psi (Effective Settling Sphericity) and an associated index of flatness, the S/L ratio. It appears from the few samples taken, that sediments from the Lakeside Ridges and the Selwyn River have different sedimentform characteristics to those on the Barrier and Beach. Fig. 9 indicates the higher proportion of flatter particles on the Beach and Barrier compared with those from the other two areas. The Beach and Barrier have a correspondingly lower proportion of compact particles. Mean S/L ratios are presented in Table 2 along with mean psi values. Both of these measures indicate similarities between the Beach and Barrier samples, and between Lakeside Ridges and River samples. They both also indicate a broad differentiation between Barrier and Beach and those from the Lakeside Ridge and River situation.

These distinctions and similarities raise questions which are of importance to those which were asked earlier. It is necessary to ask what the relationship is between sediments in the Lakeside Ridges and those in the Selwyn River. One must also ask what the distinction between the Lakeside samples and the Barrier and Beach samples signifies.

Succeeding sections will attempt to answer questions which have been raised in this and earlier sections. This section has been concerned only with asking them. It has tried to view the area and its problems in a spatial context. Without consideration of the areal relations of the landforms it is difficult to note the implications of the problems which are discussed in the succeeding sections.

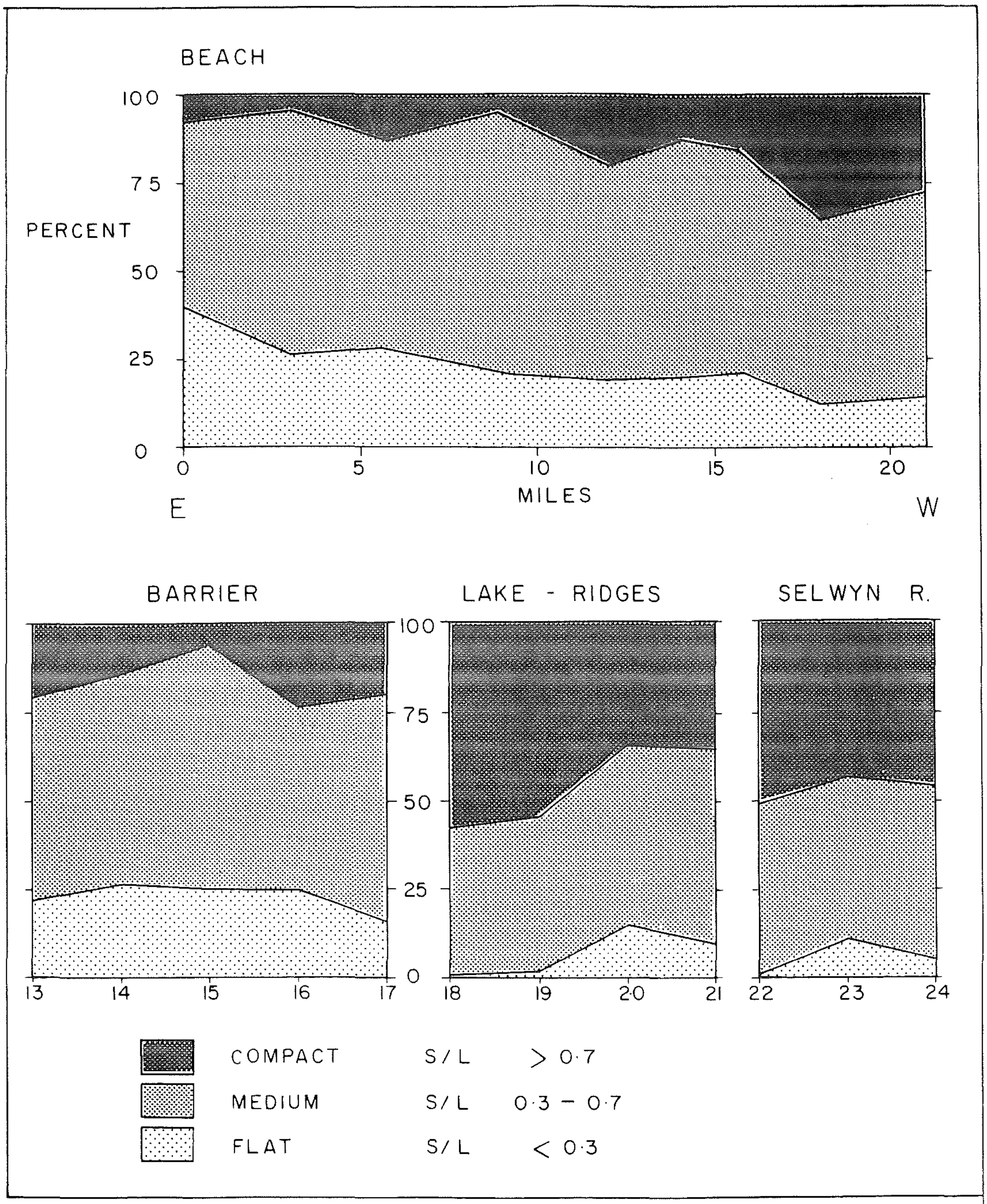


Figure 9. Proportions of particles in different flatness classes in Beach, Barrier, Lake-side Ridges, and River situations.

Table 2. Particle Form Characteristics of Sediments from the Present Beach, Barrier, Lakeside Ridges, and Selwyn River.

Analysis No.	Mean Psi	Std. Deviation	Mean S/L
Beach Samples			
4	0.63	0.11	0.43
5	0.65	0.12	0.44
6	0.58	0.10	0.36
7	0.59	0.09	0.40
8	0.62	0.11	0.41
9	0.59	0.08	0.38
10	0.56	0.11	0.38
11	0.56	0.09	0.36
12	0.52	0.08	0.33
Barrier Samples.			
13	0.59	0.10	0.39
14	0.59	0.09	0.38
15	0.55	0.09	0.36
16	0.59	0.10	0.39
17	0.60	0.10	0.41
Lakeside Ridges			
18	0.71	0.09	0.52
19	0.70	0.08	0.50
20	0.63	0.11	0.44
21	0.68	0.08	0.47
River Samples			
22	0.70	0.08	0.51
23	0.66	0.11	0.48
24	0.68	0.09	0.49

+ S/L is the ratio of the Short diameter to the Long diameter.

Summary

From the previous sections it is apparent that several questions, worthy of consideration exist in this area. The diversity of opinion about the origin of various landforms and, about the sequence of recent coastal changes, indicates a problem which must also be faced in this study. This problem is one of a scarcity of ready information. It will be shown in the following sections that various lines of investigation, hitherto neglected in studies of the area, allow the answers to most of the problems so far raised, to be given with some degree of certainty.

In the following sections a more complete description of the landforms will be given and problems related to the realisation of the study's aims will be investigated. The beach environment will be studied in the next section; part of it will investigate present directions of coastal movement. The rest of the section allows an understanding of coastal processes and landforms; this is vital for a full evaluation of the landforms on the western and northeastern lakemargins.

Succeeding sections describe, explain, and discuss the different major landform groups. A sequence of coastal changes will gradually become evident and the associated problems will be clarified. An understanding will thus be gained of Lake Ellesmere's effect on landforms and also the extent of marine influence on the landforms around the Lake. A final section will draw much of the evidence together and illustrate the sequence of coastal changes around the study area.

BEACH ENVIRONMENT

General

Knowledge of the present beach environment is important when evaluating conclusions gained from a study of the landforms in the rest of the area. The processes on the present beach will be similar to those on coasts in this area over the last 15,000 years. Responses may have altered however, as changes in beach geometry, shoreline orientation, or sediment parameters have occurred. This section will study the character of the present beach zone, some processes and beach responses, and the present directions of coastal movement.

Beach Character

The beach deposit is of mixed sand and shingle sizes, present as a moderately sloping foreshore landwards of a step at the break point. Andrews and Van Der Linden (1969) recorded dips of the lower foreshore, midway along Kaitorete Barrier, as 8° with dips of the associated strata in the beach face between 3° and 8°. The step marks a sudden increase in water depth to the nearshore bottom. Breakers of a plunging or surging type break on or near the step, and their swashes sweep the foreshore.

The sand-shingle beach between Poranui Pt and Coopers Lagoon shows consistent variations across the beach. Cobble sizes are present at the step, while granule and coarser sand sizes are in the swash zone. A band of pebbles and cobbles usually marks the swash-limit. If the swash zone is restricted by low wave conditions, stringers of sand and pebbles occur at higher levels on the beach to the limit of wave action.

There are three sets of relationships between the beach and its coastal hinterland. The changing coastal character encompassed within these situations indicates directions of recent coastal movement along the Northern Canterbury Bight. The three types of beach relationship are:

1. A barrier beach is present at the outlets of Lakes Ellesmere and Forsyth, separating both lakes from the sea. In this situation the beach face presents a moderately sloping foreshore and the backshore descends at a more shallow angle to the lake-margins. This is illustrated in Fig. 10. This figure shows the difference in slopes of the foreshore and backshore. Part of Lake Ellesmere is present in the right background of the photograph. Although narrow, this beach forms a stable deposit: it is maintained in storm conditions while beach erosion occurs in the latter two beach categories.

2. West of Taumutu a beach is present as a narrow zone separating low-lying sediments from the sea. The moderately sloping beach face is similar to that in the first beach type. The backbeach situation differs however in that beach sediment forms an over-wash fan covering low-lying hinterland sediment. Dunes are present, either as a thin sand cover on the backbeach or as low sandhills less than 10 ft high (Fig 11.). Towards Taumutu a storm in March 1970 exposed hinterland sediment in the beach face and cut it back. Fig 11 shows the covering over of this beach basement, following the storm, by the lower-energy wave regime. This exposure of beach basement, shown in Fig 11, indicates that

Figure 10. View west along barrier beach at Taumutu, separating Lake Ellesmere (right background) from the sea. Note gentle backshore, and steep foreshore (right).

Figure 11. View west along beach west of Taumutu showing beach basement exposed in the upper foreshore by storm in March. Dunes in right background have wave-cut margins.

the beach forms a shallow cover on the underlying sediment. The whole beach zone is moving landwards as the basement is cut back.

3. The beach in front of Kaitorete Barrier differs from the first two categories in the relationship of the backbeach with the hinterland. Unlike the first two types, the backshore beach deposit rests against sediment at a similar level. The beach can be seen in Fig 12 to be a low angle foreshore area sloping from sealevel to a restricted backshore area adjacent to the dunes. Dunes form the landwards margin for most of the length of the Barrier. Dunes decrease in extent eastwards and are absent for the easternmost 3 miles. Wave-trimmed coastal margins of the dunes for the western 5 miles of the Barrier, indicate some recessional movement of the shore. The wave-cut margins are illustrated in Fig 12. Short-term observations suggest that this recession is limited at present.

PORANUI PT RIDGE ON BACKSHORE.

For the eastern 2 miles of the beach in front of Kaitorete Barrier a beach ridge is present on the backshore at a height of +24 ft. The ridge at this height apparently marks the limit of wave action in the present wave regime. In Fig. 13 it lies along the dashed line in the foreground. The ridge in the background is the first of the adjacent Barrier Ridges. It indicates the increase in level (by 4 ft) from the backshore ridge to the adjacent Barrier ridge. The vegetation seawards of this Barrier ridge marks the swale between it and the ridge on the backshore, and suggests an

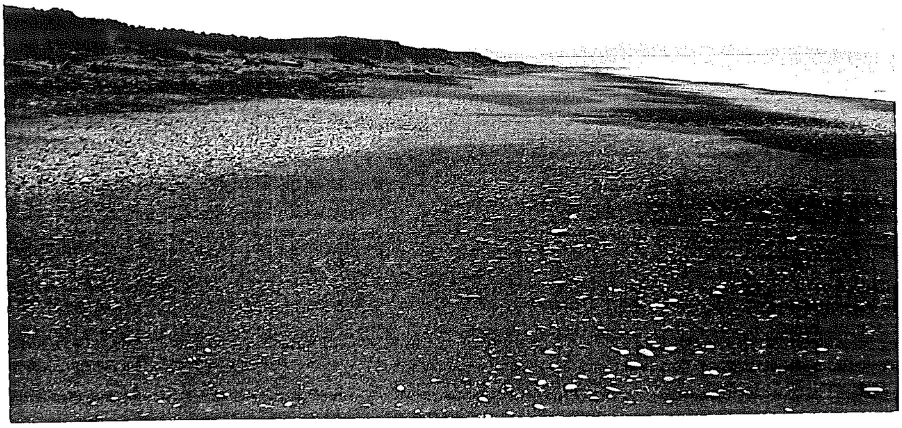


Figure 12. The moderately sloping beach face at Profile 6 with wave-trimmed dunes on the backshore. View east towards Banks Peninsula.

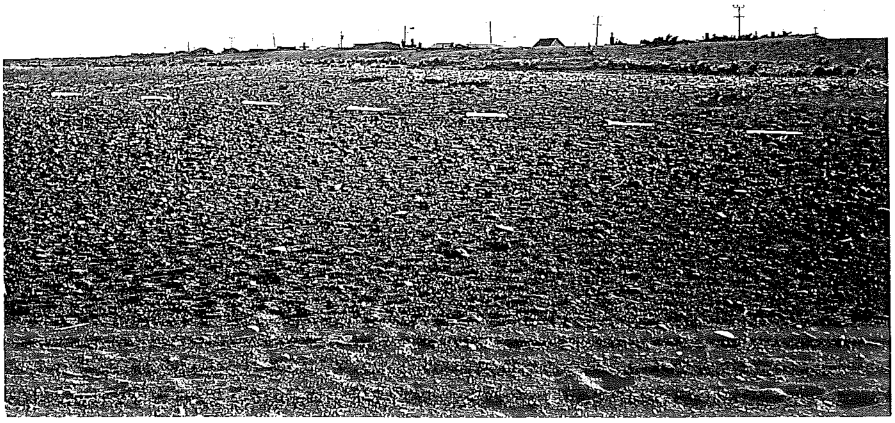


Figure 13. View is landwards from the beach at Poranui Pt. Beach ridge on backshore is in foreground (indicated by dashed line). Adjacent Barrier ridge, seawards of Batches, is 4 ft higher than backshore ridge.

absence of wave-influence in the swale. A southerly swell with a 10 second period and waveheights up to 10 ft sent swash to a vertical height of 15 ft on the beach. Waves overtopping the present backshore ridge would therefore be of considerable magnitude. Thus the height of this beach ridge appears to be adjusted to the maximum waves in the present wave regime.

The lower level of the ridge on the backshore, in apparent adjustment to the beach environment, raises an important question: does the lower backshore ridge record a fall in sealevel since the formation of the adjacent Barrier Ridges? The answer to this question is related to the assessing of three factors which influence the height of ridges above sea-level. Lewis and Balchin (1940) note the three variableswhich are:

1. Storm wave parameters - larger waves can form higher ridges if all else remains constant.

2. Amount of sediment entering the coastal area - rapid progradation of the shoreline may cause lower ridge-heights. The low-frequency high magnitude storms may not be able to work on all beach ridges.

3. Sediment particle size characteristics - higher ridges are formed where larger particles are predominant.

If these three factors can be held constant a considerable variation in ridge-height will probably relate to a variation in sealevel.

It is suggested later in this section that storm waves entering this beach zone are probably of similar magnitude to those of the last 15,000 years. Particle size characteristics are also later shown to remain consistent across the Barrier. Thus these two variable appear to have remained constant. However the second variable is more difficult to assess. This is because accretion may be occurring at present.

Accretion is suggested in Table 3, which lists a comparison of the shore-position on an old map with those on recent aerial photographs.

Table 3. Shoreline Positions at Poranui Pt during the last 104 years

Survey	Stack to shore distance (chains) +
1862 Black Map 115	9
1952 Aerial Photo	11.5
1966 Aerial Photo	11.5

+ Distance is measured from the seaward side of the sea-stack present on the eastern side of the barrier beach, to the waterline.

The difference in distance between shoreline and stack suggests a two and a half chain seaward movement of the shore in the last 100 years. This 'movement' may however be related to the surveyor's definition of the shore and to inaccuracies related to the sketching in of the shoreline.

Two and a half chains of accretion in the 90 years prior to 1952, would mean that progradation, if real, is still occurring on the eastern Barrier.

The ridge on the backshore may be recently added and not yet fully developed. However, it was earlier noted that the absence of wave action on the ridge landwards of that on the backshore suggests full development. The uncertainty as to continuing rapid progradation means that doubt must be expressed as to the backshore ridge's full development.

Coastal Processes

WAVES.

Recent writers agree that the South Island East Coast has a high energy wave environment related to swell-waves from a southerly quarter and less significantly from the northeasterly sector. The study area faces the south and is open to the full force of waves from this direction. Waves from a more northerly quarter than southeast only approach the coast after considerable refraction; this relates to the sheltering effect of the Peninsula to waves from these directions.

Indications of the high energy nature of the wave environment have already been given. Wave data collected during the study confirm the importance of larger waves in the wave regime. A significant proportion of large waves were recorded: waves 5 ft and higher occurred 26% of the time. The histogram of the continuous wave data, shown in Fig 14, indicates significant minor modes at wave heights of 4 and 8 ft.

A consistent variation in waveheight along the Barrier occurred for waves approaching from directions north of southeast. The more southerly waves were of similar magnitude for the length of the Barrier. Easterly swells

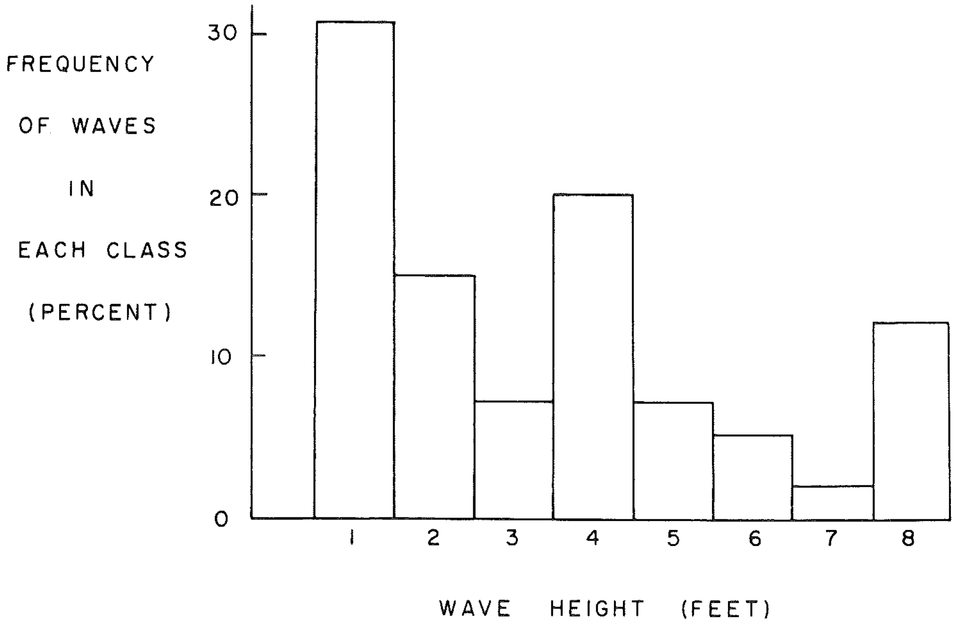


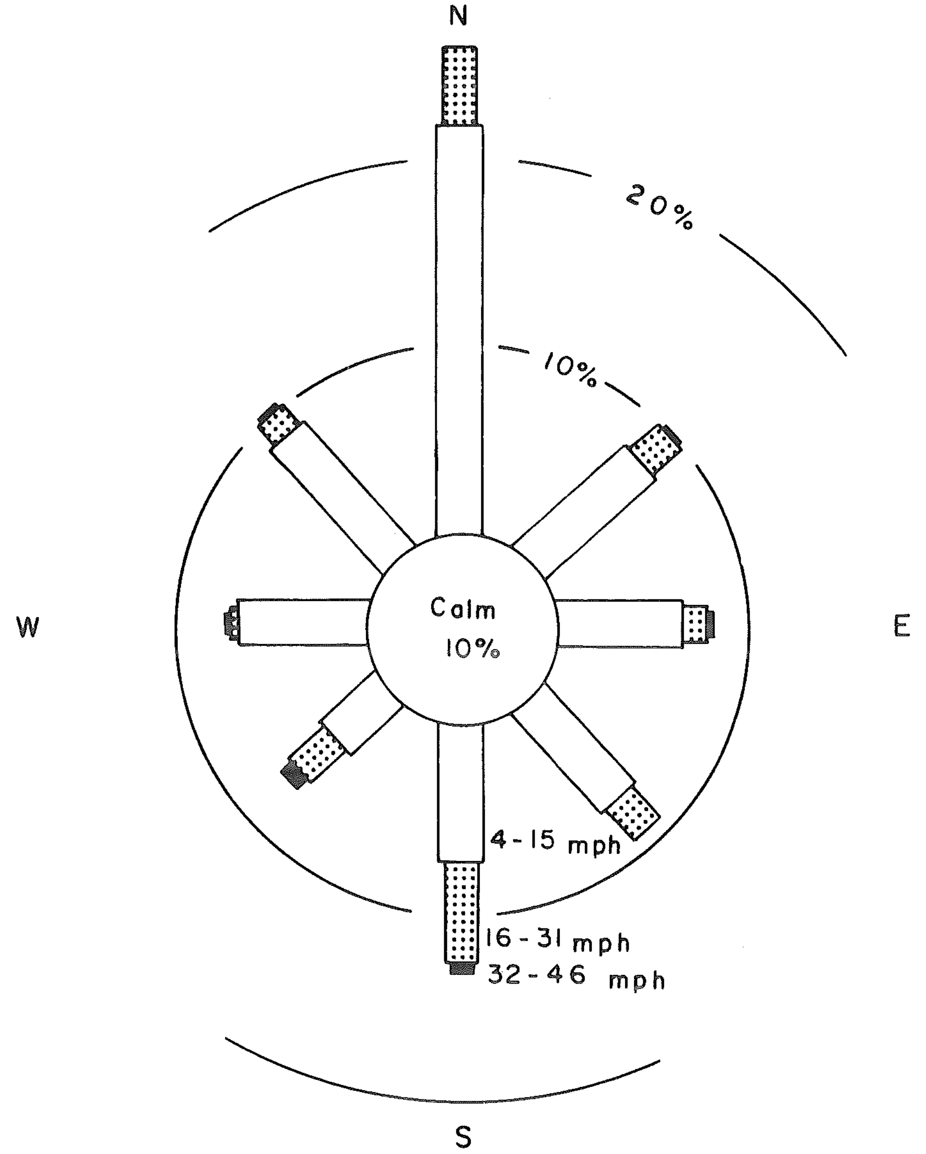
Figure 14. Frequency of occurrence of wave heights at [illegible] Flat between 7th April and 17th May, 1970.

showed consistent decreases in height over the eastern 3 miles. On 7th May, 1970, an easterly swell increased in height from 4 ft at Profile 1 to between 6 and 8 ft west of Profile 2. The waves broke with a westerly component to their swash. This is different to the swash-direction of the southerly waves; their swash was directed shore-normally or with an easterly component of motion.

From this brief review it can be concluded that this area is on a high energy coast. An open fetch to the south means that this coast is open to the full extent of waves from storms passing across, and south of, the South Island.

WIND.

The study area's exposure to the south means that strong winds from this sector can exert considerable influence on the coastal sediment budget. The averages of 5 years wind velocity records taken at Taumutu are summarised in Fig 15. This figure indicates that a significant proportion of high winds do occur from this southern quarter. Gusts up to 60 mph and hourly average windspeeds greater than 40 mph, have been recorded at Taumutu from the south and southwest. Such winds have formed the dunes on the seacoast and on certain inner parts of the Barrier. These winds have also lead to forms of dune decay: the blowouts and the parabolic dunes. The precise effect of wind on these features will be described in a later section.



SOURCE: NEW ZEALAND METEOROLOGICAL SERVICE

Figure 15. Mean wind conditions recorded at Taumutu between 1950 and 1958 (excluding 1955).

PAST VARIATIONS.

Extrapolation of present littoral processes to the last 15,000 years can only be carried out in a generalised sense. This is because climatic changes may involve changes in the magnitude, frequency, and tracks of normal weather events and storms. The resultant wind and wave regimes can subsequently change.

The nature of the wave regime is easier to deduce than the wind regime. It was previously stated that the present coast has unlimited fetch to the south and southeast, and is thus open to waves from storms to the south. A minor storm path currently crosses New Zealand but the major storm path is south of the country. Changes in the Upper Westerlies, and subsequent storm tracks, in the Southern Hemisphere during the last 15,000 years are unknown. Opinions even differ as to the probable changes that would occur in the General Circulation in glacial times, 15,000 years ago. However, a southern or northern movement of the present storm tracks would not lessen the size of waves able to reach the study area because of the area's openness to the south and southeast. It is also doubtful whether a northward shift of the storm tracks would produce maximum wave dimensions greater than those at present. This is because storms of considerable magnitude cross the area at present, forming waves higher than 15 ft.

The nature of the wind regime in the study area during the last 15,000 years is unknown. Two deductions can be made from the location of the study area specifically, and of New Zealand generally. Firstly, the exposed nature of the study area to winds from the southern quarter means that winds from such directions would always have been fully developed when reaching the area. Secondly, New Zealand's location in the middle latitudes makes it unlikely that an environment devoid of high winds was ever present.

It is thus concluded that the wind and wave regimes of the past 15,000 years had high magnitude events of a scale similar to those of the present regimes. The frequency of occurrence and the directional importance of high magnitude conditions may have changed for both regimes. But changing frequency and directional importance is not of great significance in a study which is interested in the long-term responses.

Beach Responses

BEACH CHANGES.

Volumetric beach changes reaffirm the importance of low frequency high magnitude events on this coast. Profiles surveyed following a storm in March 1970 indicated net erosion averaging 0.63 cubic feet per square foot of profile. Volumetric beach changes also suggest that no consistent longshore pattern of change exists. They confirm that beach responses on these sand-shingle beaches are very complex.

The net erosion that occurred during the March storm is shown in Fig 16A to represent a net loss to the beach west of Profile 2. This suggests that sediment moves from the beach face during storms into, or past, the breaker zone. Kirk (1967) concluded that the dominant movement during a storm is shorenormal. The loss of sediment over the step represented a fall of 3

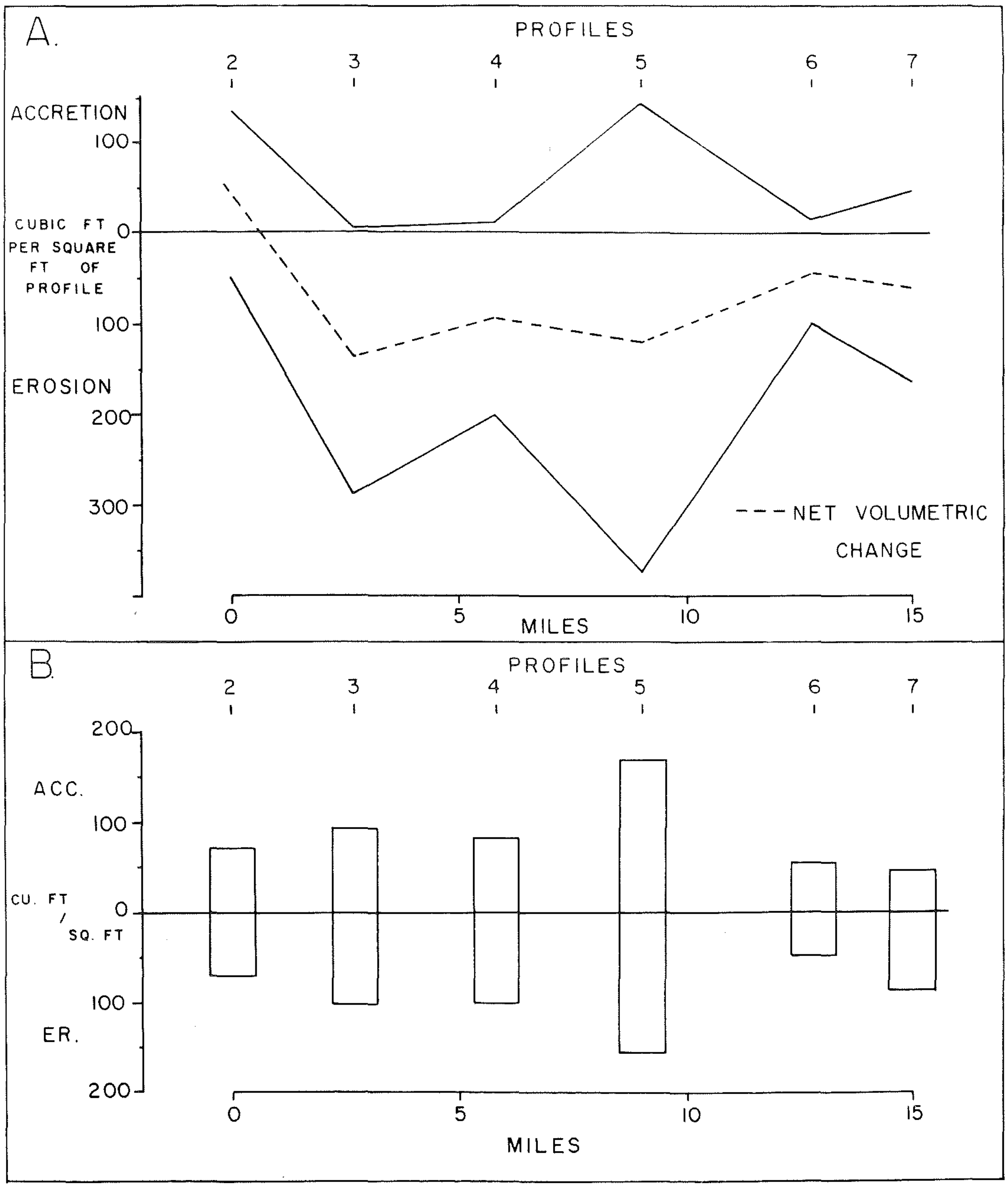


Figure 16A. Volumetric beach changes, between February and March, 1970 surveys, for each profile.

Figure 16B. Average volumetric changes for profiles 2 to 7 between December 1969 and August 1970.

to 4 ft in the lower to middle foreshore in some profiles. By the May survey the beach profiles were similar to the February and December surveys, indicating that the material was returned to the beach during conditions following the storm.

Volumetric beach changes showed no apparent trend of profile change that could suggest any longshore movement of material from one part of the beach to another. Fig 16B indicates that average volumetric changes for profiles during the four surveys vary irregularly between successive profiles. Fig 16A similarly shows an irregular pattern for the storm.

There is no evidence in these volumetric beach changes of longshore sediment movement relating erosion at the western end to accretion at the eastern end. The following analysis of beach sediment however, supports this conclusion only in part.

BEACH SEDIMENT.

Sediment size and shape parameters, like the volumetric beach changes, show a complex longshore response to the wave environment. The parameters: mean grain size and sorting, particle form, and particle sphericity (psi), do however give varying indications of a longshore movement of sediment to the east at present. This is contrary to the tentative evidence suggested by volumetric beach changes and by Kirk (1967).

Particle Size.

At the time of sampling mean grain size and sorting show a complex pattern between Coopers Lagoon and Poranui Pt. Fig 17 indicates the considerable

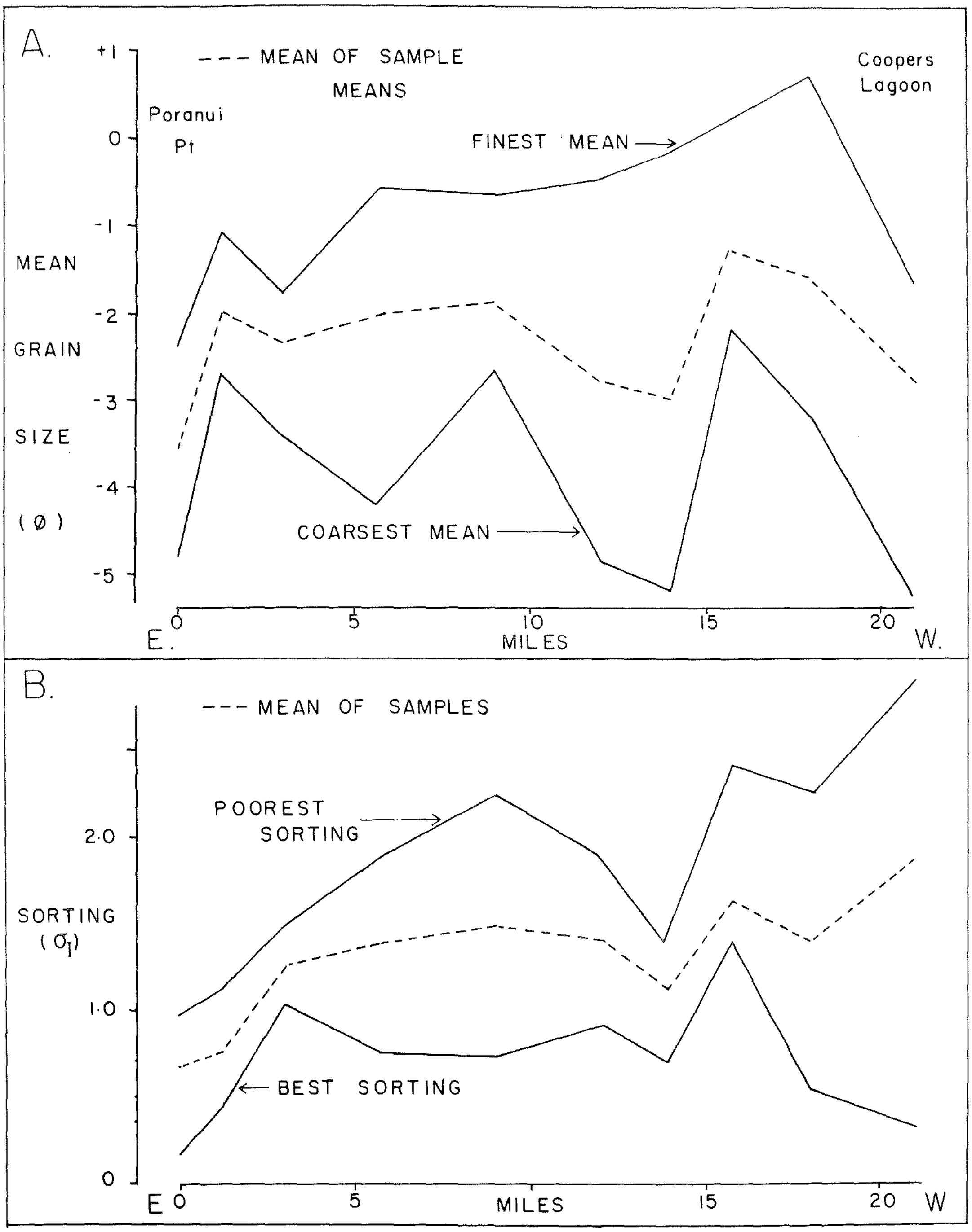


Figure 17A. Longshore variation of mean grain size between Poranui Pt and Coopers Lagoon.

Figure 17B. Longshore variation of sorting between Poranui Pt and Coopers Lagoon.

crossbeach and longshore variation. No longshore trend is immediately apparent, but Owens (1966) found a significant trend when performing trend-surface analysis on beach sediments over the eastern 3 miles of the beach. He noted a trend towards coarser mean grain size towards Poranui Pt and towards the backbeach. A decrease in the proportion of sand sizes present on the beach and an associated decrease in the extent of coastal dunes are both evident over this eastern 3 miles. The average mean size and sorting parameters in this survey indicate this change between Profiles 1 and 2. (Fig 17). For the rest of the beach to Coopers Lagoon no grain size or sorting trends are apparent.

Pebble Form.

Pebble form shows possible trends in the flatness of pebbles between Coopers Lagoon and Poranui Pt. While this is not evident in mean psi values a broad distinction is evident between Barrier beach samples (except Profile 5) and beach samples to the west. These lines of evidence, when combined with the trend in mean grain size at Poranui Pt, suggest longshore changes in sediment character. These changes could reflect longshore sediment movement at present.

Fig 9 indicates a general eastwards increase in the proportion of flatter particles for the beach samples. There is an associated decrease in the proportion of more compact particles. Mean psi values and mean S/L values, presented in Table 2, indicate a distinction between the Barrier beach samples and the samples from west of it. The two western samples (numbers 4 and 5) have higher mean psi values and mean S/L values than those on the Barrier beach.

Longshore Sediment Variation.

The trends in mean grain size and sorting at the eastern end of the Kaitorete Barrier suggest a beach environment which is not quite at equilibrium for the length of the Barrier. Owens (1966) related the mean grain size change to the selective westward movement of sand sizes with an obliquely approaching swell from the northeast. In a later section this sediment change is related to a progressive eastwards loss in sand sizes from the beach, both offshore and through dune formation. This trend does not provide conclusive evidence for continuing longshore sediment movement at the present. But it does suggest an apparent disequilibrium in the Barrier beach's sediments with those of the beach to the west.

The implications that the longshore particle form trends have for an eastwards littoral drift, are likewise uncertain. The presence of a sediment with a higher proportion of flatter particles, those particles with less effective settling properties, on the Barrier beach suggests that this sediment may be composed of more stable particles than further west. The immediate source of beach sediment was suggested to be the rivers and receeding coastal cliffs of recent alluvium between the Rakaia and Rangitata Rivers. The increase in more stable particles eastwards would thus appear to indicate the selective removal of the more mobile particles from the beach, away from the source of sediment.

The presence of more stable particles with distance eastwards, does not provide conclusive evidence for sediment movement at present. It may reflect a relic sediment distribution from former times when littoral drift was active. On the other hand the sediment response on the present beach could reflect the action of present littoral drift associated with progradation in the east (as suggested by Table 3.)

Evidence presented so far in this section has described the character and sediments of the beach and has given an understanding of the present beach environment. An important reason for studying the beach environment, that of investigating present directions of coastal movement, has only been partly discussed so far. This aspect is now treated more fully.

Coastal Movements

Evidence so far presented indicates that the present beach zone may be divided into three portions in terms of directions of present coastal movements. These are:

1. the beach west of Taumutu - current recession.
2. the beach for 12 miles east of Taumutu - probable stability.
3. The eastern portion of the beach on Kaitorete Barrier - possible accretion.

Evidence for differing movements of the beach in these three parts will now be discussed.

BEACH WEST OF TAUMUTU.

Evidence given in the beach description indicates a retreating shoreline here. Other evidence confirms the receeding nature of this shoreline. Kirk (1969) analysed profile records at four culverts between Taumutu and the Rakaia River, which dated to 1931. These indicated fluctuating trends of erosion, with rates up to 3 ft per year at McEvedys Culvert. Speight (1950) mentioned the removal of a road connecting Taumutu to the Rakaia Mouth Settlement, and the loss of one chain of road plus a well at the head of the Rakaia Mouth Settlement.

Kirk (1969) studied the plan-shape of the beach fringing the Canterbury Bight and concluded that the curve of the coastline was too flat in the middle portion to conform to equilibrium conditions. This central area is where there is abundant evidence of present erosion. The beach to Taumutu forms the northern limit of this middle portion.

BEACH FOR TWELVE MILES EAST OF TAUMUTU.

The beach morphology on this area implies a stable beach. The wave-trimmed seaward faces of dunes in the west indicate slight possible retreat. Elsewhere the development of a foredune suggests a constant shoreline for some period of time.

Two maps surveyed in the middle of the 19th Century indicate similar shorelines for this part of the Barrier over the last century. The 'Red Map' survey of the Native Reserves taken in 1848 (R.M. 140) shows a similar distance between the shore and the stream at the end of Church Road, Taumutu.

The 'Black Map' survey of the Barrier was undertaken in the 1860's and indicates a shoreline similar to that of the present for the western 10 miles of the Barrier.

BEACH ON THE EASTERN BARRIER.

The ridge on the backshore indicates that the most recent shoreline movement has been progradation. Earlier it was suggested that progradation may still be continuing at present. The shoreline position in 1862 is marked as two and a half chains landwards of the shoreline in 1952. Sediment and volumetric beach responses indicate varying evidence for sediment movement at present into this area.

Summary

In this section the beach zone has been described and discussed. Processes influencing the beach and associated beach responses have been analysed. Directions of coastal movement have been studied and three divisions were proposed on this basis.

This section indicates that the wave environment in the Northern Canterbury Bight is a high energy one dominated by waves from the south. Stronger winds from this quarter similarly dominate the wind regime. The coast is receeding west of Kaitorete Barrier, and stable for most of the B arrier, but possibly prograding in the east. In this regard it is important to realise that movement of the coast west of the Barrier will have an effect on the stability of the Barrier's shoreline. Zenkovich (1967) writes that barriers are dynamic features, capable of movement and decay. Coastal recession west of Taumutu appears to be affecting the western portion of the Barrier, giving rise to the wave-trimmed dune margins. It may be that in the future, active coastal recession will extend to the Barrier and possibly destroy its present form.

It is thus important to view Kaitorete Barrier as present on a coast which is undergoing change. In the following section it will be shown that former movements of the western coast have lead to shoreline modifications along the Barrier in the past. This will enable an understanding of the present eastwards increase in width of the Barrier.

MARINE DEPOSITIONAL LANDFORMS

General

The landforms in two areas on Kaitorete Barrier show evidence of recent coastal adjustments in the seaward portion of the study area. Other landforms in the Ellesmere area, which have been ascribed to coastal situations, will be studied later. This section is concerned with former shorelines and sealevel positions that are suggested by ridge-axes, ridge levels, and sediments in the areas of Hooked Ridges and Barrier Ridges. The Hooked Ridges will be studied first and the Barrier Ridges second; a discussion of the shorelines indicated by these groups of ridges will then follow. In this discussion the problem of the westerly decrease in extent of the Kaitorete Barrier will be evaluated. This section indicates the longer-term directions of coastal movements in the Northern Canterbury Bight. It allows the present trends of coastal movement, discussed previously, to be viewed as part of a continuous sequence of changes involved in the evolution of the coast between Banks Peninsula and Dashing Rocks, Timaru.

Hooked Ridges

The area of Hooked Ridges is located at the eastern end of the inner Kaitorete Barrier. It runs for 4 miles west of Prices and Birdlings Valleys, and is approximately half a mile wide. Shingle ridge-axes are reflected in the growth of Scirpus americanus (three ribbed arrow sedge) in the overlying lakesilt. Fig 18 shows the easternmost portion of the area of Hooked Ridges. The vegetation pattern is complex but clearly

Figure 18. View of Hooked Ridge vegetation patterns at the eastern end of the series towards Prices Valley. Drains cross the sequence towards the present Lake.

indicates a series of hooks curving lakewards from a linear axis.

The sedge growing on the lakeside shows a growth pattern that is broadly related to the depth of shingle beneath the lakesurface. An indication of the nature of the lakesilt overlying the shingle is given in the following description of a section beneath a vegetation hook at Grid Reference S94/017233. This sequence was present:

0 to 2 ft deep	dark brown firm silt, no horizons
gradual change	
2 to 6.25 ft	moist blue-green silt (soft pug)
distinct break	
6.25 to 7.5 ft	shingle with silt matrix (largest sizes in handauger were granules).

The only significant surface variation is between the vegetated and nonvegetated surface. The vegetated surface has built up its base by as much as 1 ft. This variation is a response to the sedge's growth, however, and is not the causal factor in its presence. The vegetation is growing in most parts where shingle is at depths less than 6 to 7 ft beneath the surface. Where shingle is at greater depths the vegetation is either sparse or absent. For shingle-depths between 3 and 6 ft the vegetation growth is a response to variations in shingle depths, rather than to absolute depths.

SHINGLE SURFACE.

The shingle surface beneath the lakesilts shows a pattern of ridges and swales on the hooks and on the axes. This is illustrated in Fig 19 which shows subsurface shingle profiles measured in 5 transects in different parts of the area. The ridges and swales can be seen to show a broad correspondence to the vegetation hooks and the nonvegetated areas, respectively. The shingle surface measured in each of the east-west transects is regarded as a continuous surface indicating ridges and swales because:

1. There appears to be a continuous relationship between successive depth measurements. The depths do not appear to be random although they show a greater variation than the vegetation pattern suggests.

2. A Random Turning Point statistical test was applied to see whether the series of depth values to the shingle formed a random or nonrandom distribution. This test was applied to Transects B and C. The technique and results are described in Appendix IIIB. Both distributions are nonrandom at the 95% level of confidence, thus indicating that the subsurface shingle variation has a definite form.

Transect A shows a very broad pattern with three vague ridges and swales; Transects B and C have more definite undulating forms. These transects illustrate height differences between ridges and swales of 2 to 3 ft and 4 to 5 ft. Minor variations are also imposed on the trends. Lengths between ridges appear to vary between 80 and 200 ft.

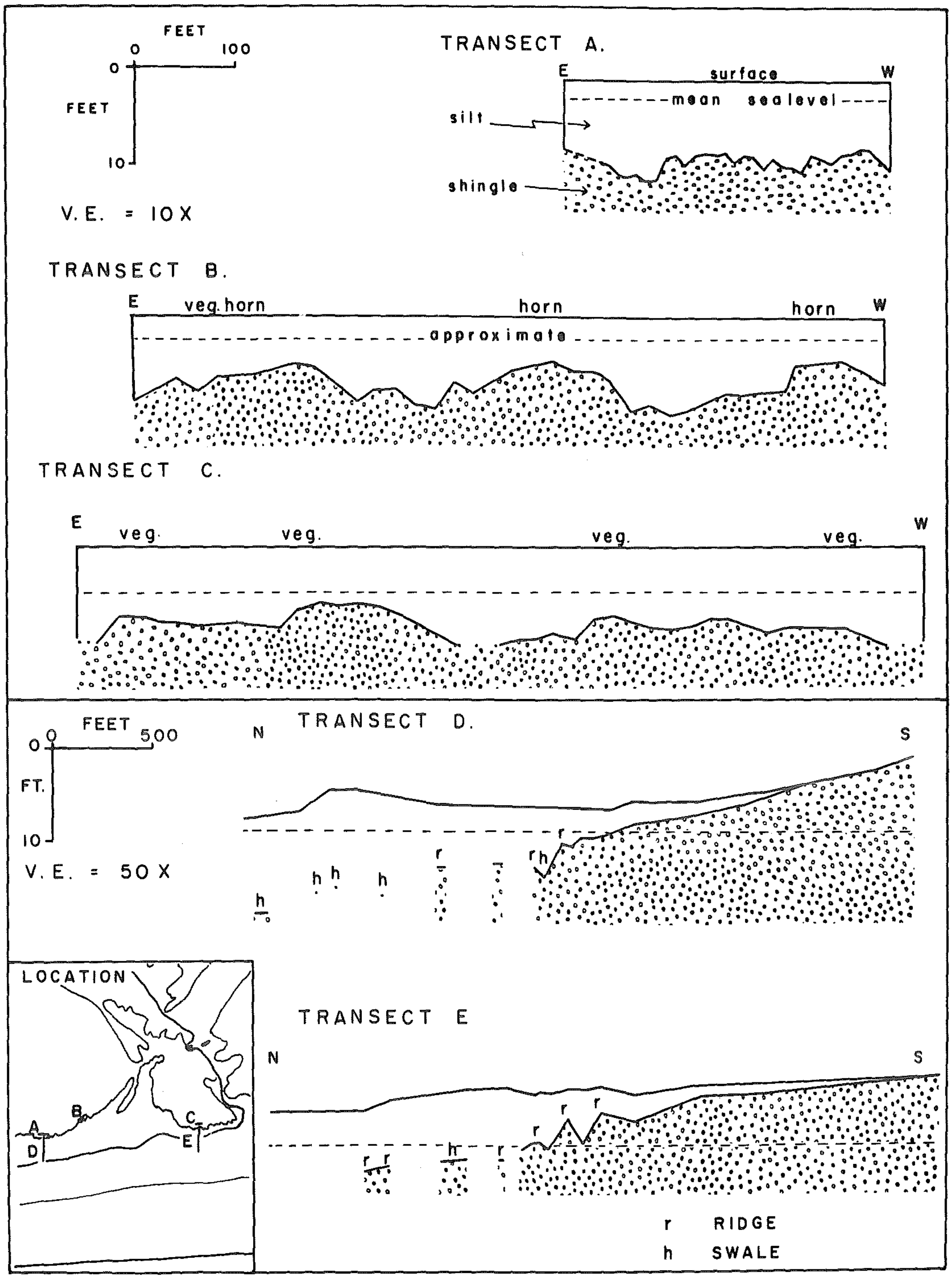


Figure 19. Surface of Hooked Ridges beneath lake silts. Transect locations are shown in inset. Transects A, B, and C run east-west; Transects D and E run north-south.

A fall in ridge-levels from the hook-axes to the ends of the hooks is demonstrated on the north-south transects by the increase in height of the shingle surface, crossing from the area of hooks to the area of axes. It is further shown by comparing Transects B and D. The axes corresponding to the hooks on Transect B cross Transect D and indicate an increase in level of 3 ft from hook-end to hook-axis. Part of Transect E traces one hook and notes a vertical increase of 0.5 ft in 115 ft.

EXTENT OF SHINGLE SURFACE.

The northern, or lakewards, extent of the hooks is unknown because ridges more than 7 ft beneath the surface lose surface expression in the vegetation. At the southern bondary of the Hooked Ridge area lakewaves have removed all traces of ridges. A featureless shingle surface slopes at a low angle away from the Lake towards Speight Ridge. The western extent of the Hooked Ridges is masked by thin shingle layers within the fine sediment. These layers prevent any possible ridge and swale response in the vegetation growth. They also make it impossible to find an extension of the Hooked Ridges beneath this area. Figure 18 indicates that the ridges at their eastern extent appear to tie with Banks Peninsula at Prices and Birdlings Valleys.

MARINE FORMATION.

The plan-form of the Hooked Ridges isshown in Fig 7 (inside back cover), using a trace of the lakeside vegetation pattern. This system of linear ridges with hooked ridges branching from them, suggests ridge formation at the end of a spit developing to the east before the presence of the Barrier. The linear ridges indicate a beach on the seaward face of a spit. The hooks suggest recurved ridges formed by waves refracting around the end of the spit. Successive curved ridges would be added to those already present as more material moved along the beach to the end of the spit. Wave conditions related to the formation of each successive ridge would vary, often cutting off or modifying earlier ridges at their lateral ends. In this way a spit is suggested to have developed eastwards until it joined onto Banks Peninsula.

AN ALTERNATIVE HYPOTHESIS.

An alternative hypothesis of formation might be suggested because of the present position of the ridges within the Lake's zone of influence. This hypothesis suggests that these ridges were formed by waves from within the Lake after the Barrier was present. It would call for progradation occurring from east to west, with ridges curving and extending into the Lake. The impossibility of distinguishing the true trend of addition of hooks makes this hypothesis worthy of consideration.

The problem with such a hypothesis is the projection of the ridges away from the shore into the Lake. In certain situations spits develop as projections from a near-straight shore but their forms and development sequences are different to those suggested by this ridge group. This group of ridges would necessarily have been a progradational sequence to have developed in this particular situation.

Their projection into the Lake cannot be explained in terms of filling a re-entrant angle of the lakeshore. The sequence of hooks is 4 miles long, and at the western end the hooks are more than 1½ miles from the spur-ends. Yet, the hooks proceed into the Lake at angles that would oppose the directions of the approaching waves. There appears to be no way of overcoming the problem, that arises with a lacustrine hypothesis of formation, of their projecting into the Lake. Thus, this hypothesis appears unacceptable.

The marine hypothesis of formation satisfactorily explains the plan-form of the ridges and is supported by the position of the Hooked Ridges landwards of the rest of the Barrier. Furthermore, it is difficult to conceive a coastal development in this area seawards of the fan surfaces without the initial presence of a spit. Thus, the hypothesis of ridge formation in terms of a developing spit from the west, is accepted. This early feature, prior to its linking with Banks Peninsula, will be referred to in the following discussion as the Kaitorete Spit.

Preservation of Hooked Ridges.

The early preservation of these ridges within the present Lake must have been related to isolation from wave action by lakelevels which were predominantly too high or too low to subject the ridges to wave-attack. At lakelevels similar to the ridge-levels, wave-attack could only have been active on the ends of the hooks. With a baselevel for the Lake similar to that of the present, deposition of fine sediment would eventually have formed the ridges' protective cover.

EARLY SHORELINES.

The Kaitorete Spit provides evidence of shorelines during the latter stages of its development. It suggests the approximate eastern shoreline when the Barrier was initially formed. Further west evidence has been destroyed or buried by the lacustrine influence. However, the inner margin of the Barrier provides a general idea of the early shorelines in the west which were associated with the presence of a spit in the east. In the absence of any other evidence it suggests a shoreline curving seawards of Taumutu at the western end of the Barrier.

RIDGE LEVELS AND FORMER SEALEVELS.

The question of how these ridges were formed has been answered, but the associated question remains: how were the ridges formed at this level? The explanation is found in the probable height of sealevel at the time of spit development. Given similar relations between sealevel and ridge height to those on the present beach, a lower sealevel accounts for ridges at this level. This lower sealevel allows some estimation of the age of the Spit and the time when the sea was largely or wholly excluded from the area between the alluvial gravels and Banks Peninsula.

Ridge Height Above Sealevel.

The relationship between the Hooked Ridges and sealevel may be similar to that between the backshore ridge at Poranui Pt and sealevel; this ridge is at a height of +24 ft. On the other hand, the relationship between height of the ridges in this area and sealevel could have been closer to that of the barrier beaches at the outlets of the Lakes.

They are at heights of +15 to +20 ft. The possibility that the ridges may have been awash at normal sealevels is unlikely because of the high-energy wave environment and the very definite ridge and swale form that is present. It is thus suggested that sealevel at the time of formation of the Spit ridges was 15 to 20 ft below the level of the Hook-axes. If relationship between sealevel and ridge height was more like that of the beach at Poranui Pt the sealevel estimations will be too high and the estimated age will be too young.

Sealevels and Age of Kaitorete Spit.

The levels of hook-axes are between 0 and +3 ft at Transect D and between +3 and +6 ft at Transect E. Assuming no movement of the land occurs, these ridges suggest a possible sealevel between -15 and -9 ft (for a sealevel 15 ft below the ridges). For a difference of 20 ft the sealevel would be between -20 and -14 ft. A sealevel between -10 and -20 ft, during the development of the Spit and the formation of the Barrier, has implications for the ages of these features and for the former sealevels within the Ellesmere area.

Sealevels between -9 and -20 ft suggest ages between 6,000 and 7,000 years B.P. for the final development of the Spit and the formation of the Barrier. This age-range is estimated from Suggate's curve of sealevel rise (Suggate, 1968). It should be noted that other sealevel curves suggest enveloping ages between 8,000 and 3,000 years.

A sealevel between -10 and -20 ft would also mean that the recent shorelines within the Ellesmere area were at a level lower than mean sealevel when they were excluded by the formation of the Barrier. This would suggest that former shorelines in this area are unlikely to have surface expression. They will probably be covered by recent alluvium and lacustrine deposits.

SUMMARY.

The Hooked Ridges have been shown to be ridges related to a spit extending itself eastwards to the Peninsula. The hooks result from refracted waves forming successive ridges on the end of the Spit during its development. Shorelines related to the Spit are clearly indicated in the east but are uncertain in the west. However, the plan-form of the inner Barrier margins suggests a shoreline seawards of Taumutu trending to the southwest when the Spit was present.

At the time of Spit development, sealevels between -20 and -10 ft were derived from the probable relationship between ridge height and sealevel. They suggest firstly, that the Spit formed possibly 6,000 to 7,000 years ago and secondly, that the sea was excluded from the Ellesmere area at a level considerably below that of the present. Evidence of former shorelines in Ellesmere may be covered or modified by recent actions within the Lake. A study of the Barrier Ridges gives additional evidence of development at the end of the postglacial rise in sealevel and substantiates some of the conclusions reached so far in this section.

Barrier Ridges

The area of Barrier Ridges forms the seaward portion of the Kaitorete Barrier for most of its length. The Barrier Ridges indicate continuous progradation for more than 1½ miles in the east of Kaitorete Barrier. Further west, the ridges on the inner Barrier have been destroyed by wave action related to former higher lakelevels, and the Barrier Ridges are more restricted. Over the western 3 miles of the Barrier, ridge-evidence is largely obscured by low dunes.

Fig. 20 shows the eastern 3 miles of the Barrier Ridges. This figure illustrates the magnitude of progradation that has occurred on this part of the coast following the linking of the Spit with Banks Peninsula. Individual ridges can be discerned from the air because vegetation grows more densely in swales, thus outlining the ridges. The similarity in trend between Barrier ridge-axes and the beach in the left of the figure illustrates that progradation has been the most recent action here.

MARINE FORMATION.

There is abundant evidence of marine formation for these ridges. Three factors indicating their formation will, however, be outlined. They are as follows:-

1. The regular ridge and swale form of features which parallel the present beach. This aspect is most apparent in the ridges formed on the Eastern Barrier and is indicated in Fig. 20. The ridge and swale relates them to formation by waves at former shore positions.

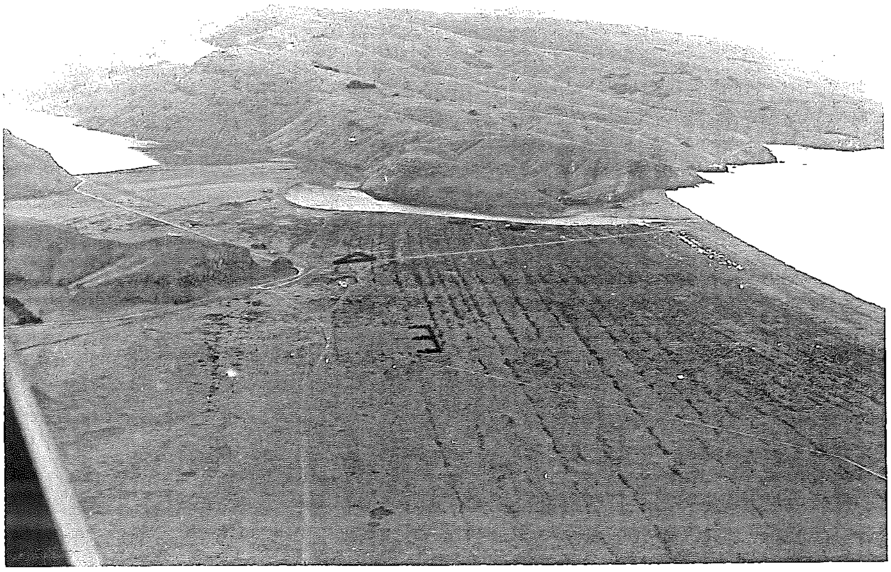


Figure 20. View of eastern 3 miles of Barrier showing Barrier Ridges in foreground and the Peninsula in the background. Lake Forsyth is between the ridges at Birdlings Flat and the hills. Devils Knob is in left foreground.

2. The similarity between bedding exposed in Devils Knob Pit and that exposed on the present beach at the outlet to Lake Forsyth. The bedding in the lower section in Devils Knob Pit is illustrated in Fig 21: it dips at angles similar to those recorded by Andrews and Van Der Linden (1969) for the beach midway along Kaitorete Barrier.

3. The similarity in sediment characteristics between the Barrier Ridges and the present beach. Figs 8 and 9, and Table 2 indicate similarities in particle size and shape parameters between 5 Barrier samples and those from the beach. Roundness also appears similar for pebbles from both situations.

RIDGE FORMATION.

The section through the ridges in Devils Knob Pit is illustrated in Figs. 21 and 22. Figure 22 shows a distinct break in the section between lower and higher beds at +18 ft; Fig 21 shows an eastwards view through the lower beds only. The similarity between the lower beds and those of the present beach has already been noted. Sediments in the lower part of the Pit section and in the present beach show bedding related to a great variation in sediment and wave conditions on the lower foreshore. Bedding on the beach and in the lower layers in the Pit is preserved on exposure because a significant matrix of fine sand is present in some layers, thus enabling the formation of firm layers.

The prominent break in the Pit marks a change between well-bedded beach sediments and poorly-bedded ridge sediments. The poor bedding of the

Figure 21. Bedding in east face of lower portion of Devils Knob Pit dipping towards the sea. Lower foreground is scree in front of the exposure.

Figure 22. View of south face of Devils Knob Pit. Poorly bedded ridge sediments overlie well bedded beach sediments.

overlaying layers is to be expected because similar conditions at the upper swash limits of the highest energy waves influence their formation. Here, the changeable conditions that prevail lower on the beach are absent.

Kirk (1967) writes that larger particles with lower sphericities move easily up the beach-face in the turbulent swash of high energy conditions. Movement down the beach is retarded because of the lower backwash velocity and the subsequent sliding nature of movement for these flatter particles. He found that particles of size -4 to -5 Ø with sphericity values of 0.5 to 0.6 psi were the most stable particles on the beach fringing the Canterbury Bight. Samples collected from the Barrier Ridges between the Pit and the sea, have mean sizes of -4 Ø and mean sphericity values between 0.55 and 0.6 psi (Table 2 and Fig 8.) Smaller particles, or similar-sized particles that are more sphericle (those moved by rolling), are more easily moved by the backwash. Such particles, which are not trapped among the more stable particles, are lost from the ridge which forms on the upper part of the beach. Thus in the ridge, particles tend to be more similar in nature and the bedding is less distinct.

The sediments and the bedding sequence that are exposed in the section through the Barrier Ridges at Devils Knob Pit, are valuable for comparison with sediments and bedding from ridges in other locations to which writers have ascribed marine origins. This exposure through the Barrier Ridges indicates the nature of deposits that have formed in a marine environment on this high energy coast.

RIDGE CHARACTERISTICS.

Ridge-Axes.

The direction of ridge-axes varies systematically with distance along Kaitorete Barrier. This is indicated in Fig 7 (inside back cover). At Poranui Pt the ridge-axes trend approximately 100° east of north. This trend changes to one between 85° and 90°, on an axis which slopes from 1½ miles to 3 miles from the eastern end between the present beach and the innermost Barrier Ridges. This trend is continued until 10 miles from the eastern end where the change of angle continues to one of 75° to 80°. By the 13th mile the angle changes further to 75°.

The seacoast is parallel to the ridge-axes for the eastern 10 miles, but for the westernmost 5 miles projections of the ridge-axes trend across the coast at increasing angles up to approximately 18°. The ridges are evidence of former shore positions and thus indicate former shorelines of the western Barrier, and further west, to be seawards of the present coast. This suggests that the coastal recession west of Taumutu is part of longer-term coastal retrogradation. The similarity between ridge-axes and the present coast at the eastern end of the Barrier indicates that progradation has been the most recent action here.

The changing relationship between the trend of the ridge-axes and the present beach results from the landward movement of the Barrier's fulcrum during the development of the Barrier. Fig 23 indicates that extensions

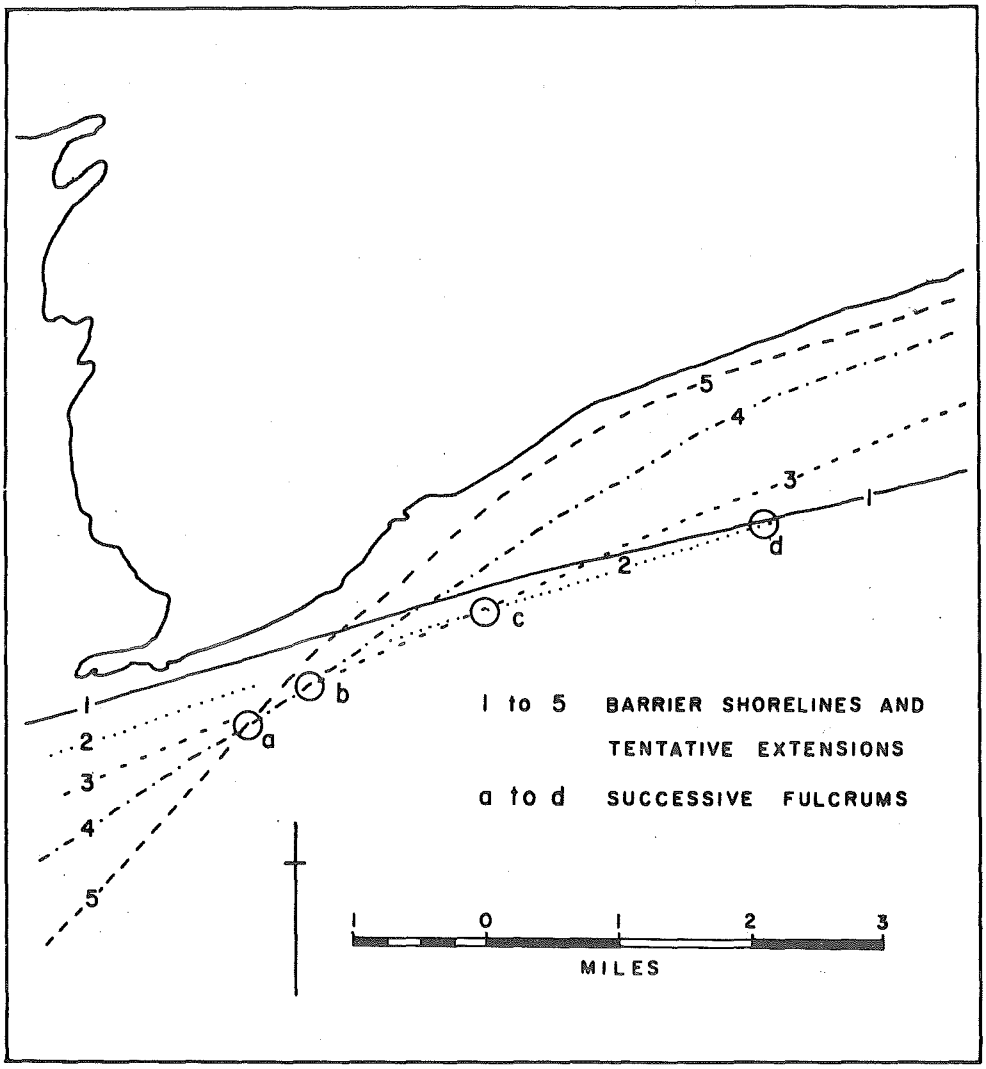


Figure 23. Tentative fulcrum positions between the Barrier and coast to the west during the Barrier's development.

of successively later ridge-axes show a northeastward movement of the fulcrum. The movement of the fulcrum has occurred as the effect of the retrograding coast to the west extended eastwards onto the Kaitorete Barrier. This demonstrates the importance of the events in the coastal sector adjacent to the Barrier.

Barrier Ridge Surface Levels.

The Barrier Ridges have their best expression at Birdlings Flat and most attention was focused on the complete ridge sequence there. Further west along the Barrier, ridges are less noticeable and ridge-evidence has been removed on the inner margins by lakewaves. However, two points arise, from investigating the surface along the whole Barrier, which need clarifying. Firstly, the ridge-surface varies along the Barrier involving an overall increase in level from less than +20 ft in the west to more than +30 ft in the east. This can be seen in the series of profiles illustrated in Fig 24: the lowest surface is on Profile VI, which is the westernmost profile, and the highest surface is on Profile II, which is the easternmost profile. Secondly, the Barrier surface shows an increase in level from the lakeward edge to the middle of the Barrier. The increase in ridge-level across Profile II will be discussed later in detail, but the surface variation across the other profiles calls for a brief review here.

The variation of the Barrier Ridge surface along the Barrier does not represent a continuous increase in level from west to east. It can be seen in Fig 24 that Profile VI is lower than the Profiles V, IV, and III, and that Profile II is higher than all of them. The surface on

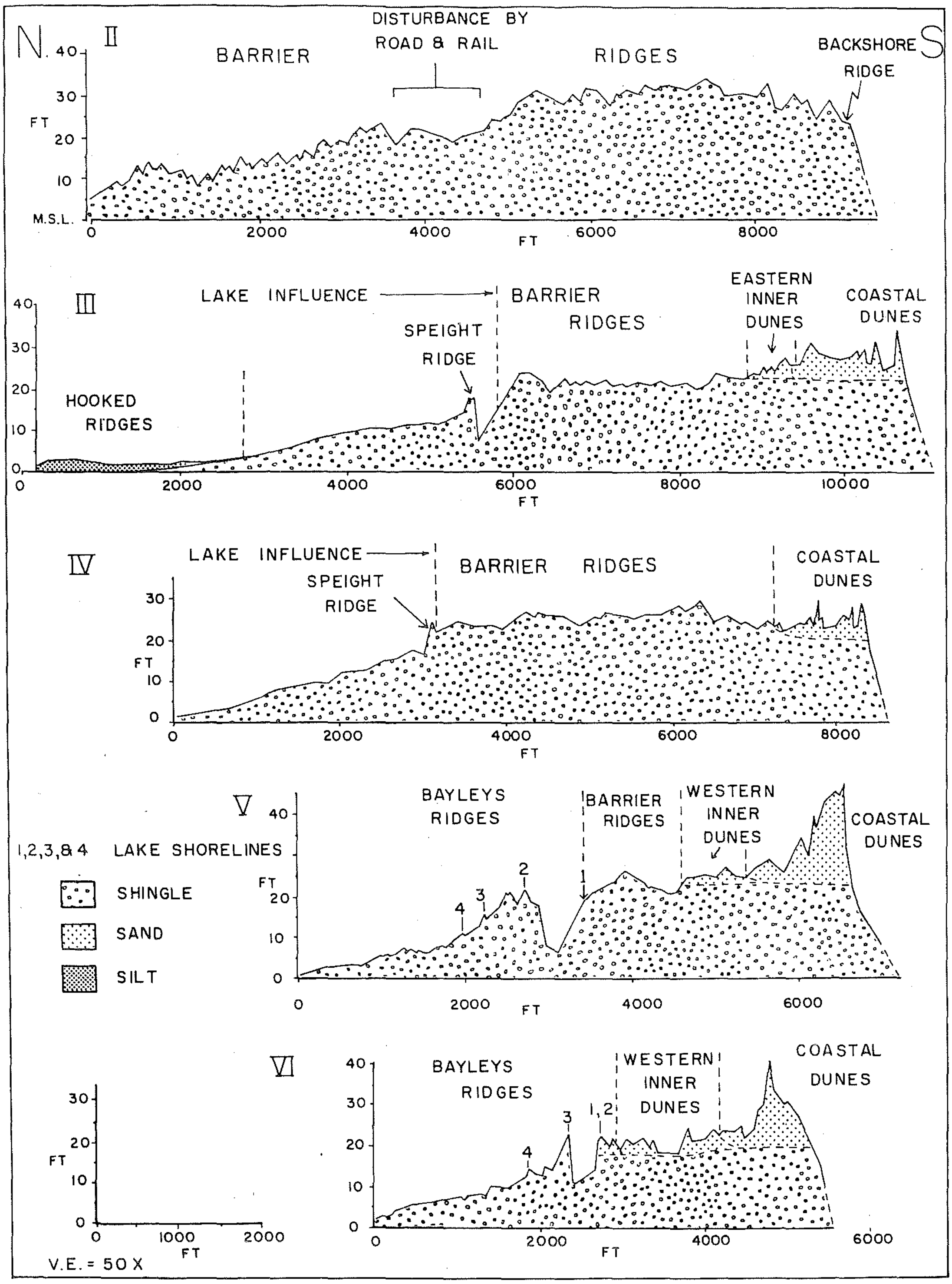


Figure 24. Profiles crossing Kaitorete Barrier showing the significant features referred to in this study.

Profile VI is between +16 and +20 ft while that on the middle three profiles varies between +20 and +25 ft. The surface of Profile II is at a level around +30 ft for most of its seawards portion.

The variation in level between the surface at Profile II and that to the west probably relates to the longshore variation in sediment character. On the beach, a decrease in sand sizes with an associated increase in pebble sizes was noted over the easternmost 3 miles. If this condition has existed for the duration of progradation in this area it would account for the westward variation in height of the ridge surface on the eastern Barrier. The ridge sediments exposed in the section at Devils Knob Pit indicate a sediment composed mainly of pebble sizes. This illustrates the similarity between sediments in the ridge and the predominant sizes on the beach at Poranui Pt. The lack of exposures through ridges west of Birdlings Flat prevented the testing of the hypothesis that more sand sizes were in the ridge-sediments to the west. However, these ridge sequences lacked the definite ridge and swale form of the sequence at Birdlings Flat, this lack of distinctness suggesting that sand does form a significant part of the ridge sediment.

The surface variation among Profiles III, IV, and V is suggested to relate to random variation of the surface along the Barrier. The surface of Profile VI is, however, lower than the rest. The decrease in level of the surface at this profile may relate to a decrease in the significance of ridges westwards. The area crossed by Profile VI is largely covered by the Western Inner Dunes. Ridge-building was conceivably minor here in a beach environment where sand was abundant.

The level of the Barrier Ridge surface thus appears to vary eastwards in response to changes of the sediments, however, this conclusion remains tentative. The longshore variation in sediment character will be further developed in the following section.

The second point that needs clarifying is the surface form across the Barrier. This variation in surface level between Lake Ellesmere and the beach is indicated in Fig 24 to be similar on each profile. The profiles show gradational increases from lakelevel across a zone of lake-influence, to the middle of the profiles; from there to the sea they maintain a similar level. Irregularities related to lakeformed ridges are present in all profiles but the general surface-trend relates to the surface of the Barrier. This general surface suggests an increase in sealevel during progradation from initial shorelines at the inner Barrier margins. Modification of the inner surface of Profiles III to VI unfortunately prevents definite conclusions being derived from this area concerning a possible sealevel rise during the development of Kaitorete Barrier. The sequence in Profile II does not have this disadvantage however, and an attempt to assess the relationship between the ridge-level variation and a possible sealevel rise will now be made.

RIDGE LEVEL TRENDS AND FORMER SEALEVELS.

The Barrier Ridges of Profile II show an increase in level from +9 ft at the back of Birdlings Flat to +30 ft over a distance of 5,000 ft (Fig 24). The ridges then vary in level for the subsequent 4,000 ft to the beach. Knowledge of the relationship between sealevel and these ridge-levels is important for considering former sealevels during the formation and development of the Barrier. It will also test conclusions that were reached earlier in this section.

The important factors related to the heights of ridges above sealevel were discussed earlier. It was concluded that variations in the wave regime are not likely to have affected the major ridge level variation. Other factors which could affect the change in ridge levels are: sediment characteristics, rate of progradation, and possible changes in exposure. A discussion will follow of the probable affects of these factors on the variation in ridge levels on Profile II.

Sediments have already been noted as having similar characteristics across the Barrier Ridges at Profile II. No sediment variation across the ridges here is large enough to lead to such a variation in ridge-levels. Thus the sediment factor is ignored.

The theoretical effect that differing rates of progradation have on ridge-heights has been mentioned earlier. Rapid progradation may lead to the addition of successive ridges before earlier ridges develop to their full dimensions. This does not appear to have happened at Birdlings Flat because of the time-period involved in the formation of

60 ridges. Weathering modification of pebbles indicates that during much of this time, progradation has been continuous. Weathering is restricted to surface staining for the seaward ridges of the sequence, while towards Devils Knob the thickness of the iron-stained alteration surface is 0.5 mm. At the earliest ridges on Profile II this zone is 1.5 mm. This indicates a considerably longer period of weathering for the earlier ridges in Profile II, which suggests progradation to have been active over a long period of time. Thus, the effect that variations in progradation rates may have had on ridge-levels, is discounted.

The third factor which could influence the increase in ridge levels is a possible increase in exposure. This might have affected ridge levels because the earliest ridges in Profile II were formed towards the rear of a coastal indentation. The dimensions of storm waves entering this former 'bay' might have been restricted by the headland on the eastern side of present Lake Forsyth. As progradation moved the shoreline to the entrance of the bay, so exposure to storm waves would possibly have increased and led to the formation of higher ridges.

Two factors suggest that the increase in exposure to storm waves across Profile II was limited. Firstly, the profile was surveyed along the western side of the valley; this side faces the south and is not sheltered by headlands. Secondly, the straight nature of the ridge-axes seawards of 2,500 ft on Profile II suggests that full exposure to storm waves has been present here. Ridge-axes are a response to the waves forming them; thus straight ridge-axes indicate that wave energy is evenly distributed along the beach, while curving ridges indicate a changing longshore pattern of wave energy and less energy at any one point. Seawards of 2,500 ft ridge-axes do not curve and are orientated parallel to the obviously fully exposed ridges near the sea. Ridges with this form suggest that waves forming them have not been involved in any loss of energy through wave diffraction in this former bay. Eastwards of the profile and landwards of 2,500 ft on Profile II, curving ridges suggest a spreading wave energy within the bay and indicate a decrease in exposure.

The ridge levels seawards of the inner 2,500 ft record an increase in level from +15 to +30 ft. It is concluded that this increase in exposure to the storm waves may have affected the earliest ridges but not the subsequent increase in ridge-levels.

The variation in ridge-levels seawards of 2,500 ft on Profile II is thus suggested to be independant of variations in the wave regime, sediments, progradation, and exposure. It appears probable that this trend in ridge-levels traces a curve of former sealevels and indicates progradation occurring on a rising sealevel which was initially lower than that of the present. This conclusion confirms the formation of the Spit and its linking with the Peninsula, at a sealevel significantly below that of the present. The trend of the Barrier Ridge levels indicates that sealevel rose 15 ft during the Barrier's development. The outer 4,000 ft of the Barrier Ridges may represent a sealevel close to the present level or 3 to 5 ft higher. This depends on the relationship between the height of the backshore ridge at Poranui Pt and sealevel. If this ridge is fully developed a sealevel of +3 to +5 ft is indicated by the ridge-levels.

The earliest Barrier Ridges which show a sealevel similar to the present indicate the shoreline approximately 5,000 years ago. This is inferred from Suggate's sealevel curve which suggests that the present level was reached about 5,000 years ago. The 5,000 years B.P. shoreline appears to have been at a position level with Devils Knob, where ridges between +25 and +30 ft were first reached.

SUMMARY.

The important points that arise from studying the Barrier Ridges are three-fold. These are summarised as follows:

1. The beach and ridge deposits which form on this coast have a distinctive character that relates to the high energy wave regime. The ridge sediment forms a fairly uniform deposit composed of the most stable particles on the beach. The beach sediment has moderately dipping bedding with sand to pebble sizes present. This marine deposit allows for comparison with possible marine sediments on the inner margins.

2. The ridge-axes show a sequence of shoreline changes which have occurred to the west of, and on, the Kaitorete Barrier. They confirm progradation of the shoreline from an initial position

at the landwards margin of the eastern Barrier. This confirms early spit-positions suggested by a study of the Hooked Ridges.

3. The ridges of Profile II show a trend in sealevel; they indicate a sealevel rise of approximately 15 ft to a level which may have been higher than the present. This confirms the conclusion, also reached in the discussion of the Hooked Ridges, of the formation of the Barrier at a sealevel significantly below that of the present.

Present Shape of Kaitorete Barrier.

The sequence of shorelines indicated by the Hooked Ridges and Barrier Ridges allows an understanding of the present eastward increase in width of Kaitorete Barrier. Figure 25 indicates shorelines at various stages of the Barrier's development. The shorelines west of Kaitorete Barrier are tentative, being derived from extensions of ridge-axes and an extension of the inner margin of the Barrier. These shorelines indicate progradation over the eastern Barrier and suggest retrogradation west of the Barrier.

The position of near-equilibrium (the fulcrum) between the two opposing trends, has been located near the western end of the Barrier (Fig 23). Part of the westward decrease in width of the Barrier can be explained by the position of the fulcrum at this end. Whereas progradation has operated freely over the eastern portion of the Barrier, it has been restricted on the west of the Barrier where it is nearer the fulcrum.

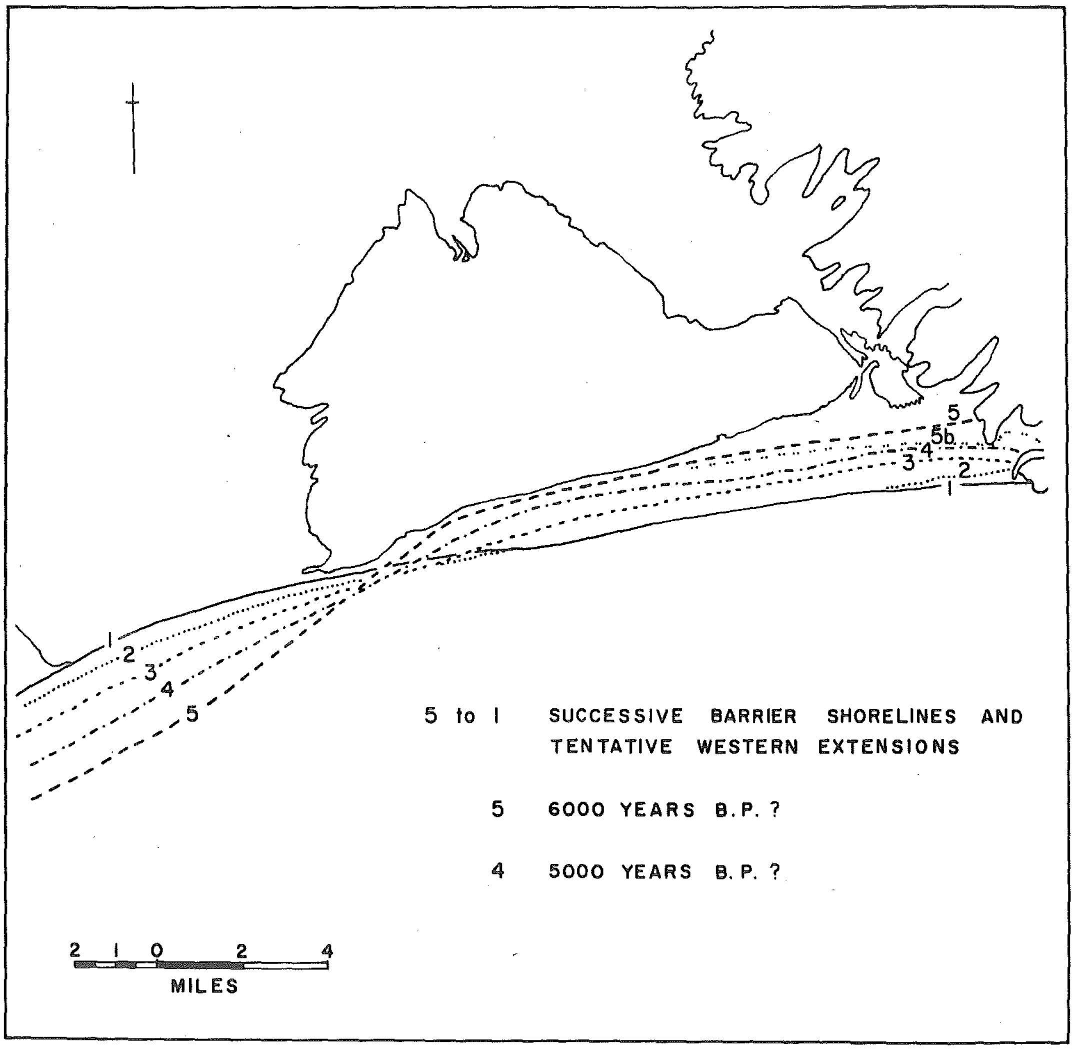


Figure 25. Barrier shorelines and their tentative western extensions.

This unequal distribution of progradation has meant that the eastern portion of the Barrier has increased in width more than that in the west.

The rest of the westward decrease in Barrier width can be explained in terms of the northeastward shift in fulcrum position. This movement has occurred as continued retrogradation west of the Barrier has brought about the extension of the eroding coastal sector to the western Barrier. Coastal recession on the western Barrier has given rise to the further narrowing of its western end. This erosion has led to the formation of the narrow barrier beach connecting the Barrier to Taumutu in the extreme situation where the former Barrier has been completely removed.

The westward decrease in width of the Barrier is thus related to two factors:

1. the limit to progradation on the western Kaitorete Barrier, because of its position near the fulcrum between a retrograding and a prograding coast.
2. the extension onto the western Barrier, from the west, of coastal erosion.

This discussion indicates that the Kaitorete Barrier has undergone a sequence of changes related to the changes in the whole of the coastal area between Banks Peninsula and Timaru. The Barrier can be seen as a dynamic feature which has undergone growth and development. It could be suggested that the Barrier is now in a state of decay. Its future development will be related to the magnitude of changes on the coast to the west of the Barrier.

Summary

The combination of the two groups of ridges show that there are two periods in the development of Kaitorete Barrier. The first period is when a spit was present, gradually extending across and separating an embayed area between the fan margins and the Peninsula. This is suggested to have occurred between 7,000 and 6,000 years ago. The second period follows the joining of the Spit with the Peninsula. This marks the exclusion of the sea from the Ellesmere area and the formation of a lake in the depression between the Barrier and the fan margins. Shorenormal progradation has led to the formation of the Barrier Ridges. At the eastern end of the Barrier progradation is shown to have extended continuously from the Spit's meeting the Peninsula to a time near the present. At the western end of the Barrier early progradation changed to retrogradation as coastal recession on the adjacent coast has affected the development of the Barrier here.

The increase in level of the Barrier Ridges that is apparent on Profiles III to VI, and present on Profile II, is thought to result primarily from a rise in sealevel, although an increase in exposure may be significant for the early ridges on Birdlings Flat. The suggested sealevel curve is from a level at -20 ft when the Spit was present, reaching mean sealevel when the Barrier had prograded level with Devil's

Knob. Comparison of the extent of particle modification by weathering across the Barrier suggests that the most seaward ridges on Profile II have formed recently. The Barrier Ridges thus do not add conclusive evidence either for the present occurrence or nonoccurrence of progradation at Poranui Pt, but evidence from them does indicate that if progradation is not active at present it has only recently ended.

The discussion so far has neglected to consider the dunes on the Kaitorete Barrier and their implications for recent coastal developments. The next section seeks to discuss these dunes together with those of the northeastern lakemargins. Discussion of the coastal dunes will allow a further consideration of the sediment budget on the present and past shores of Kaitorete Barrier. Investigation of the dunes and ridges on the northeastern lake margins will introduce the problem, so far ignored concerning the shoreline evidence in the Ellesmere area.

AEOLIAN LANDFORMS.

General

Dunes and related aeolian landforms are significant features on the Kaitorete Barrier and on the northeastern lakemargins. A study of the dunes on Kaitorete Barrier adds to the understanding of beach environments during progradation on the Barrier, while an investigation of the dunes and ridges on the northeastern lakemargins provides an answer to the question of former marine shorelines in one part of the Ellesmere area.

Dunes on Kaitorete Barrier.

Dunes on the Kaitorete Barrier have been divided into three categories on the bases of location and morphology. These three sets of dunes will first be described separately and then their implications for coastal development will be discussed.

COASTAL DUNES.

Coastal Dunes are the most noticeable dunes on Kaitorete Barrier. They parallel the beach for most of its length but decline in width and height eastward towards Poranui Pt where, for the easternmost 2 miles, dunes are subdued or absent. For the rest of the Barrier, dunes generally rise 15 to 25 ft above the Barrier surface and occupy a width of 200 yards. An approximate trace of their outline is present in Fig 7 (inside back cover). Coastal Dune sediments are moderately to moderately-well sorted unimodal sands with mean sizes between 0 and

10. The variation in form, height, and width, from west to east provides a better understanding of the beach environment.

For the western 5 miles of the Barrier wave attack on the seaward margins of the dunes was earlier noted (Fig 12). Parabolic dunes ('U' shaped dunes with two arms aligned parallel to the predominant wind and both arms pointing upwind) are present in this coastal sector. Their arms are sparsely vegetated and extend landwards from the backshore for distances up to 80 or 100 yards. The orientation of the parabolic dune axes was compared with a theoretical axis orientation derived from wind-resultants (using a modified Landsberg-Bagnold method of calculating wind vectors.) The technique and calculations are described in Appendix VIII.

Five years wind data from Taumutu was used in the analysis. Only the three onshore vectors were used, following Jennings (1957). The theoretical orientation of the parabolic dunes is 13° to 14° west of south, which compares well with the average axis trend of these dunes of 16° west of south. Of the 19 dunes 15 had axes between 12° and 18° west of south. This agreement between theoretical orientation calculated from present wind data and actual dune orientation suggests that the directions of strong winds from the southern vectors have been similar for the period involving the formation of the parabolic dunes. This could involve a period of between 500 and 2,000 years.

For 8 miles further east of the western coastal sector there is an eastward-change in character of the dunes. The width of the backbeach area increases, the wave-trimmed dune margins disappear, and a low foredune gradually gains in prominence. Blowout dunes are present in this sector, situated landwards of the foredune. Fig 26 illustrates the nonaligned nature of these blowouts, the bare centres, and the foredune forming the seawards margin. The Coastal Dunes decrease in height and width to the eastern 3 miles of the Barrier where they are present as low dunes less than 5 ft high. For the eastern 2 miles of the beach a thin sand veneer, less than 1 ft thick, is present on ridges landwards of the backshore.

WESTERN INNER DUNES.

The Western Inner Dunes are low undulating dunes deposited on the Barrier Ridges over the western 5 miles of the inner Barrier. Depths of more than 3 ft were measured; the depths decrease eastwards and these dunes are absent east of Bayley's new farmhouse. The brown colour of the dune-sand, indicative of considerable weathering, plus the truncated nature of the northern margins (related to an early lakeshore) provide evidence that these dunes are older than the Coastal Dunes. Also, sediment analyses show bimodal or polymodal particle-size distribution curves which are different to those of the Coastal Dunes. The third mode is related to scattered pebbles in the sand. These dunes are similar in sediment characteristics and form to the low dunes forming on present backshore areas in situations such as that demonstrated in Fig 10. It is suggested that the formation of these dunes is related

Figure 26. The shingle basement exposed in a blowout near Profile 2. The foredune forms the seawards margin. View southeast.

to situations adjacent to earlier shorelines. These dunes appear to represent an overall loss from earlier beach systems because they gradually disappear eastwards and are absent from the rest of the inner Barrier.

EASTERN INNER DUNES.

The Eastern Inner Dunes are a low set of dunes which are situated from 100 to 300 yards landwards of the Coastal Dunes, 3 to 8 miles from the Barrier's eastern end. A portion of this low dune area is seen in Fig 27, lying in the background between the two arrows. These dunes are about 300 yards from the Coastal Dunes which are in the foreground. The Eastern Inner Dunes, like the Western Inner Dunes, are inactive relict dunes, being vegetated and showing no signs of sediment movement.

The following 3 factors suggest their formation from the Coastal Dunes:

1. Their position inland of the Coastal Dune blowouts. The Eastern Inner Dunes illustrated in Fig 27 lie landwards of the blowout shown in Fig 26. Blowouts are frequent in this coastal sector.

2. The frequency of strong onshore winds from the south and southwest. They make it conceivable for sand to be moved inland to form these dunes.

3. Their very irregular positions and shapes, which preclude any formation related to earlier shorelines landwards of the present beach.

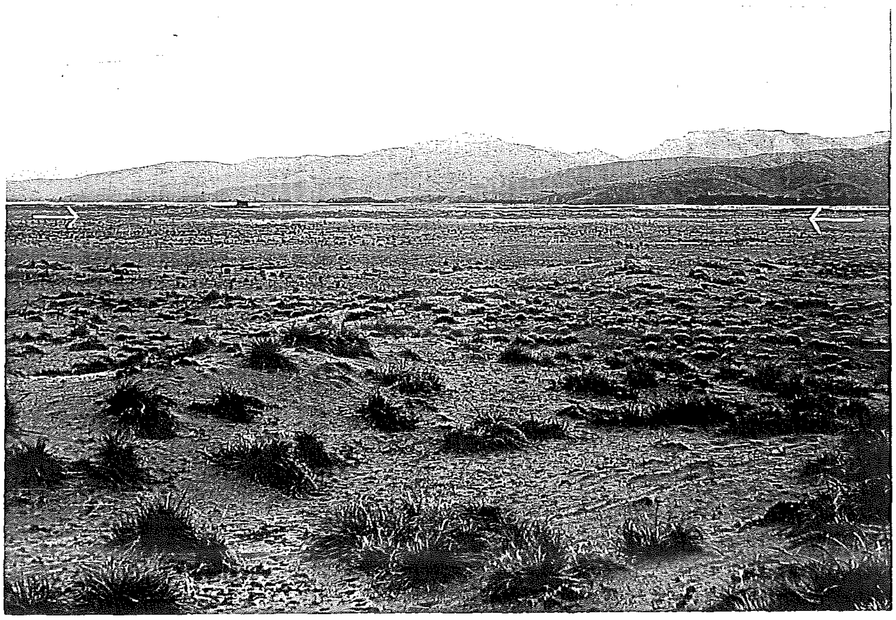


Figure 27. View north from Coastal Dunes towards Eastern Inner Dunes in the middle distance (arrows). This photograph is taken from the same position as that in Figure 26.

DISCUSSION.

Both the Coastal Dunes and the Western Inner Dunes show a progressive eastward decrease in extent, and raise the question of why this longshore trend occurs. An understanding of this longshore change lies in the knowledge of the conditions related to dune formation. Zenkovich (1967) writes that dune formation depends on the presence of both a favourable wind regime and sufficient sand reserves in the coastal zone. Exposure to strong onshore winds does not alter along the Barrier. Thus, the eastward decrease in the Western Inner Dunes and Coastal Dunes suggests a related decrease in sand reserves from the beach and nearshore zone. An eastward decrease in sand reserves in this zone must be related to progressive onshore and offshore losses along the Barrier. Offshore losses are unknown but losses through dune formation are considerable. Both sets of dunes thus confirm the importance of longshore changes in the sediments in the beach system. This tends to substantiate the conclusion, suggested from studying the height of the Barrier surface, that there is a longshore variation in the proportion of sand in the beach sediment.

The question of why the Coastal Dunes have a greater eastwards extent than the Western Inner Dunes may be answered by suggesting a change in the source of sand. An eastward movement of the sand source later in the Barrier's development would mean that, given similar longshore losses from the Beach, dunes formed later would extend further eastwards. It was suggested earlier that the fulcrum for the Barrier's development moved northeastward and that erosion extended onto the Barrier. This eastward extension of erosion indicates a movement of the source which would enable sand to move further eastwards along the Barrier when shorelines were near that of the present.

This hypothesis of events allows an explanation of the difference in eastward extent between dunes on the coast and the Western Inner Dunes. It explains why dunes are present towards the eastern end of the Barrier adjacent to recent beaches but are absent landwards. Dunes on the Kaitorete Barrier thus allow some insight to be gained into the sediment budget both in the present and past coastal situations. They also provide a means of comparison with dunes on the northeastern lakemargins when assessing whether the lakemarginal dunes have been formed in a coastal or lakemarginal situation.

Northeastern Lakemargins.

The major dunes and ridges in this part of the study area were described in a previous section. These ridges and dunes are the only prominent features in a flat, lowlying area separating the cliffed spur-ends from the Lake. Of these ridges and dunes, Davidsons Road Ridge is the only noticeable feature, rising more than 10 ft above the surrounding area. It has been suggested that these features may be related to former marine shores within the Ellesmere area. However, a comparison between the dunes on the present coast and the landforms in this area suggests that a lakemarginal hypothesis of formation is more acceptable.

Important differences in particle size parameters and morphology are present between dunes on the Kaitorete Barrier and the northeastern lakemargins. Figure 8 illustrates that the northeastern sediments have finer mean sizes than the Coastal Dunes, a difference which is further indicated in Table 4. Sediments between the Lake and spur-ends have mean sizes between 2 and 7 Ø although mean sizes from the dune samples are between 2 and 4 Ø. Those from the Coastal Dunes have mean sizes between 0 and 1 Ø while mean sizes of samples from the Western Inner Dunes are coarser still, lying between -1.5 Ø and 1 Ø (Fig. 8).

The most likely cause of the difference between the sediments in the northeastern area and those in the dunes on the Barrier, is a difference in sorting processes during transportation. Sediment sources are similar except that there is probably some contribution of silt and clay sizes in the inner area from the loess on the spurs of the Peninsula. The dunes and ridges of both areas suggest wind and wave formation, respectively. The most simple explanation is that the inner sediments have been deposited from suspension in the relatively calm lakewaters. This conclusion is supported in the northeastern area by a trend towards finer mean sizes eastwards from the main river sources. Table 4 shows that mean sizes of the lake and dune sediments in Gebbies and McQueens Valleys are finer than those of the sediments from further west. Modal sizes also indicated a similar trend.

Table 4. Particle Size Parameters of Sediments from the Northeastern Lakemargins and Selected Locations on the Present Coast.

Sample No.	Site	Mz size (Ø) Mean Size	Sorting (0_I)	Skewness
Gebbies - McQueens Valley				
10	Dune	3.68	0.58	0.41
12	dune	3.97	0.74	0.55
15	dune	4.21	1.61	0.51
18	dune	3.56	0.33	0.00
19	lake	4.80	1.91	0.71
20	lake	6.69	3.85	0.77
Lincoln - Greenpark Huts				
114	dune/ridge	2.76	0.54	-0.09
115	dune/ridge	2.31	0.36	0.09
117	dune/ridge	2.53	0.46	0.06
116	lake	2.58	0.55	0.14
Dunes on Barrier Seacoast				
107	dune	0.23	0.82	0.20
85		0.73	0.67	0.05
86		0.77	0.63	0.17
69		0.30	0.79	0.19

The morphology of dunes and ridges on the northeastern lakemarginal area shows significant differences to that of the dunes of the coast. In this inner area dunes are mostly low undulating features, less than 5 ft high. Davidsons Road Ridge is higher but its morhpology incorporates features of both dunes and ridges. Dunes on the coast on the other hand, are usually between 10 and 20 ft high. These differences in sediment characteristics and morphology between definite coastal dunes and dunes on the inner margins suggest that a lacustrine formation for the inner features may provide a more likely explanation for the landforms and sediments there.

It has already been noted that a trend in mean grain size between the sediments in Gebbies and McQueens Valleys and those further west suggests deposition from suspension within the Lake. Evidence supporting this hypothesis is also present in the relationship of the dunes and ridges with the present Lake, in the stratigraphic relations of the dunes and lake sediment in Gebbies Valley, and in the similarity between lake and dune sediments in this lakemarginal area.

The Greenpark Ridges are shown in Fig 6 to be situated parallel to the margins of the present lake, and other ridges can be easily related to earlier and, or, higher lakelevels. In Gebbies Valley a section in a drain shows that the dunes overlie lake sediments. Table 4 illustrates the similarity in sediment parameters between lake sediment and ridge or dune sediment in the Lincoln-to-Greenpark area. There is greater variation among the lake and dune sediment samples in the Gebbies Valley area, related to the varying significance of a 'fine tail.'

The 'fine tail' is more significant in the lake sediment and gives the finer mean sizes, poorer sorting, and strong positive skewnesses of samples 19 and 20 (Table 4). This tail may represent an input from erosion of the loess on the surrounding spurs.

Thus, an origin relating the dunes and ridges in the northeastern area to a formation in their present lakemarginal situation appears most likely. This mode of formation provides evidence of lakelevels higher than the present level on the northeastern lakemargins and suggests the lakeshore at higher levels to have been at the base of the spurs of Banks Peninsula. This raises important questions about the extent of the former lake and the modes of formation of other lakemarginal features. Answers to both of these questions will be given in the following section, which discusses the critical areas for this study: the inner portion of the Kaitorete Barrier and the western lakemargins.

LACUSTRINE DEPOSITIONAL LANDFORMS.

General

A sequence of shoreline changes has been suggested for this coast, occurring towards the end of the postglacial rise in sealevel, when sealevels were lower than the present. These shoreline changes involved spit development and the eventual formation of the Barrier, on a sealevel between -20 and -10 ft, which excluded the sea from the Ellesmere area. This tentative series of events has been developed from evidence on Kaitorete Barrier, in the Barrier Ridge and Hooked Ridge areas. This section studies two areas that are critical to these initial conclusions of coastal development: the inner margins of Kaitorete Barrier and Lake Ellesmere's western margins. Landforms in these areas have been related to marine shorelines, which would indicate the sea to have been within the Ellesmere area at a level equal to the present. The main purpose of this section will be to explain the various groups of landforms; it will also serve to assess the importance of a former lake for the lakemarginal area.

Landforms on the inner Barrier will be described and discussed first; part of this discussion will involve an evaluation of the evidence for higher lakelevels. This will be followed by an investigation of the ridges on the western lakemargins, firstly the Taumutu Ridges and secondly, the Lakeside Ridges.

Ridges on Inner Kaitorete Barrier.

GENERAL.

The ridges on the inner Barrier are divided into 4 groups on the bases of morphology and location. These groups are, from east to west, the Birdlings Valley Ridges, Railway Cutting Ridges, Speight Ridge, and Bayleys Ridges. The grouping is for ease of description and it is important to remember that they form a continuous ridge series. These shingle ridges extend westwards from Birdlings Valley for the length of the Barrier to the barrier beach separating Lake Ellesmere from the sea. The area of ridges is less than half a mile wide in most parts; groups of ridges are present in the eastern portion of the inner Barrier and in Bayleys Ridges, but for the rest of the inner Barrier a single ridge with widely varying characteristics, Speight Ridge, is present. The elongated nature of this ridge series gives a clue to its formation.

These shingle ridges have similar sediment properties to those of the Barrier Ridges which form their seaward margins. Figure 8 illustrates the similarity in grainsize parameters between sediments from these two areas. Form and roundness properties appeared similar in both areas too. However, the inner ridges appear quite distinct in bedding, orientation, and surface form from the Barrier Ridges.

Railway Cutting Ridges.

The Railway Cutting Ridges are a complex group of ridges at the eastern end of this ridge series. Traces of the ridge axes are shown in Fig 28. Their axial trends show three periods of ridge development, the last

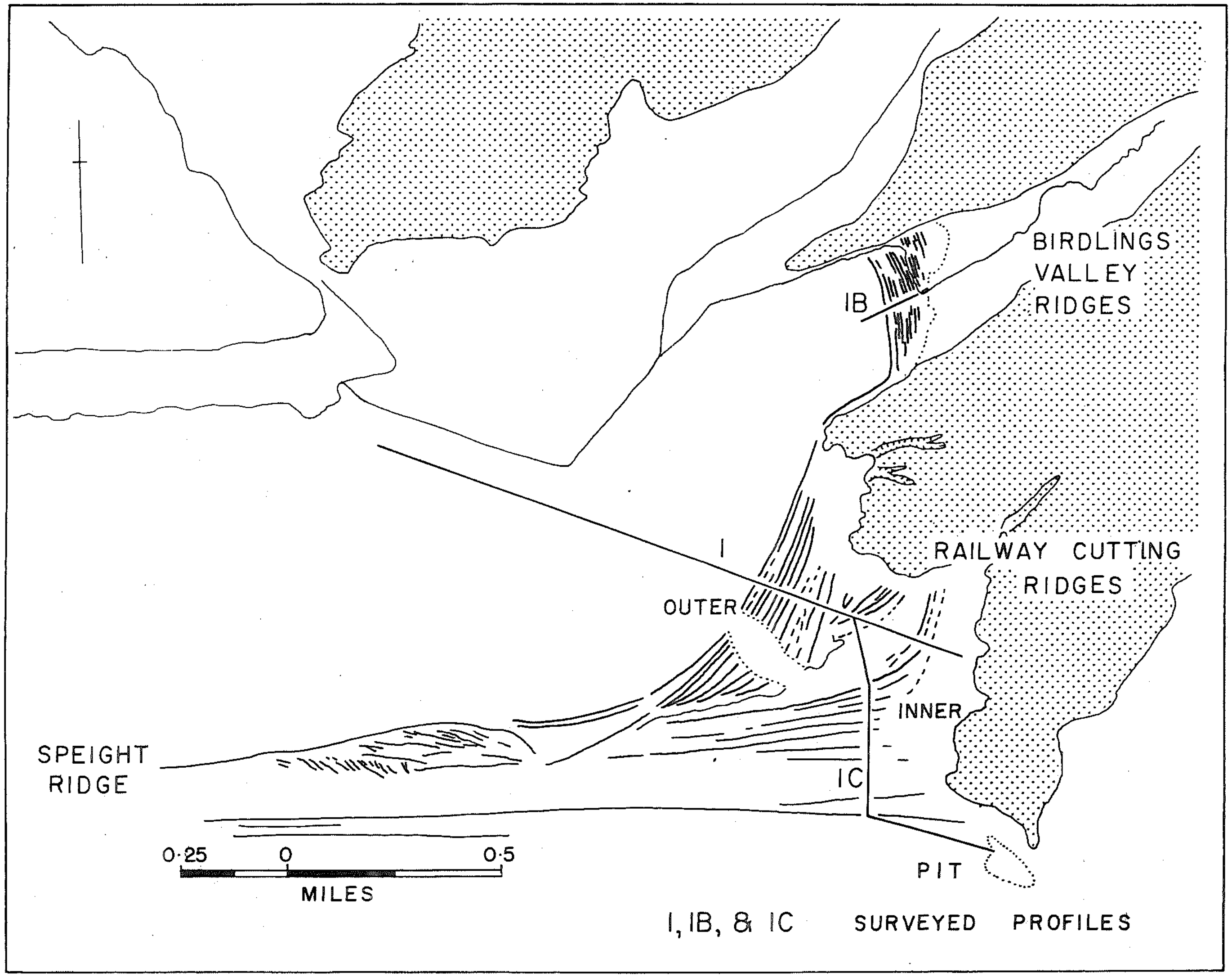


Figure 28. Ridge-axes and location of profiles on eastern inner Barrier.

filling the re-entrant between the Barrier Ridges and spur-ends, and enabling the drifting of sediment into Birdlings Valley. This succession of ridges, together with that in Birdlings Valley (indicated by arrow), is shown in Fig 29. This photograph clearly shows the situation of the Railway Cutting Ridges between the spur-ends and the Barrier Ridges (dashed line).

Profiles were surveyed across these ridges and are illustrated in Fig 30; the locations of the profiles are shown on Fig 28. The inner ridge groups have ridge levels between +14 and +17 ft, while those of the outer group range between +16 and +25 ft. The outer ridges are separated from the innermost ridges by lagoonal sediments. These ridges may overlie fine sediment or extend to the Hooked Ridge surface beneath. Speight (1930) described a pit close to the railway line where these ridges overlie sediments dipping towards the sea.

Birdlings Valley Ridges.

This series of shingle ridges is orientated across Birdlings Valley and tied to the Railway Cutting Ridges by a small shingle ridge along the southern valley wall (Fig 28). The characteristics of these ridges are shown in Fig 31; the ridges are closely spaced with a distinct ridge and swale form, and are orientated directly across-valley. A profile crossing the Birdlings Valley Ridges is shown in Fig 30. This group has ridge levels between +17 and +19 ft except for the most lakeward ridge which is +23 ft. The number and horizontal extent of these ridges decreases from the northern side to the southern side of the sequence.

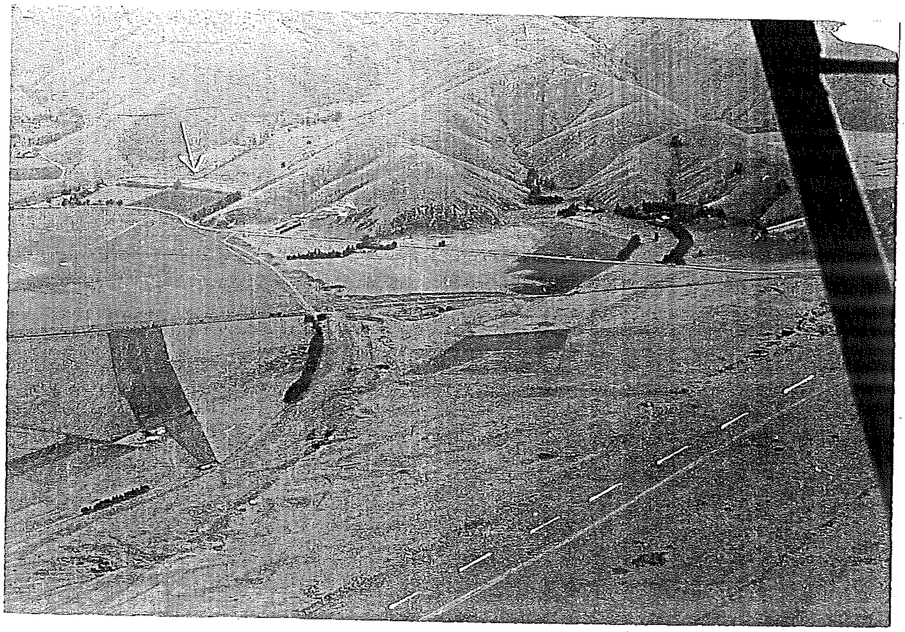


Figure 29. Railway Cutting Ridges sequence in re-entrant between Barrier Ridges on right foreground (dashed) and spur-ends in background. Birdlings Valley Ridges in background (arrow).

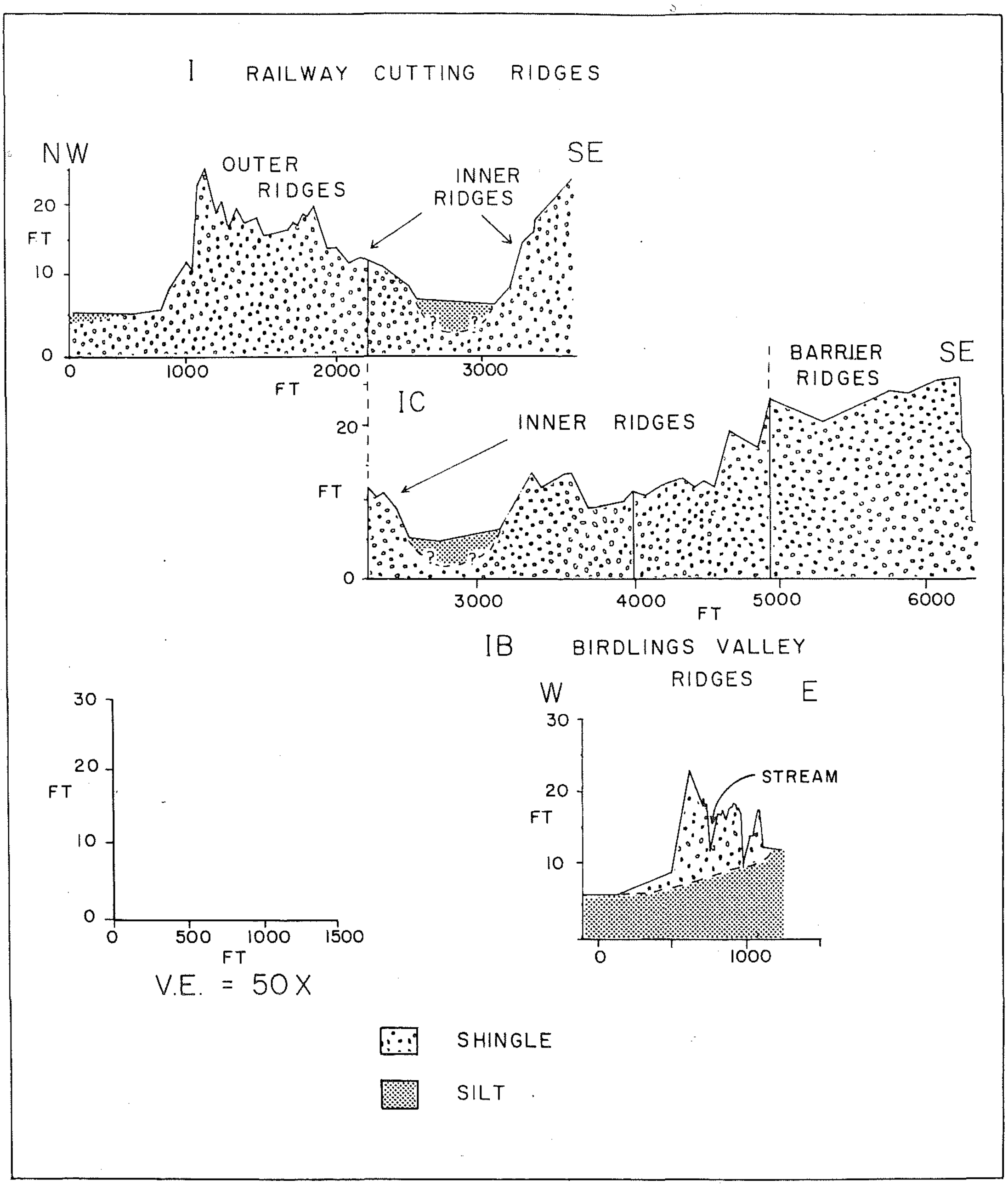


Figure 30. Profiles I, IB, and IC. Profiles I and IC cross the Railway Cutting Ridges and Profile IB crosses the Birdlings Valley Ridges. Locations of Profiles are on Figure 28.

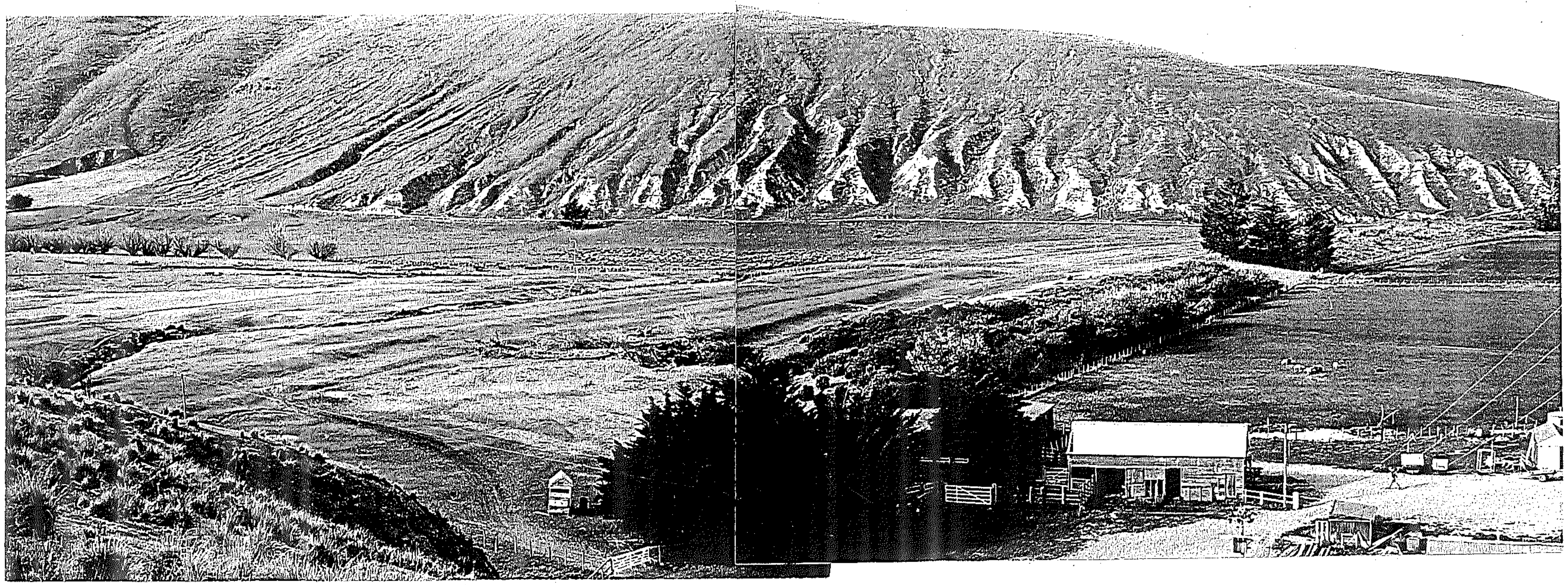


Figure 31. View southeast across the Birdlings Valley Ridges. Formation of the ridges was from left to right, and lake is to the left.

The ridge along the southern wall relates these ridges to the other inner ridges on the Barrier, and further evidence of this relationship is provided by the stratigraphic sequence in Birdlings Valley. Exposures in the stream which cuts the ridges show lake sediment beneath the Birdlings Valley Ridges. This suggests ridge formation on a lakeshore.

Speight Ridge.

Speight Ridge is a complex feature extending along most of the inner Barrier. It is interrupted 10 miles from the eastern end, by a complicated series of shingle ridges and depressions (Bayleys Ridges). The changeable nature of Speight Ridge can be seen on Profiles III and IV in Fig 24. The ridge may present a low angled northern slope and a steep southern slope, as is shown on Profile III. In other places it exhibits a steep northern slope, with little difference between the ridge-top and the associated Barrier Ridges; such a condition is present on Profile IV. The height of the Ridge varies along the Barrier between +18 and +24 ft.

Bayleys Ridges.

Bayleys Ridges are a set of ridges and depressions, 2 to 3 miles in east-west extent and up to 1,000 ft wide. Profiles V and VI show two sections of this ridge area; (Fig 24) they indicate several major ridges and depressions. There is evidence in these ridges of several 'major' shorelines. These shorelines are numbered on Fig 32, which indicates the ridge-axes in this area. The earliest shoreline is adjacent to the Western Inner Dunes and appears on the left foreground

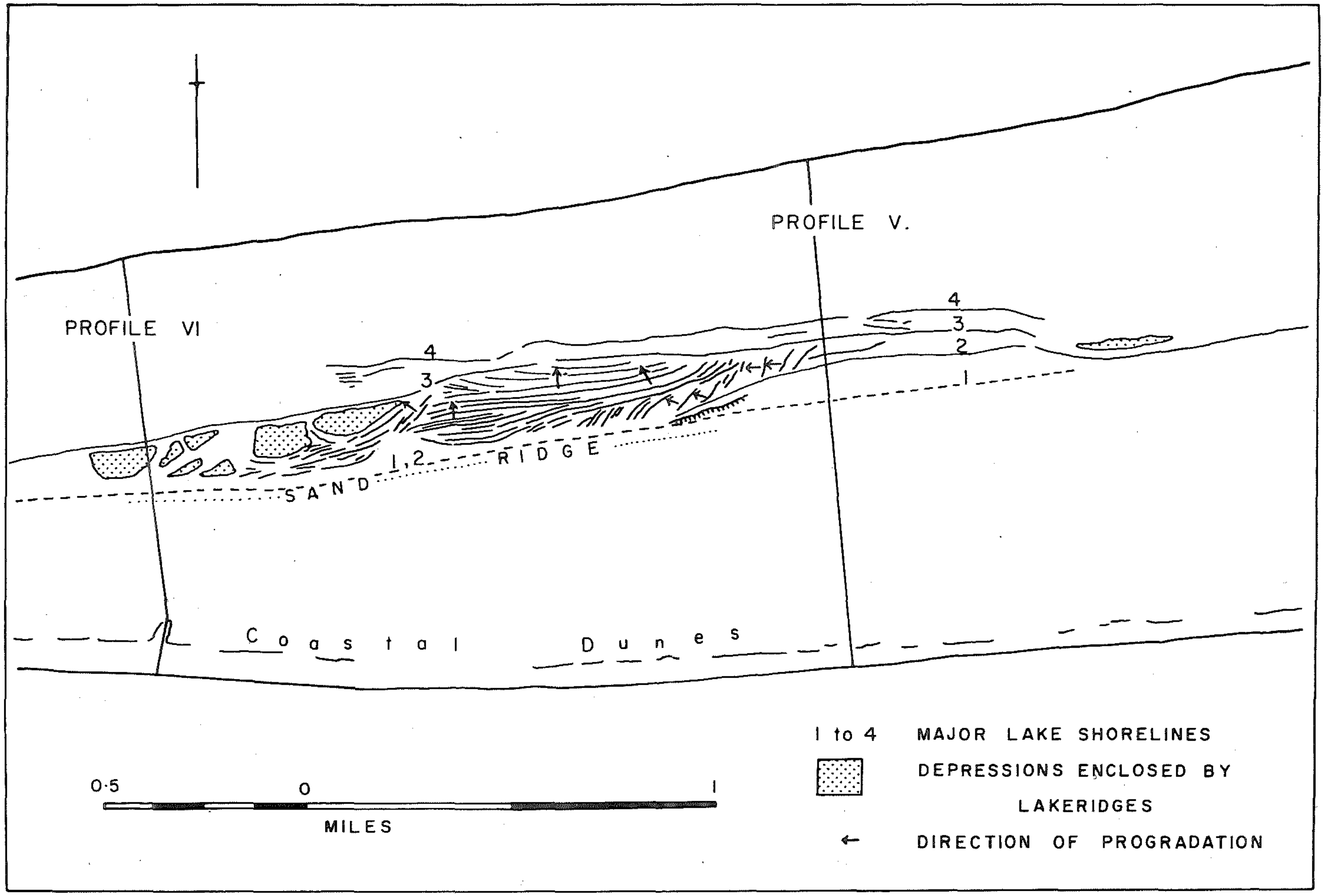


Figure 32. Ridge-axes and major lakeshore positions in Bayleys Ridges.

of Fig 33 (dashed line). This shore position suggests a similar or earlier age for the Western Inner Dunes. Later deposition formed the rest of Bayleys Ridges on Profile V. Progradation followed and led to the formation of a series of between 23 and 28 curvilinear ridges. The pattern of these ridge-axes suggests progradation westwards and northwards, related to a sediment supply from the east. A later shore truncated the outer ridges of this series and formed an irregular ridge that has continued westwards enclosing, with overwash features, depressions behind. Some of these depressions are shown in the centre foreground of Fig 33. The fourth shore position is a prominent lower shingle ridge between +11 and +14 ft.

EVIDENCE FOR FORMATION.

Evidence for wave formation is present in several exposures where well bedded deposits dip lakewards at angles up to 5°. The truncation of the Barrier Ridges by Speight Ridge shows that the inner ridges were formed following the presence of the main marine ridges. This later formation of ridges located inside the Barrier Ridges combines with two other factors to suggest formation by waves from the position occupied by Lake Ellesmere. These other factors are:

1. Bedding in Speight Ridge and the Railway Cutting Ridges dips lakewards at angles up to 5°. Figure 34 shows a clear bedding pattern dipping westward towards the Lake.

2. Overwash features are present on the backslopes (seaward side) of various ridge sets. Figure 35 indicates such landforms on

Figure 33. View west in west end of Bayleys Ridges. Steep lakeward face of Western Inner Dunes is in left background (dashed), depressions in middle background, and lake-ridges in foreground and right background (present as overwash features).

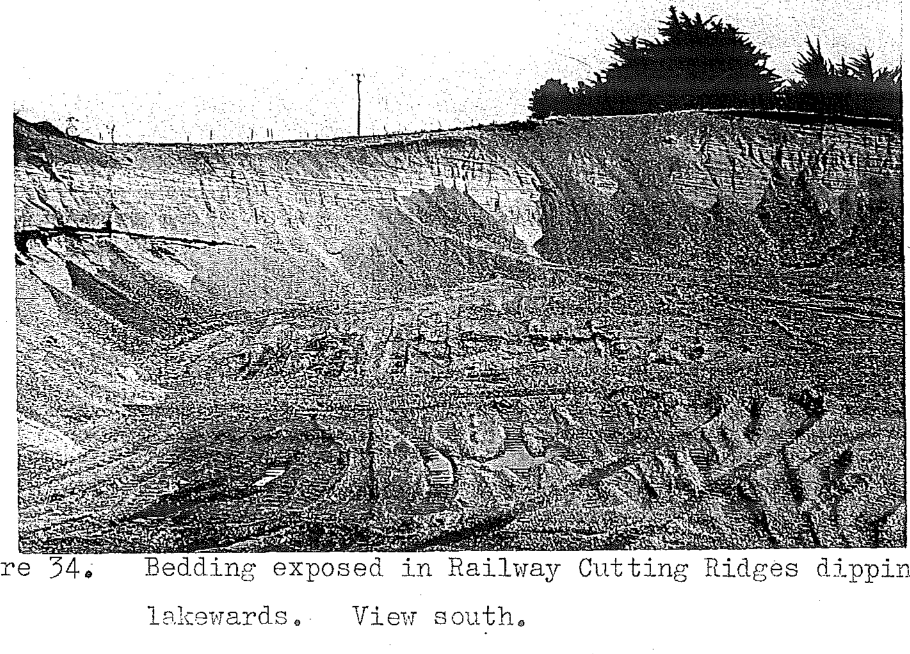


Figure 34. Bedding exposed in Railway Cutting Ridges dipping lakewards. View south.

Figure 35. View north towards Lake Ellesmere (background) from Barrier Ridges showing Speight Ridge present as a series of overwash features (mid foreground). Sheep indicate height of the ridge's backslope.

Speight Ridge, and they are also evident on Fig 33 in the right foreground.

Speight (1930) suggested that the waves forming the inner ridges were seawaves at a period of higher sealevel, when the Barrier was awash and the wave platforms were being cut. This hypothesis is rejected because a rise of sealevel sufficient to allow sea to enter the Lake would have destroyed landforms over much of the Barrier's surface. A rise of +16 to +20 ft would be necessary to enter the present lake at its outlet. Such a rise would have destroyed the Western Inner Dunes and the ridges over much of the Barrier. Furthermore, there is no evidence of such a rise in the Christchurch area.

The simplest explanation for these inner ridges on the Barrier is waves on a lake of greater magnitude than the present. Two conditions need to be satisfied to make this explanation acceptable. Firstly, the Lake must have been able to reach levels necessary for waves on it to form the ridges at their present levels (between +15 and +24 ft). Secondly, winds must have been able to form waves on this lake of sufficient size to move shingle. These two factors will now be discussed.

FORMER HIGH LAKELEVELS.

Four lines of evidence give an indication of former water-levels on Lake Ellesmere. These are:

1. Historical evidence.
2. The height of the Lake's outlet.
3. The influence of wind.
4. Morphological evidence.

Early reports record the Lake's ability to reach the base of the inner ridges on the Barrier, and to reach levels up to +10 ft, in European times. Early writers report the swampy nature of the land at the base of the spurs of the Peninsula such that several 'passes' were necessary over the spurs. An old map (Black Map 115) shows an 1862 flood level that follows the base of the ridges from the Railway Cutting Ridges, along Speight Ridge, and around the fourth shore position of Bayleys Ridges, to the western end of the Barrier. Mr. C. Miller (1970, pers. comm.) reports that lakelevels in the early 20th century reached his house in McQueens Valley, which is at a level of +10 ft or more. Harris (1947, in Wraight, 1958) wrote that the lake-level was possibly +8 to +9 ft when the Lake was opened by the Maoris in the last century. Since the early 20th century the lakelevel has been further limited to between +4 and +6 ft, and since 1947 to less than + 3.7 ft.

In pre-Maori times the maximum possible lakelevel would be governed by the height necessary to break over the Barrier at the lowest point. This lowest point at present, is the barrier beach at the western end which is at a height of +16 ft. With a wave regime similar to that of the present and a barrier across the outlet, the Lake has conceivably been at levels up to +16 ft. The continuous presence of a barrier beach is highly likely because the barrier beach is a response to the wave regime. If sealevel has been higher than the present then it is possible that the barrier beach, and consequently lakelevels, have been higher too.

Moderate to strong winds can have considerable influence on lakelevels by lowering the water-level at the upwind end of the lake and increasing it at the downwind end. Records taken for Lake Ellesmere between 1953 and 1962, summarised in Table 5, show differences in levels of up to 5 ft between two stations 14 miles apart. The absolute level increases at the downwind end will be less than these maximum differences, but will still be significant. This effect could raise the water level by several feet at the eastern end of the Lake for south to southeast winds, thus increasing the height of wave-action. The opposite action would happen with northeast conditions: the level increase would occur at the western end.

Higher lakelevels should have left shoreline evidence around the Lake's margins. Lakeshore dunes and ridges have already been described on the northeastern lakemargins; of these features, those in Gebbies and McQueens Valleys suggest lakelevels up to +10 ft. Other morphologic evidence of higher lakelevels will be discussed in the later sections. From this review of evidence for high lakelevels it can be concluded that former levels have been considerably higher than those of the present. Historical evidence indicates former levels up to +10 ft. Deductions from the water-level necessary to break over the Barrier, and from the effect of wind-induced water-level variations, suggest that levels higher than +15 ft are possible. Thus, lakelevels, with sufficient height to reach the ridges on the inner Barrier have been demonstrated as operating in an earlier Lake Ellesmere. Before the hypothesis of ridge formation by waves from the Lake can be accepted, it is necessary to assess the ability of waves of sufficient size to form on a higher lake.

Table 5. Wind Induced Variations in water-level on Lake Ellesmere.

Year	Date	Maximum difference in levels (ft)+	Max. 1 hr. wind run (kts)	Direction Degrees++
1953	10 April	4.2	40	220
	11 April	5.05	53	200
1954	10 July	3.95	48	220
1955	29 April	3.4	40	190
1957	28 September	3.15	30	050
1960	30 May	3.15	26	040

+ Recorded about the time that water-level at Taumutu changed from rising to falling or vice versa. Windspeed and direction was measured at Taumutu. Water-levels were recorded at Taumutu and Kaituna.

++ Direction is measured from True North.

Source: Hydrology Annual, Number 10, 1962: 191-192.

POSSIBLE WAVES ON A FORMER LAKE ELLESMERE.

The possible waves able to be formed on a former Lake Ellesmere were derived theoretically because the present dimensions of the Lake prevent wave formation. The theoretical calculation of wave heights, periods, and lengths for lakes is different to that for oceans because the additional factors, depth of water and plan-shape of the lake, must be taken into account. Water-depth limits wave dimensions for waves with lengths greater than two times the water-depth. Plan-shape must be considered because wind acts on an area in forming waves and narrow water bodies may restrict wave-formation.

In a deep-water lake (depths greater than half the wavelength) wind blows across an area of water and forms waves which increase in height, period, and length until maximum dimensions are reached for a wind of that velocity. The time taken to develop to the maximum dimensions, the Minimum Duration, varies with the fetch and the wind-velocity. For shallow-water lakes there is an increasing frictional loss of wave energy with decreasing depth. Thus, for winds of a given velocity the maximum wave dimensions are less than those in deep water. The limits that water-depths impose on wave height are demonstrated in Fig 36.

The second factor that must be considered is the plan-shape of a lake. The straight-line fetch does not give an accurate indication of the 'true' fetch that a wind acts over in an inland water-body. The Effective Fetch (Beach Erosion Bd, Tech. Memo. No 132) takes into account straight-line water distances within 45° of the wind direction. Fetches on Lake Ellesmere were calculated this way and the method is shown in Appendix IXA.

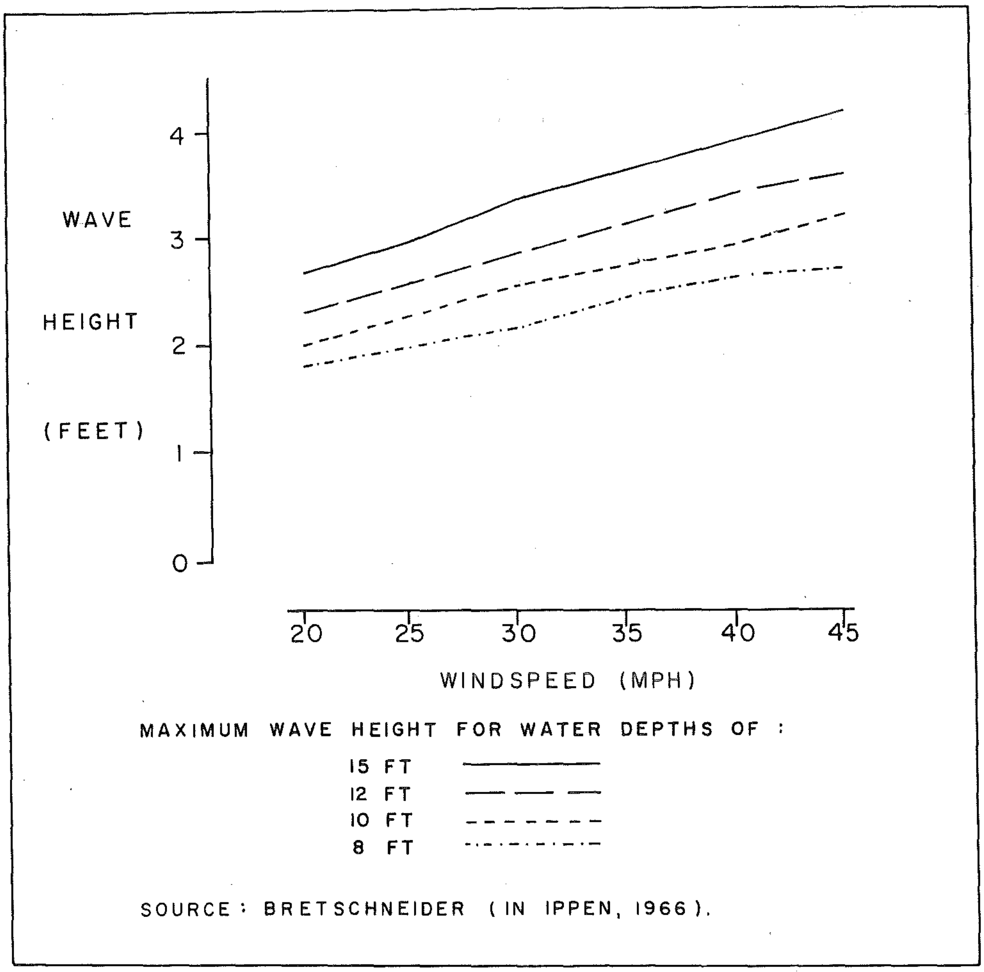


Figure 36. Maximum wave heights for given windspeeds in specified shallow-water depths, fetch is unlimited.

Analysis.

For the calculation of theoretical wave heights and periods on Lake Ellesmere, hourly records of wind velocity and duration for Taumutu during 1951 were analysed. Details of the anemometer and the recording site are described in Appendix IX B. The relationship between wind speeds recorded at Taumutu and 'average windspeeds' on the Lake, is not important because the windspeeds used are generalised to the lowest values. Variations in water-depths and possible effects of vegetation growing in the water are also ignored.

Effective Fetches were calculated for five positions around the Lake. At each location the fetches were calculated, with 30° intervals, for all directions of possible wave-approach. The locations of these five positions and their fetches are illustrated in Fig 37. Because of the elongated plan-shape of the Lake the longest Effective Fetches were between 7 and 9.3 miles; these fetches were considerably less than the longest straight-line fetches of 14 miles.

For the theoretical calculation of wave parameters water-depth is assumed to be 10 ft at the downwind end of the fetch because the analysis applied to the lake at levels of +15 ft. Sedimentation has been proceeding at an unknown rate and has been progressively lowering the depth. Therefore, initial depths may have been much greater and, when combined with wind-induced waterlevel variations, downwind depths may have been greater than 20 ft. The increase in wave height that would occur with depth increases up to 15 ft (wind remaining constant), is shown in Fig 36.

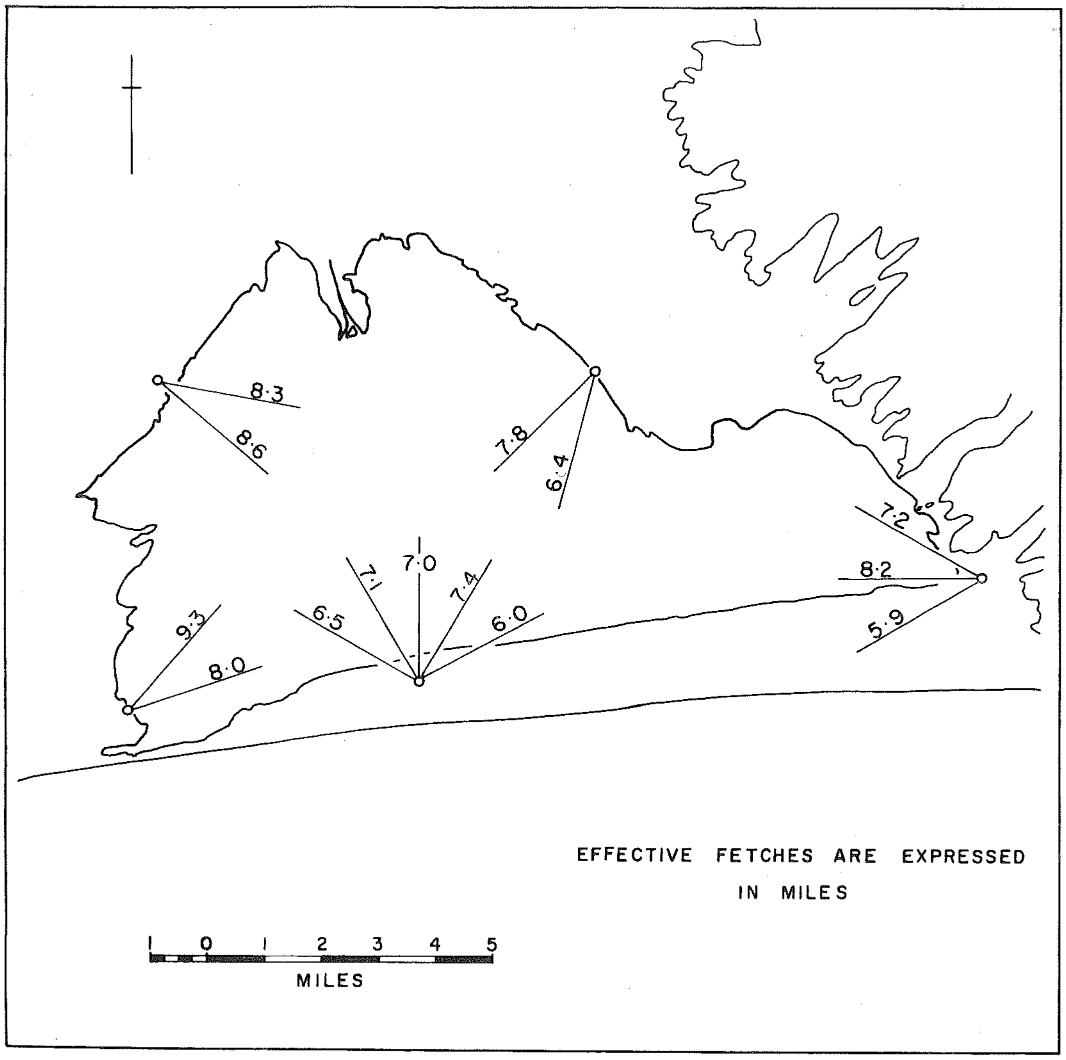


Figure 37. Effective Fetches in miles, calculated at 30° intervals for 5 positions on the lakemargins.

Selected groups of hourly mean velocity values were used to derive theoretical wave heights and periods using diagrams of their generalised deep-water relationships with windspeed, fetch, and duration values (Beach Erosion Bd, Tech. Memo. No 132, plates 34 and 35). These deep-water wave heights and periods were then limited to shallow-water maximum dimensions for a 10 ft average depth using the values indicated on Table 6. This table assumes unlimited fetch and fully developed waves. Although some increase in minimum durations can be expected, the difference in wave dimensions between the deep-water and shallow-water (10 ft depth) conditions suggests that waves would be developed to the shallow-water dimensions over the fetches used.

Wave dimensions that would theoretically have been formed at the Railway Cutting Ridges are shown on Table 7. Winds recorded during 1951 at Taumutu from the southwest and south would form waves with heights up to 3.2 ft and periods up to 4.5 seconds. Calculations for the western end of Speight Ridge show theoretical wave heights between 2 and 2.3 ft from several directions.

Orbital motion in a 2 ft high wave with a 3.9 second period can move pebbles (S.G. = 2.65) with median diameters of 25mm (medium pebbles) in 3 ft of water, and those of 4.5mm (very small pebbles) in 6 ft of water. (Hydraulics Res. Station Notes, 1969). These sizes would obviously also be moved in the swash zone where more turbulent conditions prevail. A 2.6 ft wave with a 4.25 second period can lift large pebbles (D_{50} = 8mm) in water-depths of 6 ft. Thus, waves which are theoretically possible on this lake can move the sizes that are present in the inner ridges.

Table 6. Theoretical Wave Heights and Periods over an unlimited Fetch for 10 ft water depth (Bretschneider in Ippen, 1966)

Wind Speed (mph)	Wave Height (ft)	Wave period (secs)
20	2.0	3.9
25	2.3	4.1
30	2.6	4.25
35	2.8	4.4
40	3.0	4.5
45	3.3	4.6

Source: Bretschneider, C.L. in Ippen, A.T.; 1966: Estuary and Coastline Hydrodynamics. 744 pps.

Table 7. Theoretical Wave Heights calculated for the Railway Cutting Ridges and Speight Ridge from 1951 wind velocity data limited by a 10 ft water-depth.

Eff. Fetch	Velocity (mph)	Duration (hours)	Wave Ht (feet)	Duration of waves at max. dimensions (hrs)
Railway Cutting Ridges				
240° (5.9 miles)	20	1	less than 1.9	-
	44+	3	3.2	1.55 hrs
270° (7.2 miles)	24 - 40	5	2.3-2.6	3.20 hrs
Speight Ridge				
300° (6.5 miles)	24 - 40	5	2.3	3.30
330° (7.1 miles)	23 - 30	3	2.2	1.20
	30 - 38	3	2.6	1.35+
	22 - 29	3	2.3	3
360° (7.0 miles)	20 - 26	6	2.0	5.0
	22 - 28	5	2.1 - 2.3	3.20
030° (7.4 miles)	19 - 22	4	2.0	2.10
	25+	5	2.3	3.20+
	20+	8	2.0	8
060° (5.9 miles)	no significant records			

Incomplete refraction of these wind-formed and directed waves would have led to littoral drift. Significant waves approaching the eastern inner Barrier would have approached from the west, and would thus have caused an eastwards drift. Western portions of the inner ridges are open to significant waves from more varied directions which would have caused varying drifts. This variability in wave conditions could have led to the complicated shoreline developments present in Bayleys Ridges.

The small frequency of high windspeeds, together with the probability of low lakelevels for part of the time suggests that the process of ridge building and modification would take a long time. Evidence which was given earlier suggests that a time period of 6,000 years is available for this action. Vladimirov (1953, in Zenkovich, 1967, p321) demonstrated the action, when proceeding, to be rapid. He noted 38 metres per hour longshore-movement of shingle sizes (diameters greater than 10 mm) with waves 80cm high approaching the shore obliquely. This indicates that the time period envisaged is sufficient for the formation of these features.

Summary

The ability of the Lake to reach levels sufficient to reach the ridges, and of waves formed on the Lake to move pebbles, indicates that shingle ridges on the inner Barrier could have been formed by lakewaves. This conclusion, when combined with geomorphic and stratigraphic evidence from the inner ridges, confirms the hypothesis of lacustrine formation for these ridges. This conclusion makes a consideration of the possible lacustrine influence on features on the western lakemargins necessary.

Shingle Ridges on Western Lakeshore.

GENERAL.

The shoreline features on the western edge of the Lake can be divided into two groups on the bases of sediments forming the ridges and their surface-forms. This ridge series appears continuous in surface-form, but the relationship between the two groups is obscure because of the absence of sections. Speight (1930), Suggate (1968), and Burrows (1969) wrote that these ridges are evidence of former marine shorelines. The rest of this section investigates the evidence present in the sediments and landforms, and assesses the marine and lacustrine hypotheses of formation. The Taumutu Ridges will be discussed first and the Lakeside Ridges, second.

TAUMUTU RIDGES.

These ridges extend parallel to the southwestern lakemargins for two miles in a north-south direction from Taumutu. The ridge area narrows northwards from 2,000 ft at Taumutu to 500 ft before linking with the area of Lakeside Ridges. At Taumutu the complex ridge development is seen in the trace of ridge-axes shown in Fig 7 (inside back cover). Single ridges lose distinctness moving northwards, and for the northern 1 mile there is a single broad shingle ridge. At a drain exposure near the northern limit of this area 3 to 4 ft of shingle overlie fine sand and peat at a level of approximately +10 to +15 ft. The pebbles are similar in form and roundness to those found southwards to Taumutu; northwards, sediment of a different form and roundness marks the southern limit of the Lakeside Ridges.

A profile crossing the ridges at Taumutu is illustrated in Fig 38. It shows 15 ridges over a horizontal distance of 2,000 ft. Most of these ridges are between +11 and +17 ft but two ridges, capped by a layer of sand, reach over 20 ft. The lakeward margins of this ridge group show a possible ridge between +5 and +10 ft. The height and extent of these ridges have been suggested by others as evidence of a marine formation for these ridges. However, a lacustrine origin provides a better explanation for factors which have arisen firstly, from studying the sediments in the ridges and secondly, from the presence of a freshwater mollusc in fine sand beneath the ridges.

Sediments exposed at the surface of the Taumutu Ridges are pebble to granule sizes, but the vertical extent of such sizes is uncertain. A section through the ridge immediately lakewards of Lower Lake Road, 0.3 miles south of the profile, is shown in Fig 39. This section indicates coarse sand to small pebble sizes in layers for the upper 3.5 ft overlying 4 ft of green fine sand. The upper 3.5 ft is the sediment forming the ridge. The fine sand is similar in mean grain size and sorting to the samples from between Lincoln and Greenpark Huts, which possibly indicates similar conditions of deposition. These sediments show no resemblance to the marine sediments exposed in the section through the Barrier Ridges at Devils Knob. It is very unlikely that processes on this high energy coast would form a deposit of this nature. These sediments exposed in the Taumutu Ridges indicate deposition on a lakeshore.

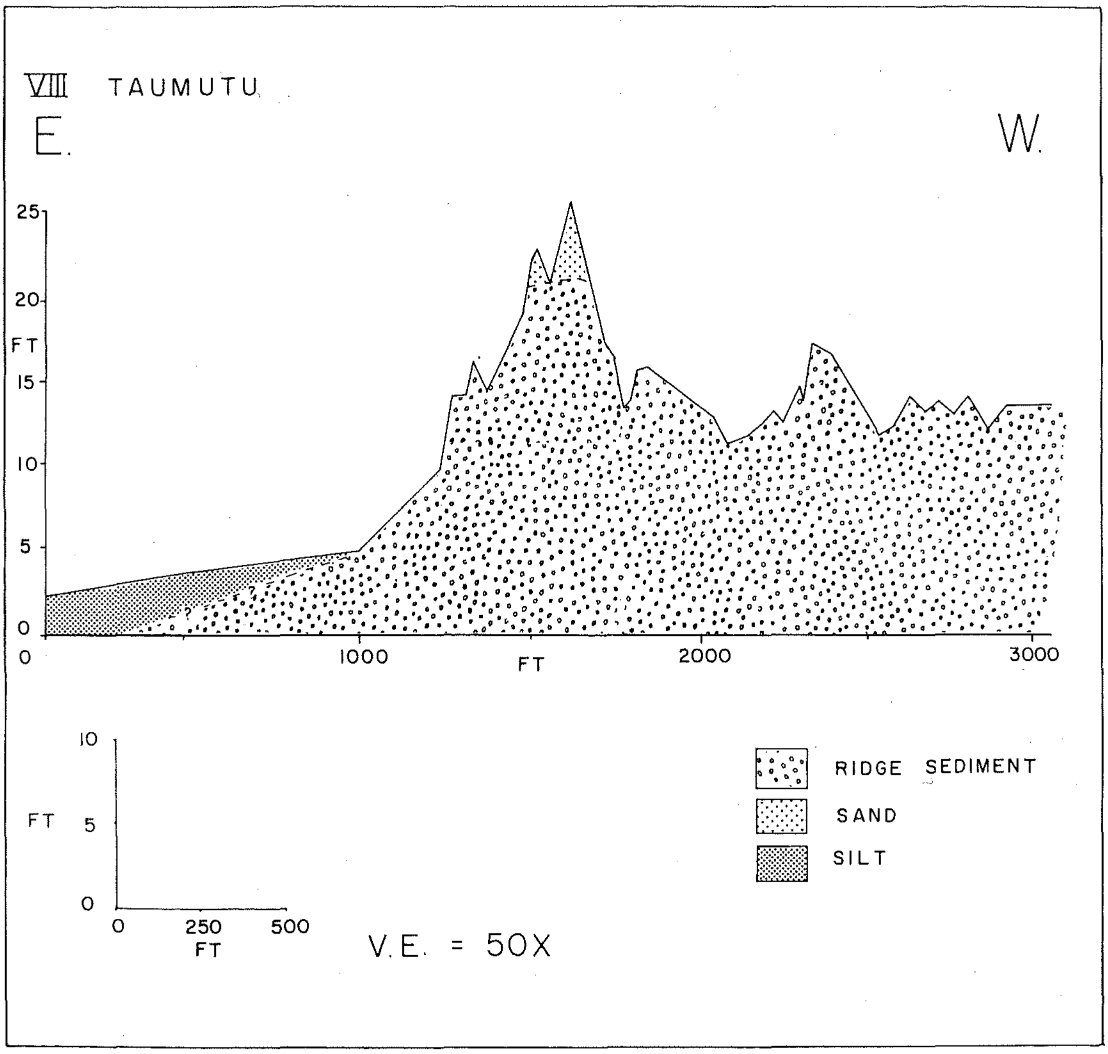


Figure 38. Profile VII surveyed across Taumutu Ridges half a mile north of Taumutu, running from the Lake in the east towards fluvial sediments in the west.

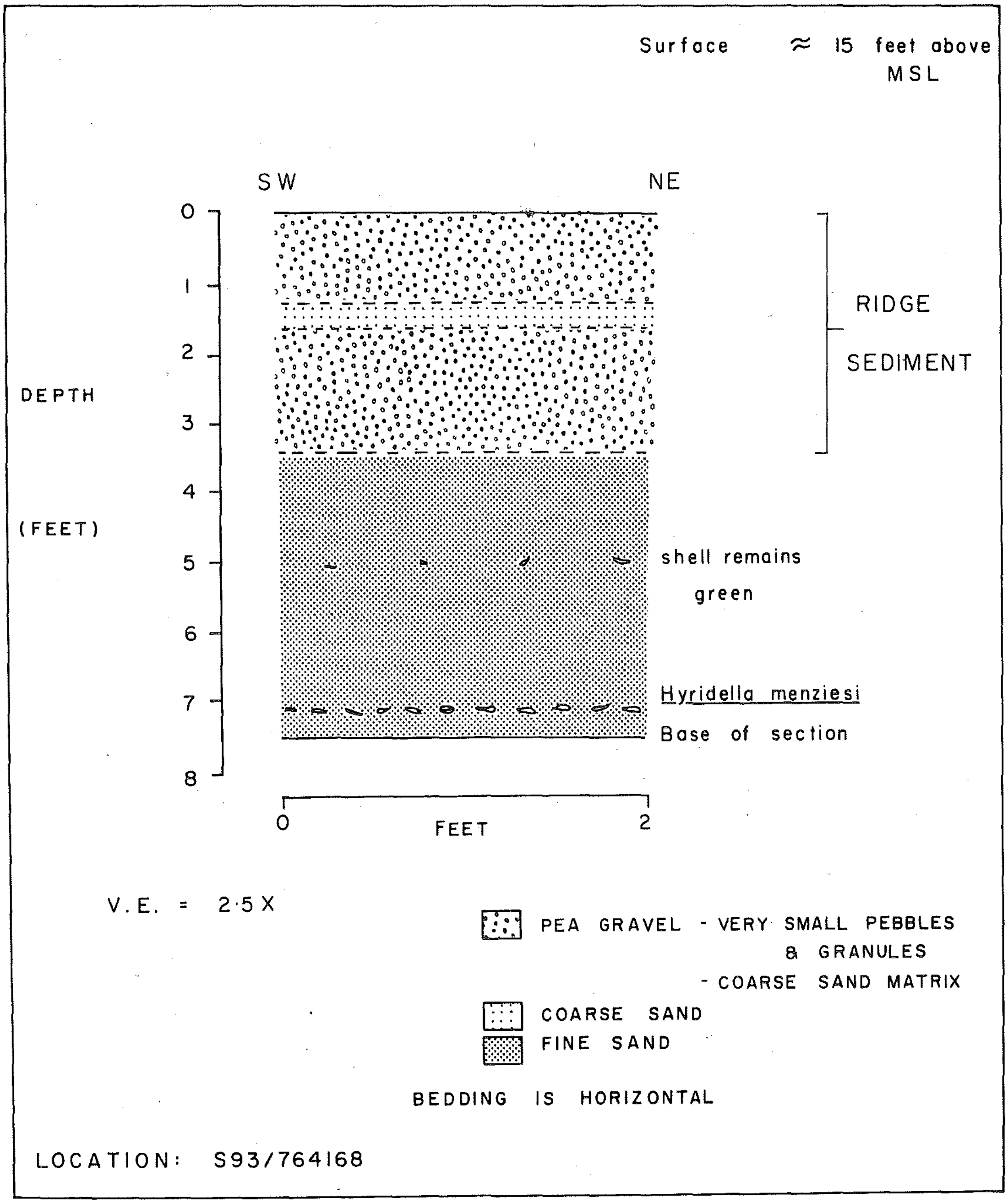


Figure 39. Section through ridge at Taumutu indicating ridge sediments overlying fine sediments.

A similar conclusion is indicated by the presence of freshwater shells in the fine sand beneath the ridge at Taumutu. A sample of these shells (S93/500) was sent to the Geological Survey, Lower Hutt, for Carbon 14 dating. Results were not available at the time of writing and conclusions from the age of the shells cannot be drawn. The shells were identified, by Mr. P. Maxwell of the Geology Department, as the freshwater mollusc Hyridella menziesi. This mollusc inhabits creeks, rivers, ponds, and lakes to depths of 100 ft in the South Island, (Suter, 1913; Stout in Knox, 1969), and suggests a freshwater environment in the area.

Doubt has been expressed that the shells have been deposited in situ because Hyridella menziesi does not inhabit the present brackish water of the Lake. Stout (1970, pers. comm), says that there is no record of these molluscs in the rivers flowing into the Lake at present. The shells, were, however, well preserved and a significant portion of shells had both valves present and were infilled with silt. If they had been introduced to the site of deposition from outside, it is most unlikely that they have been moved far. This is suggested by the number of shells present in the layer and their preservation. Also, the fine sand above and below the shells indicates that the environment of deposition has been constant. Shells are restricted to this layer and possibly a very poorly preserved layer at a depth of 5 ft.

Whether the freshwater mollusc has been deposited in situ or has been introduced into the area, the shells and sediment suggest quiet conditions in the environment of deposition at a level of +7 ft, and freshwater conditions nearby. The deposition of these shells in a marine environment is thus discounted. It is concluded from the presence of Hyridella menziesi in the fine sediment, and the nature of the sediment in the ridge and beneath it, that these ridges were formed in a lacustrine environment.

The plan-form of the ridge-axes confirms this lakeshore origin. The orientation of the ridges at Taumutu (Fig 7, inside back cover), plus the change of orientation through the ridge sequence there, suggest a shoreline movement towards a more equilibrium plan-shape facing the northeast across the Lake. This direction approximates the maximum Effective Fetch on the present Lake.

Peat, located beneath the shingle ridge at the drain exposure on Lower Lake Road, does not allow definite conclusions about this area's depositional environment to be drawn. Fig 40 shows the stratigraphic relations of the peat and overlying ridge sediments. A study of the peat was carried out by Drs. Molloy and Moar (1970, pers. comm.) and the results of the analyses are described in Appendix X. Kahikatea (Podocarpus dacrydioides) and matai (P. spicatus) are the important conifers present in the pollen analysis; Wood fragments of matai confirm its local presence. Manuka (Leptospermum scoparium) dominated the pollen count. Tree species indicate a possible floodplain or impeded drainage situation, but do not confirm a lakeshore environment. However, the sediments beneath the peat and those interbedded with the overlying ridges suggest it.

Figure 40. Peat with wood present underlies shingle from the Taumutu Ridges in a drain exposure. Vertical extent of section is 3.5 ft. Particles in the ridge sediment are up to medium pebble sizes.

Various lines of evidence in this area suggest that a lacustrine formation for these ridges is highly likely. Theoretical derivations of lake-formed wave heights reaching this location, and deductions about former lakelevels, indicate the ability of lakewaves to form these ridges. Theoretical heights of waves approaching Taumutu were calculated for the 1951 wind data and are shown in Table 8. Wave heights up to 2 ft were calculated for the northeastern direction; such waves are capable of moving all particles present in these ridges. Lakelevels from +12 to +15 ft would reach the base of most ridges. Thus, formation by waves from a lake is conceivable. In the absence of any definite evidence supporting a marine formation these ridges are concluded as being lakeformed.

LAKESIDE RIDGES.

Northwards of the Taumutu Ridges the Lakeside Ridges extend irregularly for 8 miles in a northeasterly direction. They are different to all other ridges studied, both in surface-form and in sediment-character. These deposits have an unevenly undulating, hummocky form; definite ridges are not present, although there is an irregular trend towards a lower level on the lakeward side of the ridge area. The horizontal extent of the area is likewise irregular.

North of Timberyard Pt the ridges extend in a straight line north of northeast. Between Timberyard Pt and Lakeside four shingle tongues, with axes pointing to the northeast, project into the Lake. The southern group of two projections appear in Fig 41. The Taumutu Ridges are indicated on the left of this figure, between the projections and the

Table 8. Theoretical Wave Heights calculated for the Taumutu, Lakeside, and Lower Ridges from 1951 wind velocity data limited by a 10 ft water-depth.

Eff Fetch	Velocity (mph)	Duration (hours)	Wave Ht (feet)	Duration of max dimens. waves. (hours)
Taumutu Ridges				
040° (9.3 mi)	18+	5	1.9	3.20
	20+	14	2.0	14.00
070° (8.0 mi)	no significant records.			
Lakeside Ridges				
100° (8.3 mi)	20 - 28	9	2.0+	7.00
	30	8	2.6	6.20+
	27	2	2.4	2.00
	30+	24	2.6+	22.20+
	20	8	2.0	8.00
130° (8.6 mi)	18 - 20	5	1.9	3.00
	20	3	2.0	3.00
Lower Ridge				
195° (6.4 mi)	20+	4	2.0	2.20
	30+	11	2.6	9.20
	40+	5	3.0	3.50
	30+	5	2.6	5.00
	25+	13	2.3	13.00
	30+	34	2.6	33.00
225° (7.8 mi)	30+	23	2.6	21.20
	20+	5	2.0	5.00

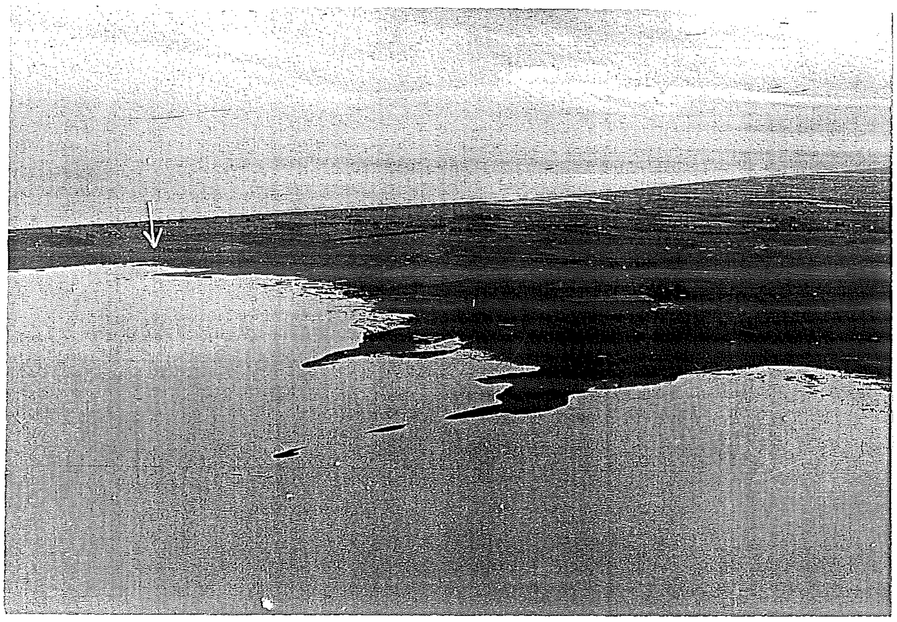


Figure 41. Two projections into the Lake near Lakeside. View southwest with Taumutu ridge sequence south (arrow) towards the sea.

present coast. These projections were suggested by Suggate to be marine-formed spits. The orientation and plan-form of these features is the main evidence for marine shorelines in this area at a sealevel near that of the present. While this evidence is difficult to refute, a study of bedding and some sediment characteristics indicates that wave-formed features in the area could be ascribed to formation on lakeshores.

Exposures through the Lakeside Ridges show differences in bedding and sediments between these ridges and those on the Barrier. A section through the ridges in a drain south of Dickies Road, shown in Fig 42, exhibits the main characteristics of the bedding in the Lakeside Ridges. The bedding, when present, is subhorizontal and relates to major differences in particle size between layers. In this section sediments in the layers are either of medium sand, possibly with scattered pebbles, or of pebbles, often with a medium sand matrix. Such bedding differs markedly to that noted in the marine sediments in Devils Knob Pit which, when present, dips seawards at angles up to 8°. Furthermore, successive layers in the Barrier Ridges do not contrast as much in sediment sizes that are present.

In addition to the differences in bedding with the marine sediments, this area exhibits considerable differences in some sediment characteristics. As was noted in an earlier section, the roundness and form properties of sediments exposed in sections of the Lakeside Ridges appear different to those of the sediments from the Barrier, and Beach. Sediments from the Lakeside Ridges are predominantly 'rounded' while those from the other

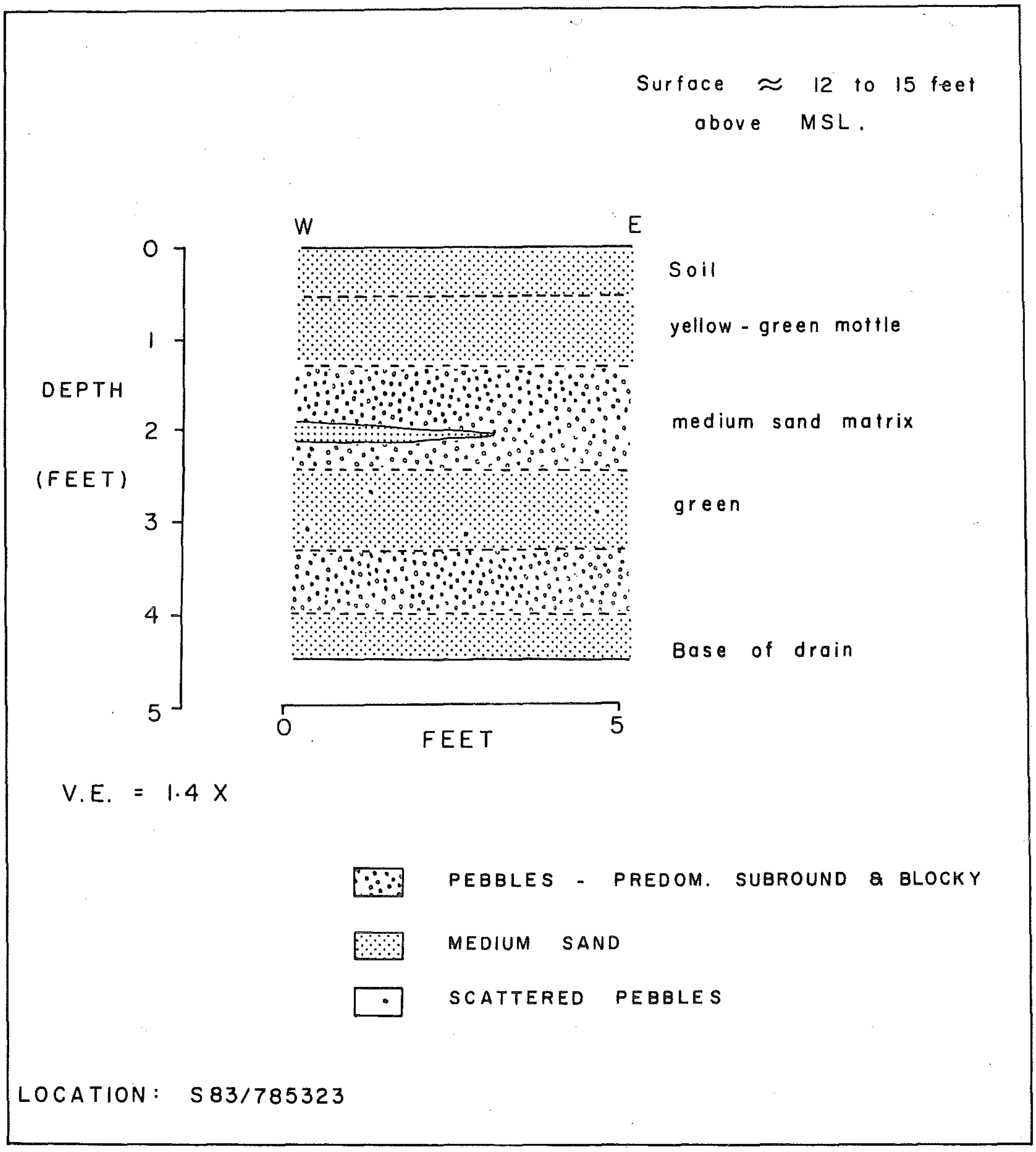


Figure 42. Section in Lakeside Ridges near Dickies Road illustrating horizontal bedding and sediments present in the different layers.

areas are predominantly 'well rounded'. Fig 9 shows that the 4 samples from the Lakeside Ridges show a consistently lower proportion of flatter particles (S/L ratio is lower) than those samples from the Barrier and Beach but show similar proportions to the 3 River samples. A study of Table 2 indicates two things. Firstly, the differences and similarities of Fig 9 become more apparent with the mean S/L ratios. The Lakeside Ridge and Selwyn River samples have values near 0.50 while samples from the Beach and Barrier have mean S/L ratios around 0.40. Secondly, there is a similarity in mean psi values between Lakeside Ridges and River samples (means near 0.68 psi) and between Beach and Barrier samples (means near 0.60 psi).

This difference between Barrier and river samples possibly reflects selective sorting on the coast on the sediments available to the beach from river and cliff. (It is conceivable that the initial cliff or river sediment was similar in form and sphericity properties to these river samples.) In the section discussing the present beach it was suggested that a selective process has led to proportionately more of the flatter particles present of the beaches. This was explained as being related to the greater stability of the larger, flatter pebbles.

The similarity between the Lakeside Ridge and River samples in mean psi values, and in proportions of flatter particles, suggests that very little, of any, sorting action by waves has acted on these sediments. Unfortunately, no statistical significance can be given to these differences because of the limited number of samples from the various environments.

The differences in bedding and sediment shape characteristics between Lakeside Ridge deposits and established marine sediments on the present coast suggest that these deposits are not marine formed, but were instead formed on a lakeshore. The hummocky surface-form of the ridges and the proximity to river sediments in the present lakeside situation, add assurance to these conclusions. The hypothesised mode of formation is that river sediments have been partly reworked by lakewaves on a lakeshore. Cobble to granule sizes are present close to the mouths of rivers and indicate river sources. Also, fluvial action is evident landwards of the ridges, becoming interrupted by the ridges; during high flows sediment was conceivable moved onto the lakeshore where waves could subsequently act upon it. Table 7 indicates that waves of considerable size could approach this shore from the Lake. A study of wellholes supports this hypothesised formation of these ridges.

WELLHOLE RECORDS.

Five wellholes were important to this aspect of the study, giving additional information about the sequence of events within the south-western lakemarginal area. The locations and sequences of these wellholes are shown on Fig 43 A and Fig 43 B, respectively. These wellholes indicate a change from alluvial gravels in the north of the area (S93/195) to sediments from a variety of environments towards Taumutu (S93/159).

Well S93/195 shows an unbroken sequence of alluvial gravel and sand to -155 ft from within the Lakeside Ridges area. The Lakeside Ridges in, and north of, this area appear to be alluvium of the Springston formation which has been modified by lakewaves. Landwards of the ridge area, north

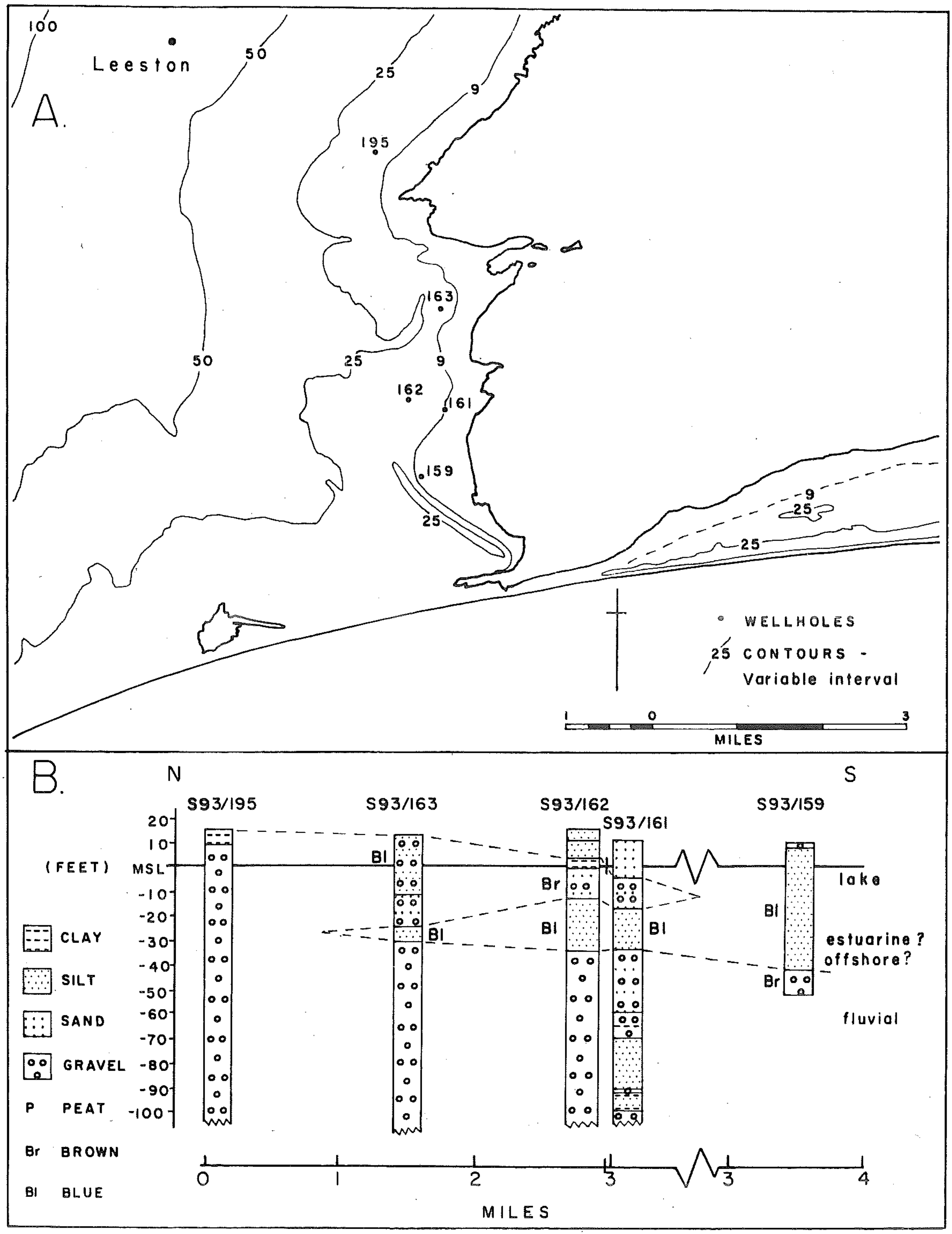


Figure 43. Recent depositional conditions suggested by wellholes on the western lakemargins. Locations of wellholes in 43B is given in 43A.

of S93/195 the fan surface confirms this, rising steadily away from the Lake.

In well S93/163 the Lakeside ridge is recorded as medium gravel and very fine blue sand to -13 ft. This description of gravel and sand is very similar to that in the section at Dickies Road. At Timberyard Pt the Lakeside Ridges thus appear to be related to river gravels deposited over estuarine and lacustrine sediments in an area east of the dipping fan-surfaces.

Southwards towards the Taumutu Ridges sand, clay, and pug is present over alluvial gravels (S93/162 and S93/161) which are at a similar level to the northern ridges. The alluvial origin is suggested by the brown colour in S93/162. The four projections into the Lake could possibly be desposits relating to rivers extending their beds in delta fashion, lakewards over lakesediment. The present undulating surface-form does support this hypothesis, but action by lakewaves could have modified any former surface. The particles forming these features are cobble sizes, however, and lakewaves calculated for the Lakeside Ridges would have a limited effect on them.

South of the shingle projections blue pug, beneath the 3 ft of shingle in the Taumutu Ridges (S93/159) suggests only lacustrine and estuarine conditions. Fluvial action did not reach this distance into the Lake. The sediments forming the Taumutu Ridges were probably drifted southwards along a lakeshore from the river or lake gravels further north. Selective sorting of the smaller and more easily eroded particles would give rise to the significant difference in sediments between the two ridge areas. Two factors support this suggestion. Firstly, waves of the dimensions calculated for Taumutu could move pebbles and smaller sizes in the area between Lakeside and Taumutu. Secondly, the changing orientation of the ridge-axes at Taumutu, with the fulcrum at the northern end of the ridge series (Fig 7, inside back cover), suggests sediment movement from northwards.

The study of wellholes indicates that the Lakeside Ridges can be explained in terms of a lacustrine origin. A hypothesis of marine formation, suggested by the spit-forms south of Timberyard Pt, introduces problems in the sediments and surface-forms that cannot be adequately resolved. Sediments are significantly different to those on the Barrier and Beach, both in bedding and some sediment properties. The surface-form is markedly different to that seen in areas subjected to this coast's high energy wave environment. It is therefore concluded that these ridges were formed by waves from the lake. Evidence of former marine shorelines is not present in the landforms of this area.

Summary.

The inner ridges on the Barrier and the western lakemargins have been formed in lakeshore situations by waves on a higher lake. Evidence of this formation for the inner ridges on the Kaitorete Barrier is present in the bedding, in overwash features, in the level and position of the ridges, and in the stratigraphic relations of the ridges in Birdlings

Valley. The Taumutu Ridges' lacustrine origin is suggested by the sediment in and beneath the ridges, the presence of <u>Hyridella menziesi</u> beneath the ridges, and the axial trends of the ridges. A formation by lakewaves is concluded for the Lakeside Ridges because of the minor amount of modification that the original fluvial sediments have undergone, the difference in bedding between this area and the Barrier Ridges, and the location near the lakeshore. The continuity of the ridge-surface with the Taumutu Ridges suggested the source for the sediments in the Taumutu Ridges to have been the Lakeside Ridge area to the north. Deposits related to a marine shoreline would have been of quite a different nature to those found in the western lakemarginal area.

The ability of former lakelevels to reach the levels necessary to form these ridges was demonstrated from historical evidence and from levels necessary to break over the present barrier beach across the outlet of Lake Ellesmere. Theoretical wave heights and periods were calculated from prediction diagrams, and restrictions to these parameters were imposed for shallow-water conditions. For waves of these parameters it was demonstrated that pebbles and smaller sizes could be transported.

The formation of these features by lakewaves means that no marine landforms in the Ellesmere area related to recent high sealevels have yet been discussed. This tends to confirm the conclusion, arrived at in a previous section, that the sea was excluded from the Ellesmere area at a level significantly below that of the present level. However, conclusions about the absence of marine shoreline evidence in the region have neglected the abrasional evidence present on the spurs of the Peninsula. This very important consideration will now be discussed.

MARINE ABRASIONAL LANDFORMS.

General

Relic shore platforms, occasionally backed by cliffs, and seastacks occur near the spur-ends of the Peninsula for 12 miles west of the present cliffed spurs at Poranui Pt. These landforms are absent at Taitapu although a seastack is present 5 miles northward of Taitapu, near Halswell. The presence of shore platforms at levels between +6 and +25 ft raises questions about recent sealevels and shorelines in the Ellesmere area. It is necessary to ask if a postglacial sealevel at a level, considerably higher than the present, formed the platforms and cliffs. The position of the abrasional features at Birdlings Flat, landwards of the Barrier, clearly indicates the earlier formation of these cliffs and shore platforms. Thus, formation on a postglacial sealevel higher than the present, would contradict the sequence of events derived from a study of the landforms on the Barrier and lakemargins. In the sequence that has been developed marine shorelines are suggested to have left the Ellesmere area with the formation of the Barrier when the sealevel was lower than -10 ft.

This section will briefly review the evidence for concluding a marine origin for these hardrock features. This will be followed by an evaluation of the age of the period of cliffing and platform cutting: whether it is recent or preglacial.

Marine Formation.

The formation of these features by coastal processes has been recognised by all previous writers. Cliffs fronted by rounded boulders suggest a cliff development related to wave attack and subaerial weathering at some earlier time. Subhorizontal hardrock surfaces, dipping seawards from spur-ends, call for the development of platforms by marine processes. Two such platforms are indicated in Figures 44 and 45. They show irregular, rough surfaces which decrease in level by between 10 and 20 ft, over distances up to 50 yards from junctions with the loess. The character of the surface, and the presence or absence of boulders, is related to the nature of the volcanic strata: its induration and its joint system.

Upstanding rock-masses at some distance from spur-ends are present at Ahuriri, Motukarara, Kaituna, and Birdlings Flat, and are most easily explained as seaformed stacks. The Ahuriri Stack shows evidence indicating development at sealevels similar to that forming the shore platforms: it is connected at the surface to the spur and it appears to have a minor platform at the western end. Other stacks may have formed at lower sealevels.

The conformity between the trend of the ends of the spurs from Motukarara to Birdlings Flat and that of the present coastal spur-ends gives further support for the marine origin. The cliff at Devils Knob is in line with those of the coast and is of similar height. The relic cliffs decrease in height westwards from Devils Knob and spur-ends are generally subdued

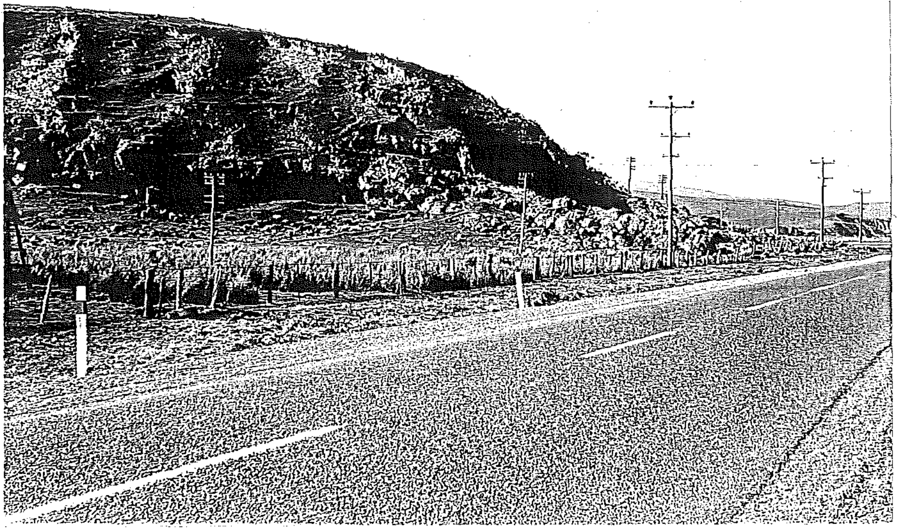


Figure 44. Shore platform west of Kaituna. Note the very rough surface with boulders present in places. The platform is backed by loess, apparently overlying it.

Figure 45. Shore platform near Kaituna dipping seawards, in front of house, and apparently continuing beneath the loess (dashed line). View east.

by Ahuriri. The definite marine origin of these features indicates a shoreline adjacent to the spur-ends, at a sealevel between +10 and +15 ft, prior to the presence of the Barrier.

Age of Formation.

Speight (1930) related the formation of these landforms to a period of high sealevel following the presence of the Barrier. Thompson (1964) wrote that height correlations with the Princess Anne sealevel suggest an age of 85,000 to 90,000 years B.P. for their formation, while Suggate (1968) and Burrows (1969) concluded the formation to be during a post-glacial sealevel higher than present. The latter two writers placed the age of cliffing and platform formation within the last 5,000 years. It is necessary to know whether the shore platforms are pre- or post-glacial in age, to test the conclusions already reached in this investigation.

The relationship between the loess and the shore platforms is crucial to an estimation of the period of formation of these features. Speight (1908) wrote that loess overlies the shore platforms. Figure 45 shows that the platform, exposed in front of the house, continues beneath the loess (dashed line). The continuation is partly obscured by claywash but vertical cracks in the loess stop at the basalt-loess contact. Horizontal bedding is present in the loess covering the platform and concretions are present in some layers; these two features indicate that the loess forms a primary deposit, and possibilities of redeposition over the platform from higher on the spur can be ignored.

The basalt-loess contact is more noticeable in Fig 46, but any bedding in the loess is obscured by vegetation and surface modifications. There is also uncertainty in other instances where basalt platforms appear to underlie the loess because of the lack of clear exposures of the loess, and the possibility arises that reworking of primary loess deposits may have lead to deposition over platforms.

Mr. J.K. Hill of the Geology Department, University of Canterbury, (1970, pers. comm.) has carried out transects on subsurface basalt on a spur north of Motukarara, located at Grid Reference S84/946339. Results indicate that a basalt surface, conformable with the platform exposed at the outer edges of the spur, is present beneath the loess. The basalt surface slopes upwards beneath thicknesses of loess (up to 70 ft thick) away from the end of the spur until, several hundred yards from the spur-end, it slopes steeply towards the surface. The form of the basalt surface suggests that the platform in this location continues beneath the loess to a former cliff, also buried by loess. Exposures of the loess covering the platform at the outer margins of this spur indicate that the loess forms a primary deposit.

AGE OF LOESS.

The stratigraphic relations of loess and shore platforms suggest, in several instances, that the formation of the platforms predates the deposition of the loess. The age of loess deposition allows an estimation of the relative age of the shore platform cutting in this situation. The

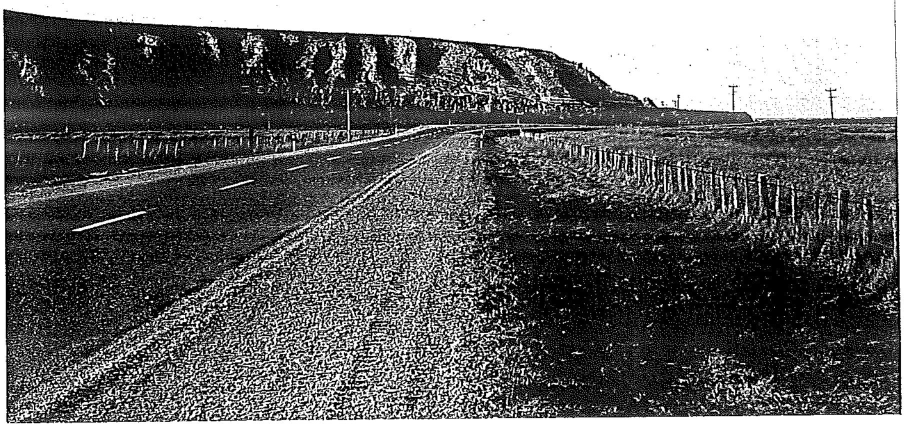


Figure 46. Platform extends beneath the loess east of McQueens Valley. Surface alteration and vegetation prevent the ascertaining of the presence of bedding.

generally accepted hypothesis of loess accumulation on Banks Peninsula and the East Coast of the South Island is by wind transport of silt and clay sizes from glacial outwash. Raeside (1964) adds that loess may have been derived from fine sediment on the continental shelf during sealevel recessions in recent glacial periods. Loess has thus been related broadly to glaciations.

Sequences of at least 6 loess layers in localities in South Canterbury and North Otago have been tentatively related to the Otiran (upper 3 layers) and Waimaungan (lower 3 layers) Glaciations of Gage (1961). (Suggate's (Suggate, 1965) revision divides these two glaciations into three glaciations). At least 4 beds are present on Banks Peninsula exposures. In the bedded exposures over the shore platform there appear to be four or more beds. Thus, the lower loess could possibly be older than the Otiran Glaciation.

From the relatiohship of the loess overlying the platform, it appears that the platforms have been formed during some preglacial high sea-level prior to their burial by loess. The sequence of shorelines, derived from studying landforms on the Barrier, is therefore accepted because there is no definite evidence of shorelines within the Ellesmere area near the present level.

Exposure of Platforms and Cliffs.

Former postglacial shorelines would have been at levels that were too low to have exerted much influence on the exposure of the platforms. Other evidence suggests that the sealevel was between -20 and -10 ft when shorelines were excluded from this area. The present partially or wholly exposed shore platform and cliff situations are suggested to have taken place, along a lakeshore.

Lakelevels of +15 ft would bring the lake-edge to the base, or partway up, the present exposed portions of the shore platforms. Waves of considerable height could have developed on the Lake before sedimentation infilled the area lakewards of the platforms. This area faces into the southwest across a considerable stretch of water, and the strongest winds with the greatest frequency and duration occur from this direction, at the present time.

Theoretical wave heights calculated for locations adjacent to the spur-ends confirm that waves, large enough to erode loess, could have developed on an earlier lake. Wave heights that were calculated for the Lower Ridges are shown on Table 8 to be up to 3.0 ft. The Effective Fetch for this location is similar to those of the more westerly spur-ends. Spurs towards the eastern end of the Lake would have experienced waves similar to those of the Railway Cutting Ridges (Table 7). Calculations for these ridges also showed theoretical wave heights up to 3 ft. Higher lakelevels and the waves produced on such a lake could account for all of the cliff and platform exposure in the area between Ahuriri and Birdlings Valley.

Some confirmation of this hypothesis of exposure by lakewaves is provided by the significant proportion of silt sizes in the lake-sediment samples in Gebbies Valley. The silt sizes in these samples form a marked 'fine tail' which comprises up to 20% of the sample weight. Silt-sized particles form the dominant proportion of the Banks Peninsula loess. The significant tail to an otherwise normal curve is interpreted as being derived from the erosion of loess by waves, as well as by running water, in this area.

Such an explanation is supported by the presence of cliffs in the loess in two valleys west of Kaituna. Figure 47 indicates that two scarps are present on opposite sides of one valley; the westernmost scarp is within 150 yards of a shore platform and cliff. The cliffed loess demonstrates the action whereby lakewaves progressively cut back the loess, exposing whatever hardrock features are buried beneath. Loess cliffing in this situation also confirms that platform cutting is not a recent action in this area: it is unlikely that a recent high energy seacoast environment would have cut a hard-rock cliff and platform while only cliffing loess which is this short distance landwards.

The suggested relative sequence of events relating to these landforms on the spur-ends of Banks Peninsula are as follows:

1. Cutting of the shore platforms, cliffs, and stacks with sea-level at the level of the platforms.

2. Deposition of Loess when shorelines were absent from this area.

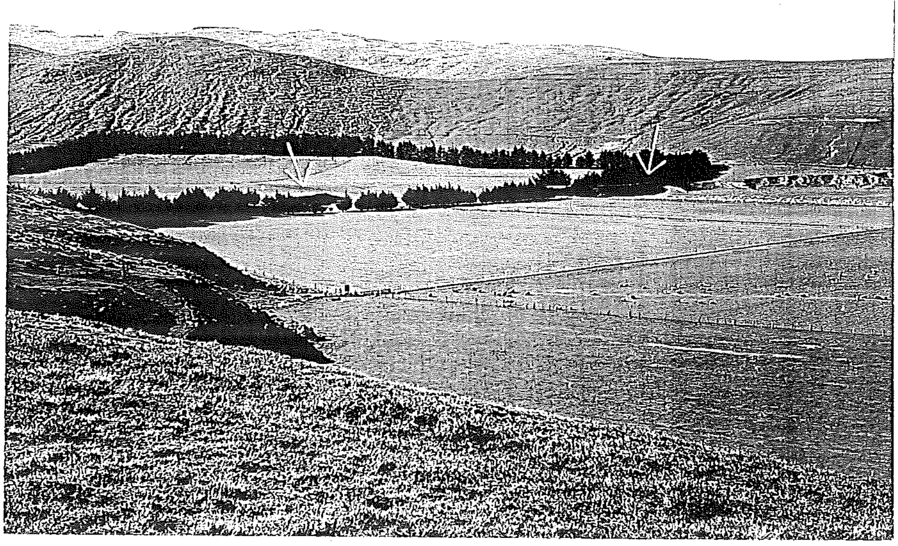


Figure 47. Cliffing (partially obscured) in loess adjacent to seacliffs on the left foreground. Arrows indicate the cliffs. View east, west of Kaituna.

Several periods of loess-deposition occurred, involving burial of the relic platforms and cliffs on the spur ends.

3. Exposure of the platforms and cliffs by lakewaves trimming back the loess during the presence of the Lake.

Summary.

Marine abrasional features are present towards the end of spurs between Poranui Pt and Taitapu. They may extend further north to Halswell. Evidence of their formation is present in the landforms, their surficial features, and their situation adjacent to present coastal cliffs on the southwest side of the Peninsula. From the stratigraphic relations of the loess overlying shoreplatforms it is concluded that the period of cliffing and platform formation is pre-glacial, but no estimation of the age of such an action is made. Lakewaves with former high lakelevels appear to have been capable of exposing the platforms and cliffs to their present extent. This means that there is no real evidence of recent shores within the area at levels close to present sealevel. This evidence tends to confirm earlier conclusions about the formation of the Barrier at a lower sealevel towards the end of the post-glacial sealevel rise.

From the evaluation of shoreline evidence in different parts of the Kaitorete Barrier and lakemarginal areas a sequence of recent shorelines has become increasingly apparent. The sequences of Hooked Ridges and

Barrier Ridges indicate the action of shoreline rectification over the last 7,000 years; there is evidence of early spit development followed by progradation and, on the western barrier, retrogradation. Other ridge groups on the inner Barrier and western lakemargins confirm the exclusion of shorelines from Ellesmere at a sealevel lower than the present, and the relic shore platforms do not contradict these conclusions. The following section will summarise these important coastline changes in the Northern Canterbury Bight. It will attempt to place them within the broader sequence of shoreline changes in this area, consequent with the postglacial rise in sealevel.

RECENT MARINE AND LACUSTRINE SHORELINES.

General

Recent marine shoreline changes that occurred with the postglacial rise in sealevel during the last 15,000 years will be described and discussed in this section. This will involve a general consideration of shorelines prior to the development of the Spit, when landward movements of the shore were most important. The only direct evidence for these early shorelines is from wellholes in Ellesmere, but indirect evidence is introduced to allow some generalised conclusions of these early shorelines to be derived. Marine shorelines will be described with greater certainty following the presence of the Spit. Sequences of shoreline changes in parts of the Lake demonstrate similar changes to those that have occurred on a larger scale on the coast.

The following discussion assumes that, in absolute terms, the level of the land has been constant for the last 15,000 years. Changes of the land-sea relationships indicated in the Kaitorete Barrier are ascribed to changes in sealevel. Events prior to 7,000 years B.P. are placed in a broad time-scale by relating the sealevel to Curray's postglacial sealevel curve (Curray, 1965). Events between 7,000 years and 5,000 years B.P. are approximately dated with reference to Suggate's sealevel curve for the Christchurch area (Suggate, 1968). Thus, any absolute changes of the land-level in the study area, if present, will not influence the dates of events in this time-period.

Postglacial Shorelines Preceeding the Spit.

Tentative positions of early shorelines are illustrated in Fig 48. Five successive shorelines are indicated between 16,000 and 7,500 years B.P. They exhibit the dominant aspect of coastal changes during this period: the rapid landward movement of shorelines related to the postglacial rise in sealevel. Such a movement meant that shores were moving landwards with little longshore adjustment taking place. This figure suggests that shorelines in Northern Canterbury Bight moved landwards by 25 miles in 8,500 years. The 16,000 and 13,000 years B.P. shorelines relate to present submarine contours while later shorelines are derived from submarine contours, extended fan-surfaces, and subsurface information in the Ellesmere area.

15,000 TO 10,000 YEARS B.P.

The shoreline at a sealevel of -300 ft (16,000 years B.P.) is suggested to have been approximately 30 miles seawards of the present coast. This position is related to the level of the present submarine surface, but is placed several miles landwards to compensate for the effects of subsequent deposition. Deposition is suggested to have been minor in the vicinity of the 200 to 300 ft submarine contours because they maintain similar distance-to-shore relationships around Banks Peninsula, a minor sediment source, as north and south of it.

The shorelines for sealevels at -200 ft (13,000 years B.P.) and -100 ft (10,000 years B.P.) are likewise placed landwards of, and parallel to, their equivalent submarine contours. Towards Banks Peninsula the shallower contours, including the 120 ft contour, exhibit responses to

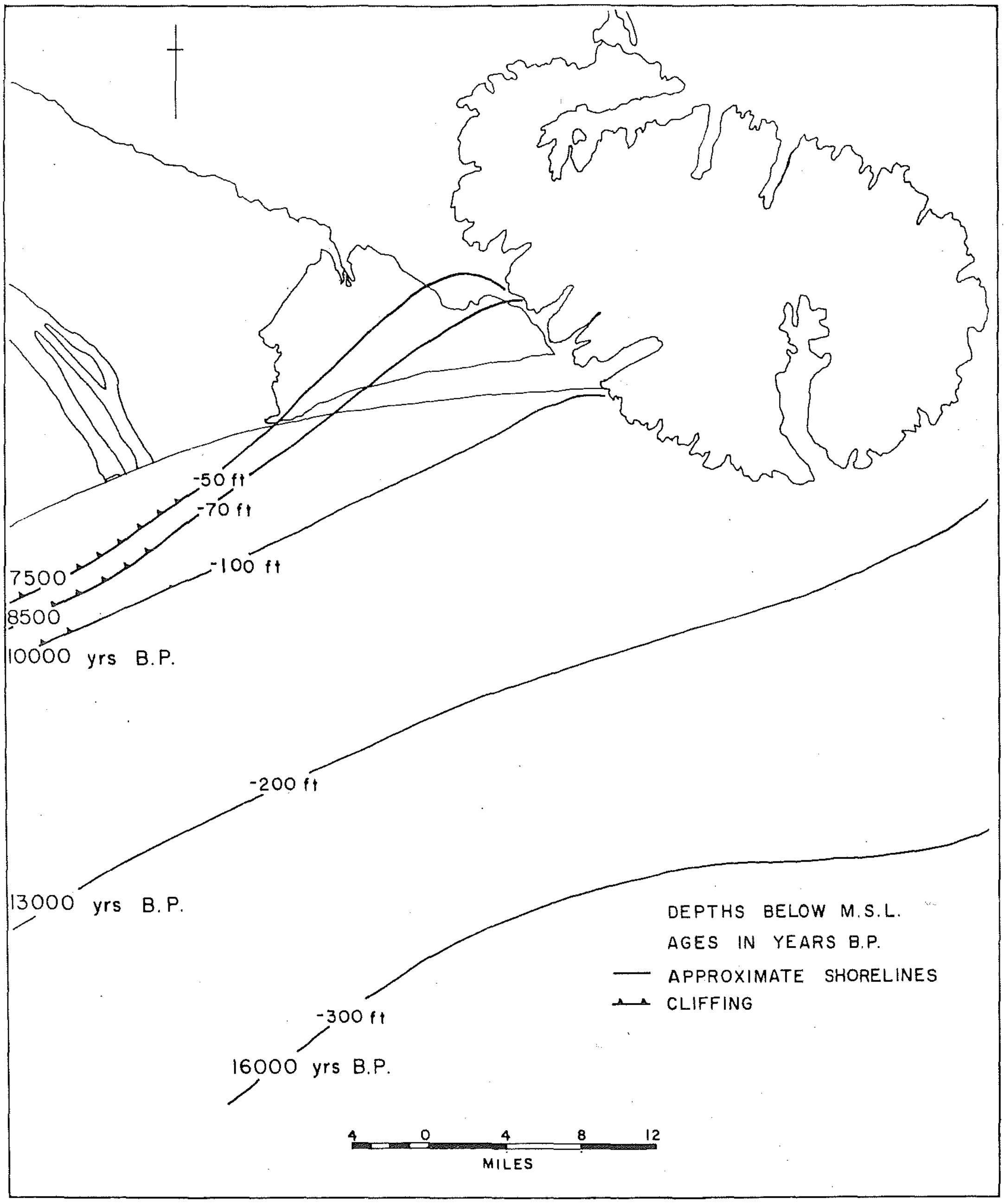


Figure 48. Approximate shorelines between 16,000 and 7,500 years B.P.

present sedimentation conditions, indicating recent deposition to have been active. Shorelines related to these shallower levels were thus probably considerable distances landwards here. The -100 ft (10,000 years B.P.) shoreline is extended parallel to its trend near Rakaia and indicates a shoreline meeting the Peninsula at Poranui Pt.

Nothing is known of the character of early shorelines but certain deductions can be made as to their possible nature. The rapid sea-level rise during this period would have caused quick landwards movement of the shoreline. It is suggested that the sediments were composed mainly of sand sizes and the character of the beach and nearshore zones was that of a sand beach. This is concluded from seaward extensions of fan surfaces on the Canterbury Plains; Fig 49 illustrates that the most gently dipping surface, that of the Springston formation, dips towards a level of -300 ft 12 miles from the coast near Rakaia. Sediments deposited by rivers on the lower angle surface seawards of fan surfaces are suggested to have been sand sizes and finer sizes. Until shorelines intersected the fan surface, beaches in the Northern Canterbury Bight are thus suggested to be sand beaches, markedly different in character to those of the present coast.

10,000 TO 8,000 YEARS B.P.

Between 10,000 and 8,000 years B.P. shorelines near Rakaia would have intersected the alluvial fan surface about 6 miles seawards of the present beach. This would have meant a change in the nature of the beach from a sand beach to a mixed sand-shingle beach similar to the present. The

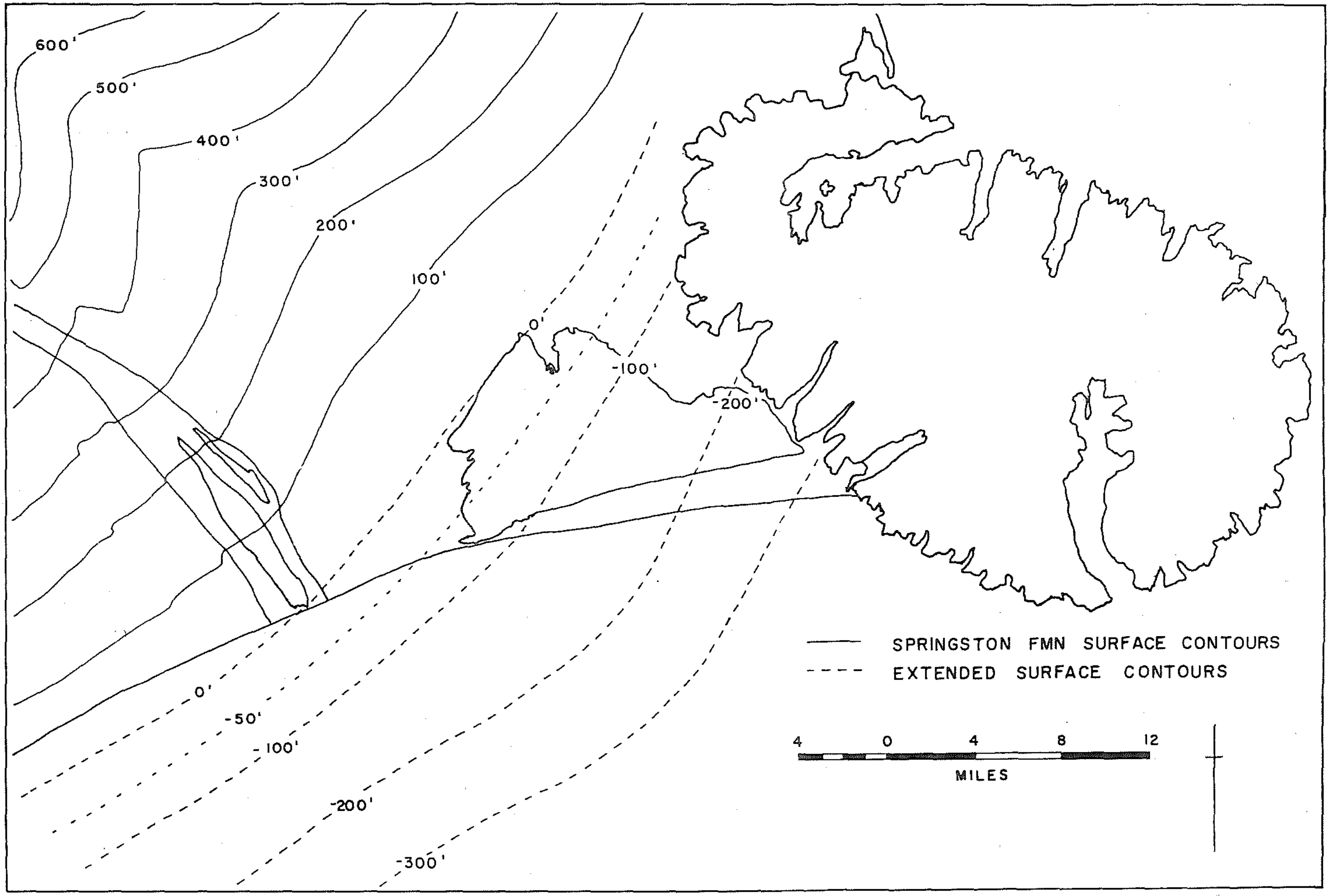


Figure 49. Contours of the surface of the Springston and Burnham formations and the surface extended seawards.

curve of the fan surface, illustrated on Fig 49, indicates that transgressing shorelines further north did not intersect the fan surface until later. It is suggested that the rapid rise in sealevel during this time resulted in little northward sediment movement; with rapid landwards movement of the shore, cliffing would have been restricted and the sediment volumes available for littoral drift would consequently have been small. The beach system may have appeared like that between Taumutu and Rakaia at present. This situation is demonstrated in Fig 50 where cut on the foreshore and deposition of beach sediment on the backshore in high energy conditions, occurs as the whole system moves landwards.

Shorelines in the Ellesmere area following 10,000 years B.P. are uncertain, but some indication is given by a sequence of wellholes between Greenpark and Lincoln. This sequence is illustrated in Fig 51 B, and their locations are shown in Fig 51 A. The sequence indicates dominantly silt and sand sizes over gravels. Two Carbon 14 dates which place this sequence within time-limits are described in Appendix XI. The date 9,400 ± 120 years B.P. for wood in a possible estuarine situation probably indicates sealevel at the time (Suggate, 1968). A similar date from Lincoln, 3 ft below the surface (8,895 ± 130 years B.P.) indicates the age of the Springston surface there. The surface at about 9,000 years B.P. was thus +20 ft near Lincoln and -70 ft near Greenpark. The shingle layer which is at the base of the fine sediment at successively lower levels towards Greenpark possibly relates to this surface. Suggate's interpretation of environments at well S83/212 suggested shorelines to

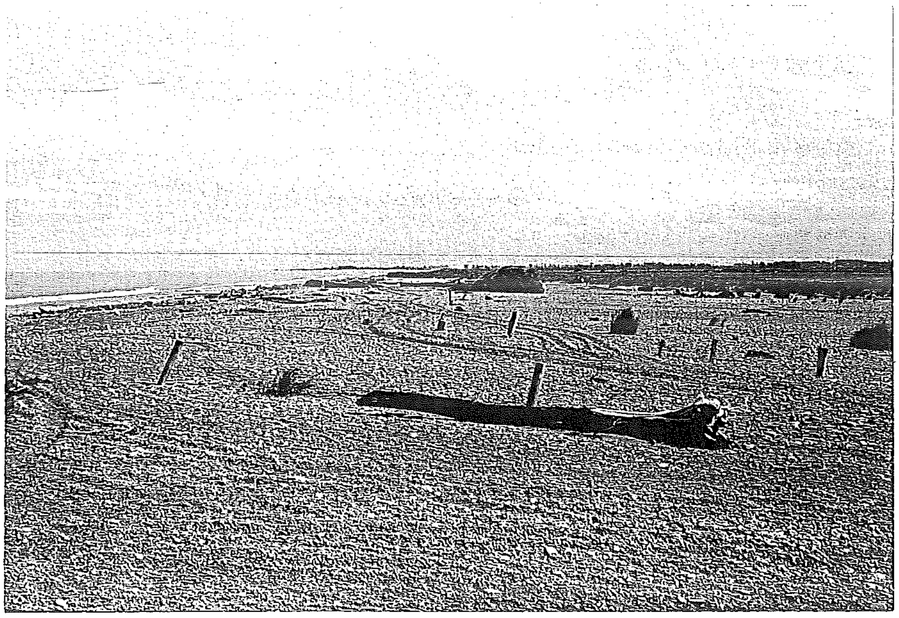


Figure 50. Looking westwards towards Coopers Lagoon from backshore. The low-sloping backslope of the beach is covering low-lying sediments landwards.

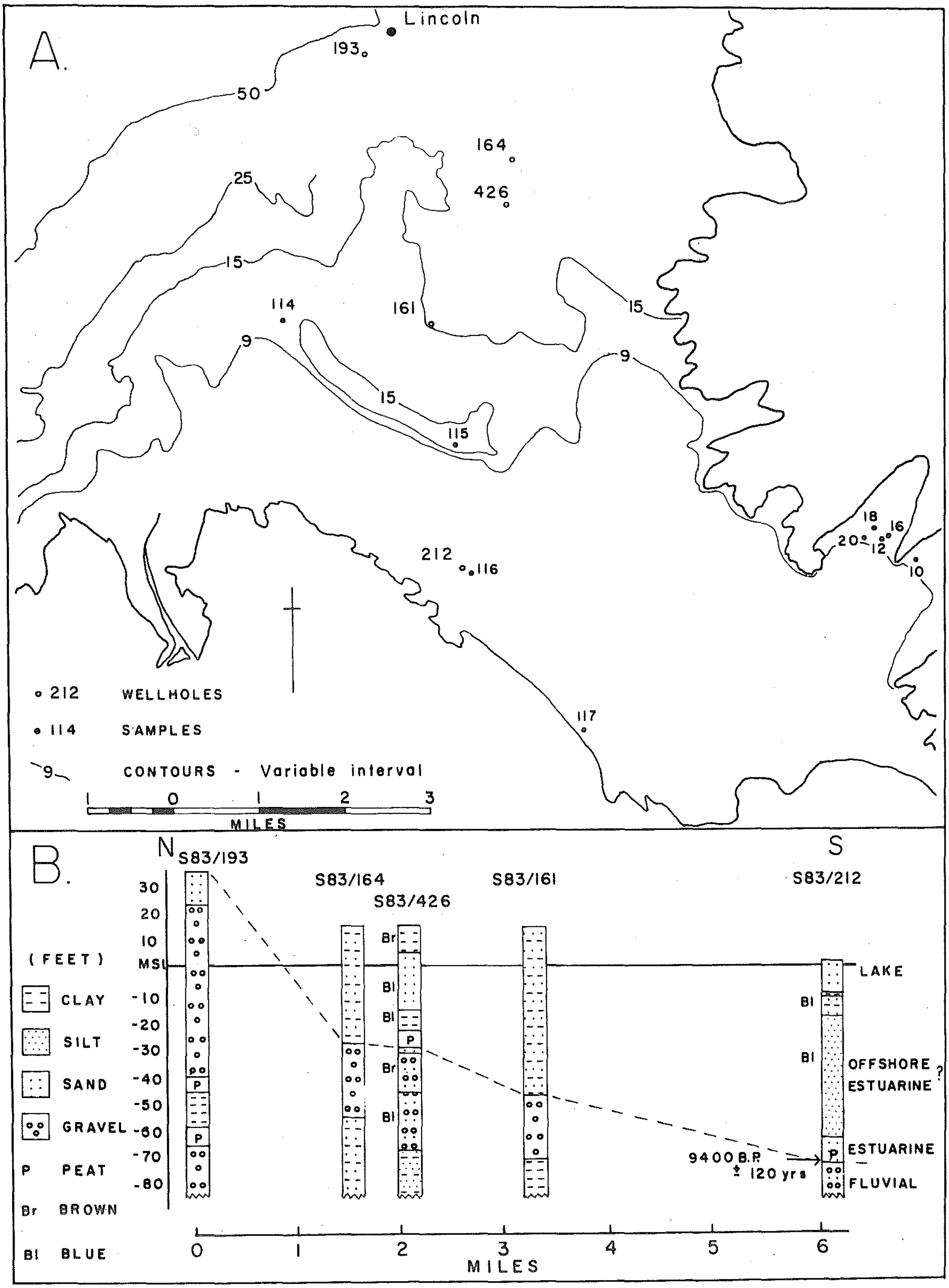


Figure 51. Wellholes and their locations on the northeastern lake-margins. Locations of the wellholes are illustrated in 51A and the sequence is shown in 51B.

the north and west following 9,000 years B.P. The fine sediments at the surface in these wells relate to lacustrine deposition but beneath this, they probably reflect estuarine or offshore conditions.

The stability of shoreline positions in the restricted Ellesmere area would depend on the rate of sealevel rise and the amount of sediment entering the area. Rapid sealevel rise is suggested by the sealevel curve until -25 ft (7,000 years B.P.). The sediment amounts entering the area are unknown. Sediment inputs from rivers are uncertain; the Rakaia River may have flowed into the area in addition to the Selwyn River, but the Waimakariri River's contribution has been minor. The small input of the Waimakariri is suggested by the surface date of the Springston formation at Lincoln. The amount of longshore input from the rapidly migrating coast to the south is suggested to have been small. The rapid sealevel rise, combined with the probably small addition of sediment to this restricted area, suggest that shorelines in this area moved landwards during this time. The shorelines following the -70 ft shoreline are thus, suggested to have been initially landwards of Greenpark. This is illustrated on Fig 48 by the -50 ft shoreline (7,500 years B.P.).

SLOWING SEALEVEL RISE AND COASTAL RECTIFICATION.

The slowing rate of sealevel rise following 8,000 years B.P. brought about important changes in the direction of shoreline movements which culminated eventually in the development of the Spit. These changes are shown on Fig 52. The differing positions of the two shorelines indicate that longshore coastal adjustment to the wave regime became more important as the rate of sealevel rise slowed. Transgressive coastal movements

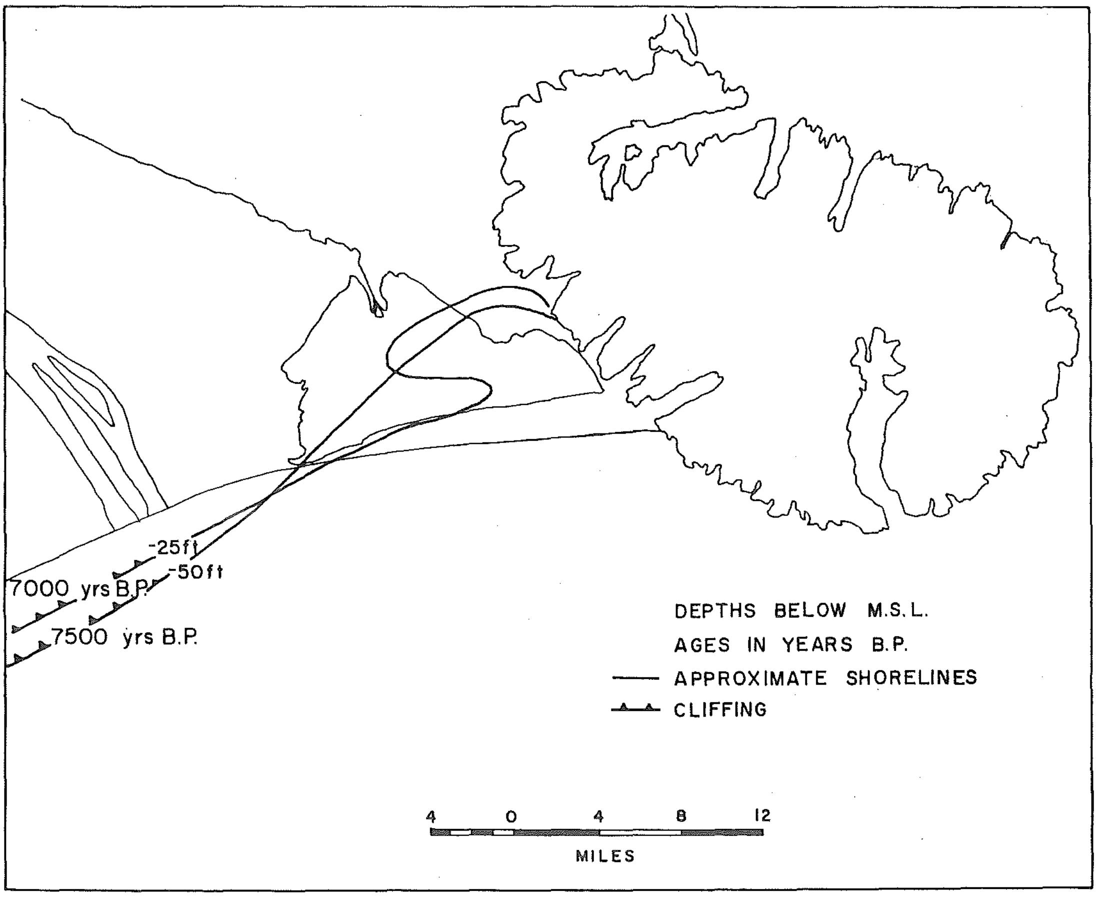


Figure 52. Approximate shorelines between 7,500 and 7,000 years B.P. prior to the development of the Spit.

changed to shoreline movements attempting to attain a better balance in wave energy along the whole coast. Erosion and cliffing proceeded south of the Rakaia River on a coastline which was and still is, too flat for equilibrium conditions. Increases in littoral drift probably resulted in progradation north of Rakaia in the indented area between the fans and the Peninsula. This led to the seaward movement of the 7,000 years B.P. shoreline in Fig 52.

If events did happen this way the coast built out towards the Peninsula near Taumutu, leaving lagoonal areas landwards. The Spit would subsequently have developed from the projecting shore and continued the trend towards Banks Peninsula. The main evidence supporting such a series of events is the plan-form of the Barrier itself. The shoreline indicated by the Barrier's inner margins, west of the Hooked Ridges, is seawards of the fan surface near Taumutu (Fig 53 (+)). The Spit appears to have formed at an angle to the former coast across an inlet. Steers (1964) notes the tendency for some spits to form at right angles to the main direction of wave approach. This appears to be the situation here, because the main directions of wave approach are the south and southeast; waves from more northerly directions approach the area only after considerable refraction around Banks Peninsula.

Later Shorelines.

KAITORETE SPIT.

The Spit developed on a slackening sealevel rise 7,000 to 6,000 years B.P. The wave regime in Northern Canterbury Bight resulted in a net

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(+) This figure is also present in an earlier section (Figure 25.)

northeastward movement of sediment to, and along, the seaward margins of the Spit. Deposition occurred at the eastern end, related to the decreased transporting capacity of the waves refracting around the detached end of the Spit. Continued deposition at this end, demonstrated by the sequence of hooked shingle ridges near Banks Peninsula, resulted in the Spit's eastward extension and eventual linking with the Peninsula. The continuing sealevel rise during this period is possibly indicated by the eastwards increase in level of the hook-axes. The joining of the Spit with the Peninsula was significant for subsequent development of Ellesmere. It removed the shoreline from the Ellesmere area, formed a lake in the depression landwards, and allowed for later shorenormal progradation to take place.

KAITORETE BARRIER.

Following the formation of the Barrier the coastline between Taumutu and Poranui Pt prograded in attempts to form an equilibrium planform with the adjacent coastal area. This shorenormal progradation has proceeded over the whole Barrier with beach ridges marking positions and trends of successive shorelines. Figure 53 shows five successive shorelines during the development of the Barrier and the coast to the west. The earliest shoreline (position 5) is the shore at the time of the Spit's linking with the Peninsula, and shoreline 1 marks the present beach.

At the eastern end of the Barrier the coastline prograded from a position adjacent to Birdlings Valley to a position level with Devils Knob (shoreline 5b in Fig 53.) The coast apparently stabilised its position here while progradation occurred in Birdlings Flat by material that was drifted around the base of Devils Knob and along the northern valley wall. Beach ridges were added in Birdlings Flat while the coast to the west remained stable. This occurred until the ridge sequence in Birdlings Flat was level with the rest of the shore.

Sealevel was still rising during this period and is represented by the increase in ridge levels on Birdlings Flat. It is also shown in the increase in level from the inner Railway Cutting Ridges to the Barrier Ridges on Profile 1B (Fig 30). This abrupt level increase suggests that the sediment landwards of this Barrier Ridge was deposited at a considerably lower sealevel with the sudden increase in level resulting from the constant shore position during the subsequent sealevel increase.

When the shore in Birdlings Flat was at a position level with that to the west, progradation continued along the whole Barrier again. The similarity in levels between ridges in this position and those for the rest of the Barrier suggests that sealevel had reached a position similar to the present level. According to Suggate's curve of sealevel rise the present level was reached 5,000 years ago; this suggests an age of 5,000 years B.P. for a shoreline in this position (Shoreline 4 in Fig 53).

While coastal progradation proceeded along the Barrier, coastal retrogradation continued southwest of the Barrier. This action is demonstrated by the landwards position of later shorelines in the west in Fig 53. This recession gradually brought a northeastern movement of the fulcrum for the Barrier's development, which eventually caused a change from progradation to recession for the western portion of the Barrier.

Progradation has continued in the east, probably at a slowing rate towards the present. Shorelines have thus steadily moved seawards in the east, but in the west they have crossed and trimmed back former shorelines as the coast further west moved landwards. The retreat of the western Barrier shore has contributed to much of the present westerly decrease in Barrier width.

Dune development on Kaitorete Barrier.

Dune formation was limited to the western 5 miles of the Kaitorete Barrier for most of its development. The dune formation contributed to a longshore loss in the sand reserves of the beach system, which prevented dunes forming further east. It was only late in the Barrier's development that erosion of sand from dunes and sediments on the western Barrier, and immediately west of it, led to sand reserves on the beach sufficient to allow dunes to form along most of the Barrier coast. Dune decay has recently been active along much of the Barrier; for much of the middle portion vegetated dunes are present up to 500 yards landwards of dune-blowouts, while at the western end dune decay has been accentuated by wave-trimming of their seaward margins. Blowouts and parabolic dunes are both present in this western sector.

Recent Progradation.

Uncertainty about sealevels during the last 5,000 years prevents estimation of the ages of later shoreline positions. By extrapolating from the rate of progradation at Birdlings Flat between 6,000 and 5,000 years

B.P. the present shore position would have been reached approximately 3,000 years ago. However, the slight weathering of pebbles from the outer Barrier Ridges, when compared with the considerable weathering of those from the inner Barrier Ridges, suggests that the addition of the later ridges took place at a slower rate. Therefore, the most recent shorelines are much younger than 3,000 years. Indeed, the small amount of weathering modification of the most seaward pebbles, compared with that of pebbles in the earliest ridges, suggests that the latest ridges were added within the last 1,000 years. Analysis of the present beach sediments indicates that progradation could be proceeding at the present, but evidence is not conclusive.

Lake Shorelines.

The lake-associated landforms indicate the considerable influence that the Lake has had on marginal areas since it was formed about 6,000 years ago. Lakeformed ridges up to +25 ft are present around the Lakemargins and indicate the action of lakewaves on high lakelevels. Relic shore platforms, formerly buried beneath loess on the spurs of the Peninsula, have been exposed by lakewaves and further demonstrate the importance of a former high Lake Ellesmere. The extensive northeastern lakemargins, with sand ridges and dunes present, call for considerable deposition since the initial lakeshore positions were adjacent to the spurs. These factors demonstrate the considerably influence that a former, high Lake has had on the Ellesmere area.

On the inner Kaitorete Barrier Speight Ridge is the most prominent lakeshore feature; it is a distinct feature with widely varying characteristics for more than 8 miles along the Barrier. In different parts it demonstrates the considerable erosion that took place on former lakeshores, while in other parts it indicates large amounts of deposition. Often it is present as a significant ridge which is higher than the backing Barrier Ridges, this form indicating the ridge's depositional nature. Overwash features were noted in two situations of this kind. In other locations the lakeward slope is below the level of the associated Barrier Ridges and the ridge is a very minor feature on the top of what has been a sloping lake shore. The situation here appears to be largely erosional. Along the whole of the inner Barrier, higher than +4', lakewaves removed evidence of early Barrier ridges.

Early lakeshores in the area of Bayleys Ridges formed a steep lakeward face on the Inner Dune and Barrier Ridge margins. Subsequent shoreline development, affected by waves from various directions, led to the complex arrangement of ridges and depressions here. The ridges in this area indicate the occurrence of considerable deposition, which involved sediment movement from the east.

In contrast to Speight Ridge and Bayleys Ridges, the Railway Cutting Ridges and those in Birdling Valley are completely depositional ridge groups. Ridge sequences at the Railway Cutting Ridges show how the lakeshore developed towards a more stable plan-shape, orientated to the westerly approaching waves. The innermost ridges follow the line of the Barrier Ridges and then turn towards the cliffs, but later ridges show a separate development. The outer ridges allowed beach drifting into Birdlings Valley and the formation of the ridges on a fine sediment basement between two valley walls.

On the western lakemargins high lakeshores allowed waves to act on alluvial sediments. For the northern position lakeshores formed irregularly undulating shingle ridges in sediments of the fan surface. Near Lakeside river deltas extended over lakesediments into the Lake and resulted in the development of irregular projections. At Taumutu, towards the southern margins of this group, fine sediment deposition filled the re-entrant between the retreating beach and the alluvial fans. Eventually ridges formed in this area by beach drifting sediments along a lakeshore from the fluvial sediments to the north. The change in orientation of the ridges at Taumutu shows the attempts of the shore to develop normal to the direction of significant wave approach. This ridge development demonstrates similar actions to those which, acting on a larger scale, lead to the recent shoreline development in the Northern Canterbury Bight.

In the area northeast of Lake Ellesmere lakesediment and dunes in Gebbies and McQueens Valleys, plus cliffed loess in two valleys west of Kaituna, indicate initial lake shorelines to have been at the bases of the spurs. The considerable erosive power of the lakewaves has been demonstrated in the removal of loess overlying the shore platforms and cliffs. Lake-ridges and dunes nearer the present lakeshore illustrates effects of lower controlled levels in the last few hundred years. Ridges have formed in the fine sediment from the present restricted wave activity on a lower lake.

Present Coastal Trends.

Recent profile trends from four culverts between the Rakaia River and Taumutu, plus morphological and historical evidence, suggest that the coast west of Taumutu is currently receeding. Morphological evidence suggests a similar trend for the western 5 miles of the Kaitorete Barrier. Further east the beach is backed by a foredune which is partly or completely developed. This situation is suggestive of a beach either in equilibrium with the present beach environment, or prograding. The conformity between the coast and the recent Barrier ridges suggests either possiblity. Recent historical evidence, a ridge on the backshore, and analyses of present beach responses provide some evidence for active progradation over the eastern 2 miles of the beach.

The future shoreline changes depend on the amount of coastal recession west of the Kaitorete Barrier. A landward movement of the shore near the Rakaia River of 2 or 3 miles might bring about recession along more of the Barrier's shore. However, a comparison of the present shape of the coast with the theoretical plan-shape satisfying equilibrium conditions suggests that the Barrier complies closely with the future equilibrium plan-form that the Canterbury Bight is working towards. Thus, it is felt that the Kaitorete Barrier is close to equilibrium with the present coastal environment and that little recession or progradation will take place in the forseeable future.

CONCLUSION.

This study was undertaken with six aims, and it is felt that each of these has been achieved, either wholly or in part. The first aim has been accomplished only in part; major landforms have been described and attempts have been made to explain their formation. Where pertinent to the discussion, sediments have also been described. The explanation has, however, been inconclusive in parts: the question of the full development of the backshore ridge at Poranui Pt remains, and there is uncertainty about the validity and significance of particle form changes between the various environments.

Fulfillment of the second aim was likewise only in part. The present directions of coastal movement were adequately assessed in the western and central portions of the Barrier, but uncertainty remains for the eastern few miles as to whether equilibrium or accretion is present. Historical evidence and some results of sediment characteristics suggest accretion as occurring, but uncertainty remains.

The third and main aim has been achieved. A sequence of recent coastal changes in the Northern Canterbury Bight has been described in as much detail as present evidence allows. The coastal changes during the last 7,000 years are well documented but those earlier are, at best, tentative. The dating of events is less satisfactory, being based on established postglacial sealevel variations and not on dates related to shore positions. A fuller system of wellholes around the lakemargins might give greater knowledge of early shorelines within the Ellesmere area. Also, subsurface data from the offshore area might lead to the more accurate placing of shorelines there.

The sequence of shorelines during and following spit-development allows a greater understanding of the dynamics of this coastline. A progradational shoreline development has occurred at an earlier period than in Pegasus Bay. Progradation appears to have been initiated on a rising sealevel south of the Peninsula but on a stable or falling sealevel north of the Peninsula. This difference between the two areas results from different relationships between the fan-surfaces and Banks Peninsula; the former southern coastline was indented adjacent to the Peninsula because of the curvature of the fan-surfaces there. Progradation was initiated earlier there in the sub-equilibrium situation than further north. Also, the differing orientations and equilibrium plan-shape considerations on the two coasts have meant a different sequence of shore movements in each area.

The fourth purpose of the study, to investigate the extent of marine influence on the landforms around Lake Ellesmere, was accomplished. It was concluded that landforms in this area have not been affected by coastal processes. This was indicated by the coastal development shown in the Hooked and Barrier Ridges and confirmed by the landforms adjacent to the Lake.

The eastwards increase in Barrier width has been explained as resulting from two factors, both related to the fulcrum for the Barrier's development.

Part of the decrease is due to the presence of the fulcrum at the western end of the Barrier, allowing only minor progradation on the coast there. The rest of the decrease in width can be attributed to the northeastward movement of the fulcrum, indicating the extension of the eroding sector onto the western Barrier.

The sixth aim was fulfilled. The effect of Lake Ellesmere on the landforms in the surrounding area was found to be considerable. Waves on a former, higher lake were of sufficient size to move pebble sizes and to erode loess. Considerable volumes of sediment on the inner Barrier were eroded and redeposited, often in large ridge groups. It was demonstrated that waves eroded loess on the spur-ends of the Peninsula, exhuming relic shore-platforms and cliffs. Theoretical wave parameters calculated for a higher lake confirmed the ability of waves of sufficient magnitude to form. Unfortunately, the present artificial control of the former Lake. prevents testing of these conclusions.

It is felt that this study has made a significant contribution to the geomorphic knowledge of one coastal area in Canterbury; it has explained landforms more fully between Banks Peninsula and Coopers Lagoon than has already been done. The coastal changes that have occurred in the study area have been demonstrated to be part of a long term response to the location of this area between the alluvial fans and the Peninsula. The situation as a coastal indentation, at the northern end of a shoreline on a high energy coast, led to the spit-formation and the subsequent barrier-development. The Lake has been shown to have exerted a marked influence on landforms of the inner area since this time. The hitherto neglected effects of the former Lake have led writers in the past to conclude differing sequences of events to those reached here. It is hoped that future investigations carried out in this area will test and evaluate the conclusions reached in this study and provide a fuller account of the sequence of recent shoreline changes in the Ellesmere area.

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APPENDIX

I Aerial Photographs used in this Study.

II Locations of Profiles on Kaitorete Barrier and across Ridges at Taumutu.

III A Locations of Hooked Ridge Transects.

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XI Carbon 14 Dates Referred to in the Text.

Appendix I. Aerial Photographs used in this Study

Run Number	Photo. Numbers
1952 Aerial Survey:	
2113	64 to 84
2114	64 to 80
2115	61 to 78
2116	62 to 86
2117	63 to 90
2118	62 to 66
2119	55 to 58
2120	52 to 55
3156	42 to 46
3157	42 to 45
3158	42 to 51
3159	28 to 53
3160	29 to 55
1966 Aerial Survey:	
5144	8 to 13
5145	6 to 14

Appendix II. Locations of Profiles on Kaitorete Barrier and across Ridges at Taumutu

Profile 1: Kaituna Inlet to McIntosh's farmhouse (S94/027237-053224). It was surveyed from the lake-edge across Jones Rd. and the main highway, to the hedge in front of the farmhouse.

Profile 1B: Northeast gatepost of a pair of gates in the fenceline running between the ridge-area and the main highway. From this point the profile crosses the ridges to the silt behind, approx. parallel to the fenceline. (S94/048247-052241).

Profile 1C: Joins Profile 1 to the Devils Knob Pit (S94/046226-055215). It was surveyed from a fencepost on Profile 1 (west side of main highway, the second fencepost north of former telegraph-post(about 10 feet high) across the former railway line to the Pit. The Profile has a bend in it on the Barrier Ridges.

Profile 2: Birdlings Flat Profile. From valley at back of Birdlings Flat (at north end of shingle ridges near the swamp 40 feet west of the drain), to the sea at the west end of the line of batches (S94/067228-056201).

Profile 3: From 30 feet west of fenceline (extending from Speight Ridge to the lakeshore), surveyed from water's edge parallel to the fence, the line of survey was extended in a straight line to Hapgoods Quarry and the sea. (S94/974232-973196).

<u>Profile 4</u>: Where Speight Ridge turns from east-west to north-east-south-west back to east-west, the profile is surveyed from lakewards of the east end of the bend (lake-edge) across the ridge to the sea. (S94/908213-912188).

<u>Profile 5</u>: From the lake-edge, half way between two fencelines which extend into the Lake (lakewards of a point 200 yards east of Bartlet and partners' farm buildings), the profile extends across ridges to the sea near Bayley's west boundary fence. (S93/862202-863180).

<u>Profile 6</u>: Profile passes from the lake-edge across the eastern end of the westernmost major depression, and 150 to 200 yards west of a belt of pines, to the sea via a parabolic dune's blown out middle. (S93/832196-835177).

<u>Profile 7:</u> Taumutu. From the lake-edge, where a drain enters a small inlet on the lake, across the ridges at the southeast end of a belt of pines, and in a straight line across the field behind. (S93/762185-753177.)

<u>Profile 8</u>: Across the barrier beach at the mouth of the Lake, west of the artificial opening of the Lake. (S93/766168-767167).

Appendix III A. Locations of Hooked Ridge Transects.

Transect 'A' (west to east) - S94/974232 approximately; on aerial photograph 2116/80 - the two vegetation projections west of the fenceline which trends into the lake and the one projection east of it. Surface is 1.3 feet above MSL.

Transect 'B' (west to east) - S94/986236 - 983234; A. Photo. 2116/80 - the three vegetation horns west of fence running into lake (fence of west end of former runway.) Surface is 0.5 to 1.0 feet above MSL.

Transect 'C' (west to east) - S94/017234 approximately; A. Photo. 2115/74 - westwards from end of vegetation horn opposite extension of fenceline from Speight Ridge towards the Lake-edge. Surface is .... feet above MSL.

Transect 'D' (north to south) - S94/974232 to 974224, along Profile III.

Transect 'E' (north to south) - S94/017237 to 017227; it crosses from lakewards of Transect 'C' and runs towards Speight Ridge.

Appendix III B. Random Turning Point Statistical Technique

Technique: Cole J.P., King C.A.M.; 1968: Quantitative Geography. J. Wiley & Sons 692 pp.

A series of observations are plotted as an ordered sequence. The points are joined and the number of turning points are counted. A turning point is defined as 'a point which is a peak or trough on the graph' (p129). At least 50 observations should be plotted.

The number of turning points in a random distribution at a 95% confidence level is

$$2/3\ (n - 2) \pm \left(\sqrt{\frac{16n - 29}{90}}\ X\ 1.96\right)$$

where n is the number of observations.

If the number of turning points falls outside this range there is a 95% probability that the distribution is non-random. This technique was applied to Transects 'B' and 'C'.

Transect 'B' n = 45 t = 13 (turning points).

For a random distribution the number of turning points at a 95% confidence level is 28.66 ± 5.45. The number of turning points falls outside the range and therefore there is a 95% probability that the shingle surface profile varies non-randomly., i.e. that the surface variation has some pattern.

Transect 'C' n = 49 t = 15

$$t_{(random)} = 31.3 \pm 5.67.$$

The actual number of turning points falls outside this range. There is therefore a 95% probability that the distribution (shingle-surface profile) is non-random.

One of the conditions for applying the technique is not satisfied in either transect. Both transects have less than 50 observations. The writer feels that the number of observations in each transect is close enough to 50 to accept the conclusions reached.

Appendix IV. Grain Size Parameters.

Samp. No.	Location	Mzϕ	σ_I	Sk_I	K_G
Beach Survey, March.					
48	S93/703152 1A	-2.85	2.59	0.19	0.55
49	1A	-1.64	2.88	-0.61	0.49
50	1B	-1.65	2.56	-0.56	0.57
51	1D	-4.33	0.83	-0.36	0.84
52	1C	-5.30	0.37	0.02	1,03
54	S93/756164 2A	-0.83	2.20	-0.58	1.83
55	2B	-3.19	1.51	0.24	0.75
56	2C	0.76	0.53	-0.03	1.01
57	2D	-3.10	1.14	0.67	2.29
59	S93/795173 3A	0.22	1.39	-0.32	1.25
60	3B	-2.15	1.41	0.20	1.64
61	3C	-2.00	2.44	-0.64	0.56
62	3D	-1.24	1.36	-0.53	1.03
64	S93/829177 4A	-2.34	1.27	0.09	0.74
65	4B	-0.21	1.30	-0.21	1.57
66	4C	-5.13	0.93	0.34	0.61
67	4D	-4.30	0.63	-0.17	0.74
70	S93/863180 5A	-3.13	1.82	0.09	0.87
71	5B	-0.52	0.90	0.21	1.18
72	5C	-4.83	1.17	0.60	0.99
73	5D	-3.04	1.43	0.29	1.12
75	S94/916188 6A	-2.69	2.23	0.47	0.64
76	6B	-0.70	1.06	-0.10	1.25
77	6C	-1.46	1.91	-0.12	0.76
78	6D	-2.68	0.71	-0.36	1.00
80	S94/972176 7A	-1.27	1.33	-0.09	1.03
81	7B	-0.64	0.75	0.22	1.12
82	7C	-4.18	1.59	0.67	0.77
83	7D	-1.98	1.84	0.16	0.81

Samp. No.	Location	Mzϕ	σ I	Sk I	K G
88	S94/972196 8A	-1.79	1.44	-0.53	0.63
89	8B	-1.90	1.05	0.15	1.44
90	8C	-3.38	1.49	0.16	0.81
91	8D	-2.20	1.14	-0.27	1.34
93	S94/040200 9A	-2.68	0.76	-0.15	0.88
94	9B	-1.94	0.73	0.29	1.46
95	9C	-2.06	1.12	-0.08	1.03
96	9D	-1.15	0.44	-0.23	1.09
98	S94/069201 10A	-4.91	0.83	0.07	0.60
99	10B	-3.71	0.73	-0.05	1.31
100	10C	-3.41	0.98	-0.14	1.06
101	10D	-2.43	0.20	-0.01	1.07
Barrier Transect					
106	S94/050202	-3.76	1.05	0.34	-0.70
108	S94/050204	-3.66	0.61	0.05	2.38
109	S94/050206	-3.91	1.19	-0.18	1.43
110	S94/050211	-4.25	0.70	-0.20	0.94
111	S94/056214	-3.68	0.49	-0.05	2.55
Lake-formed Ridges, Barrier.					
31	S93/836187	-0.16	1.13	-0.06	1.18
32	S93/836187	-1.01	1.25	-0.12	1.30
33	S93/837187	-1.05	1.24	-0.04	0.96
40	S93/866196	-1.27	1.76	0.66	0.69
112	S94/049238	-2.47	0.49	-0.24	1.36
113	S94/049238	-2.48	0.87	-0.36	1.11
Lake-formed Ridges, Western Lakemargins					
41	S93/763178	-1.11	1.40	0.23	0.51
42	S93/763178	2.59	0.42	0.09	1.15
87	S93/745238	-4.61	2.22	0.52	1.44
103	S93/768296	-3.58	2.23	0.38	1.06
104	S93/768296	-3.15	1.20	0.37	1.20

Samp. No.	Location	$Mz\phi$	σ_I	Sk_I	K_G
Western Inner Dunes					
24	S93/836187	0.41	1.08	0.25	0.69
25	S93/836187	0.46	1.23	0.15	0.78
26	S93/836187	1.15	0.75	-0.36	1.28
34	S93/844184	1.18	0.77	-0.12	0.90
35	S93/844186	-0.53	2.48	-0.39	1.11
36	S93/843188	0.92	1.05	0.04	0.85
37	S93/843188	0.56	1.37	0.06	0.80
38	" "	-0.31	1.85	-0.09	0.99
39	" "	-0.71	1.67	-0.07	1.00
Coastal Dunes					
69	S93/829177	0.30	0.79	0.19	0.98
85	S94/972196	0.73	0.67	0.05	0.81
86	S94/972196	0.77	0.63	0.17	0.98
107	S94/050202	0.23	0.82	0.20	1.10
Northeastern Lake-formed Ridges and Dunes					
Gebbies and McQueens Valleys					
10	S84/983330	3.68	0.58	0.41	2.51
12	S84/979334	3.97	0.74	0.55	2.50
15	S84/978332	4.21	1.61	0.51	3.61
18	S84/976334	3.56	0.33	0.00	1.09
19	S84/976334	4.80	1.91	0.71	3.24
20	S84/975333	6.69	3.85	0.77	1.20
Lincoln-Greenpark Huts					
114	S83/847375	2.76	0.54	-0.09	0.99
115	S83/885352	2.31	0.36	0.09	1.18
116	S83/889325	2.58	0.55	0.14	1.12
117	S94/914293	2.53	0.46	0.06	1.05

Appendix V. Formulae and Verbal Scales for Particle Size and Particle Sphericity.

Particle Size Parameters (Folk and Ward, 1957).

Graphic Mean:

$$Mz = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Inclusive Graphic Standard Deviation:

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

σ_I less than 0.35 ϕ	very well sorted
0.35 to 0.50 ϕ	well sorted
0.50 to 0.71 ϕ	moderately well sorted
0.71 to 1.00 ϕ	moderately sorted
1.00 to 2.00 ϕ	poorly sorted
2.00 to 4.00 ϕ	very poorly sorted
greater than 4.00 ϕ	extremely poorly sorted

Inclusive Graphic Skewness:

$$Sk_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2\,(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2\,(\phi 95 - \phi 5)}$$

+1.0 to +0.3	strongly fine skewed
+0.3 to +0.1	fine skewed
+0.1 to -0.1	near symmetrical
-0.1 to -0.3	coarse skewed
-0.3 to -1.0	strongly coarse skewed

Graphic Kurtosis:

$$K_G = \frac{\phi 95 - \phi 5}{2.44\,(\phi 75 - \phi 25)}$$

K_G less than 0.67	very platykurtic
0.67 to 0.90	platykurtic
0.90 to 1.11	mesokurtic
1.11 to 1.50	leptokurtic
1.50 to 3.00	very leptokurtic
greater than 3.00	extremely leptokurtic

Reference: Folk, R.L.; Ward, W.C. (1957): Brazos River Bar: A Study in the significance of Grain Size Parameters. *J. Sedim. Petrol.* 27 (1): 3-27

Effective Settling Sphericity (Folk, 1965)

psi (Effective Settling Sphericity) $= \sqrt{\frac{S^2}{L.I}}$

where L is Long diameter

I is Intermediate diameter

S is Short diameter

and the three diameters are measured at right angles.

Reference: Folk, R.L.; 1965: Petrology of Sedimentary Rocks. University of Texas Publication. 159 pps.

Appendix VI. Locations of Samples used for Form, Roundness, and Sphericity Analysis.

Analysis Number.	Sample Number.	Location
Beach Samples		
4	51, 52	McEvedys Culvert S93/703152.
5	56, 57	Profile 7 S93/756164.
6	61, 62	Profile 6 S93/975173.
7	66, 67	Between Profiles 6 and 5 S93/829177.
8	72, 73	Profile 5 S93/863180.
9	77, 78	Profile 4 S94/916188.
10	82, 83	Profile 3 S94/972196.
11	90, 91	Profile 2 S94/019198.
12	100, 101	Profile 1 S94/069201.
Samples from transect across Barrier		
13	106	A1 S94/050202.
14	108	A3 S94/050204.
15	109	A4 S94/050206.
16	110	A5 S94/050211.
17	111	A6 S94/056214.
Lakeside Ridges Samples		
18	103	(c) S93/768296.
19	104	(b) " "
20	87	Pit at Lakeside S93/745238.
21	119	Dickies Road section S83/788322.
Selwyn River Samples		
22	120	Coes Ford S83/807363.
23	121	Main Road Crossing S83/768373.
24	122	" " " " "

AppendixVII. Location of Beach Profiles on Kaitorete Barrier

Profile 1: From seaward end of fence on backshore, east of the road crossing the outlet of Lake Forsyth. (S94/068202).

Profile 2: Half a mile seawards from end of track leading to concrete blockhouse about three miles west of Birdlings Flat Settlement. Peg is a two by one inch wooden peg located 20 feet north of large tree-root, about 5 feet high, on the backshore. (S94/019198).

Profile 3: About three miles west of Profile 2, at the end of road leading to Hapgoods Sand Quarry (turn left before the first cattlestop about six miles along Bayleys Road.) Measurements taken from the top of a partly buried fencepost (the last post on a continuation of Bayley's east boundary fence through the sand-dunes.) This post is located 50 yards east of the entrance to the beach from the firing pad for upper air rockets (three large bolts in a concrete base.) (S94/972197).

Profile 4: Half a mile seawards from the lone pine tree approximately two miles east of Bayley's house. Turn south across field on a direct line between windmill (north of road) and the pine tree. Peg is three inches by two inches and is located partway down the foredune. On the top of the foredune there may be a small pile of logs. (S94/916188).

Profile 5: Quarter of a mile seaward from the safe driving limit of Bayley's west boundary-fence. Measurements taken from the top of a round fencepost (a new post) on top of foredune. Profile runs normal to the shore from this point and is about 20 to 30 feet west of fenceline on the lower part of the beach. (S93/862181).

Profile 6: Seawards along the fence-line about three-quarters of a mile east of the end of the Barrier proper. Fench crosses the 'road' and really marks the safe driving limit along the Barrier. Peg is located about seven feet below the fencepost on top of the foredune. (S93/792173).

Profile 7: Church Road, a quarter of a mile west of the Taumutu settlement. Across the stream at the end of the road. Peg is located on the backbeach on the right-hand side of opening to the sea. It is seawards (about one foot) of an upright tree-stump. (S93/756165).

Appendix VIII. Landsberg-Bagnold method of calculating Wind-Resultants (adapted by Jennings, 1957.)

Landsberg-Bagnold method

$$b = s \sum_{j=3}^{12} n_j (v_j - Vt)^3$$

b - individual vector of vector diagram

s - 10^{-3}

n_j - frequency of wind in given direction with speed (V) in mph.

j - Beaufort speed no., 3 to 12. j = 3 is Vt (threshold veloc.)

Vt - speed of 10 mph (threshold velocity for drifting sand.)

All vectors are used in this method. Jennings modified this for coastal dunes to include only onshore wind vectors.

Applied to parabolic dunes on Western Kaitorete

Averages of wind data collected at Taumutu between 1951 and 1956 (1955 excluded) were used in the calculations. Only onshore vectors (southeast, south, and southwest) were used. Beaufort wind scale divisions were absent and wind categories of 10mph, 24 mph, and 39mph were used.

b_{se} = 6.050 units

b_s = 22.360 units

b_{sw} = 19.635 units

A wind vector diagram was drawn and the resultant was measured. The Onshore Resultant is 13° to 14° east of north.

The average angle of dune axes is 15.8° east of north and 78% of readings were between 12° and 18°.

Appendix IX A. Determination of Effective Fetch

Method:

1. 15 radials are constructed with 6° between each radial (out to 45° each side of the central direction).
2. Each radial is extended until it reaches the opposite shore.
3. The length of each radial is multiplied by the cosine the angle between the radial and the central direction.
4. Values for each radial are summed; the sum is divided by the sum of the cosines of all individual angles.

$$F_{eff} = \frac{\sum F_i \cdot \cos \alpha_i}{\sum \cos \alpha_i}$$

α is the angle to the main wind direction.

Reference: Waves in Inland Reservoirs - Summary Report on Civil Works Investigation Projects CW-164 and CW-165. Technical Memorandom Number 132. 1962.

Appendix IX B. Anemometer Station at Taumutu

The instrument was a 'Dines pressure tube' anemometer. It was located near the eastern end of a small headland at Taumutu, S93/768175 (1943 Edn.). The anemometer head was 34.25' above ground level. Ground level is 10' above MSL.

All directions recorded are in degrees true.

This information together with that about the quality of the wind records, was supplied by the N.Z. Meteorological Service, Wellington.

Appendix X. Pollen Analysis: Peat from Drain, Lower Lake Road, Lake Ellesmere.

Location: Peat is located at the base of a drain crossing Lower Lake Road (S93/751205).

Analyses were performed by Dr's. B. Molloy and N.T. Moar of the Botany Division, D.S.I.R., Lincoln.

Wood and bark specimens from the peat were Matai (Podo. spicatus).

Seed fragments present in the peat were Elaeocarpus hookerianus (Pokaka).

Pollen Analysis:

Pollen Type	Percentage. Pollen Total.
Trees	
Podocarpus dacrydioides (kahikatea)	7
P. Ferrugineus (miro)	1
P. Spicatus (matai)	9
P. totara type (totara)	3
Podocarpus (distorted)	5
Dacrydium cupressinum (rimu)	1
Phyllocladus (tanekaha, toatoa)	2
Small trees and shrubs	
Ascarina	+
Coprosma	3
Coriaria	tr
Elaeocarpaceae (pokaka)	2
Hebe	tr

Pollen Type	Percentage Pollen total.
Leptospermum scoparium (manuka)	37
Myrsine	1
Myrtus type	2
Plagianthus type	1
Papilionaceae	tr
Pseudopanax	1
Rubus (Rosaceae)	1
Tetrads	1
Grasses	
Cyperaceae	16
Compositae	1
Astelia	tr
Leptocarpus	1
Gramineae	tr
Ferns	
Monolete ferns	3
Trilete ferns	tr
Sphagnum	tr

Appendix XI. Carbon 14 Dates Referred to in the Text.

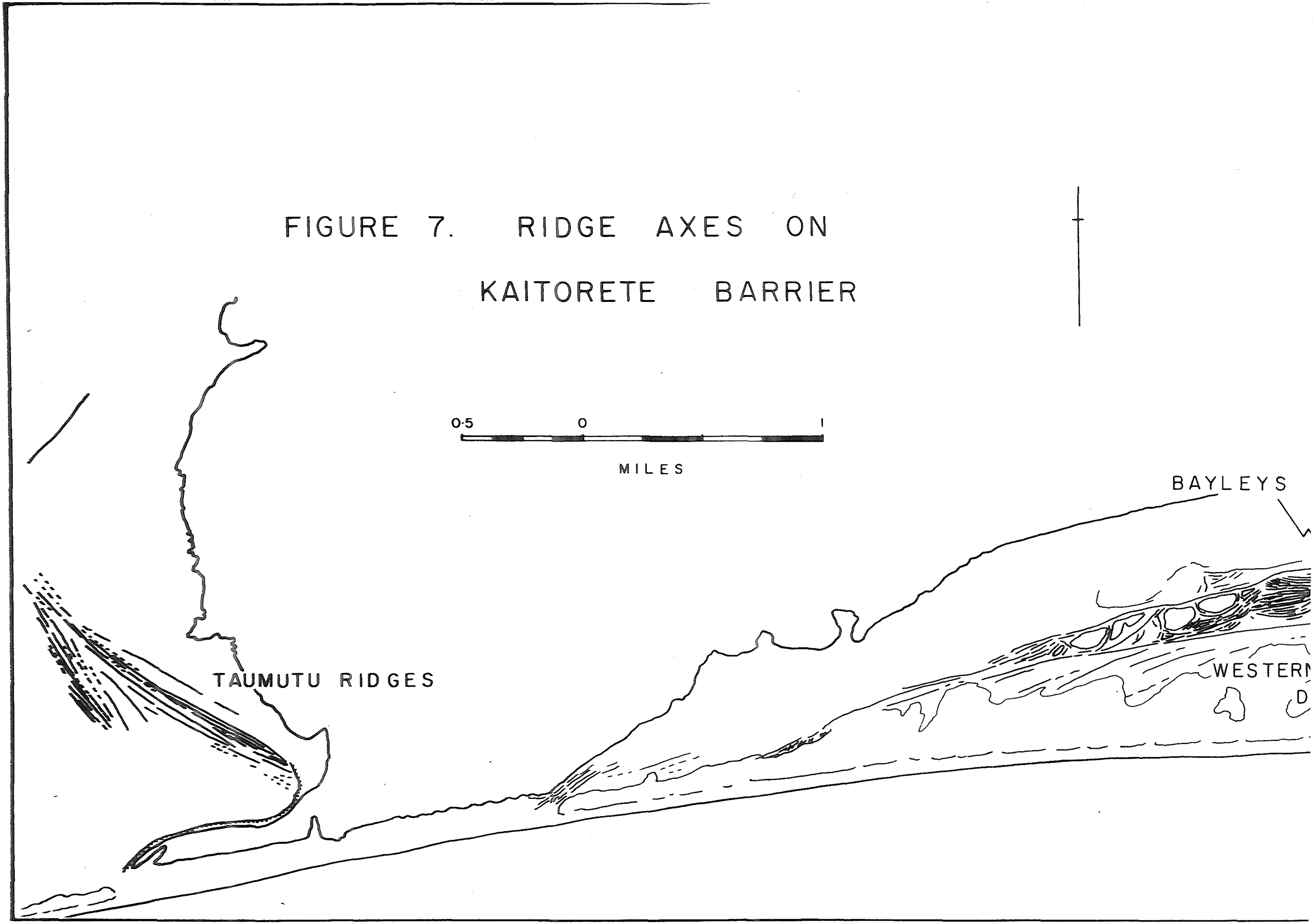
S83/501, 9400 yrs ± 120 years B.P., located at S83/891322 73 feet below mean sealevel. Wood was dated from peat at the base of grey sand in well-hole S83/212.

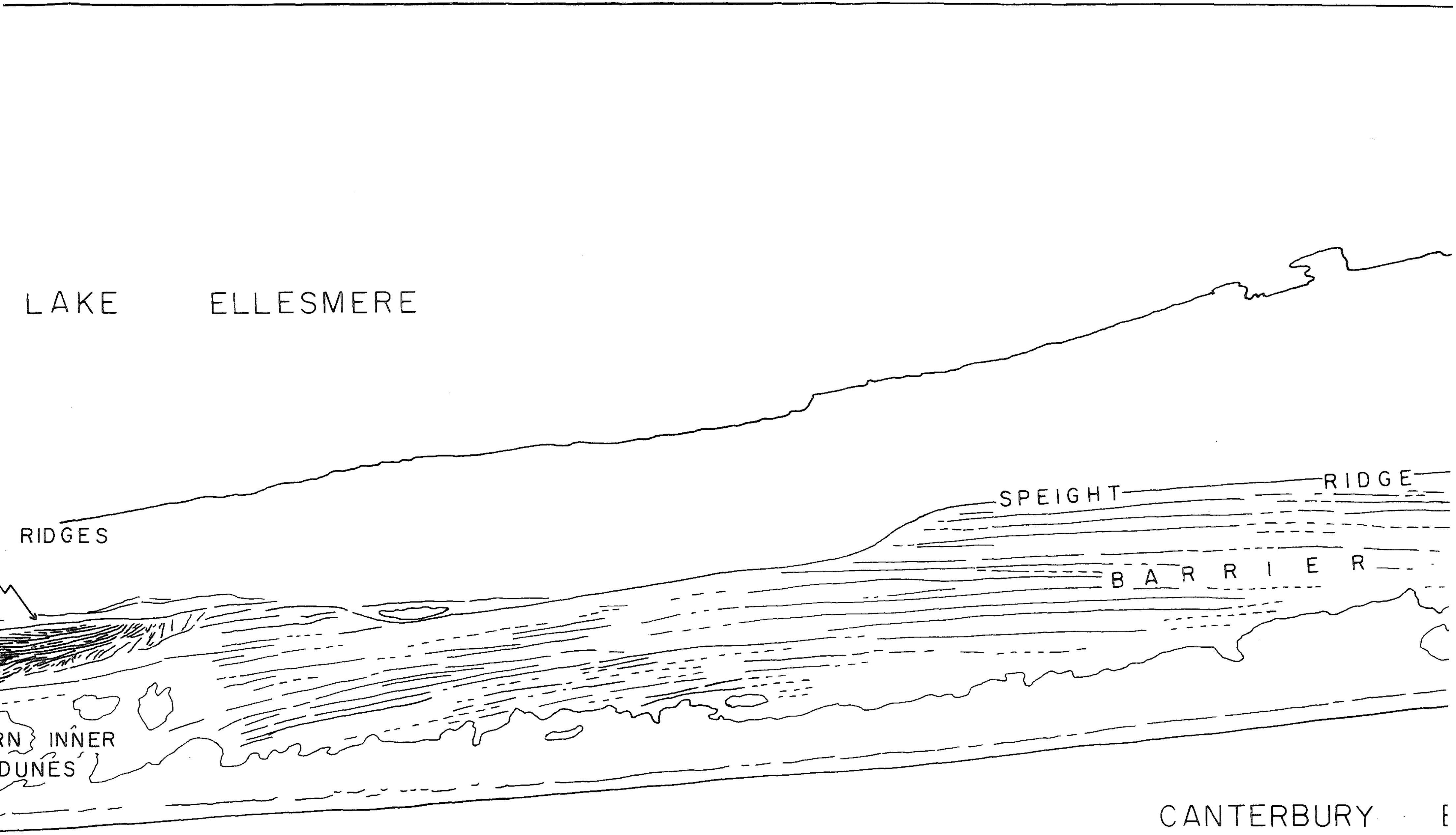
Reference: SUGGATE R.P. 1968: Postglacial Sealevel Rise in the Christchurch Metropolitan Area, N.Z. Geologie En Mijnbouw 47 (4): 291-297.

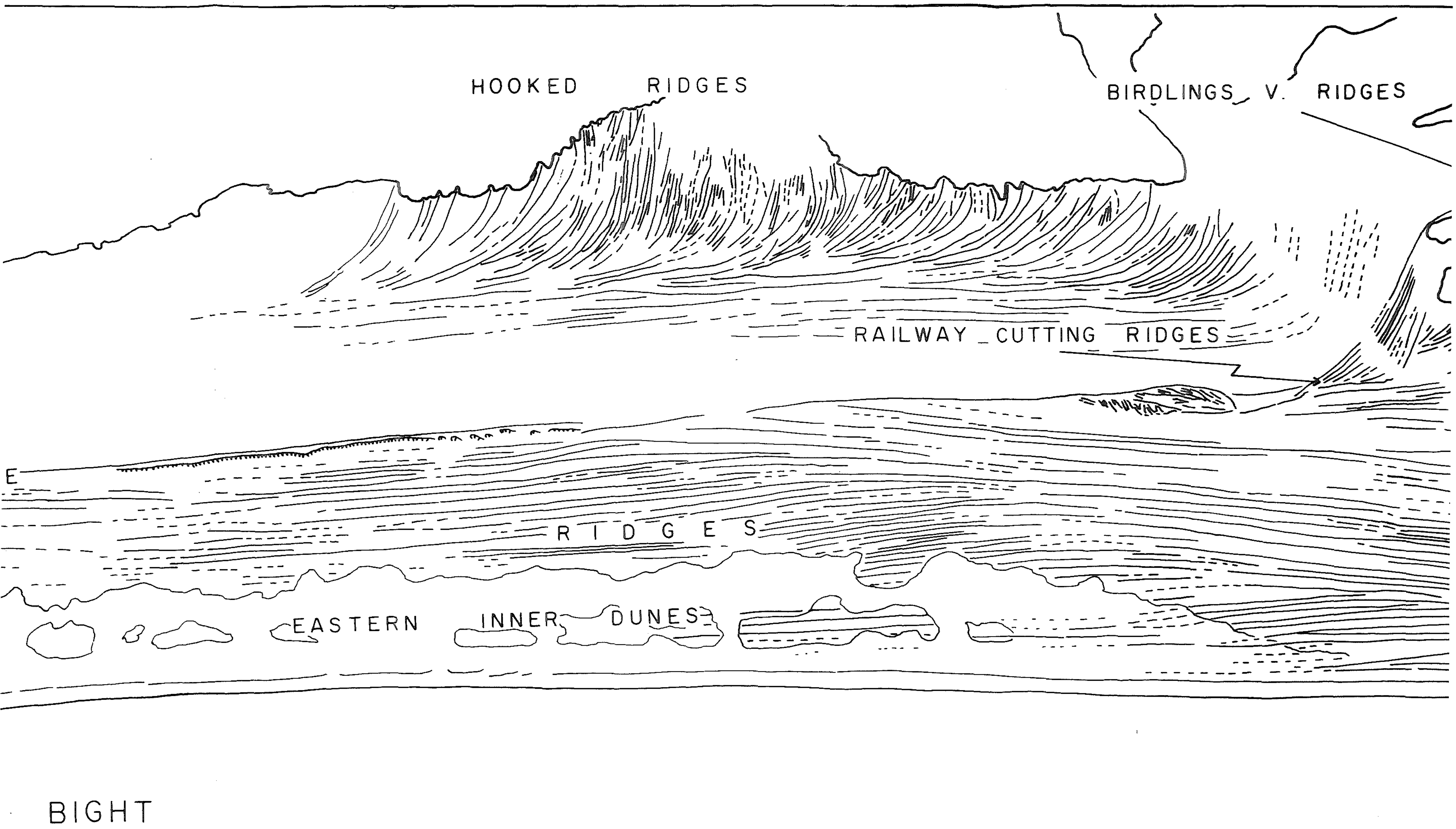
S83/511, 8895 yrs ± 130 yrs B.P., located at S83/862418 approximately 20 feet ± 5 feet above mean sealevel. The dated wood sample was three feet ± 0.5 feet beneath the surface. Wood (*Podocarpus dacrydioides*) in peat, was resting on sand beneath silty clay.

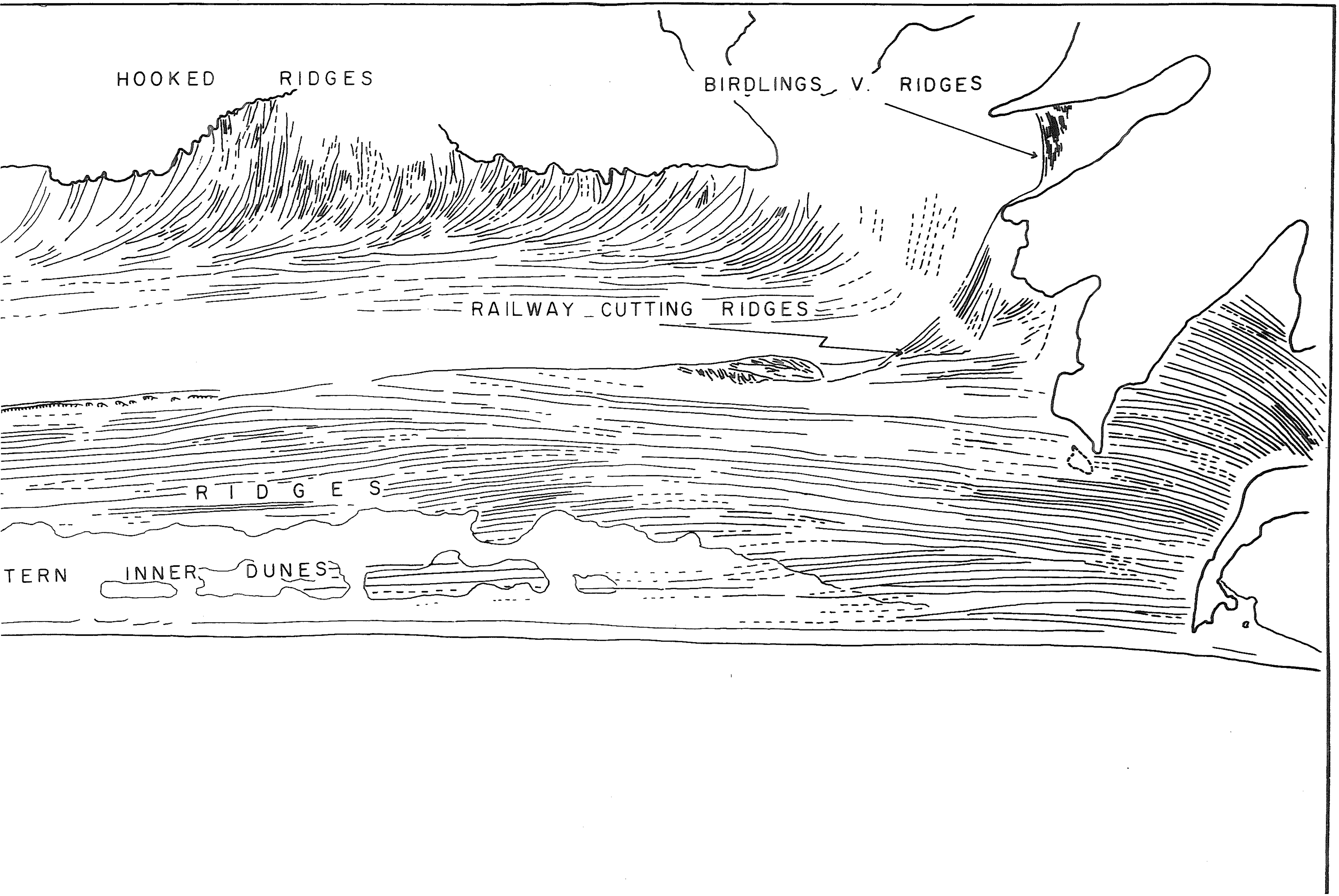
Reference: SUGGATE (1968, op. cit.)

FIGURE 7. RIDGE AXES ON KAITORETE BARRIER




LAKE ELLESMERE
RIDGES
SPEIGHT RIDGE
BARRIER
RN INNER
DUNES
CANTERBURY


HOOKED RIDGES
BIRDLINGS V. RIDGES
RAILWAY CUTTING RIDGES
E
RIDGES
EASTERN INNER DUNES
BIGHT


HOOKED RIDGES
BIRDLINGS V. RIDGES
RAILWAY CUTTING RIDGES
RIDGES
TERN INNER DUNES
a