Studies of the Scottish Shoreline

by

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Preface

This thesis is the product of three years' research in the Department of Geography, University of Glasgow. I have spent part of the time in the field and have travelled the western and north-eastern coast of the Mainland, the islands of the Inner Hebrides and the Orkneys islands. The results of my research are here arranged in three parts. Part I comprises a discussion of the shoreline configuration of Western Scotland. An hypothesis of differential submergence is put forth in an attempt to explain the shoreline configuration. Evidence in support of this hypothesis is sought for from the construction and interpretation of a bathymetrical map of Western Scotland and from the study of soundings and of the longitudinal and cross profiles of rivers of the present drainage. I have drawn many profiles of both land and submarine features and calculated the gradients of the river thalwegs and valley sides, with the result that I have arrived at an estimation of the amount of differential submergence. Chapter I and II have been accepted by the Editor of the Geografiska Annaler of Sweden for publication within this year.

Part II is wholly devoted for the study of raised shorelines. Of the many areas in which I have observed and examined, I have included only those regions to the raised shorelines of which I have been able to devote adequately detailed study. In describing the field observations, I have used a terminology and working principles which it seemed good to explain in chapter V. In chapters XIII and IX studies of glaci-fluvial deposits have been included, as they are in these two chapters, connected with the discussion of raised shorelines and the physiographical history of the regions.

Part III is composed of papers on the present day shore deposits. Perhaps the interpretation of the Ayres of Orkneys and the classification of storm deposits are the more outstanding points in this part. Chapters XI and XII have been published in the Geological Magazine and the Scottish Geographical Magazine respectively and it is hoped shortly to publish chapter X.

In the appendix, I have included three short papers. The easay on Pollen Analysis is the result of three months' laboratory work. I learned the technique from Dr. G. Erdtman of Sweden and found it applicable to Scottish climatic and chronological problems of recent times. This paper was read before the Geological Society of Glasgow on April 8th., 1937, and will be published in the Transactions of the Society in the coming year.

The maps, text figures and plates are entirely my own work.

It is a pleasing duty to acknowledge the aid of Mr. A. Stevens, Head of the Department of Geography, University of Glasgow, for his most valuable supervision over my research, his help in revising the manuscript and his interest and encourgement in various ways. I am also deeply indebted to Professor E. B. Bailey, Dr. T.W. Tyrell and Dr. W.J. McCallien of the Department of Geology, University of Glasgow for their various asistance in connection with my research. To Dr. G. Erdtman is due my gratitude for his kindness in demonstrating his new technique of Pollen Analysis and to Professor J. Walton of the Department of Botany, University of Glasgow, for his permission of utilizing the laboratory for pollen studies. Special thanks are due to Mr. Bowen, formerly member of staff in the Department of Geography, University of Glasgow, who has revised a part of the manuscript; and to many friends and fellow workers who have rendered me valuable services.

C O N T E N T S.

Part I

Theoretical Discussion of the Configuration of the Shoreline of Western Scotland.

Part II

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Part III

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Appendix

Part I

THEORETICAL DISCUSSION OF THE CONFIGURATION OF THE SHORELINE OF WESTERN SCOTLAND

Chapter I

Introduction

The Western shoreline of Scotland stretches from Cape Wrath southward down to the Firth of Solway, having an approximate length of about 1,500 miles. Fringing the western shore, there are as many as 5,000 islands which together have a total shoreline length of about 1,500 miles.* The shoreline on the mainland is very indented indeed. Arms of the sea have penetrated deeply inland, sometimes to as many as thirty miles. On account of this indented character, the west shoreline is probably twice as long as the east. The coastal region of Western Scotland has abundant fresh-water lochs. Their resemblances to the sea lochs are so close that they cannot fail to be of common origin. Geologically, the western shoreline is essentially formed in hard, resistant crystalline rocks. To the north of the Great Glen Fault, Lewisian Gneiss predominates, the latter is separated from the southern schist formations by intervening Torridonian sandstone of probable pre-Cambrian age. Some of the islands, for instance, Skye and Mull, are formed of Tertiary igneous rocks, while the Outer Hebrides form an isolated chain of Lewisian Gneiss. The geology of this shore is in sharp contrast to that of the east which is chiefly formed in younger rocks largely of paleozoic age, and, in some localities, boulder clay and raised

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* The figures are arrived at by measuring upon the one-inch O.S. maps with a curvimeter.

beaches margin the present sea. There are, however, regions where the crystalline schists do reach the shore and in some localities older rocks form headlands. Apart from the geological differences, the eastern shoreline has few fresh-water lochs comparable to that of the west and has no islands worth mentioning. The only indentation of the otherwise straight shoreline is found where river mouths have been drowned. These 'firths' are the lower parts of the well-established drainage issuing at the eastern shore.

Such conspicuous differences between the western and the eastern shorelines have been noticed by many students of physiography who have constantly attempted to seek their origin. Gregory pointed out that the sea lochs are restricted to hard and resistant rocks and that they are arranged in a net-work which has no consistent relation to either geological structure, by which he means the grain of the rocks, or to ancient river systems. (Gregory, I pp.156) He further denied the genetic relation of the lochs with glacial erosion because there is no consistency between the shape and position of the deepest hollows in the loch basins and the direction of ice-flow as determined from striation of rock surfaces. Believing that both sides of Scotland have been uniformly glaciated, he rejected the suggestion of a possible differential glacial erosion. (Gregory, I, pp.162) He suggested that Western Scotland has been uplifted and shattered by regular, intersecting cracks which determined the genesis of the present sea lochs. Along these cracks, rivers were initiated and their valleys were later modified by ice erosion into trough-shaped valleys. There are, however, many sea lochs with regard to which Gregory failed to demonstrate dependence on shatter belts and which are left unexplained otherwise. We cannot doubt the structural control in the physiographical development of a region but this control may not be genetically related to individual physiographical features. This control, to a very great extent, is revealed by coincidence, as it were accidental, in the course of physiographical evolution. So far as present geological knowledge goes, the structural cracks are much more ancient than the existing drainage pattern and the cases in which they coincide with basins ans lochs are too few to justify general conclusions.

Geikie was a strong advocate of the idea of submergence. He believed that the sea lochs of the western coast are old valleys submerged beneath the sea and that they give evidence leading to the idea of a greater submergence in recent times of thewestern side of Scotland than of the eastern. (Geikie, A. pp.127) Submergence is widely accepted in all circles, even by extreme glaciologists. Geikie examined the successive stages of the sea loch development and found that the amount of submergence is the main factor in determining the depth to which the barrier of the loch basin might be submerged, If the submerged land gradually rose, the lochs would be isolated and converted into fresh-water lakes. He went on to say that the straths of Eastern Scotland would have been converted into sea lochs like those of the west, had sufficient submergence affected the eastern side of the country. The correctness of the submergence theory is supported by the reconstruction of buried river channels connected with the existing rivers of Scotland.* It is indicated by such reconstruction that the former land surface stood some 500 feet higher than at the present day and that fromer sea level probably coincided with the outer edge of the present continental shelf.

Geikie has also suggested that the deep basins revealed by the numerous soundings of the fresh-water lochs of Scotland were glacial in origin. He gave many examples showing that in some cases, rock basins coincide with fractures, but he favoured Ramsay's view that the glens were ice formed and the Scottish lochs, without exception, were also the product of glaciation. "Those that are held in rock basins exhibit along their margin, on their islets and on their bottom, as far as it can be examined, the same polished and striated rock surfaces which are found universally throughout the Kingdom." (Geikie, A. pp.181)

Peach and Horne followed more or less the same line as Geikie, admitting the importance of ice wotk as well as a certain influence by shatter belts and fractures on the origin of the sea lochs and lake basins. Submergence is appealed to

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* The boring records: Pre-glacial valley of Mersey,160 ft. below sea level; former land surface at Furness now 45 0 ft. below the sea; buried valley of Bo'ness now 500 ft. below and the buried valley of the Clyde now 210 ft. below the sea.

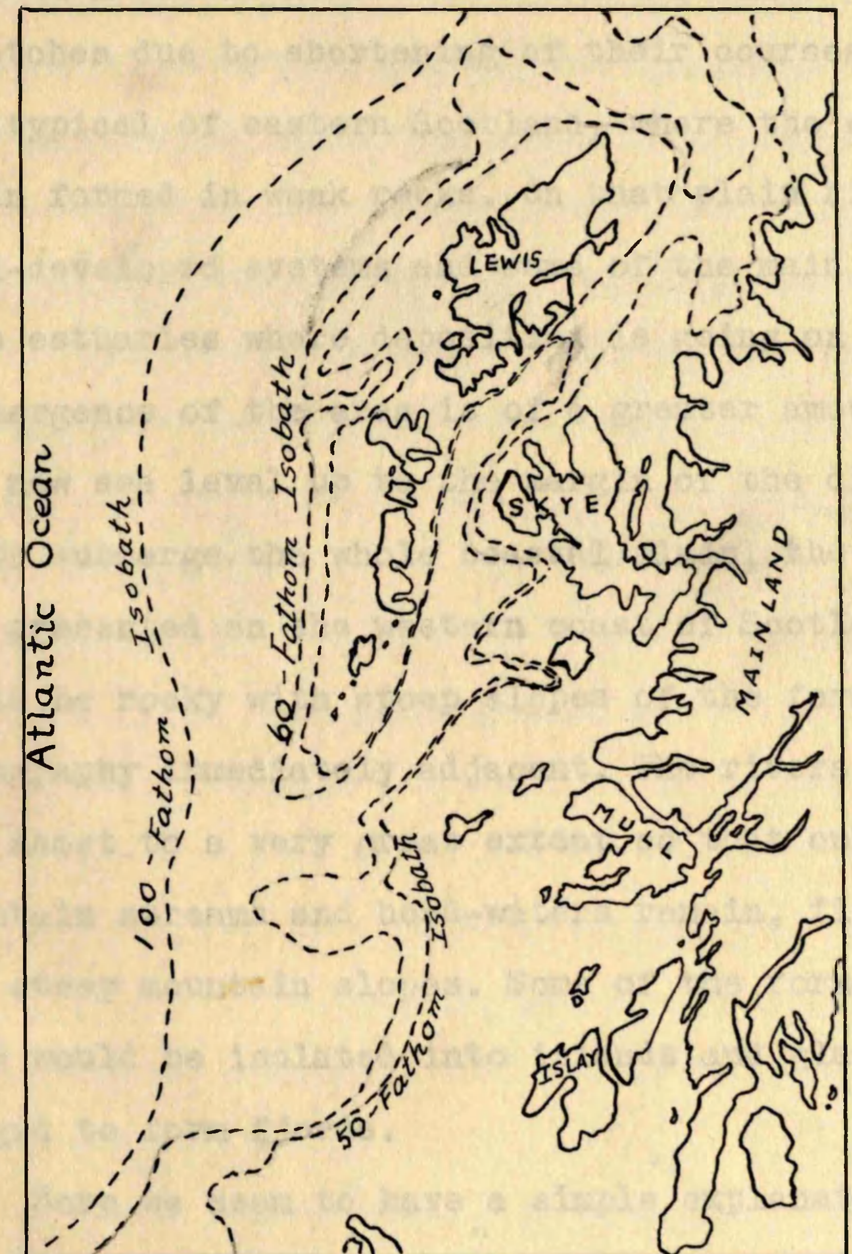
by Horne who believed the submarine plain of the North Minch is of fluvial origin. He also mentioned the possibility of a greater submergence of Western Scotland than the eastern.

However explanations of these coastal features differ, on one point they all agree: that submergence gives the final touch to the formation of the sea lochs. Valleys may be guided by structure, may be eroded by ice, but if they had not been submerged, whether due to increase in sea volume by melting of the ice or due to a positive movement of sea level, there would have been no fjords.

Let us study this problem from a physiographical view point. Theoretically, a shoreline in its youthful stage of development is manifestly more indented in character than a mature shoreline which has been subjected to marine action long enough to remove the major irregularities. The shoreline of Scotland is known to have been submerged and its features must depend not only on later development since the submergence but also on the former configuration of the land area before the submergence. The simple difference of stage of development may account for features of local importance but certainly not for the numerous features which accompany the shorelines of Scotland. Moreover the hardness of the crystalline rocks which formed both the whole western Highland shoreline and the Central part of the eastern Highland shoreline would greatly resist marine erosion following the submergence of Scotland while the soft formations bordering the rest of the east coast would give way easily. Nevertheless, rock resistance seems to have exerted little influence in producing differences between the scenery of the eastern and the western shores of Central Scotland. Both sides are composed of the same crystalline rocks and, yet, the eastern side is much less indented than the western. Although in a few places alternate hard and soft layers have been differentially eroded by the sea giving rise to striking examples of the control of rock resistance, (Kilmartin and Knappdale districts) generally the western shore of Scotland shows neither the effect of differential erosion due to difference of rock resistance, nor the effect of the grain of rocks on the formation of the sea lochs. Some of the sea lochs, for instance, Loch Leven and Loch Duich, lie transversely to the structural axis of the rocks.

Unless the submergence involves a peneplane surface or a young undissected alluvial or similar plain, the submergence of a former land surface always leads to an irregular initial shoreline of submergence. The nature of the irregularities would be further determined by the amount of submergence: irregularity normally increases with increasing submergence. A land area having mature drainage, gentle relief and a coastal plain bordering the sea may have a divide-region of high relief where the physiographical development has still a youthful aspect. If the sea rises and only partially submerged the coastal plain, the initial shoreline of submergence would

Fig. 1. Map showing the 50-, 60-, and 100-fathom isobath of Western Scotland. Minor irregularities have been greatly generalised.



be irregular with few drowned mouths of trunk rivers which are the equivalent of the estuaries or 'firths' of Scotland. There would still be a coastal plain but narrower than before. Rivers draining into the sea would tend to aggrade within lower stretches due to shortening of their courses. These conditions are typical of eastern Scotland, where the coast is partly a plain formed in weak rocks. On that plain rivers belong to well-developed systems and some of the main streams drain into estuaries where deposition is going on rapidly. If the submergence of the area is of a greater amount and has brought the new sea level up to the margin of the divide-region, so as to submerge the whole coastal plain, the result is what is now presented on the western coast of Scotland. The shoreline would be rocky with steep slopes of the former mountainous topography immediately adjacent. The rivers would have been cut short to a very great extent so that only the former mountain streams and head-waters remain, flowing swiftly down the steep mountain slopes. Some of the former high mountain tops would be isolated into islands and glacial trough submerged to form fjords.

Here we seem to have a simple explanation for the differences in configuration between the shorelines of western and eastern Scotland. But there is still one point which will be considered in later chapters but will here be briefly mentioned. The lochs of the western coast are different from the firths of the eastern coast in the respect that the later are undoubtedly submerged rivers, for their bottoms have a gentle seaward slope, while the former have trough-shaped valleys with irregular bottoms arranged in basins separated by barriers. Such characters are not merely the result of a greater submergence but also involve glaciation.

Having suggested this hypothesis in explanation of the existing shoreline features of Scotland, we now proceed to examine more closely and seek to prove that Western Scotland has been submerged to a greater degree than the east.

Chapter II

The Submarine Features of Western Scotland

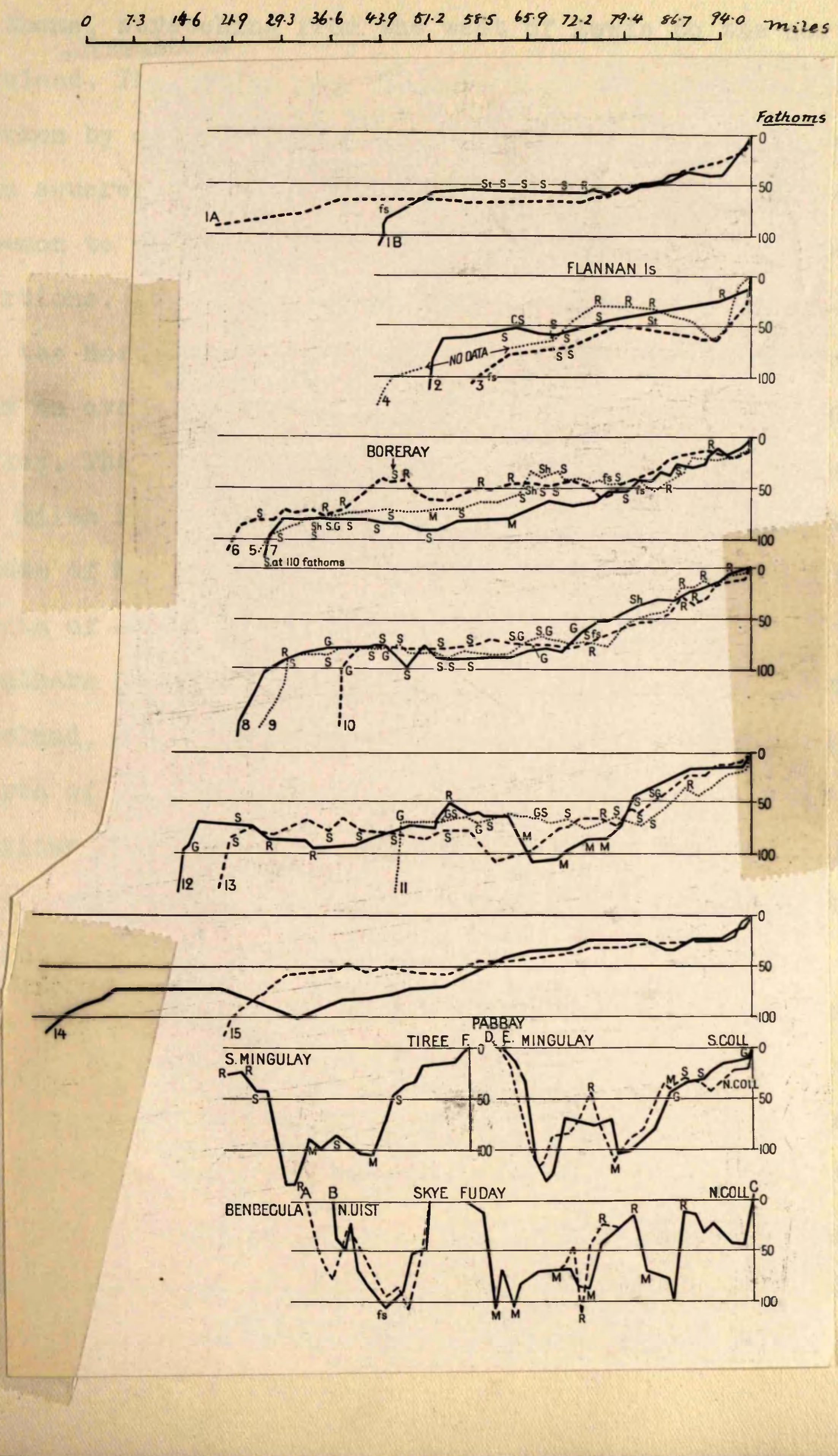
The bathymetrical map (Map I.) is drawn from the Admiralty chart No.2635. Surveyed contours are shown for depths of 10, 30, 50 and 100 fathoms while the interpolated lines at every ten-fathom interval have been drawn by the writer. West of the Outer Hebrides, the soundings are few in number below the depth of 60 fathoms, yet the contour drawn in this region appear fairly accurate. They are drawn with referenc to the features shown in the profiles projected along lines of soundings. Owing to the great variation of the depths in the sea lochs, no attempt is made to contour them.

I. Continental Shelf

According to Mackinder,(pp.25) the sea bed around the British Isles slopes down from the 100-fathom line, which marks the outer edge of the continental platform, to depths as great as 1,000 fathoms. Examining the continental shelf from the map, it is found that bordering the Outer Hebrides, the sea bed slopes gradually away from the islands. There is a well-featured continental platform at the average level of 74.9 *

* Calculated by the writer from total number of soundings available.This procedure seems justified to the extent that the soundings available represent fair sampling.

Profile 1 - 15, A-F.



fathoms, stretching from the west of Lewis to the north of Ireland. The platform is almost continuous, although it is broken by deeper trenches and higher shoals. The trenches in the squares (sq.) B 5 and B 11 with the bank at the corner common to squares B 8 and C 9 divide the platform into three portions. The northern portion bordering the Flannan Islands in the North and the St. Kilda group of islands in the south, has an average depth of 74.9 fathoms and a maximum width of 18 miles. The outer edge edge of it due west of St. Kilda, is about 65 miles from Harris. The Middle portion stretching from the south of St. Kilda to the island mentioned above has a maximum width of about 35 miles and an average depth of 74.3 fathoms. The southern portion is rather broken and narrow when approaching Ireland, having a maximum width of about 18 miles and an average depth of 75.6 fathoms. It is very interesting to note that the maximum development of the platform is in the middle portion while towards both north and south, it gradually becomes narrower and finally disappears.

With the disappearence of this 75-fathom platform, its place is occupied by a high-level one, which occurs immediately north of the 75-fathom platform in the northern portion at an average depth of 55 fathoms. It lies in front of a line from the Butt of Lewis to Flannan Islands and is triangular in shape. (Sq. E 1, E 2 & F 1) A high platform occurs also to the N.W. of Ireland at an average depth of 52.4 fathoms and have a maximum width of 26 miles.

Whether this difference of level is the result of a structural cause: either the down warping of the land in this region or the down faulting of this particular block;* or is due to the development of the 75-fathom surface at the expense of the 55-fathom surface is still an open question. The difference of the thickness of marine deposits is unlikely to be responsible for such great difference of depth amounting to 20 fathoms.

The covering of loose deposits on the sea bottom and the difference in level of the platform seem to indicate that the platform is not formed by marine erosion. When more closely examined, the submarine features suggest that the continental shelf is a submerged land surface. Attention may first be directed to the existence of a trough valley between the Flannan Islands and Gallon Head, Lewis and secondly, to the basins on the continental shelf. The trough valley, trending N-S, reaches a depth of 79 fathoms. A low col of 45 fathoms separates the valley from its seaward continuation which turns to the S.W., sloping gradually and draining over the continental scarp through a narrow passage, (Sq. B 5) south of the Flannan Islands. The course of this valley is sinuous suggesting the course of a former river. Soundings along the thalweg of the

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* Compare Map I with Figs. I and II of O. Holtedahl's "On Fault Lines indicated by the Submarine Relief in the Shelf Area west of Spitsbergen." Saertrykk av Norsk Geog. Tidsskrift, Bind VI Hefte 4, Oslo 1936.

valley revealed rock at from 67 to 78 fathoms, thus indicating that the valley is rock floored.

South of the valley, in squares B-C 6, a basin is seen having a depth of about 85 fathoms. It is completely encircled by soundings greater than 80 fathoms except to the north where a narrow opening connects it with the valley. It is covered with mud and sand, and its shape can hardly be attributed to fluvial erosion. It is explicable as a hollow excavated by ice, during the Ice Age, into the present continental shelf. The ice in the basin might well have drained out through the narrow gap at B 5 and jointing the ice stream of the valley and it might have overdeepened the passage to over 90 fathoms.

Another basin occurs south of Outer Hebrides in squares C-D 9 & 10, north of Stanton Banks. This basin, also completely encircled by higher grounds, has a maximum depth of 104 fathoms. It is covered with sand and mud. As it will be shown later, this basin bears direct relation to the inland submarine features. South of Stanton Banks, another basin having a depth of about 100 fathoms can be traced. The area west of the basin has not been adequately charted and it is therefore uncertain whether or not there is a trench in B 11 leading from the basin to the outer edge of the shelf.

A few minor features may be mentioned. The outer edge of the continental shelf is sometimes very steep,(Profiles 11-13) bending downwards to depths over 180 fathoms at an sharp angle.

The scarp bordering the northern parts of the continental platform is generally less steep and in places it is rounded-off at the edge. The smooth form of the edge is probably due to ice action during maximum glaciation.(Prof. 1 B, 2-6, 8-10, 14-15.)

Rock is more commonly met with at high levels. Rock platforms occur below both the Flannan Islands and the St. Kilda groups islands. Rock shelves are found at the levels between 10-30 fathoms and between 40-50 fathoms.

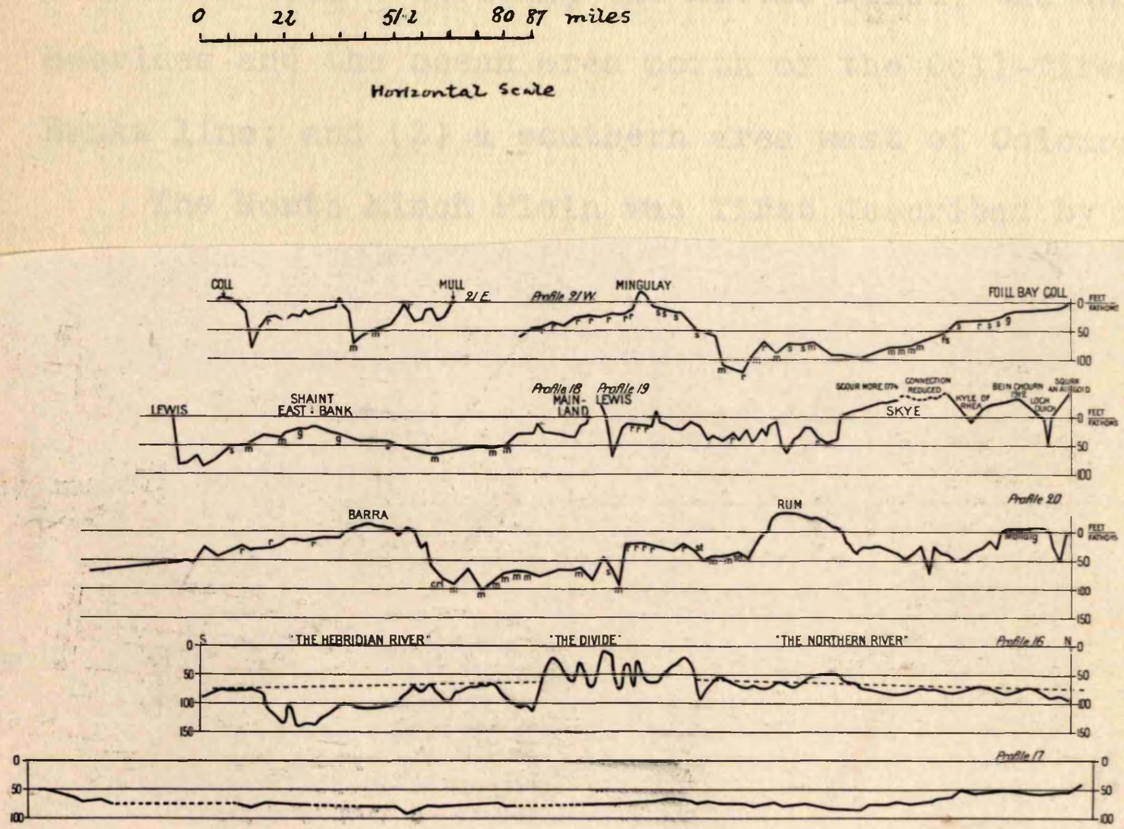
Judging from the depth of the outer edge of the submarine platform in the west of Scotland, the former sea coast lay approximately along the isobath of 85 fathoms.(510ft. 155 m.)

II. Deeps and Former Drainage (Map II.)

The sea bottom between the mainland and the eastern coast of the Outer Hebrides is extremely irregular. It is characterised by steep rises and descents, depths of over 100 fathoms may be found adjacent to shoals of 20 or 30 fathoms. From the profiles (prof.18-21), the sea bed is known to consist of valley and trenches, mostly trough-shaped,* and deeps reaching 130 fathoms or more. The persistence of these irregularities of the sea bottom is due to the fact that this region has been protected by the bulwark of the Outer Hebrides from severe wave

*The degree of slope of afew of these troughs have been calculated by the writer and are indicated respectively on the profiles. It is sufficient here, to say, that they have an average slope of about 1 in 18.

Profile 16 - 21



erosion and the former topography of the submerged landsurface is therefore preserved.

This area can be divided onto three parts: (1). A northern portion north of the Trotternish Point, Skye - Shiant Islands - Ru Uishenish,Lewis line, known as the North Minch Plain; (2) A central area comprising the Little Minch, the Gulf of the Hebrides and the ocean area north of the Coll-Tiree-Stanton Banks line; and (3) a southern area west of Colonsay and Islay.

The North Minch Plain was first described by Peach and Horne as a plain carved out by rivers which once flowed northward.(Peach,I pp.457) The gentle topography of the sea bottom is shown in profile 18. The sea bottom slopes gradually northward and reaches 90 fathoms at the edge of the square F 1.(Profs. 1 A, 16) The southern part of this area shows more diversified relief of valleys and ridges. (prof. .19) The Shiant East Bank stands out as a shallow divide between the two valleys on its east and western sides. The valley running northward on the western side, bordering the island of Lewis has a bottom depth of 60 fathoms and it gradually attains a depth of 70 fathoms around the Butt of Lewis. The bottom is remarkably flat and is covered with mud. The valley east of the Bank is about 70 fathoms deep and a low col of 40 fathoms separates the valley from its northern continuation, which gradually attains the depth of 70 fathoms in square H 2. These two valleys are the remanants of the former rivers to which the formation of the

North Minch Plain is attributed. They probably meet at the 70-fathom basin in square H 2, where the main stream turned to the N.W. draining over the continental scarp beyond F 1. The continuity of the depression, the smoothness of the bottom and the gentle gradient of the slope, being 1 in 3900 between the 60 and 70 fathom-isobaths, support the suggestion of the fluvial origin of the submarine features.

Attention must here be drawn to the deeps of this area. On the western side of the North Minch Plain, narrow deeps occur immediately north of Shiant Islands. These deeps coincide with the trend of the upper parts of the western river suggested above. On the eastern side of the area, a deep occurs east of Rona and Rassay islands, and can again be considered as being the head-waters of the former eastern north-flowing river.

The river system seems to have been initiated on a 50-fathom surface. The valleys developed at the expense of this surface and reached maturity, leaving the 50-fathom surface as low interfluvial plateaus.

The central area lies south of the rocky barrier of Trotternish Point, Skye - Shiant Islands - Ru Uishenish, Lewis line. A narrow but deep trough, over 132 fathoms, is conspicuous along the coast of the small islands south of S. Uist. This trough is 35 miles long being carved in a 70-fathom surface ~~xxxkk~~ by which it is surrounded. There are six deeps scattered about in the area of the Little Minch as if they were isolated basins. They all trend N-S and are obviously connected with the southern trough, which runs along the Outer Hebrides and seems to be a former river valley with southward flow. It turns to the west around the southern tip of the ridge on which the Long Island stands and drains into a basin on the continental shelf.(See p. ,Sq.B-C 8,9.) This 'Hebridian River' is one of the main rivers in the southern drainage system.

To the east and south of Rum, there are two chains of narrow deeps, one trending southward and the other westward. They join in the square F 8 and then proceed S.W. connecting with the Hebridian River in square E 9. These represent the main rivers with their two upper tributaries. The head-waters of the southern tributary of the Rum river can be traced to the deep S.E. of Muck, the deep N. of Coll and that at the northern entrance of the Sound of Mull. The deeps around the northern side of Rum are probably a tributary to the Sound of Sleat river which connects with the southern tributary of the Rum river.

Thus the submarine features in the northern and the central areas indicate that there are two drainage basins and the divide of the two lies across Skye, which locally rises to over 3,000 feet above the present sea level. The divide runs E-W across southern Skye and then turns northward across Trotternish, Skye to the Shiant Islands where it turns north-west-ward connecting with the hills of the Lews. The lowest part of the divide lies now at the depth of 50 fathoms.(300 ft.) Soundings support this view of a water parting, for rock is frequently struck along this particular line.

The sea bed of the southern area slopes westward.(prof.14) The notches along the 30-fathom line indicating a number of stream courses.(F 11) A narrow deep is seen on the southern side of the island of Coll. It is situated on a conspicuous straight line trending S.W.* Probably there was also a river flowing along this straight line and draining into the 100-fathom basin beyond Stanton Banks. The islands Coll, Tiree, Skerryvore and the Stanton Banks are therefore the divide between this river and that of the central area. Another river perhaps flowed from east to west from somewhere west of Islay to join the Coll-Tiree river.

Hence the submarine features of western Scotland are those of a submerged land surface with well-developed drainage systems. The river valleys can be traced on the map.(Map II) It is also found that the drainage has been maturely developed at the expense of a 50-fathom surface. Maturity is indicated by the well-developed drainage patterns, the gentle gradient of the main rivers (prof.16) and the density of the texture of the drainage. Generally, valley bottom extends to depths of the order of 70 fathoms, in which deeps of over 130 fathoms,

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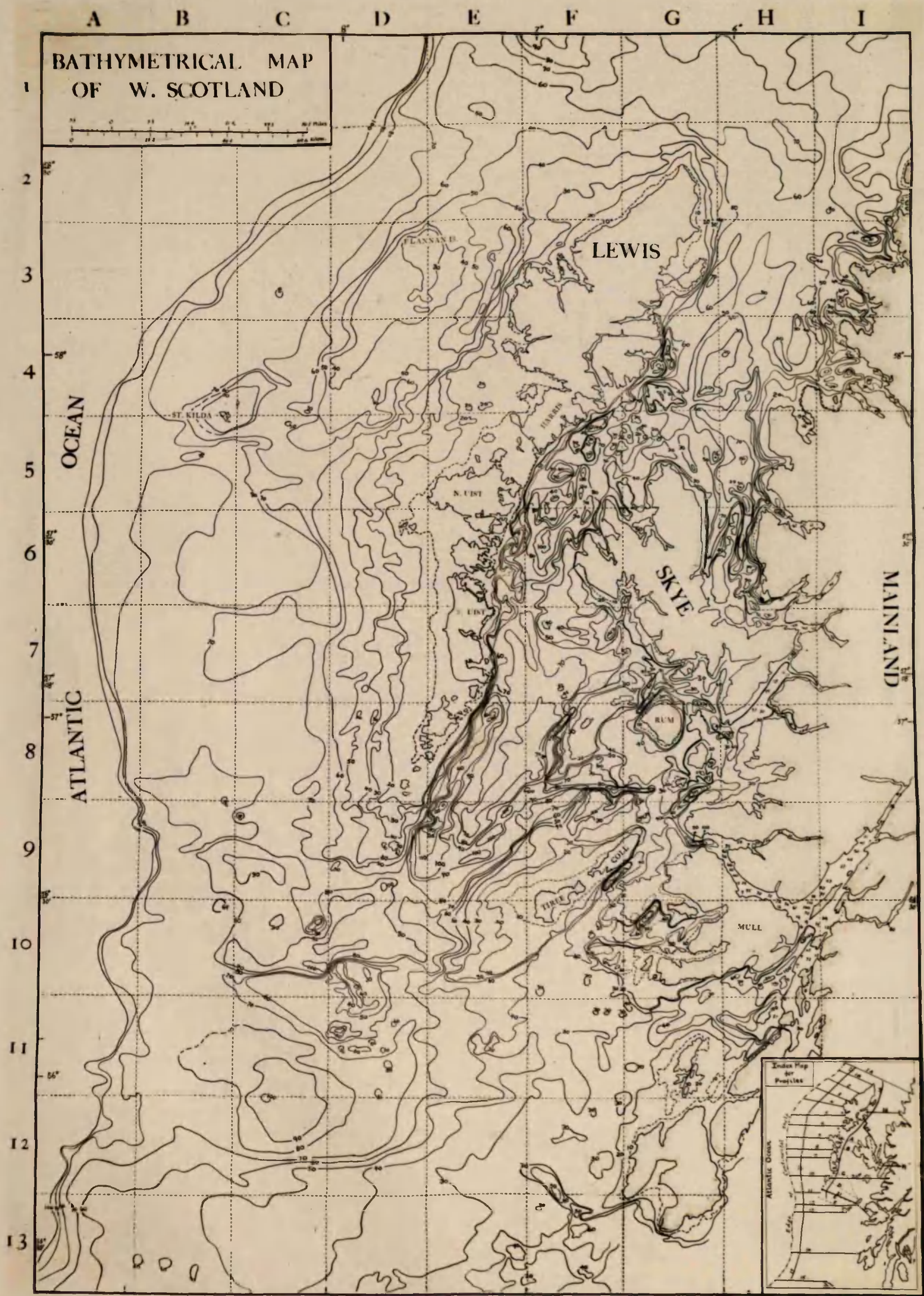
* There is good evidence to connect this depression with the Moine Thrust plane. (See p.28)



BATHYMETRICAL MAP
OF W. SCOTLAND
A
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C
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1
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10
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12
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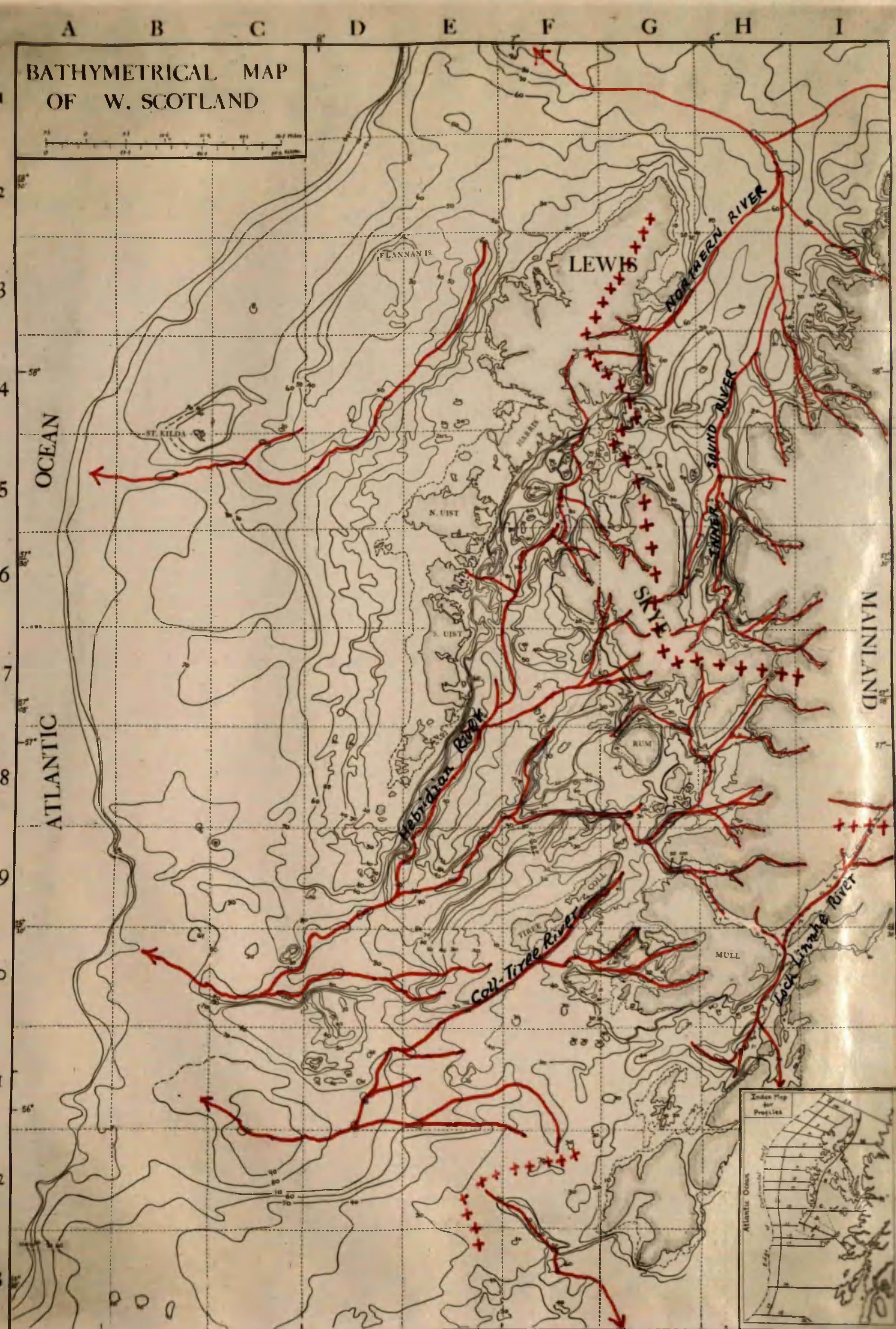
LEWIS
SKYE
MAINLAND
ATLANTIC
OCEAN
ST. KILDA
N. UIST
RUM
MULL

MAP I



→ Streams and main rivers
+++ Water shed.

MAP II

corresponding to a general incised depth of some 120 feet, have been carved. Though many of the soundings in these deeps touch mud and occasionally fine sand, some of the deeps show rock floors.

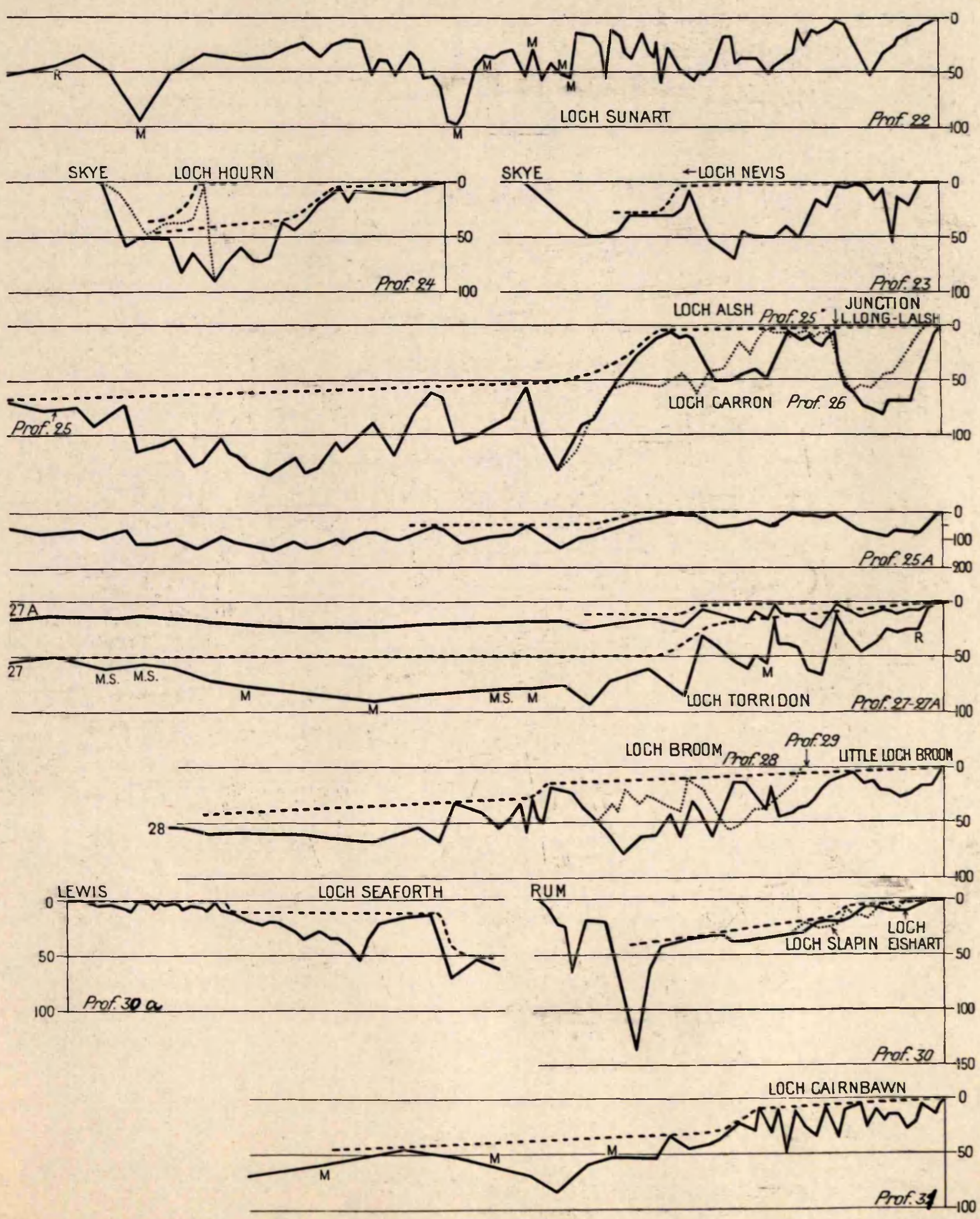
III. <u>Relation of the Sea Lochs to Former Drainage</u>

The submarine features must not be considered alone, for they belong to a partially submerged land surface and their higher, unsubmerged forms must, therefore, also be taken into account. In examining the sea lochs, many authorities have held the opinion that they represent the submerged continuation of land valleys, while no one has pursued in detail the actual continuations under the present sea. The map shows that the sea lochs of Western Scotland exhibit a general radial pattern. Their directions vary from NW-SE in the north, to E-W in the central parts and the NE-SW in the south. The course of the submerged rivers which has been demonstrated above connect naturally, in their main and in their tributary valleys, with the sea lochs and the drainage pattern so indicated has such a normal character that it is a legitimate conclusion that the valleys containing the sea lochs represent the headwaters of a normal drainage system. The sea lochs, therefore are the link between the present day land drainage and that extending under the waters of the western sea.

The former drainage is reconstructed in Map II. It shows that the mainland lochs of NW-SE trend can be connected with

Profile 22 - 31

Horizontal Scale is similar to that of Profile 1 - 15. Broken lines showing knick-points on generalized profiles.



the north-flowing river along the Inner Sound Deep. The main Inner Sound river recieves tributaries from Loch Laxford, Loch Cairnbawn, Loch Broom, Little Loch Broom (Profs 28,29.), Loch Duich, Loch Alsh (Prof.25), and Loch Carron (Prof.26). The sea lochs of Lewis either trend to the east or to the south-east, that is in other words, they all run to join the northern river. Lochs of northern Skye are the exceptions and these can be explained by captures of the northern drainage by the southern, for the Little Minch Area is diversifed by deeps and shoals indicating an intimately dissected upland which may perhaps have been the divide before the capturing had taken place.

The lochs of the central region agree with the general conception. The lochs on the mainland: Loch Hourn (Prof.24) and Loch Nevis (Prof.23), though trending NW-SE, appear to be tributaries of the Sound of Sleat river which once flowed SW into the southern tributary of the Rum river.(Profs.23-25) On its way to join the Rum tributary, the Sound of Sleat river collected, from its west side, the streams of Loch Eishort, Loch Slapin (Prof.30) and Loch Scavaig of Skye and that of the north Rum Deep. From the east, the river recieved the waters of the west-trending lochs: Loch Ailort and Loch Sunart (Prof.22) and the northern part of the Sound of Mull. Lochs of western Skye drained into the Hebridian river.

The lochs in the southern area trend NE-SW, except the Loch na-Keal and Loch Scridan of Mull which connect with the Coll and Tiree river. Loch Linnhe is a good example of the SE trending lochs. Though it is a part of the Irish Sea drainage, which does not come within the scope of the present discussion, it may be worthwhile pointing out that before the Ice Age, the Great Glen may not have been a through valley. The present divide in the Great Glen lies between Loch Oich and Loch Lochy; but probably then was south of Loch Eil, in pre-glacial times, a divide between longer rivers, one flowing NE, the other SW. All the normal tributaries of the NE-flowing river, now represented by Glen Urquhart, Glen Moriston, Loch Garry, Loch Char-Kaig and Loch Eil, join the Great Glen at an acute angle with the upstream direction; while all the tributaries of the SW-flowing Loch Linnhe river join that river at a similar angle, notably Loch Leven, Loch Creran, Loch Etive and Loch Feochan.* An obsequent direction of the tributaries towards the main river is rarely encountered. Soundings showing the extreme shallowness of the passage from Loch Eil to Loch Linnhe support this view. The lochs of southern Uist are all inclined to show the same normal angle of junction with the main river to which they were once tributaries.

A study of the profiles projected along a great number of the sea lochs of the mainland shows that all the sea lochs consist of deep basins almost invariably barred by thresholds of various depths. By connecting the highest points of the barriers, it appears that if the bottom of the sea lochs had

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* The minor tributaries may have different angles of junction, but one must consider the possibility of alternation of their courses since the Ice Age, by glacial erosion, by inter-glacial fluvial action and by capturing.

not been glacially overdeepened, they would lie almost in all cases approximately between depths of 0-25 fathoms. Beyond the mouth of the sea lochs, the submarine slope steepens abruptly and then smoothes out to join with that of the suggested submarine rivers. That the part of steepened gradient is probably a 'knick-point' of significance is indicated by the conspicuous correlation of the profile of Loch Carron with that of Loch Alsh*.(Profs.25-26) Both rivers, according to the hypothetical reconstruction outlined above, were once tributaries to a main river flowing along the Inner Sound Deep. Their correlation is therefore evidence showing the validity of such reconstructions. The 'knick-point' in both cases can be correlated with that of other profiles, with repect to its position on the profile and the amount of the total drop from the loch level to the main hypothetical river bottom. As will be shown in later chapters, the profiles of thepresent rivers draining into the North Sea generally have a zone of steepened gradient before entering the sea, this knick-point, if it can be correlated with those submerged under the western sea, would indicate a greater submergence of western Scotland than of eastern by 150-300 feet.

IV. Glacial Cycle: Overdeepening and Thresholds

It has been suggested that the submerged land surface has been well preserved, and it is necessary to show that that

*Profiles of a less exaggerated vertical scale(12xHorizontal) have been drawn for Profs.25-27. These show the same 'knick-point' features.

surface has been glaciated and the irregularities accentuated in the process. The profile (prof. 16) projected along the thalweg of the 'Hebridian River' across the divide and the North-flowing river along Lewis, shows a gentle sloping surface on both sides of the divide. The northern surface slopes northward from the divide and the southern one southwards. The divide is a higher central area between 10-30 fathoms, cut by deep valleys down to 75 fathoms. These are the head-water valleys of the suggested drainage.

It has been mentioned that the former drainage is found to have been incised on a 50-fathom surface with a valley bottom at the 70-fathom level. But the profiles ahow that in many places, both north and south, deep basins have been cut into the 70-fathom surface reaching depths over 100 fathoms. Manifestly,these deep basins cannot be the work of running water or the valley form produced by the former river flowing in its 70-fathom bed.

These deep basins or sometimes troughs were very probably produced by glacial overdeepening of the floor or pre-glacial river valley. Ice overdeepens a valley when two ice stream converge, but the effect of overdeepening fades off in a comparatively short distance down stream leaving a deep basin with a shallow threshold or barrier at its mouth. Such ice erosion is not carried out during the maximum glaciation but during a later phase of valley glaciation. At that stage,on

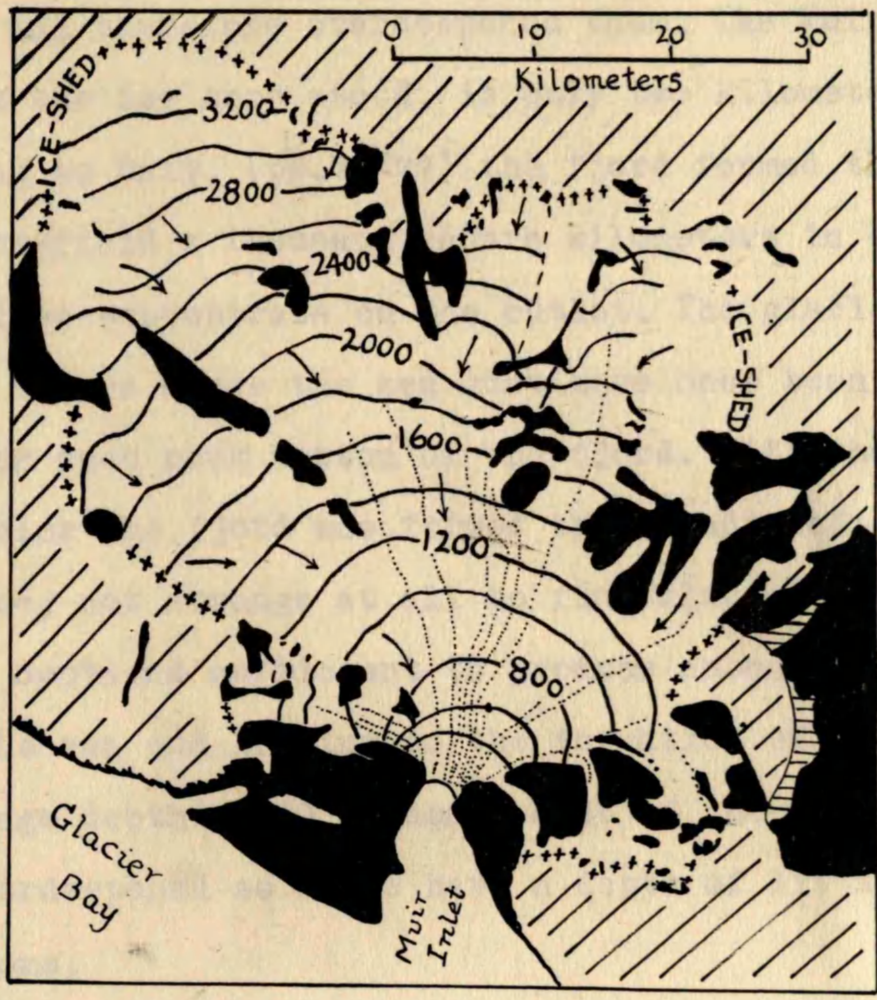

Fig. 2 Map of the Muir Glacier in the year of 1890. Heights in feet. (After Daly)
Solid black, ice free parts of mountains. Arrow and dotted lines, surface moraine. Horizontal rulings represents a lake. Oblique hatches show the rest of the ice shed. The snow field is 1,000 sq. Kilm. or 15 times as great as the Gorner Glacier of Switzerland.

the west coast of Scotland, there were confluent ice streams, which sometimes flowed over divides, but concentrated in the valleys and therefore overdeepened them. The Muir Inlet, a fjord, in which the ice once stood, is only two kilometers wide. According to Daly, (pp.75-77) the fjord formed the main outlet of a snow-field a thousand square kilometers in extent. Lines of moraines concentrate on the outlet. The glaciers whose surface was 381 meters above the sea must have once been resting on the 344-meter deep rock bottom of the fjord. With the retreat of the glacier the fjord was formed by the advancing sea. It is, therefore, not strange at all to find glacial overdeepening in western Scotland sufficient to produce submergence of 132 fathoms below the sea and leading to the formation of sea lochs with an average depth of 50 fathoms. Most of the sea lochs have only been overdeepened so as to have a depth of little more than 30 fathoms.

Daly, when discussing the differences in topography between Norway and Sweden, has suggested difference in the conditions of glacial erosion as the cause. " The ice of theinterior was free to move in almost all directions, while each snowfield of western Norway was drained chiefly or entirely through one narrow valley. Here the ice flow was concentrated and had to be relatively rapid. In Sweden and Finland the flow was not much concentreated and had to be less rapid. But, other things being equal, the rate of Glacial erosion doubtless rises at least as fast as the speed of the flow of ice increases." (Daly, pp.73-75)

The case of western and eastern Scotland is essentially similar.

Glacial overdeepening of the Norwegian lochs has been demonstrated by Professor Ahlmann,(Ahlmann,pp.241.) and the average maximum depth of the overdeepened basin is about 150-250 fathoms(Approx. 300-500 m.) Comparing the figures with those for western Scotland, the latter appear to be well within conservative limits. That the sea lochs are overdeepened by ice is well illustrated in the case of Loch Fyne. The upper reaches of the loch have a depth of 82 fathoms and are separated from the lower portion by a threshold at the maximum depth of 34 fathoms. Below the confluence with Loch Gilp the floor of Loch Fyne drops abruptly to 89 fathoms and reaches 104 fathoms East of Tarbert. The joining with the Loch Gilp ice has therefore brought about the corresponding amount of overdeepening. Another example is Loch Carron. The upper part of the loch is only 60 fathoms deep while at the junction of lower Carron and Loch Kishorn, the loch is deepened to 133 fathoms.

Turning now to the submarine basins, overdeepening of the former 70-fathom surface is chiefly responsible for their formation. Studying the valleys in the profiles A-F and 18-21, one notices that they are of the usual trough-shaped appearence typical of glacial valleys. It is necessary to point out that the rounded-off spur south of the 'Hebridian River' suggests a threshold to the trough and has probably been over-ridden by ice.

The direction of ice flow indicated by striae is sometimes oblique or even at right angles to the trend of the overdeepened sea lochs or submarine troughs. It may be argued that the ice direction indicated by the striae may not prove to belong to a period of valley glaciation. On examining the glacial striae on geological maps and by attributing the low level glacial striae, below the 1,000-foot contour, to a stage of valley glaciation the writer is strongly impressed by the accordance of the ice flow with the present existing drainage. It is a well known fact that during this stage, many sea lochs of the mainland of Western Scotland had become the outlet of a wide-spread ice field. Loch Carron and Loch Torridon may be cited as examples. The sea lochs around the island of Skye no doubt were fed by local glaciers descending from the Cullins and it is easy to explain the overdeepening of the Inner Sound Deep, first by the limited space for the flow of ice between Scalpay and Crowlins islands and secondly, by the confluence of the Skye ice with that of Loch Carron. The isolated basins west of Skye and east of Uist were perhaps excavated by Skye ice streams.

The writer, however, found that it is difficult to explain the formation of the deep along the southern part of the Outer Hebrides. J.Geikie suggested that this trough is a deflection basin formed when the lower layer of the maximum ice was deflected by the southern islands of the Outer Hebrides.(Geikie,J.I,pp.289) Though his deflection theory does not appear to be sound enough to have attracted belief from all quarters, there is some truth in his argument. The main difficulty is that the direction of this trough lies almost at right angles to the direction of ice flow indicated by striae found on neighbouring isles. But, as Holtedahl puts it: " we do not know about the direction of ice movements at the various stages of the ice-age; ..... neither do we know about the direction of the striae on the longitudinal sub-marine grooves." (Holtedahl, pp.142.)

It has been mentioned that the overdeepening was carried out during the later stages of the Ice Age by confluent valley glaciers. This is probably the case, for, according to Daly, the "removal of bed rock by a local glacier may well be ten to fifty times faster than that by a continental ice sheet, which is equally fed with snow, so far as the removal is controlled by mere friction. In addition, the valley glacier has the powerful aid of frost action at the triple contact of rock. ice and air - with corresponding ability to quarry rock. Such plucking goes on not only at the amphitheatre or cirque at the head of each glacier, but also along both of its sides, all the way to its lower end." (Daly, pp.75) To the period of valley glaciers, therefore, the modification of Scottish sub-aerial and sub-marine features should be attributed.

Fine sand, mud and occasionally gravels are found, forming a cover on the sea bottom, masking summits as well as depressions. These deposits cannot be of 'recent' origin. Coastal erosion has not been at all great since the melting of the ice and the sediments thus derived would be of small extent and thickness. The coastal rivers are generally small amd poorly developed and would carry little or no sediments into the sea. Larger rivers usually end in estuaries, in which a large part of the fluvial sediments will be captured before this enters the open sea. Nor can the deposits be the soil of the pre-glacial land surface which would easily wiped-off by the ice. It seems inevitable that they must be glacial deposits, mostly fine materials.

V. Other Features

Let us now examine some of the features not discussed above. The first thing that strikes the eye is the occurence of a large number of steep descents, sometimes having a steep gradient amounting to 1 in 15. (E. of Fuday, N.Uist, & N.Coll.) These scarps are found either representing fault-lines or boundary lines of structural significance. They coincide in many cases with the suggested river valleys and the existing deeps but it by no means follows that they have controlled their formation.

The scarp bordering the east coast of the Outer Hebrides has been variously regarded as determined by a fault, a thrust-

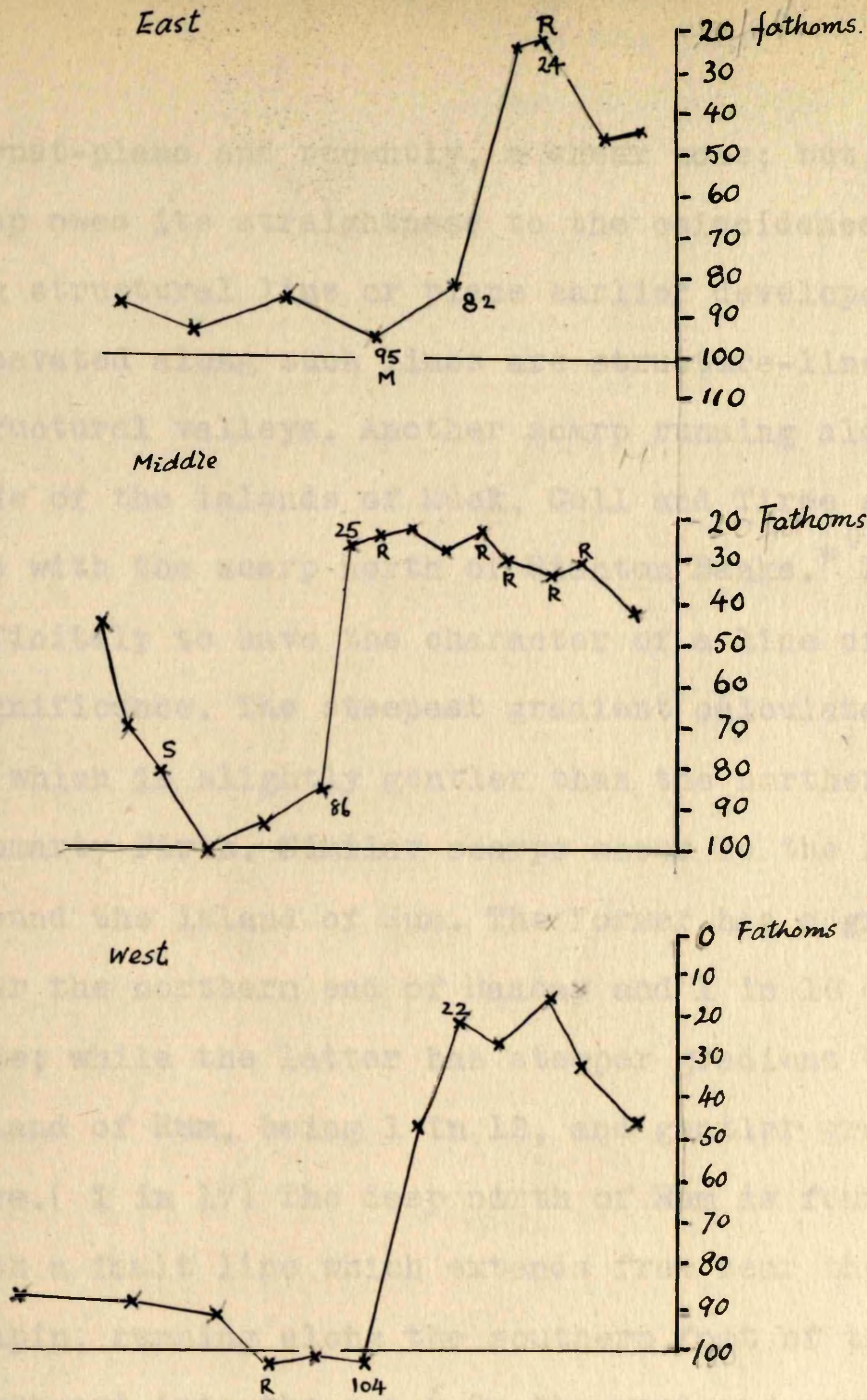

Fig. 3 Sections across Stanton Banks in three directions showing the abrupt scarp bordering the Banks.

thrust-plane and recently, a shear zone; but, in any case, the deep owes its straightness to the coincidence with a pre-existing structural line or plane earlier developed. Valleys excavated along such lines are structure-line valleys but not structural valleys. Another scarp running along the southern side of the islands of Muck, Coll and Tiree seems to be continuous with the scarp north of Stanton Banks.* (Fig. 3) It seems very definitely to have the character of a line of structural significance. The steepest gradient calculated is about 1 in 16 which is slightly gentler than the northern slope of Cromarty Firth. Similar scarps occur in the Inner Sound and around the island of Rum. The former has a gradient of 1 in 4 near the northern end of Raasay and 1 in 18 on the mainland side; while the latter has steeper gradient bordering the Island of Rum, being 1 in 12, and gentler gradient bordering Skye.(1 in 17) The deep north of Rum is found to coincide with a fault line which extends from near the head of Loch Slapin, running along the southern foot of the Blaven, Skye, southward into the sea. On the west and south side of Rum the deeps follow two lines almost at right angles to each other and have presumably been excavated along fault-lines.

Closer study shows that these fault-lines have cut the sea bottom into blocks such as a Coll and Tiree block, a Canna block and a Rum block. The islands Coll and Tiree stand on

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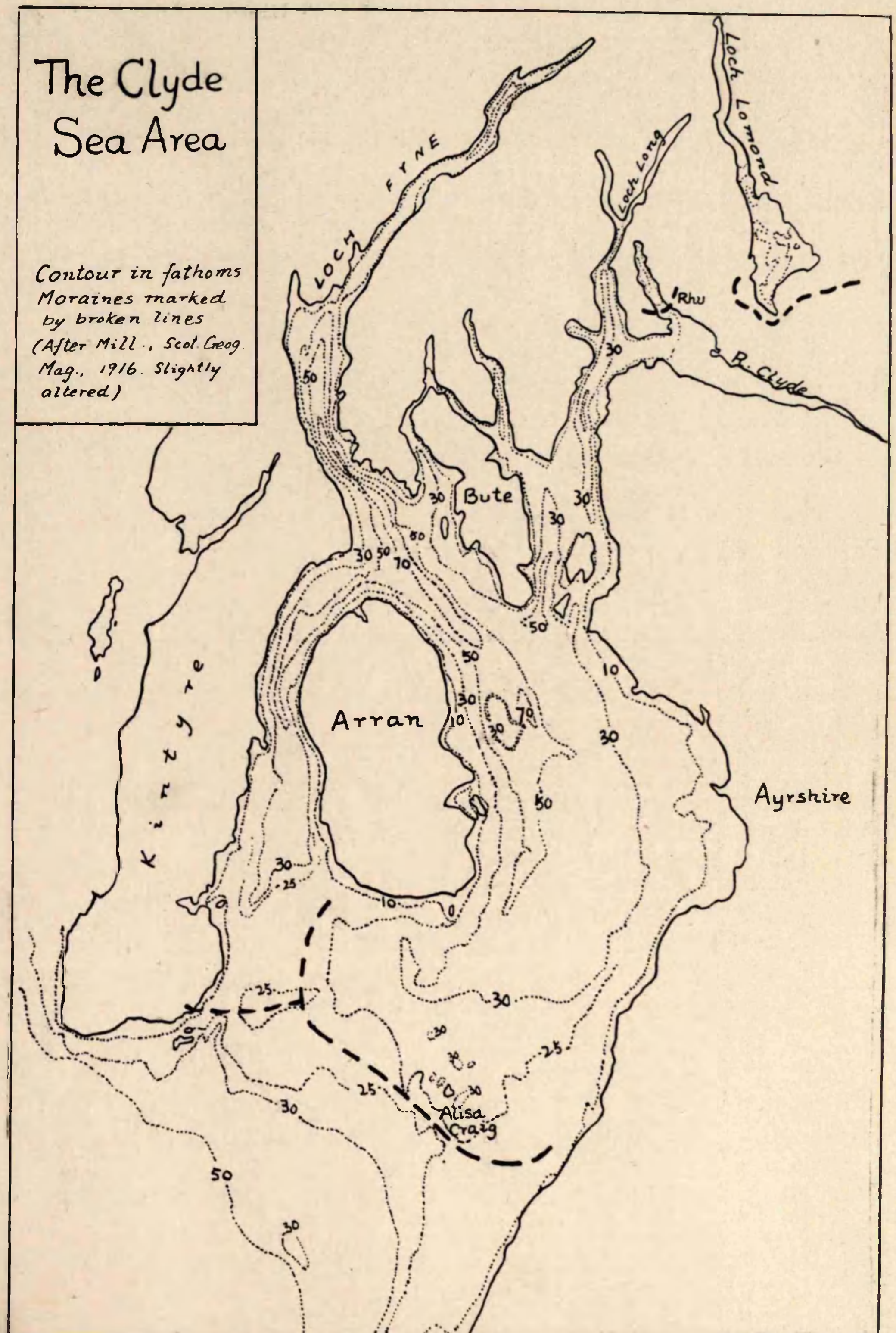
* See note p. 23.

Fig. 4 Submarine Features of the Clyde Sea Area.

(to face page 29)



the eastern edge of a 10-20 fathom platform which slopes gently for a distance westward.(Prof. 21 W.) This platform shows a striking resemblance to that of the Outer Hebrides, shown in profiles 20 and 21 W. The island of Canna appears to be a 'monadock' on a 30-fathom platform, while Rum stands on a 20-30 -fathom platform.(Prof.20) This breaking up of the sea bottom must have been accomplished during Tertiary times and the features revealed by erosion before the Ice Age.

Viewing as a whole, the Outer Hebrides are also a huge block dipping down to the west. According to Horne, this block has been isolated by fluvial erosion.

The profiles A-F show well the shape of the deeps. They are generally trough-shaped and sometimes take the form of deep trenches. The steepness of their gradient is as a whole comparable to that of land valleys.

VI. Submarine Features of the Clyde Sea Area (Fig. 4)

Having dealt in detail with the submarine features bordering the western Highland shore, a short account of those of the Clyde Sea Area should be included to represent the Midland Valley. The Clyde Sea Area, as defined by Mill, (Mill, II p.15) embraces the sea region north of a line from the Mull of Cantyre to Corsewell Point in Wigtownshire, including Loch Fyne, the Kyles of Bute, Loch Strivan, Holy Loch, Loch Goil, Loch Long, Gareloch and Loch Lomond.

The rocks north of the Highland Boundary Fault are chiefly slates, phyllites, mica-schists and biotite gneiss of the Dalradian series. South of the fault-line the region is composed of rocks varying in age from Ordovician to Permian. The Old Red formation and the Carboniferous sediments and volcanics are by far the most abundant. Only in the island of Arran do Tertiary rocks become important.

Submarine features show that the Clyde Sea Basin has a barrier plateau marking the southern margin between the boundaries of the Sea Area and the Firth. Within the barrier plateau, there are some exceptionally deep water areas as those around the north of the island of Arran and that between Bute and the Cumbraes, while the Ayrshire coast is a low area with a gradually sloping submarine topography. The view here taken regards such variations in the existing submarine relief as of ancient origin. It is, to a very great extent, a former land surface now submerged.

The deep basins are generally long and narrow troughs of deep water, the deepest of which reaches 92 fathoms. These troughs seem to have been developed on a surface between 30 and 50 fathoms. A river flowing down the course of the present Loch Fyne, turning round the north of Arran and running along the east coast of the island would enter southward into the Irish Sea river. Tributaries to this main river are those draining out from Loch Long, Loch Ridden and the Kyles, Loch Lomond and the Clyde and other lochs. This system developed in pre-glacial times when the sea level stood much lower, probably at the level of 50 fathoms.* Since these Clyde Sea rivers were only tributaries or head-waters to the once extensive Irish Sea river, the level of their bottoms (35 fathoms in the case of Clyde) would lie higher than that of the trunk river which was first having a general bottom of 50-fathoms and was later cutting down to 70 fathoms.

The same glacial processes affected this area as that affected the western sea. But in this region rock resistance does play a part in producing narrow and steep-sided valleys in which the glaciers were restricted. The ice-streams following the pre-existed valleys drained into the Irish Sea Channel. The Clyde Glacier pouring down the present Clyde Sea, obstructed by Ailsa Crag has carried the riebeckite granite of the crag down the postulated course along the Irish Channel to Ireland and Wales.(Wright, p.56) On retreat a great terminal moraine** was probably built on the Barrier Plateau which is on the average 27 fathoms deep.(calculated by the writer) It is a wide ridge on which stands Ailsa Crag. The moraine is represented by a very narrow ridge on the plateau about the depth of 25 fathoms. South of Ailsa Crag which would obstruct the ice-flow, the moraine is at its narrowest.

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* See pages 15 and 17.

** Compare with O. Holtedahl's "Some Remarkable Features of the Submarine Relief on the North Coast of the Varanger Peninsula, Northern Norway." Mat.Naturv.Klasse 1929 No.12 pp.9-12.

Soundings on the top of the moraine indicate the presence of mud but no rocks. This may indicate that the origin of this moraine is not far different from that of Rhu Point which is composed of contorted laminated clays being pushed up from loch bottom by the advancing valley glacier. (McCallien, pp.388)

Small basins which may be kettle holes are only to be found at the rear of the moraine and on all sides of Alisa Crag except the south.

Near the end of the second stage of glaciation, the ice left as terminal moraines those of Loch Lomond, Rhu.Point and, perhaps, the Otter spit of Loch Fyne.

It follows that the bottom of the Clyde Sea can be interpretated as a pre-glacial drainage area, glaciated and finally submerged. It must be mentioned that this reconstruction of the drainage is not inconsistent with the hypotheses of Clyde-Tweed or Clyde-Forth or other suggested drainages; for such a drainage system may have occured at more ancient date, while that outlined above by the writer is perhaps better regarded as almost immediately pre-glacial.

VII. Conclusions

1. The west coast of the Outer Hebrides borders a well-featured continental platform, which is higher in the north and south but lower in the middle.

2. The Minch, the Little Minch, the Gulf of the Hebrides and the area south of it havea very irregular submarine topography which shows that the amount of marine erosion since the submergence has

been relatively small.

3. The irregularities suggest a dissected land surface with mature drainage systems. These systems have been reconstructed and the divide between the northern and the central area has been attributed to the rocky barrier along the line drawn from Trotternish,Skye - Shiant Islands - Ru Uishenish, Lewis.

4. The drainage systems were initiated on a 50-fathom surface and the rivers thus developed having incised the surface to an average depth of 20 fathoms, their beds now lie at an average depth of 70 fathoms.

5. The direction of the sea lochs is found to coincide with the head-waters of a former drainage system, and by the study of profiles projected along the course of the sea lochs, an estimation of the amount of greater submergence of western Scotland is made.

6. The pre-glacial sea level is believed to be much lower than the present day. It lies first at the 50-fathom level and later shifts to the 85-fathom isobath.

7. During the Ice Age, glacial overdeepening has taken place in the former head-waters of the rivers as well as in the r thalwegs of the main rivers.

8. Submergence of the overdeepened glacial troughs has given rise to fjord topography.

9. The submarine features of the Clyde Sea give similar features as those present in the western sea. A readvance terminal moraine is found on the barrier plateau, 25 fathoms below the present sea.

Chapter III

Some Features of the Existing Drainage

The writer has dealt with the submerged portion of a once extensive drainage on the western coast. Continuation landwards of this submerged drainage and connection with the existing drainage should be also considered. Below in some detail are given certain features of the existing drainage.

I. Rock Basins and the thalwegs of rivers

It has been previously mentioned that the sea lochs of Western Scotland generally consist of rock basins almost invariably barred by thresholds of various depths. Loch Cairnbawn is situated in a rock basin which has a maximum depth of 61 fathoms and which is separated from the sea by a submerged barrier 30 fathoms deep. The lochs Glencoul and Glendhu are cut off by rocky barriers from the Cairnbawn to which they join. Parts of the barrier is exhibited by the small islets guarding the entrance from Loch Cairnbawn. Similar conditions are found in the cases of Little Loch Broom, which has a basin 57 fathoms deep and is barred by a barrier of 26 fathoms; of Loch Ewe, Loch Torridon and Upper Loch Carron. The threshold of the last named loch is only 6 fathoms deep and a part of which is standing above the loch forming a conspicous land-mark for Strome Ferry.

It is not necessary to enumerate all the examples but may be worth while to say that the abundance of rocky islets scattered along this coast, most of them situated at or near the mouth of sea lochs, suggests thresholds. Standing anywhere high up along the shore, these islets impress upon one the recentness of submergence.

Features, alike those present in the sea lochs, are also found on land and are exhibited by the numerous fresh-water loch basins. Let us examine the Lochinver district more closely. The Hotel there owns rights of fishing in more than a hundred lochs. A glance at figure 5 perhaps will show how abundant are these small lochs in that district. Within four square miles, there are about 50 lochs and tarns. As the region is practically free from glacial deposits, these lochs must occupy low-lying basins of rock. They have irregular outlines variations in depth and shape of the basin and are largely influenced by shear zones, fault-lines and what is more effective: the weak ultrabasic dykes which transverse the gneiss.

Waters of these lochs drain to the sea through small burns which cut deep into the rocky barriers forming gorges and rapids or sometimes picturesque waterfalls. After dropping down from the loch level, the stream may enter a lower loch, or, when near the coast, drain directly into the sea with a youthful gradient. Repetition of such phenomena produces a

Fig. 5 Lochs (solid black) in Rock basins, N. of Lochinver.

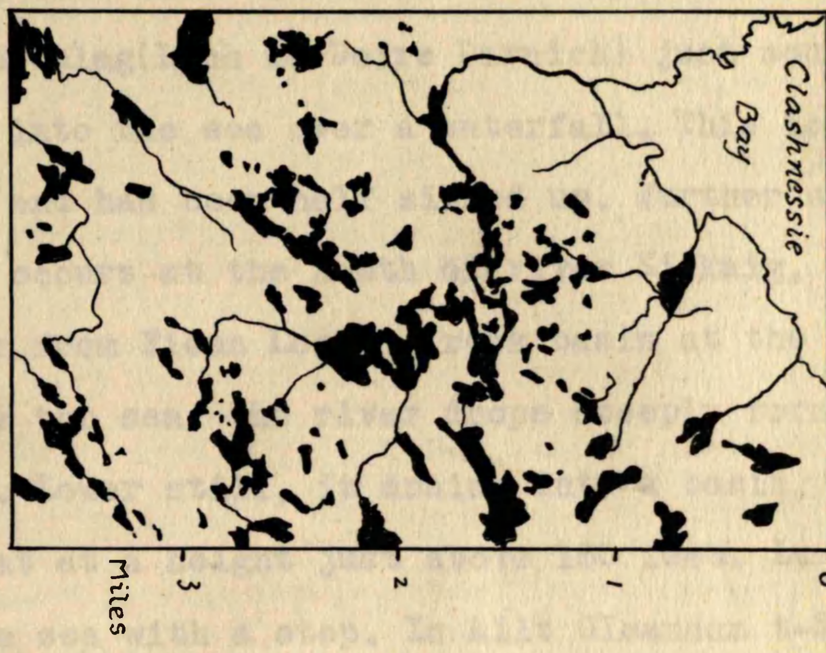

Fig 5

Lochs (solid Black) in rock basins. N. of Lochinver.

series of lochs in steps. Such features are clearly shown along the coastal road from Lochinver to Ullapool. The river which drains Loch Culag(Loch na Doire Daraich) just south of Lochinver, flows into the sea over a waterfall. This loch is only 9 feet deep and had been half silted up. Further south, the same feature occurs at the mouth of river Kirkaig, which derives its water from Fionn Loch, a rock basin at the level of 357 feet above the sea. The river drops steeply forming the Falls of Kirkaig. Lower still, it drains into a basin, small but amazingly flat at a height just above 150 feet. It then descends into the sea with a step. In Allt Gleannan t-Srathaim, the writer could trace four successive flat-bottomed basins and steps. The river drains out from Loch Buine Moire down a gorge through the rocky barrier of the loch into another flat basin which, in turn, narrows into a gorge, through which, the river drops into a still lower flat and so on, reaching the sea after tumbling over rapids and falls. Loch Buine Moire is separated from Loch Sionascaig by a narrow barrier of rock about 300 yards wide and not more than 50 feet high. The latter lochhis the head-water reservoir of a separate system of loch drainage to the south.

Similar relation of steps and flats occur also in large scale drainage systems. The river Inver offers a good example. Loch Awe may be taken as the main head-waters of river Inver. Situated 500 feet above sea level, the loch is separated from a south flowing river by a barrier 500 yards wide and less than 50 feet high. The river from the loch flows northwards through a rock barrier just north of which it recieves the tributary,Allt nan Uamh. Beyond the barrier, the river swings freely in an open valley and flows gradually into Loch Assynt at Inchnadamph. This represents the first flat and step series. The length of this section is approximately 4½ miles. Loch Assynt, 215 feet above sea level, is 5 miles long, representing the flat part of a second series of steps. The river Inver properly so called, begins its course at the eastern end of Loch Assynt and makes a few sharp angled bends. This is partly due to the removing of the basin rim and partly due to cramped conditions of bed. The river has failed to cut downwards at the beginning of its journeys fills the whole of the low-lying rocky ground outside the basin rim as a valley. Three miles down stream we reach the rapid zone characterized by high banks and rapids. This zone is only 1½ miles in length and its end marks the termination of a second series of steps. At the height of 100 feet above sea level, the river drains into a basin, now overhung with evergreen trees. This marks the beginning of the third series of features which ends by a fall zone of rapids and in some parts, gorges; and drains into the Loch Inver.

The same evidence is afforded by the river Okyell. (Prof. 31) River Okyell derives its source from the southern slope of Ben More Assynt. The corrie-loch Dubh Loch Mor and the waterfall $\frac{3}{4}$ mile down stream form the first series of step features. Then the river slopes 1 in 67 for $4\frac{1}{2}$ miles down stream, forming the second step series. After that, the river valley passes into the 'glen' which is topographically a larger river valley with a U-shaped cross section. On the flat bottom of the glen is situated Loch Alish. The gradient is not very steep and the fall is 1 in 140. The gradient steepens slightly (1 in 105) before reaching Okyell Bridge, 125 feet above sea level. The length of this fall zone is only a mile. This is the third series of step features. Beyond the Bridge, the topography changes into an extremely wide opened, flat-bottomed, U-shaped valley in which the river winds freely and alluvial terraces are best developed. This portion having a length of about 15 miles has only a gradient of 1 in 778.

The foregoing evidence clearly indicates that the valley thalwegs of the Scottish rivers generally consist of a number of steps and flats. Sometimes, the flat is completely occupied by a loch, while in other instances, the flat is the sediment-filled bottom of a U-shaped valley. There are also numerous small rock basins of fresh-water lochs which are not related to any particular rock strata, but, the fact that many of them do coincide with zones of shearing, faulting and fracturing should not be overlooked. There are equally many lochs usually of large areas and arranged in chains which do not coincide with any particular structural weakness. These have been supposed to be determined by older consequent valleys, which once stretched beyond the present coast.(Peach III pp.468-71) It is along the profiles of these old 'consequent' valleys one will find more striking step formations. That the glaciers of the confluent valley stage followed these old valleys is indicated in page 25, and there is little doubt that the successive steps and rock basins have been produced by ice sculpture. In post-glacial times they were connected by rivers which have succeeded in cutting through the barriers.

II. <u>Gradients of thalwegs and cross section of river valleys</u>

Studying the gradients of the thalwegs of Scottish rivers it is possible to define some of the common Scottish terms for physiographical denotation of valley profiles. The term "strath" usually signifies the lowest part of a river valley which is sufficiently long and has a wide-open, U-shaped, flat-bottomed valley, in which the river meanders freely and alluvial terraces are well-developed. The gradient is generally well over 1 in 300, though cases of steeper straths are also found. The term "glen" will be used to denote a smaller U-shaped valley, in which the river does not meander or does so to a limited extent. Alluvial terraces are generally absent. The gradient of a glen is between 1 in 100 and 1 in 300. The "fall" or when sufficiently long, a "fall zone" is a part or a belt of steeper gradient between strath and glen or other similar flats along the thalweg of a river. The gradient is generally between 1 in 50 and 1 in 100. (Profile 32-35)

From calculations of the valley-side gradients, a large number of Scottish rivers and fresh-water lochs have valley slopes steeper than 1 in 5, many lying between 1 in 1 and 1 in 3. Such steep gradients are found at all parts of the thalweg. The gradient of a valley side of a strath would be about the same as that of a glen. This signifies that while the longitudinal profile of the river valley is equally influenced by fluvial action and glaciation, the valley sides have been greatly steepened by ice action which almost obliterates the former side slopes of fluvial valleys. That the fresh-water lochs, which lie in most cases in rock basins of glacial origin, have the valley-side gradient identical with that of land valleys strengthens the above suggestion.

There are in quite a number of places, traces of old valley bottoms, at levels above the present valley floors. Those may have been left as terraces above a rejuvenated valley stretch, for example, near the divide on both sides of Strath Peffer as can be seen from the railway to Strome Ferry. They may also be left 'hanging' by the development of valleys running transversely to the older valley. This seems to have occurred in the case of Allt A'Chrosaig, (Profile 34) a tributary to the Carron river in Western Ross and of the Dundonald River, Ullapool. Allt A'Chrosaig has its upper section a floor lying between 800 and 1,100 feet, having a gradient of 1 in 400, but it drops to the Carron at 1 in 1. The more usual interpretation of a hanging valley seems inapplicable here, and the upper portion of Allt A'Chrosaig appears to be a remanent of a much older drainage. The Dundonald river south of Ullapool rises on a plateau averaging about 1,000 feet above sea level. The river slopes for the first four miles in a gradient 1 in 600 down to 900 feet above the sea where it begins to drop steeply for another three miles to 170 feet at a gradient of 1 in 21. It is extremely possible that the plateau is a part of the 1000-foot platform.

III. Estimation of the difference of Submergence

Another peculiar feature is exhibited by the through-valley from Strath Fleet, along Loch Shin, Loch Merkland, Loch More, Loch Stack to Loch Laxford on the western shore. (Profile 35) From Kyles of Sutherland 4 miles upstream, the gradient of the thalweg is 1 in 180, beyond that, for 27 miles across Scotland the gradient is only 1 in 950. A low col, 200 feet above sea level separates Loch Merkland from Loch More. Starting from the eastern end of Loch More for another 14 miles westward to sea level, the gradient is 1 in 530. Immediately below sea level the generalized gradient of Loch Laxford (1 in 107) impressed one as the submerged counterpart of the steep gradient portion or 'knick-point' mentioned on the east. The submarine slope then continuous at a gradient of 1 in 350 which is as gentle as the 'straths' of the existing valleys. Examining the profiles of the bed of many of the sea lochs, knick-points similar to that of Laxford seem to be of universal occurence.

and if these submerged knick-points of the west are to be correlated with those which are unsubmerged on the east, there is again indication of an unequal submergence of Scotland to the amount previously suggested.(see pp. 21)

Regarding the knick-point of the eastern rivers of Scotland, a good example is given by the river Spey. The fall of the river shortly before it reaches the North Sea, is at the rate of 1 in 330. This gradient, comparing with the 'Strath' section of the river which is 1 in 1100, is a very steep drop, and in fact, the st_eepness has prevent even the highest spring tides to flow any further up the river than half a mile above Speymouth.(Hinxman,I,pp.190) This fall, according to Hinxman is probably due to the rejuvenation of the lower portion of the river, when the land was uplifted and with it, the first raised shoreline and associated deposits.

Another example may be quoted from the rivers Conon and Beauly. The Conon (Profile 33) drops at a rate of 1 in 62 from the height of 250 to 150 feet above sea level. Below this fall zone, the river has developed a 'strath' in recent raised beach deposits dated from the first raised shoreline period. The junction of the Orrin river to the Conon is also a fall zone being 1 in 52. The fall zone of the river Beauly begins from Eilean Aigus, where, the river cuts into Old Red Sandstone. This fall, produced by the elevation of land, is dated as about the same time as the first raised shoreline. The Carron river of the east, also shows a similar drop of 1 in 76, before it flows into the strath. This fall zone ends at the inner margin of the first raised shoreline.

The writer has pointed out the general occurrence of a submerged knick-point on the west and has suggested the correlation of it with that found in the eastern rivers. The knick-points were formed by the elevation of land during late-glacial times and indicate the approximate time of the occurrence of the unequal submergence.

Chapter IV

The Differential Submergence of Scotland

The writer has not merely claimed that the pre-existing drainage and subsequent glacial modification of it. have contributed to the formation of the present subaerial and submarine topography; there is implicit a belief in differential submergence in Scotland. Such an idea is really not a new one for it had been voiced by Geikie as early as 1901 and later by Mackinder and Horne. Geikie, pointed out that more extensive submergence of the Western Highlands might account for the indentation of the western shore,(Geikie,A. pp.136) while Horne claimed that it is extremely probable that there has been less submergence on the east coast than there has been on the west. (Rep.Roy.Comm.Coastal Erosion & Protection, under Horne p.15) Mackinder held that possibly a deeper sinking of Scotland accounts for the differences between the Irish and Scottish oceanic coasts. (Mackinder, pp.22)

In search for evidence supporting the conception of a differential submergence, the writer has put forward his interpretations of the submarine features and has attempted to show the degree of differential submergence. Further evidence may be had from studies of the raised shorelines which have not yet been satisfactorily made and the significance

fully appreciated. According to Wright, the Scottish raised shorelines analogous with those of Scandinavia encircle Mull as a centre, where the highest pre-glacial shoreline reaches 135 feet above the sea, and diminish in height outwards from the centre. (Wright, W.B., Geol. Mag. 8, 1911, pp.97-109) With the exception of the north, where the 100-foot raised shoreline stands at about the same level as in the centre, the analogy generally holds. There are, however, certain regions in which raised shorelines are absent. (Nansen, pp.130) Submerged peat beds found on some parts of the Caithness coast have been interpreted as due to a recent submergence of this area. (Nansen, pp.130) There are no raised shoreline in the Orkneys except the questionable occurrence of some gravels in Hoy. Flett, from the study of submarine topography around Orkney, has suggested submergence to account for the disappearance of raised shorelines. It is generally believed that the Outer Hebrides, the Shetlands and the Faeroe Islands have no raised shorelines.*
The English 15-foot pre-glacial shoreline disappears fairly suddenly on approaching Scotland. This is possibly due to the submergence of its Scottish counterpart.

Though certain facts seem to indicate a possible submergence fairly recent in date, the glaci-isostatic adjustment of the crust, as is shown by the distribution of raised shorelines,

* A recent article in the Geological Magazine (74, pp.194, 1937) has mentioned the occurrence of raised beaches in Flannan Islands and North Rona. Stevens informed the writer of probable raised shoreline in Lewis and N. Uist at very low levels. He also recollected some features which might be interpreted as raised benches on the Caithness coast. Reid reported the occurrence of raised beach on the northern coast near Durness. (Geol. Mag. Vol. 66, 1929, pp.177-80.)

has regular oscillations which cannot explain a greater submergence of Western Scotland than eastern by 150 feet. (see pp.21) Such a differential submergence demands an independent movement of the crust itself, and tilting seems to be the only plausible explanation. If Scotland had been tilted so that its western side dipped down to the Atlantic, a subsequent uniform submergence would give the features of differential submergence. If such tilting occurred in pre-glacial times, the later glacial-eustatic changes of the sea and the glacial-isostatic adjustment of the land during the Ice Age would not have altered the fundamental ground for differentiation by later submergence. This date is by far more advantageous than a post-glacial date, for there is a possibility of correlating the movement with the later phases of igneous activity, which have affected Iceland as well as Western Scotland.

It must be admitted that this suggestion leads to a necessity for further studies. More evidence must be sought for first, in support of the hypothesis of differential submergence, secondly, to elucidate the cause of such submergence, thirdly, to determine the degree of the difference and fourthly, the date of the tilting which laid the foundation for later differential submergence. Evidence may be derived from careful studies and interpretation of raised shorelines, of existing drainage, and the most important of all, the complete understanding of the Scottish glacial history.

Part II

THE STUDY OF RAISED SHORELINES

Chapter V

Terminology and Principles

I. Terminology (Fig. 6)

Before going into the discussion, it is perhaps necessary to re-examine the terms used in connection with the study of shorelines. Many of them are in common use while plenty of others are specially invented in different countries and are sometimes ill-defined. The misuse and the duplication of terminology always leads to confusion in any branch of scientific study, and it is therefore important to give a clear definition of those terms used in the present paper.

A 'beach' is a shore-form of accumulation built by the sea within the shore zone, lying between the limits of high and low water*. Forms built above high water, though not distinct from the above category in their lithological characters are called 'back-shore terraces'; while those which extend seaward beyond the outer limit of low water are termed 'shoreface terraces' and occur in the 'shore-face zone'. Thus the classification of beach forms is three-fold

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* It must be mentioned that Johnson did not limit the term beach to deposits between high and low water marks but used it in a loose sense to include all deposits in back-shore, fore-shore, and shore-face zones.

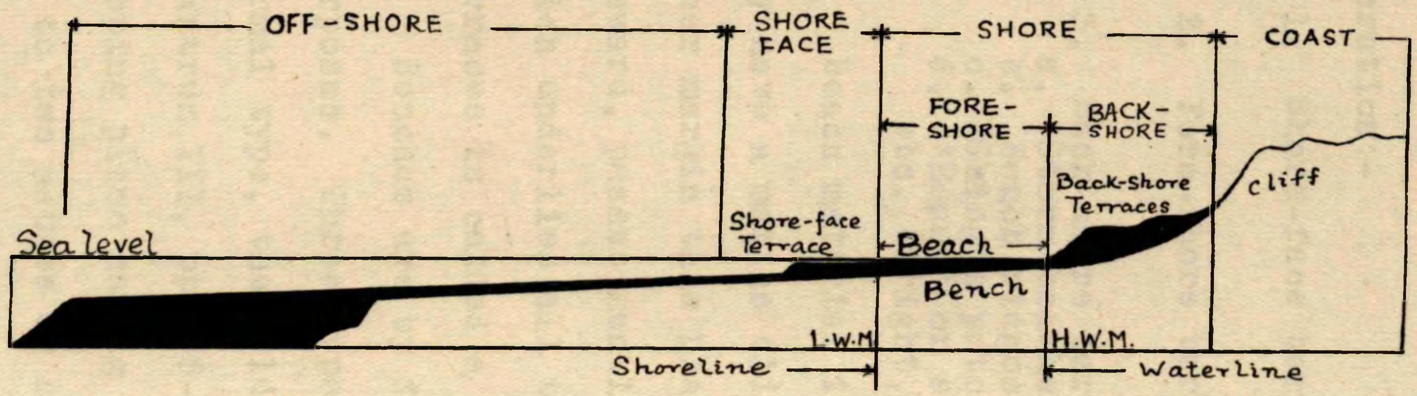


Fig. 6. (After Johnson, with slight modifications

depending upon their position and relation to the high and low water marks. We distingushed the following forms of accretion:-

1.	Shore-face terrace	Below extreme low water line.
2.	Fore-shore terrace or beach	Between extreme high and low water lines.
3.	Back-shore terraces a. Storm beaches b. Beach ridges in various forms c. Shingle patches d. 'Heads' or sub-aerial deposits, etc.,(Wright,pp. 97-99)	Above extreme high water line.

Beach material is underlain by a rocky platform which may have a marine cliff at its landward margin. From its inner margin this platform slopes with decreasing gradient seaward, passes gently into the sea. The part of the platform which underlies all the back-shore, fore-shore and shore-face terraces is called a bench.

Benches are by far the best criteria for correlation purposes. Three types of benches may be distingushed: the normal type, the 'Old-hat' type and the storm-wave type. (Bartrum,III, pp.135-143) An ordinary bench is a wave-cut sloping plane having an inner margin from a few centimetres up to two metres or more above ordinary high tide.(Johnson, VII, pp.160) The level of the bench defined as the elevation of its inner margin, depends on the exposure, tidal range, width of the bench and the rock into which it is cut. Davis (pp. 1062) has shown that a platform cut during a stable sea level assumes a very faint slope, while one which has been eroded during a period of progressive submergence, has a steep seaward alant, other things being equal. The two other kinds of bench have their pecularities ~~and are~~ due to causes other than normal wave erosion,and are of less importance in respect to the present purpose.

A 'raised beach' denotes a former beach now situated above the level of the sea by which it was built up whatever the cause of the elevation may be. Other shore-forms found above their original level must also be referred to as 'raised'. Because of the restricted usage of the term 'beach' mentioned above, it is therefore necessary to denote the collective phenomena of 'raised' deposits and erosional features by the term 'raised shoreline' which will embrace not only beach deposits but every shore form and will include the former landward limit of the shore zone.

To specify the level of a certain raised shoreline by heights in relation to the present sea level is not safe for various reasons which will be discussed later. Attempting to correlate merely by heights either measured personally or derived from records of other workers is an inexact practice. Johnson has already shown the difficulty of interpreting a large number of records of elevation and attributed to this practice the large amount of confusion which has arisen in correlation. Some workers group terraces included within a range of more than a hundred metres in a single group and try to correlate it with another group similarly made-up. Grouping within such a large range renders exact correlation impossible, and sometimes dangerous. In Scotland, terms like 'highest, higher and lowest raised beaches(shorelines) have been widely used and it is also a general practice to use height to specify an individual shoreline, for instance the '25-foot raised beach'. So far as the writer can gather, in Scotland beaches have been specified by all the following elevations: 15-, 20, 25, 30, 40, 50, 70, 80, 100, feet etc.. In one case a beach referred to as the 40-foot raised beach is said to be the equivalent of the 50-foot beach but its actual level is somewhere about 70 feet. Sometimes one may even gather expressions such as: the 100-foot raised shoreline in this region rises to a height of 80 feet above high water mark. For the sake of simplicity it is therefore suggested that the terms 'first, second and third raised shorelines' be used exclusively to indicate the three raised shorelines commonly recognized in Scotland, the first being always the highest in any locality. There will be no choronological siginificance in this terminology nor it is possible to correlate the sequence in one locality with that of another until account is taken of the respective positions of the individual members of the sequences.

On a raised shore carrying a beach, the beach, being eroded in the active cycle to such an extent that the underlying rock bench is exposed, is called a 'contraposed shore', (Fig 7. c) a term first introduced by Clapp (pp.537-40) to indicate the marine equivalent of the phenomenon of a superimposed river. Further erosion of such shore will lead to the development of 'composite cliffs'. At this stage of shore development, the cliff has ~~there is~~ a steep lower face of rock and a less steep upper face of more or less incoherent detritus.(Davis,pp.1056) It sometimes happens that two or more cycles are presented in one given locality by the appearance of two or more cliffs in succession and at different altitudes. When the erosion of the former raised bench is so great as to have wiped off all the evidence of composite cliffs and only left 'heads' fringing the new cliff behind the present shore, the shore is said to have reached its covered-head stage, at and beyond which, all characteristics of a contraposed shoreline will be absent.(Fig 7. e) The erosion of a shore which gradually develops into a cuspate form due to local strengthening by living rock, as seen in the Santa Monica coast is called 'rock-defended cusp'.(Davis, pp. 1053-4.)

II. Principles

Having made clear the terminology of the study of shoreline, we will devote some time to an analysis of the numerous difficulties which hinder the reasonable correlation between widely separated as well as neighbouring places.

A. Original Configuration

The configuration of a raised shoreline largely depends upon that of the former shoreline. Wave action is both constructive and destructive. The sea builds temporary shore forms which are subjected to numerous changes once they have been formed, and erodes the shore into benches and platforms, etching the coast into cliffs in which may occur numerous marine caves. When all these forms are raised uniformly, the raised shoreline will show considerable varieties and irregularities. The prograding section of such a shoreline has generally a higher elevation than the retrograding section, because in the former the sea is capable of building shore forms above high water mark, while in the latter, the sea cuts down the former surface to below low water. If the amount of relative elevation is so great as to expose the former abrasion platform, the raised shoreline will show an even, gentle sloping rock platform with a thin layer of veneer ending landwards in the fore-shore cliff of the fore-shore terrace, but continued under beach deposits to the cliff. In such a raised shoreline there will be two cliffs: one at the rear of the former back-shore zone and another in front of the former shore-face zone, both belonging to a single marine cycle.

Frequently fallen rocks and screes from the cliff will be heaped up at its foot or mask the cliff-face. A notable example is seen in Gribun Point, Mull, where the marine bench below is obscured by abundant sub-aerial detritus. The additional height given to the beach by the subaerial deposits often gives a false impression of a higher sea level. In the south-east and north-west shores of Bute, the steep cliffs which are usually found at the rear of the raised bench have contributed so much detritus to its inner edge in some places that there the apparent level of the shoreline is very notably increased. By far the most impressive sign of a raised shoreline is the clean cut raised bench, which when viewed from a distance, appears to be an almost even surface cutting across the skyline and rising abruptly into a cliff. On closer examinations it will show considerable irregularities on the surface, and frequently a thin layer of debris masks the foot of the cliff. Such a cliff-backed bench is well preserved on many sections of the Scottish shoreline, notably the western coast of Kintyre, where a stretch of almost continuous cliff-backed bench is seen from Machrihanish as far north as West Loch Tarbert, a distance of above twenty-five miles.

Former sea caves, cut in the cliffs, often have bottom fillings. It is difficult to fix the former sea level from the raised caves, the elevation of whose floors depends upon many factors besides the level at which the sea stands. The bottom filling of a cave may indicate a level higher than the former ordinary sea level, because, in flowing into a cave, the water has been forced through a narrow entrance, its surface rises and much of its volume is therefore raised bodily. The inflowing water carries materials into the cave but the outwash is weaker and deposition occurs within the cave. Nor is it safe to draw conclusions regarding former levels from measurements of the height of the caves floors. Conditions of marine erosion within a cave are peculier and the depth to which this erosion may proceed is not limited in the same way as the level of the bench beyond the cave threshold. At Hawk's Nib, S. Bute, a cave and an undercut notch occur close to each other, the former being appreciably higher than the latter probably pointing to the difference of the height of of the former high and low water mark.

The configuration of a raised shoreline also depends on the stage of development the shoreline has reached. As a shoreline is generally more irregular when young than when mature, a mature shoreline, bounded by extensive benches and beaches and an old shoreline which is very smooth in outline, would present smooth outlines when raised. The development of a shoreline is not uniform and therefore a raised shoreline may present appearances corresponding to all stages of development even in neighbouring places.

Shore forms and other features of storm wave origin are sometimes mistaken for raised shore deposits and platforms. Bartrum and Stearns have pointed out that abnormal platforms of the present sea are frequently confused with raised platforms and give rise to suggestions of recent changes of level. Undoubtedly such forms occur on the Scottish coast at present which if were raised, might be undistingushable from any ordinary raised bench. Platforms occurring in western Colonsay and Oronsay have been reported as pre-glacial raised benches. These benches might perhaps be recent storm wave platforms.

Storm built forms, notably beach ridges and storm beaches are found high above high water mark. The writer has examined the storm built forms of S.W. Scotland, where shingle thrown to h heights over a hundred feet above the present sea has been mistaken for raised beaches. In Orkney islands, beach ridges occur in many forms: either as tombolo or as bars enclosing lagoons behind, or as spits jutting out into the open water.

B. Later Erosion and Deposition

When with all its irregularities, a shoreline is raised above the marine level, subaerial and fluvial agents act upon the newly emerged surface. In course of time it will be modified by deposition as well as by erosion. Most of the former constructional forms being composed of loose deposits will be rapidly eroded and destroyed. The raised cliff subject to intense sub-aerial erosion may give rise to talus and scree at its foot masking the boundary line between the raised cliff and the raised bench.

When_ever a shore is raised the former constructional forces may in the new cycle turn into destructional forces and erode the former deposits exposing the more resistent underlying bench. As the erosion proceeds, the shoreline passes through the composite shoreline stage and the 'cover-head' stage successively and the features of the former shoreline will be completely removed and a part of the history of the shoreline evolution will be missing. The missing links are perhaps as many as those preserved and naturally affect any conclusion based only on the existing evidence, without taking into account the evidence which has been lost. Furthermore negative movements of the strandline expose all evidence presented by a 'raised shoreline' while the positive movement submerge and conceal all such features. This would further complicate any attempt to a complete analysis of the history of a shoreline.

Shorelines which have been raised for a long geological period and probably high above the present sea level, are subjected to more extensive fluvial erosion as well as to other erosive agencies. Rivers cut down into the raised beaches may produce a cliff on one side and swing laterally on the opposite side, thus producing on the same raised beach differences in appearance and configuration. A river may, during its mature development, dissect the surface of a raised beach, altered the raised cliff and wash away the deposits. On the other hand, a raised delta which is the product of the combine action of river and marine deposition, may be cut by successive raised shorelinesinto a series of terraces, which would be mistaken for separate raised beaches instead of an ancient product of a single phase of deposition.

Raised shoreline are also known to have been modified by subsequent glacial action. Those pre-glacial cliffs and benches found in the Western isles of Scotland are glacial moulded, striated and masked with boulder clay. Blown sand may have accumulated on the former shore forms and obscures the identity of former shore features or assume the characteristics of a sandy raised beach.

C. Sea Level Divergencies

Taking into account the above consideration, workers have attempted to express the differences between former and present sea level in numerical terms with reference to some datum numerically defined with reference to the level of the present sea. But the sea level is not fixed nor is it subjected only to regular variation. The level at any moment of the sea is subjected to many disturbances due to tides, waves in general, and as affected by shoreline configuration in particular. Numerical specifications of raised shorelines may be referred to low water or high water or half tide level or ordinance datum or mean sea level. As differences depending on the standard of reference may be considerable, much caution must be exercised in applying there badly standardised measurements. Johnson has enquired into the value of mean sea level as a basis of measurement for the displacements of the strand. Mean sea level as he explained, is the average level of the sea, or in other words, is a plane about which the tide oscillates.(Johnson, V,X.) But this level is a warped surface though warped to a less degree than the high tide surface. This level is subjected to variation due to numerous astronomical causes as well as to geographical causes. It is found by Johnson and Winter that mean sea level is sensitive to changes of the form of shore and that it varies in height with the shape and position of the shore features. Embayments have an abnormally high mean sea level as compared with bays and the mean sea level is also abnormally high on a windward shore. Later investigations on the shores of New England, further conform Johnson's conceptions and it is thus believed that certain phenomena, for instance, submerged forests and the lowering of the bench marks, which had once led to the believe of a recent submergence of the New Jersey and Massachusetts coasts is probably only a matter of the changes of the mean sea level.

Lucke's study of the Barnegat Inlet, New Jersey, has confirmed Johnson's views. The high mean sea level in embayments, especially in the case of a lagoon bounded sea-wards by a bar with a shallow and narrow inlet, is due to the restriction of the flow of the ebb tide.

The mean sea level of a region can only be accurately determined by means of long periods of observation. There are only a few localities where such records of observations are available. It is therefore not a precise and reliable method at the present moment to use numerical values for specifying a raised shoreline with regard to mean sea level.

D. Measurements and Determinations

Other complexities result from the faulty measurements of features which either have no significance or are of non-marine origin. The measurements taken are sometimes the height of the inner margin of a raised bench above high water mark which is frequently determined by the highest limit at which certain seaweeds can grow. But the inner margin of a terrace with a cliff at its rear is by no means always the right position for the determination of a former level. In case of a rock-cliff-backed bench, the inner margin of the bench would give a former sea level a little higher than the margin.(Fig. 7 a) But if the bench is cliff-backed by an eroded raised beach cliff, the sea which deposited the beaches would be much higher than the inner margin of the bench. (Fig 7, b) If the terrace, though rock-cliff-backed, is form of beach deposits the level would be a little lower than the frontal margin of the deposits, provided of course, that the deposits have not been eroded.(Fig. 7 ,c.) If the terrace is a delta, the sea level will be below the inner margin but above the frontal margin, (Fig. 7 ,f.)while in the case of a beach foreland, the sea level would be considerably lower than the frontal margin of the terrace. (Fig. 7 , d.).

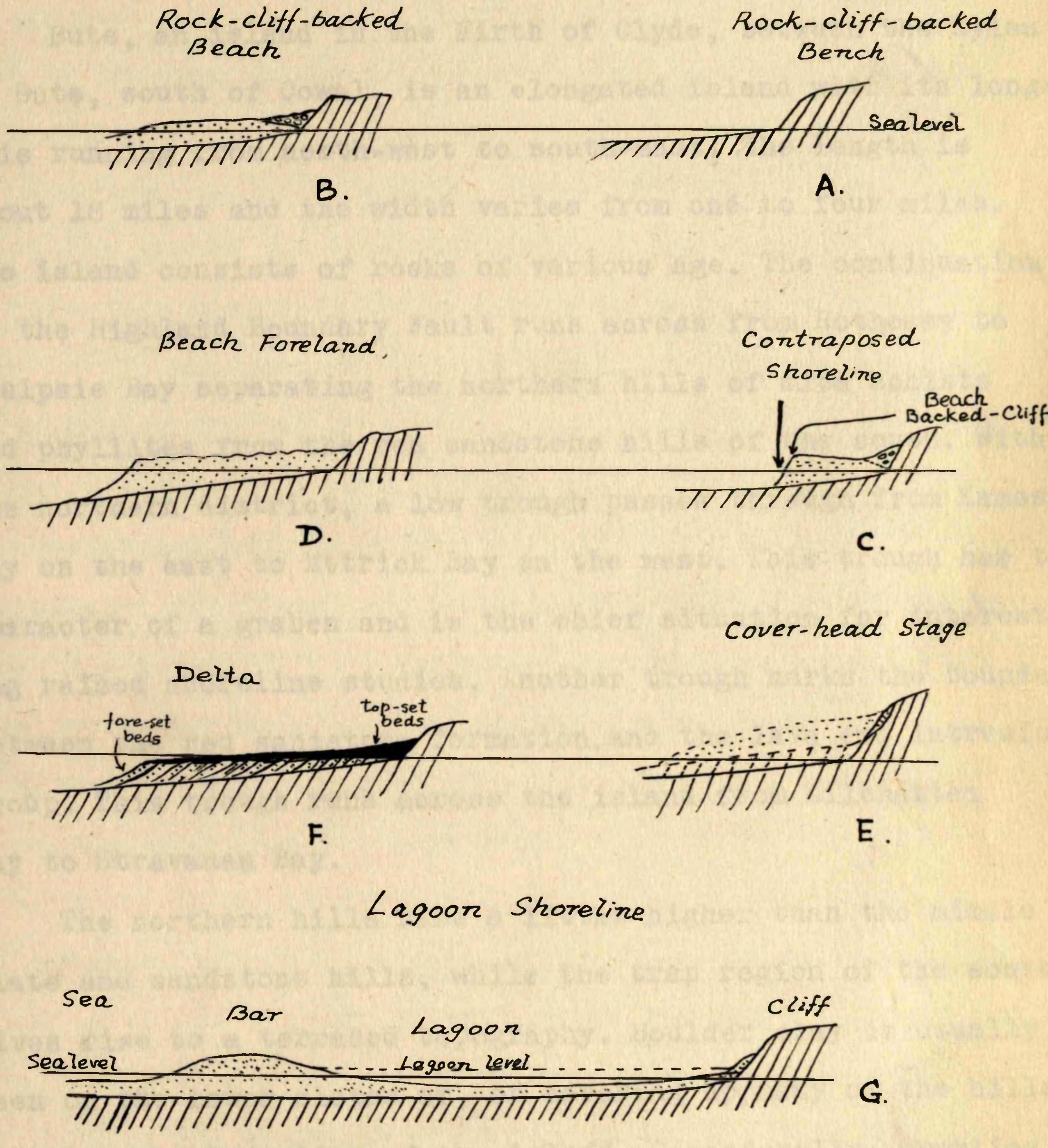


Fig 7 A-G. Diagrams showing relation of various shore-features with sea level.

Chapter VI

The Raised Shorelines of Bute

Bute, an island in the Firth of Clyde, between the Kyles of Bute, south of Cowal, is an elongated island with its longer axis running from north-west to south-east. The length is about 18 miles and the width varies from one to four miles. The island consists of rocks of various age. The continuation of the Highland Boundary Fault runs across from Rothesay to Scalpsie Bay separating the northern hills of mica schists and phyllites from the red sandstone hills of the south. Within the northern district, a low trough passes through from Kames Bay on the east to Ettrick Bay on the west. This trough has the character of a graben and is the chief situation for interesting raised shoreline studies. Another trough marks the boundary between the red sandstone formation, and the lava and intrusion group. This trough runs across the island from Kilchatten Bay to Stravanan Bay.

The northern hills rise a little higher than the middle slate and sandstone hills, while the trap region of the south gives rise to a terraced topography. Boulder clay is usually seen on the lower slopes of, or covering up, many of the hills in the central portion of the island. Occasionally, drumlins formed some oval hills standing on the moor.

Perhaps the raised shorelines of the island is more interesting than other physiographical features and very little has been done on the subject. There are papers which only deal with the raised beach shells. The Memoir of Northern Arran gave a very brief description of the raised shorelines of Bute.

In general the raised shorelines are best preserved in the troughs or the tracts of low-lying land across the island. The one-inch geological map shows four successive raised shorelines in the Kames-Ettrick trough. In other localities, there are generally three raised shorelines.

For the purpose of this study, the raised shoreline have been plotted on six-inch O.S. maps. The greater part of the work was done by following a continuous shore feature, such as a cliff, which can be reasonably taken for a marine feature. The lithological characteristics of deposits have also been examined. From experience on this island a working view of the distingushing features of each of the raised shorelines was attained. The elevation of the inner margin of the shoreline has been measured from convenient bench marks or taken directly from these marks when adjacent to the inner margin of a given shoreline. Due consideration is given to the problem of estimating the actual former level of the sea with reference to the shore features.

The inner margin of the first raised shoreline is everywhere marked by a low cliff which, in itself, does not give any evidence of marine origin; but it marks the boundary between boulder clay and a deposit of sub-angular gravel which closely resemble in grain and colour the coarser material of the boulder clay.

The existence of the second raised shoreline is doubtful. Localities where this shoreline is shown on the one-inch geological map have been investigated. They do not show material or topographical forms definitely to be correlated with an intermediate stand of the sea. The deposits occurring within the boundary of this shoreline indicated on the one-inch geological map are largely well-rounded ferruginous gravels. The inner margin of a shoreline is not well-marked.

The third raised shoreline is the most characteristic. Rock cliffs and rock benches are common and almost form a circuit around this island. Caves, motches, stacks are found along the rocky cliff, indicating marine origin. Deposits, including shelly sand which contains species still living in adjacent waters, are generally sandy, and there are interesting shore forms built up by wave action. The presence of Atlantic to Sub-Boreal peat beds under raised beach deposits affords "pollenistic" evidence for the dating of this shoreline.

I. The First Raised Shoreline

The term 'first raised shoreline' is used by the writer to indicate the highest shoreline which is also the oldest. The former denotation for this shoreline is 'the highest raised beach' and it is sometimes mapped by three or four inverted crows on the one-inch geological map.

The shoreline has been mapped by the writer according to the general characteristics found during his survey. In northern Bute this shoreline occurs at Kilmichael. (about 80 feet O.D.) It can be traced northward to a rocky bench which forms the headland of Rudha Dubh. The rocky bench of Buttock Point, best seen from passing steamers, is a portion of this shoreline whose height has not been measured but which rises above the fifty-foot contour. (Fig. 8) On the east coast the first raised shoreline stretches for a short distance north and south of Rudhbodach farm. To the north of Kames Bay, the headland region of Ardmaleish Point is a broad bench over 84 feet O.D.* in elevation at Ardmaleish farm. It slopes seawards to below the 50-foot contour and is cut-short by a marine cliff of a later raised shoreline. (Pl. II.)

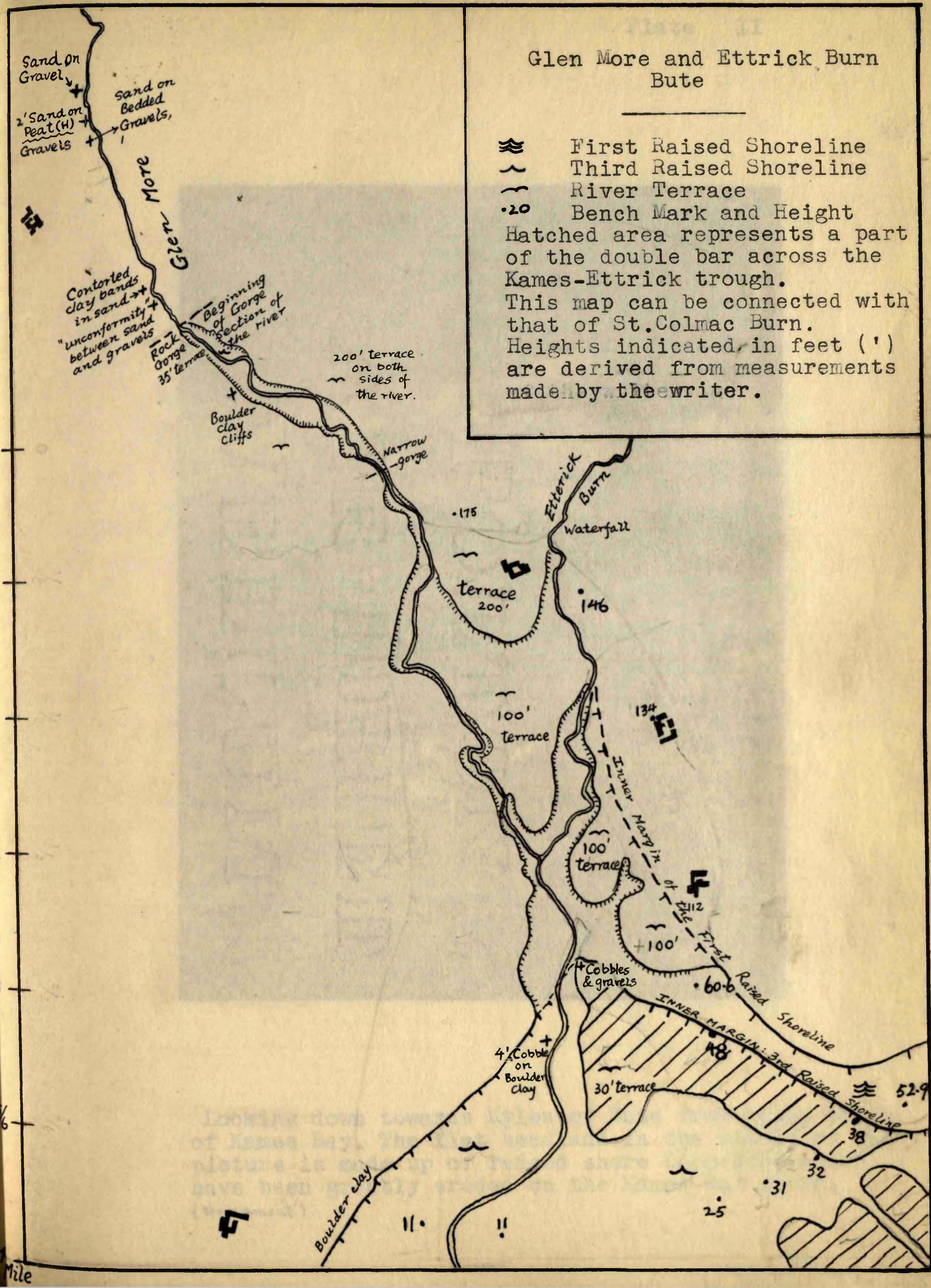
Within the Ettrick-Kames trough, the shoreline can be traced as a narrow bench running up the valley side of Ettrick Burn.(Fig. 9) The deposits are sub-angular gravels with red sandy matrix. Along a burn 800 yards west of Kames Castle, a deposit of largely sub-angular gravels is seen. A low cliff separates this deposit from boulder clay above. This cliff is therefore regarded as marking the inner margin of a raised shoreline at which boulder clay was resorted and deposited in adjacent localities by the sea which formed it.

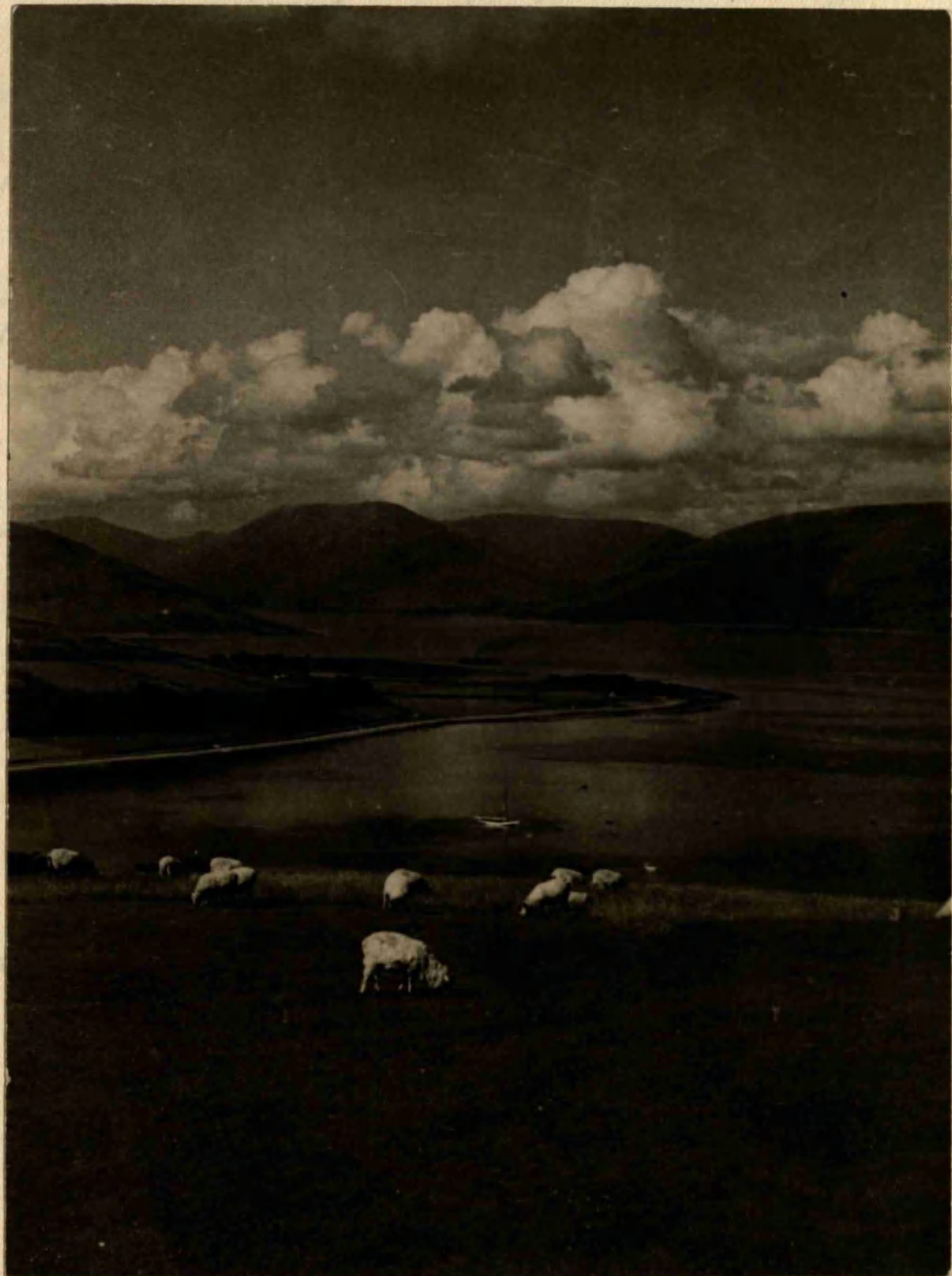
* Unless otherwise indicated, whenever O.D. is referred to, it will be understood that the height is taken from available bench marks on the six-inch O.S. maps.

Plate I

The valley of the present Glen More shows features which must be of very ancient date. The mature character of the valley is seen here some 500 feet above sea level. The present Glen More Water flows in this valley until it descends to the level of 200 feet where it begins to drops very steeply down to sea level. A 50-foot deep gorge is cut along this fall zone and changes of level subsequent to gorge-cutting were recorded by fluvial terraces within the gorge. (By courtesy of Dr. Lamont.)

Fig. 9


Glen More and Ettrick Burn
Bute
First Raised Shoreline
Third Raised Shoreline
River Terrace
•20 Bench Mark and Height
Hatched area represents a part of the double bar across the Kames-Ettrick trough.
This map can be connected with that of St.Colmac Burn.
Heights indicated in feet (') are derived from measurements made by the writer.
Sand on Gravel
2' Sand on Peat (H)
Gravels
Sand on Bedded Gravels,
Glen More
Contorted clay bands in sand
"unconformity" between sand and gravels
Beginning of Gorge Section of the river
Rock Gorge
35' terrace
200' terrace on both sides of the river.
Boulder clay Cliffs
Narrow gorge
Ettrick Burn
Waterfall
•175
terrace 200'
146
100' terrace
134
Inner Margin of the First Raised Shoreline
100' terrace
112
100'
Cobbles & gravels
•60·6
INNER MARGIN: 3rd Raised Shoreline
48
4' Cobble on Boulder Clay
30' terrace
52·9
38
32
•31
25
11
11
Boulder clay
Mile



Looking down towards Kyles of Bute from hills south of Kames Bay. The flat headland in the middle of the picture is made up of raised shore deposits, which have been greatly eroded on the Kames Bay shore.
(Dr. Lamont.)

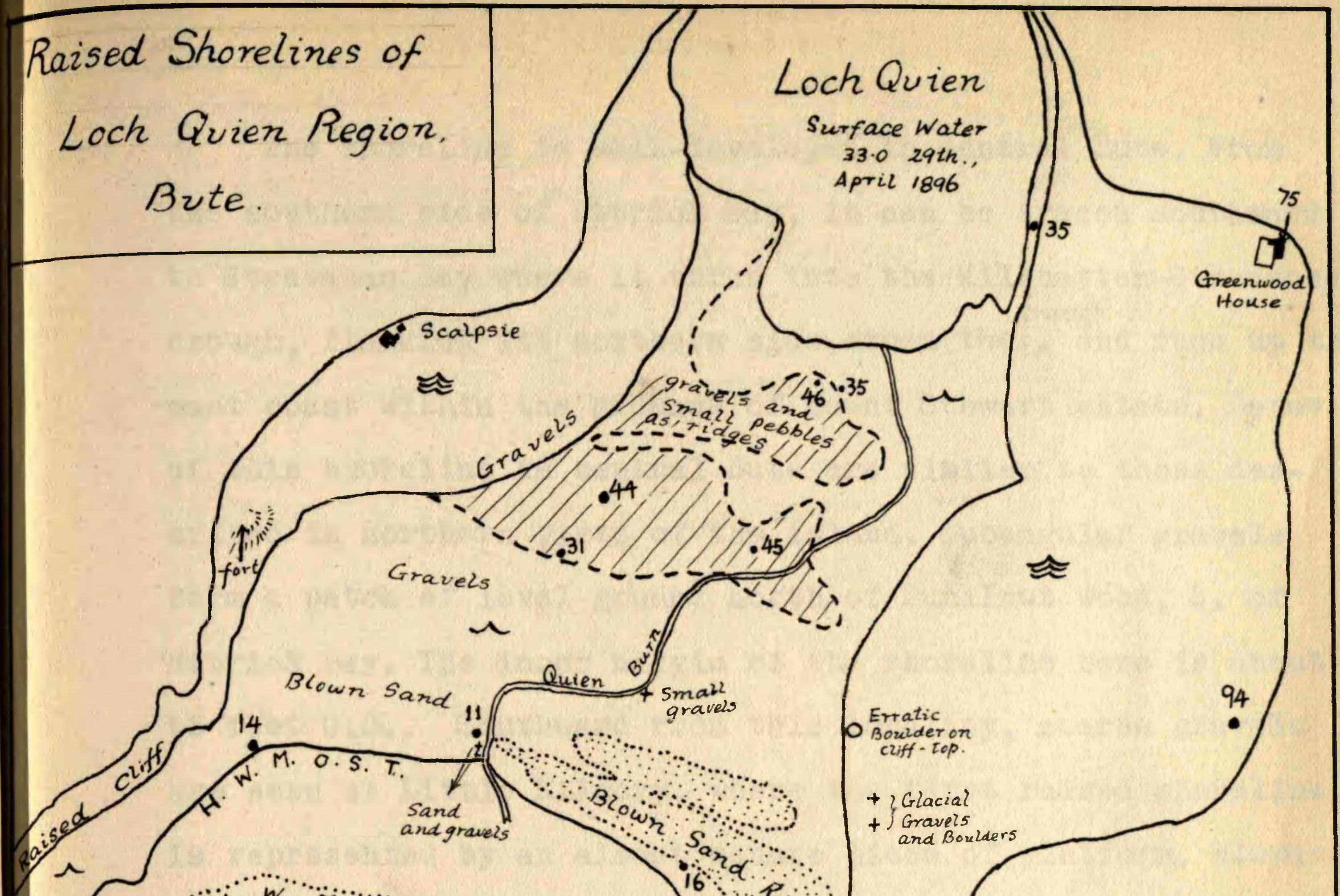

Raised Shorelines of
Loch Quien Region,
Bute.
Loch Quien
Surface Water
33·0 29th.,
April 1896
35
75
Greenwood
House
Scalpsie
Gravels
gravels and
Small pebbles
as ridges
46
35
44
31
45
fort
Gravels
Blown Sand
Quien Burn
Small
gravels
Erratic
Boulder on
Cliff-top.
94
11
14
H. W. M. O. S. T.
Raised Cliff
Sand
and gravels
Blown Sand Ridges
Glacial
Gravels
and Boulders
16
L. W. M. O. S. T.
12
18
Shelly
beach gravels
97
136
Schist
Granite
Scalpsie Bay
Granite
Raised Marine Cliff of the 3rd Raised Shore
Raised Bench Cliff-backed
(scattered with boulders)
Reddish
Boulder
Clay with
Striated
Boulders
Ardnahoe
Caves
0
1/6
1/3 Mile

Fig. 10

The shoreline is well-developed in central Bute. From the southern side of Ettrick Bay, it can be traced southward to Stravanan Bay where it turns into the Kilchatten-Stravanan trough, flanking its northern side, cross the trough and runs up the east coast within the grounds of Mount Stewart estate. Deposits of this shoreline in central Bute are similar to those described in northern parts of the island. Subangular gravels form a patch of level ground north of Dunalnut Wood, S. of Ettrick Bay. The inner margin of the shoreline here is about 93 feet O.D.. Southward from this locality, coarse gravels are seen at Little Kilmory, where the first raised shoreline is represented by an almost square piece of platform, sloping from 61 feet O.D. seawards. Gravels of similar character are abundant below the inner margin of this shoreline at Ardscalpsie Point. Below the Quien Farm, Loch Quien, well-rounded gravels forming a piece of meadow between the fifty-, and the hundred-foot contour lines. On the top of the third raised cliff, well-rounded gravels are exposed. Glacially striated boulders are found among the deposits. This exceptionally well-rounded gravel deposit may well be of glaci-fluvial origin. (Fig. 10) The situation of Loch Quien in a through valley across the island, must have been one of the main channels for the discharge of glacial water from the melting of ice.

On the west side, the deposits are largely covered up by the woodland of Mount Stewart. Near Bruchag Farm, west of of Kerrylamont Bay, red sandy, subangular gravels are found. Sub-angular gravels occur in the road side north of Kingarth Hotel and on the cliff west of Ardnahoe Farm. In more inland parts of Bute, this shoreline is seen on the east side of Kirk-dam, south of Rothesay, where the inner margin of the raised shoreline is a little below 97 feet O.D.. Boulder clay is seen above the inner margin which is marked by a steeper slope. Sub-angular gravels overlying boulder clay is exposed along the sides of a burn, a little north of Kilmory and another stream south-west of Stewart Hall.

In Southern Bute the shoreline is traced in the west side of the island from Stravanan Bay to Garrochty farm having its inner margin at about 78 feet O.D.. The deposits seen along the coast of Lubas Bay and Dunagoil Bay are composed of small, well-rounded pebbles of quartzite.

The elevation of the raised shoreline varies in different places. In general, it is higher towards the south, for along the southern slope of central Bute, it rises to over 117 feet O.D.. This local elevation may be interpreted as indicating a direction of more effective wave erosion during the first raised shoreline period especially having in mind the corresponding direction at the present day. The heights of the inner margin of the first raised shoreline which have been determined are given in Table I. It is estimated from them that the range of elevation is probably from 90 to 120 feet O.D..

II. The Second Raised Shoreline

This shoreline is less continuous than the first, and in some localities indicated on the one-inch geological map its occurrence is extremely doubtful. In quite a number of places, deposits of the third raised shoreline seem to have been mistaken for the second raised beach; for instance, the double bars of Ettrick Bay*, have previously been mapped as two successive raised beaches, represented by two and three inverted crows respectively. The shoreline however is well-developed in the Ettrick-Kames trough. On the shore of Kames Bay, where the third raised beach has been considerably eroded, deposits of the second raised beach lie adjacent to the present coast.(Pl. III 1) The beach ends seaward in a low cliff whose crest is about 12 feet O.D.‡ and appears to have no conspicuous inner margin. The line separating it from the first raised shoreline is very difficult to find. The probable inner margin is taken as a line between two kinds of deposits, sub-angular and well-rounded gravels respectively. A section of fine sand overlying pebbles and gravels is seen along a small burn 400 yards north of Kames Castle. The gravels well-rounded and bedded, contrast remarkably with the rewashed material from boulder clay exposed in higher elevations.

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* See page 70

‡ This sign ‡ indicates elevations measured by the writer.

Fig. 1. Encroachment of the sea on the raised beach, Undragnion Point, Kames Bay, Bute.

Fig. 2. Section of Raised Beach deposits in St. Colmac Burn, Ettrick Bay, Bute.

Along the St. Colmac Burn, Ettrick Bay, (Fig. 11, 12.) well-bedded gravels and pebbles are exposed just below Acholter Bridge, 75 feet above O.D.. (Pl. III fig. 2) The upper surface of the deposit is 8 feet below the bench mark giving a probable inner margin of between 55 and 65 feet. The gravels are largely formed of schists and slates. The gravel bed is overlain by a silt-layer, 4 feet thick. This silt layer contains lenticles and beds of peat a short distance down stream. (Pl. III fig. 1) Pollen analysis has proved that the peat is of Atlantic age, the equivalent of the 25-foot raised beach, hence the silt layer must be separated from the gravel bed below, which is regarded as the second raised beach.

Near Ocadia, fifteen feet of ferruginous gravels are exposed overlying red conglomerate, both forming the raised marine cliff of the third raised shoreline. This deposit, closely resembling that exposed in a burn near Kames Castle, is taken as the second raised beach. Traced along the continuous marine cliff of Old Red sediments, the raised beach gravels are to be found in discontinuous exposures. A terrace of gravels can be seen at Mid Ascog.

The shoreline occurs on both sides of the Kilchatten-Stravanan tract. It has a height between 56 and 69 feet.* That which occurs on the southern side has its prolongation further to the south along the west coast. It is composed of more or less angular gravels seen about half a mile south of the Kingarth Church. (Table II)

FIG. 11.

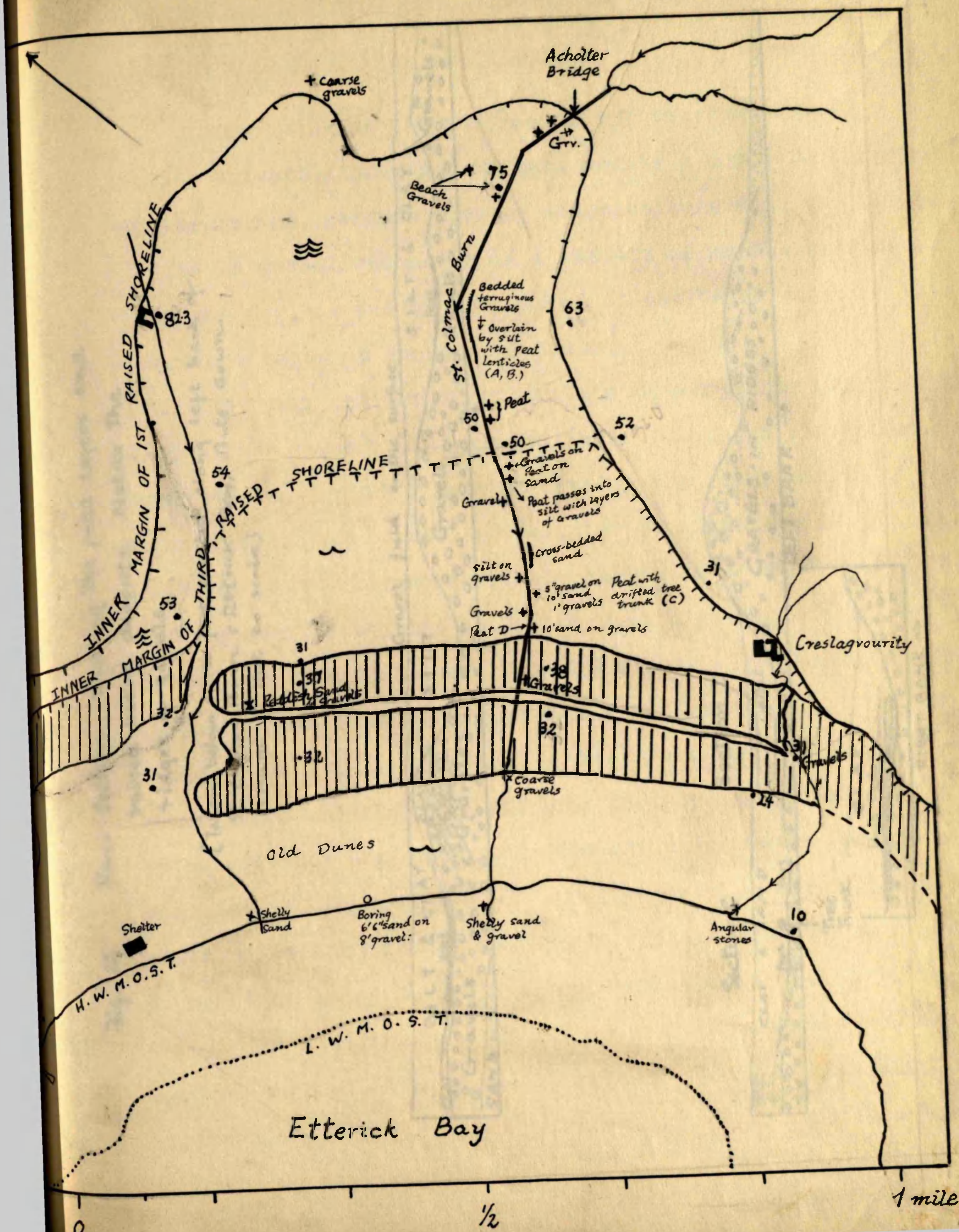
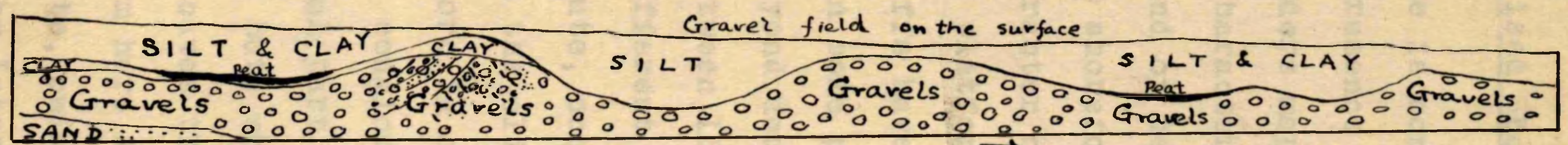
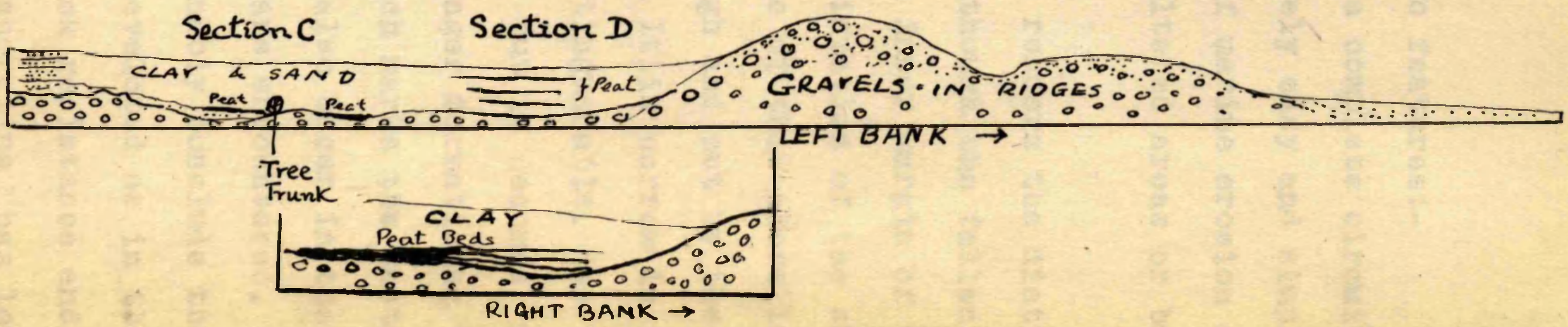

Acholter Bridge
Coarse gravels
Grv.
Beach Gravels
75
St. Colmac Burn
Bedded ferruginous Gravels
Overlain by silt with peat lenticles (A, B.)
63
Peat
50
50
52
INNER MARGIN OF 1ST RAISED SHORELINE
82·3
54
INNER MARGIN OF THIRD RAISED SHORELINE
Gravels on Peat on sand
Gravel
Peat passes into silt with layers of gravels
Cross-bedded sand
silt on gravels
5" gravel on 10' sand 1' gravels
Peat with drifted tree trunk (C)
31
Gravels
Peat D
10' sand on gravels
53
Creslagrourity
31
37
Reddish Sand & Gravels
38
Gravels
32
32
32
31
Gravels
31
Coarse gravels
24
Old Dunes
Shelly Sand
Boring 6'6" sand on 8' gravel:
Shelly sand & gravel
Angular stones
10
Shelter
H. W. M. O. S. T.
L. W. M. O. S. T.
Etterick Bay
0
½
1 mile

Fig. 12 River Section, showing the peat Layers and raised beach deposits. Notice the ridges of gravels.

[Taken below of 50-foot contour along left bank of St. Colmac Burn & Ettrick Bay, Bute, down stream. Not to scale]





III. The Third Raised Shoreline

This shoreline is conspicuous for two features:-

1. Its universal presence forming nearly a complete circuit of the island, renders mapping comparatively easy and simple.
2. Its universal character of a feature of marine erosion at headland regions and of deposition in sheltered areas or bays, where a variety of shoreforms occur.

The rocky character of southern Bute renders the distinction of the raised platform difficult. Although the fallen rocks from the steep cliffs have covered up the inner margin of the former shoreline in some places, the continuation of the shore features proves beyond doubt the existence of this shoreline. It is generally between 15 and 20 feet high and cut by the former sea into different kinds of rocks. It is narrow in the northern part of Bute, occasionally undistingushable, due to fallen debris from the cliff at its rear, but it becomes much wider where the shore is cut into the younger formations; the red sandstones and conglomerate cliff which marks the eastern coast of the central part of Bute. Caves also occur in the southern sector of Bute where trap rocks are encountered. It is by means of these caves that one can resonably conclude that, though the platform here is not as well-developed as in the central part of Bute, owing to greater rock resistance and has been obscured by later deposits, the shoreline has left its mark in this region.

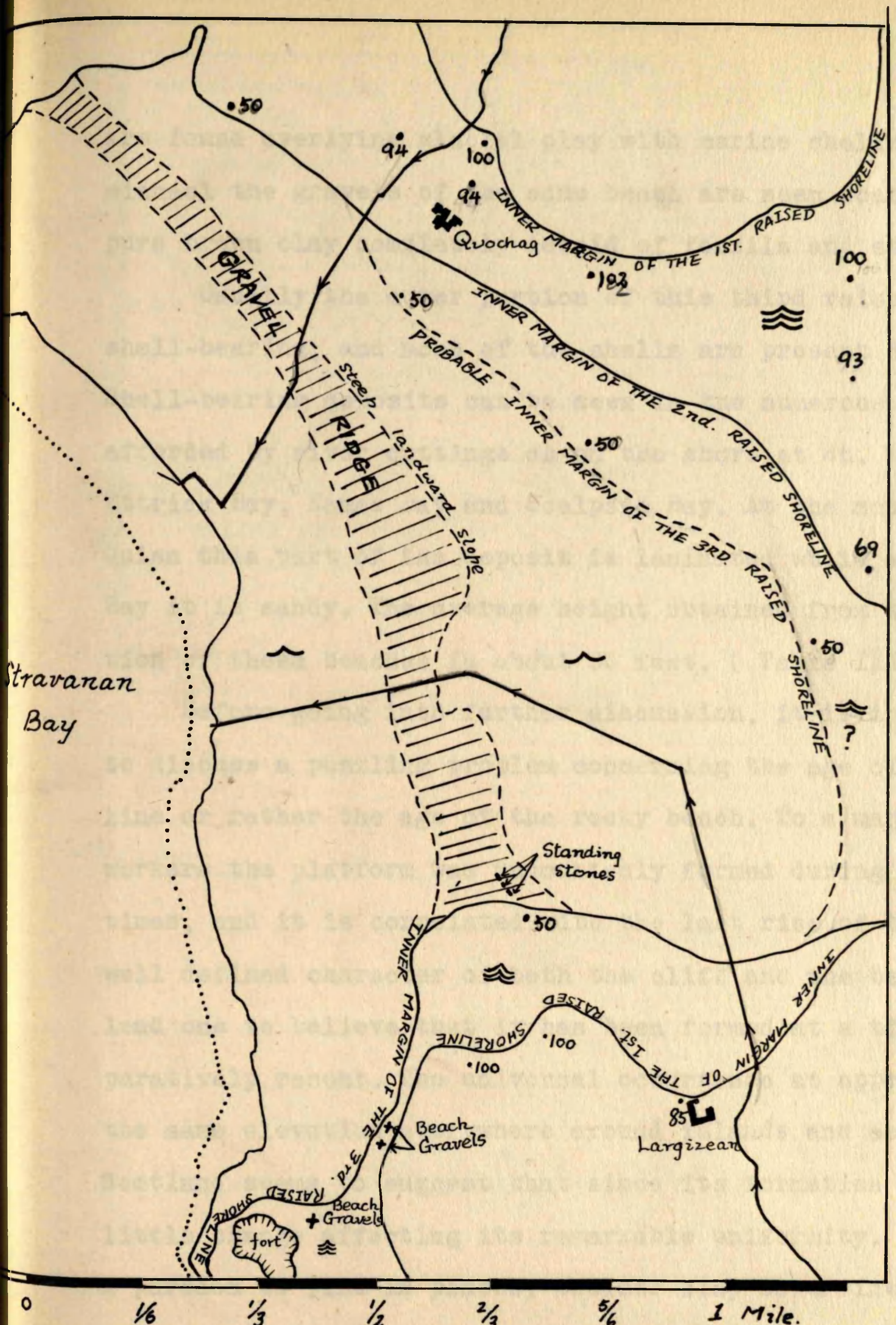
The depositional facies of this raised shoreline is very interesting. In every low tract across the island, raised beaches were built at both ends of the tracts. The Kames-Ettrick tract was almost completely filled with such deposits. The beach of Ettrick bay consists of two beach ridges in the form of two bars across the former bay which extended about a mile inland from the present Ettrick Bay shore. These two bars can be seen running in a direction NW-SE from the Ettrick Smithy to Creslagvourity Farm. (Figs 9 , 11 .) The inner bar is about 38 feet* high while the outer bar is five feet* lower. Behind the inner bar, the ground surface rises uniformly landwards without a break of slope to about 75 feet O.D.. The deposits occur along the St. Colmac Burn show that the two bars described above must have ponded back water into a lagoon in which alternating deposits of silt and decayed vegetation were laid down. The full interpretation of these features is given in the separate note dealing with the pollen analysis of the peat layers found in the deposits. It will be sufficient here to mention that the peat is found to be of Late Atlantic to Sub-Boreal age, being formed contemporaneously with the existence of a sea level probably at the height of 30 feet. During the last rise of the sea, the level of which at this locality was about 30 feet, most of the Ettrick tract was submerged. Then came the formation of the two bars ponding water into a lagoon, which, being gradually filled up, was altered into a marsh.

Sediments, deposited during seasonal floods and occasional storms, covered up the vegetation which decomposed into peat layers. On the north-west end of the bars, there seems to be a gap representing the former tidal inlet to the lagoon. This gap is relatively shallow and one may reasonably admit that within the lagoon, the water level was perhaps a few feet higher that outside.

Similar ridges are found on the southern shore of Loch Quien,(Fig. 10) rising to a height of 40 feet.* The altitude of these has led the Survey to map them as the second raised beach, but the actual height is due to blown sand deposit which also occurs on the bars of Ettrick Bay. The bar itself is formed by small rounded gravels. A dune ridge about 16 feet high occurs on the shore of the bay, and in front of the ridge patches of shell bearing beach material is seen amid the blown sand.

Further south, a bar is met with on the third raised shoreline of Stravanan Bay. (Fig. 13) The bar is by far the longest seen in Bute. It has a NW-SE direction and is formed of sand and pebbles varying from 3mm. to 3cm. in diameter and stretches completely across from cliff to cliff. On Kilchatten Bay side, the deposit of this period is largely blown sand with a gravel foundation, but ridge form is not distinctly presented. There are some other beach deposits worth while mentioning. At Balankilly Burn, N. Bute, five feet of ferruginous gravels

FIG. 15


50
94
100
94
Quochag
INNER MARGIN OF THE 1ST. RAISED SHORELINE
100
102
GRAVEL RIDGE
50
INNER MARGIN OF THE 2nd. RAISED SHORELINE
PROBABLE INNER MARGIN OF THE 3RD RAISED SHORELINE
Steep landward slope
93
50
69
50
Stravanan Bay
?
Standing Stones
50
INNER MARGIN OF THE 3rd RAISED SHORELINE
INNER MARGIN OF THE 1ST. RAISED SHORELINE
100
100
85
Largizean
Beach Gravels
Beach Gravels
fort
0
1/6
1/3
1/2
2/3
5/6
1 Mile.

are found overlying glacial clay with marine shells. At Kilmichael the gravels of the same beach are seen scattered on a pure brown clay completely devoid of fossils and stones.

Usually the outer portion of this third raised beach is shell-bearing, and most of the shells are present day forms. Shell-bearing deposits can be seen in the numerous sections afforded by river cuttings or on the shore at St. Ninian's Bay, Ettrick Bay, Kames Bay and Scalpsie Bay. At the mouth of Loch Quien this part of the deposit is laminated while at Kilchatten Bay it is sandy. The average height obtained from the examination of these beaches is about 30 feet. (Table III)

Before going into further discussion, it is interesting to discuss a puzzling problem concerning the age of this shoreline or rather the age of the rocky bench. To a majority of workers the platform was undoubtedly formed during post-glacial times, and it is correlated with the last rise of the sea. The well defined character of both the cliff and the bench would lead one to believe that it has been formed at a time comparatively recent. The universal occurrence at approximately the same elevation everywhere around islands and coasts of Scotland seems to suggest that since its formation there has been little change affecting its remarkable uniformity. It is,however, a parodox to find in places, boulder clay occurring immediately below the cliff and masking the boundary between the cliff and

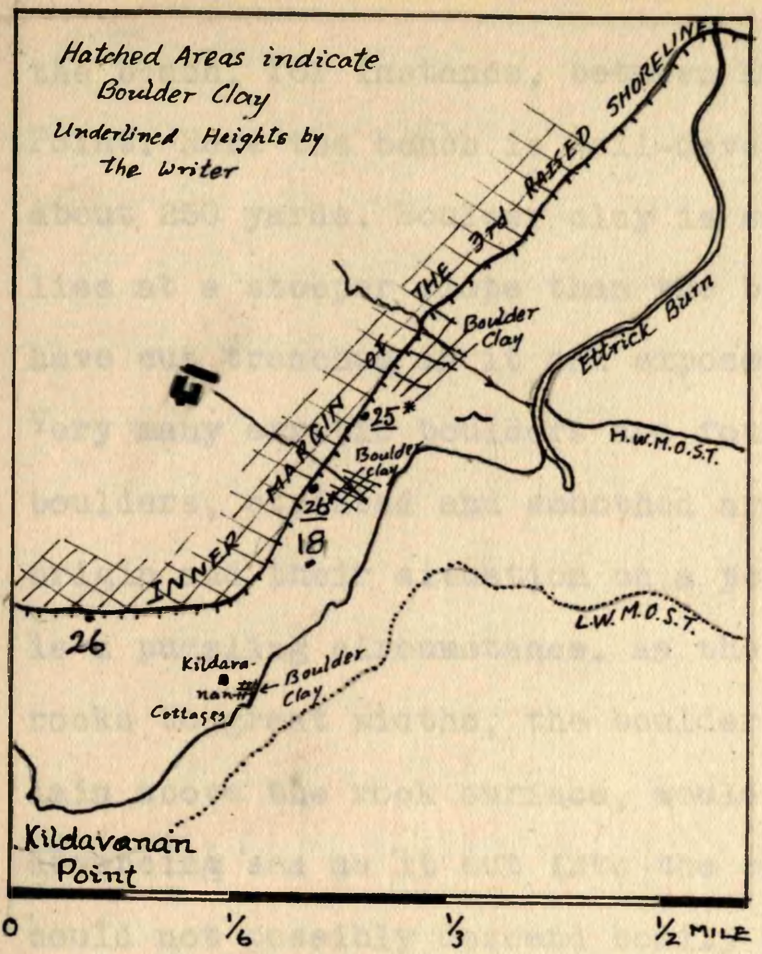
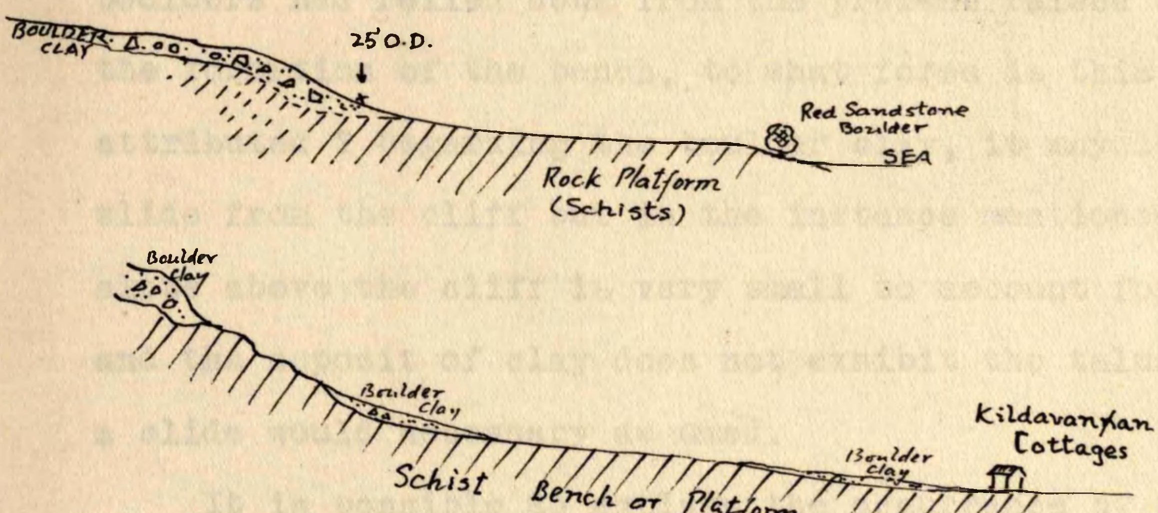


Fig. 14

Showing the Occurrence of Boulder Clay on the 3rd Raised Bench, at Kildavanan Point, Bute



the bench, for instance, between Ettrick Burn and Kildavanan Point. Here the bench is well-developed, with a width of about 250 yards. Boulder clay is seen along the cliff and lies at a steeper slope than the bench so that small streams have cut trenches in it and exposed the deposit. (Fig. 14.) Very many erratic boulders are found on the bench. These boulders, striated and smoothed are certainly of glacial origin and their situation on a post-glacial erosional bench is a puzzling circumstance. As the bench was cut in solid rocks to great widths, the boulders, if previously they had lain above the rock surface, would have been destroyed by the advancing sea as it cut into the solid rocks. The boulders could not possibly descend bodily unaltered as the sea cut from under them, the coastal rocks on its advance. If the boulders had rolled down from the present raised cliff after the formation of the bench, to what force is this to be attributed ? Regarding the boulder clay, it may have been a slide from the cliff but in the instance mentioned above, the slope above the cliff is very small to account for such slipping and the deposit of clay does not exhibit the talus form which a slide would necessary assumed.

It is possible to explain the occurrence by a new suggestion, which, revolutionary as it may be, seems worthy of consideration. The difficulty will be eliminated if we suggest that the bench itself is pre-glacial. Subsequently, it was completely masked by boulder clay with numerous erratics. The removal of the boulder clay to reveal the ancient topography is of easier accomplishment than the erosion of rocky benches. The boulders would not necessarily be subjected to much wear when working their way downward by the removal of the supporting boulder clay. A difficulty arises in explaining the almost complete removal of boulder clay on a 25-foot pre-glacial bench and at the same time, the preservation of boulder clay on the 100-130-foot pre-glacial benches of Mull and other places. In Mull, striation on cliff and bench and the occurrence of large areas of boulder clay on other benches are quoted as supporting the pre-glacial dating of the 100- to 130- foot bench. It must be noted that on the 25-foot bench, marks like striation have been found on Dunoon shore and there are one or two localities in which boulder clay is seen on the bench.* Further evidence, however, is necessary before this new suggestion can be soundly established, but the writer does not hesitate to point the possibility of such an explanation.

IV. Conclusions

We have in the above discussion made clear the distribution, the shore features and the approximate height of the raised shorelines that occur in Bute. Conclusions in the

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* Boulder clay overlying rocky bench is seen on the present shore , near Downcraig, NE of the Great Cumbrae.(Pl. IV, 2.)

Plate IV

Fig. 1 Raised Beach Deposits exposed along St. Colmac Burn, Ettrick Bay, Bute.

Fig. 2 Raised beach gravels of boulder clay which overlay the 25-foot rocky bench, Eastern shore of Great Cumbrae.

present state of knowledge on the problem must be tentative and no doubt there are still many points which need to be considered. In mapping the highest raised shoreline, the writer has had a long struggle with himself. The deposits of that particular shoreline everywhere have a sub-angular character and have no clear distinction to differentiate them from boulder clay. The colour of the gravels in the clay, the state of occurrence, without distinct stratification and generally poor preservation of shore features made the writer uncertain whether he was dealing with true beach material or with boulder clay. Everywhere the inner margin of the red sandy deposit is very ill-defined and if one take for granted that the more or less steep acsent at the rear of this deposit is the former shore-cliff, it would still possible to find some still higher 'raised shorelines'. It is therefore very uncertain whether there is any genuine 100-foot raised shoreline on this island, though the writer has mapped some probable ones.

There are places where the boundary between two raised shorelines is totally absent. In Kames Bay the boundary between the first and the second raised shorelines is ill-defined. They are connected together in a continuous slope but with changes in the nature of the deposits. The same boundary difficulty exists in between the second and the third raised shoreline of the Kames-Ettrick trough.

Table I. Heights of the First Raised Shoreline

Locality	adjacent bench mark in feet O.D.	Estimation from contours & B.M.
Kilmichael		80.0
Rocky bench of Buttock Point		50-100.0 contour
Rudha Dubh		over50.0 contour
Rudhbodach Farm,NE Bute.		over 100.0 "
Ardmaleish Farm,	84.0	
Ettrick Burn		60-90.0 feet
Dunalnut Wood	93.0	
Loch Quien	above 94.0	
Kirk-dam,Rothesay	below 97,0	
Stravanan Bay toGarrochty Farm	78.0	
N. Kingarth	117.0	
Kerrycroy bridge	119.0	

Table II. Heights of the Second raised shoreline

Localities	bench marks	estimation
Ettrick Burn	above 60.6	
Acholter Bridge	above 75.0	
seaward from the bridge	below 62.0	
Creslagvaurity	below 51.0	
Kilmichael	above 64.0	
Kilchatten	56- 69.0	

Table III, Heights of the Third Raised Shoreline

Locality	Adjacent Bench Mark in feet O.D.	Shore feature	Estimated heights in feet
Scalpsie Bay	below 31.7	beach	26.7
N. of Kirk Dam	below 37.0	beach and fluvial deposits	31.0
Rothesay	26.6-37.0	"	26.0
S. of Port Bannatyne	below 25.9	bench	26.0
Ettrick Bay	above 20.9		
Inner margin of second bar	below 31.9	deposits	(measured) 25.0
NE Kildavanan		bench	25, 26, H.W.M.
At Kildavanan Point	25.0	bench	26.0
NW of Kildavanan Point	21.8	bench	23.0
Point House,Ardbeg	above 29.0	bench	30.0
North side of Kames Bay	below 31.0	deposits	26.0

The estimation of the height of the shoreline is based on the general principle that the level of the sea is generally higher than the bench by one or two feet at most and lower, to a very great extent, than the beach and other deposits. The last amount is ~~hypothetical~~ to be arbitarily chosen and five feet seems to be a reasonable number. Detail measurements would be necessary for precise correlation.

Chapter VII

Raised Shorelines on the Mainland Coast, Firth of Clyde.

The mainland coast includes a stretch of land bordering the sea from Gourock southwards to Ayr. The northern sector of this coastal area is essentially a promontary region liable to wave erosion rather than deposition while the southern sector from Ardrossan to Ayr with the exception of the promontary on which Troon was built, is essentially a sheltered bay favourable to deposition.

There are three raised shorelines.(Fig. 15) The first one is well presented in certain localities while doubtful in other places. The second one occurs only at intervals and the third can be traced continuously along the whole coast.

I. The First Raised Shoreline

This shoreline occurs only at a few localities north of Ardrossan. The wedge -shaped bar on which Ardgowan Castle is situated, is formed of gravel and sand and extends above the 100-foot contour. The shoreline is found again at Wemyss Bay reaching 112 feet O.D. although there are acattered gravels seen higher than this level. It occurs about 80 feet O.D. at Largs. The beach deposits are gravels and pebbles of small size, well-bedded, with a slight SW dip down the river Noddsdale. At Raillies Village, the deposit is composed of sand overlying gravels, having a total thickness of about 13 feet. Cuttings along the northern portion of the Moor Burn Road, exposed gravels. In a cutting on the east side of Auchenmaid Drive, gravels are seen underlying a boulder bed of sub-angular stones which are probably screes from the hills. Since the formation of the first raised beach, the land rose and the river cut into the beach deposit forming a number of erosional fluvial terraces on the eastern bank of the river Noddsdale. (Fig. 16. Pl. V 1.)

The same shoreline might be expected to occur at West Kilbride but there is no definite evidence to show its existence. The deposit exposed between the 50- and 100-foot contours is boulder clay, sections of which can be seen along a small stream west of Carlung House, north of West Kilbride, at a height about 60 feet O.D.

South of West Kilbride, the shoreline occurs for the first time in a more continuous form from Ardrossan to Kilwinning, where it ends abruptly in a thick deposit of glaci-fluvial gravels. The raised shore deposits are similar in character to those of Largs and are best exposed along the new road north of Mayville, Stevenston. The glaci-fluvial deposits, on the other hand, are a ridge of well-rounded gravels. Most part of the ridge is cultivated, and the character of the deposits can only be examined on the surface. In a section on the river Annick, coarse gravels which dip to

Fig. I Screes on Raised Beach, Auchenmaid Drive, Largs, Ayrshire

Fig. 2 Laminated Sands of the Third Raised Shoreline, Bogside, Ayrshire.

the north-west, is seen 'unconformably' overlain by beds of sands and pebbles. The coarse gravel bed is of glaci-fluvial origin and a striated boulder is seen embedded in the sand overlying the gravels.

Leaving the gap between Kilwinning and Drybridge for further consideration, the shoreline may be followed almost continuously from Drybridge southward to Heads of Ayr. At Drybridge it attains a height of about 95 feet, It oscillates between the 90 and the 100-foot contours as far south as Prestwick, and then gradually falls to 80 feet. There are only a few localities where deposits can be examined and most of the shoreline is traced by a continuous break of slope. A good section of laminated clay overlain by pebbles is seen at Brieyside Bridge, Monkton. The clay contains Arctic shells e.g. Astarte compressa and Natica clausa and the overlying pebbly sand layer has well developed ripple marks.

II. The Second Raised Shoreline (figs. 15,16.)

Going south from Gourock, this shoreline is first encountered at Largs. It is 75 feet high. This terrace here as in Bute, is often fragmentary and seldom can be traced for long distances. The deposits show no clear distinction from those attributed to the first raised shoreline. At Largs, the shoreline marks the inner margin of a sloping fan-like deposit south of Gogo Burn. Standing somewhere near the 70-foot contour line and looking towards the Clyde, one cannot find even the slightest trace of a break in the slope. The ground not only slopes towards the sea but also to right and left and the fan spreads in front of the Gogo Burn and drops abruptly at 25-foot contour to the stretch of low meadow along the shore. On the northern side of Gogo Burn the gentle slope upward from the sea only reaches a height of about 45 feet and shows a break of slope at the 20 feet level. In Noddsdale Burn, a similar phenomenon is observed. The radially slopes indicate that the second raised shore form of Largs was a delta, or rather, a confluent delta formed in front of the two rivers. This delta has been partly removed by erosion to a base level determined by a subsequent lower level of the sea.

The second raised shoreline from Ardrossan to Kilwinning has a general height about 71-75 feet. The deposits of this shoreline are exposed in Penny Burn a mile east of Stevenston where they showed gravels dipping southward and overlain by a peat bed 1½ feet thick. Above this lie six feet clay.

A portion of this shoreline is indicated in Eglinton Park by a break of slope. The general height is uncertain but it rises above the 50-foot contour. This shoreline is cut into the glaci-fluvial deposits. The same shoreline is traceable from Stane Castle to Dreghorn a distance about two miles, at an average height of about 60 feet. Here it is also carved in the glaci-fluvial deposits, which occur at much lower levels along the river bank of Annick Water.

From Drybridge southwards to Auchans, the height of the shoreline varies greatly, reaching sometimes 75 feet but sometimes dropping to 55 feet as at Auchans. It is traceable only as a low coastal feature. From Auchans southwards, it is continuous to Loans. The inner margin, marked by a slight break of slope, crosses the road north of Laigh Hillhouse, and is about 60 feet high. This portion of the second raised shoreline has not previously been mentioned or mapped but there exists a break of slope at the suggested level must not be overlooked though other evidence are at present wanting.

Southward at Monkton the height remains about the same. Here all three raised shorelines seem to pass into a single gentle slope in which none is clearly distingushed. Deposits examined in river sections show ferruginous gravel overlain by brown clay. Laminated clay is seen at Clune a mile east of Prestwick.

In general, the second raised shoreline seems to show a slight lowering of level southward. A part of the shoreline is cut in glaci-fluvial deposits thus rendering its age determinable. It has been pointed out that the first raised shoreline was replaced between Kilwinning and Dreghorn by thick deposits of glaci-fluvial gravels. It is probable that before or during the first raised shoreline period, this section of

Ayrshire lay adjacent to an ice front from which the glaci-fluvial gravels were derived and deposited displacing the shoreline seawards while elsewhere, the sea has been able to leave its mark. The association of glaci-fluvial deposits with the first raised shoreline is well demonstrated in Islay which will be discussed in chapter VIII, and in many other places, especially in the highland fjords. There the first raised shoreline is believed to have been displaced by ice tongues then occupying the fjord valleys. Hence it is clear that the second raised shoreline is later than the glaci-fluvial deposits. Since it seems that there were no readvance of the ice after that time, the post-glacial in Ayrshire actually commences from the second raised shoreline period.

III. The Third Raised Shoreline (Figs.15,16.)

This shoreline is continuous as it is in Bute. North of Ardrossan, it is represented by a continuous cliff-backed platform the inner margin of which generally oscillates between 25 and 35 feet, though sometimes higher levels have been recorded. It rises landward to greater height in estuaries and embayments but lies much lower on open coasts, a fact also presented in the study of the same shoreline of Bute. Deposits of gravels, sometimes cobbles, occur upon it and nearer to the present shore, eroded sand dunes and shelly beds are often seen.

At Largs the shoreline has its inner cliff at the height of 45 feet O. D., but there is a still lower break of slope which is essentially a local phenomenon at the level of about 20 feet, below which a strip of low-lying meadow extends along the shore. This has been attributed to a younger age than the third raised shoreline. It may, however, be a deeper part of the 45-foot shoreline corresponding to a part beyond the shore-face terrace.

As has already been observed with regard to its development in Bute, this shoreline is characterised by its abundance of depositional shore forms. The situation of the Ayrshire coast is such that it favours marine deposition. A large part of the present coastal plain can be attributed to deposition during the third raised shoreline period. For the sake of convenience in the discussion here the region is divided into two: the first includes the stretch of coastal plain from Saltcoats to Troon and the second includes that from Troon southwards to Ayr.

A. Region I

On figure 15, one will see the curious loop made by the river Irvine south of Bogside. This hair pin bend of the river is not a normal meander. The river Garnock also makes a sharp right angle bend SW of Kilwinning and runs a straight course for more than a mile southward to join the river Irvine.

Along these two rivers there are sections which show the deposits of the third raised shoreline. Emerging from the second raised shoreline near Drybridge, we proceed down the river Irvine, Sections of ferruginous gravels are met with on the morthern bank of the river. (A. fig. 15.) Further down, in a small stream which joins the Irvine river below a waterfall, sand and gravels are seen overlying a forest bed composed mostly of decomposed tree trunks which in turn overlies a bed of sandy clay. This is the forest bed reported by Smith of Jordanhill. (B. fig. 15.)

Returning to the main river and following it down stream, a section of raised beach deposits is seen on the left bank at the bend where it flows north into Irvine. The deposit is composed of five feet of ferruginous gravelly sand on a sand bed the base of which is not seen, Above the ferruginous deposit is a layer about 20-25 feet thick of cross-bedded sand with few gravels. The upper part of this is dark coloured due to oxidation and indicates a buried land surface on which lies blown sand in dune forms. From the thick sand bed shells of recent species have been collected as follows: Littorina littorea, Pecten, Mya and Patella. Flanking the west side of the north-flowing river is a series of sand dunes without any apparent linear arrangement rising about 30 feet above sea level. These sand dunes are in fact connected with the coastal dunes stretching from Troon to Saltcoats. The deflection of the river Irvine is possibly due to the growth of this ridge of sand dunes northward from Troon to Irvine. Beginning within the town Irvine a low cliff can be traced 'meandering' its way northward and fading away when it reaches Eglinton

Park. It is referred to as a still lower raised shoreline, but it is clear that the cliff may be a relic of the erosive activity of the river itself, which has wandered from the course marked by the cliff.

Along the new road built a little north of Meadowhead, gravels are exposed overlying boulder clay. Smith refers to hard peat found on the river bank further down stream near Burnside Cottage. Not far north from the head of the bend is Bogside where an excellent section of raised shoreline deposits can be examined. The section occurs in a sand pit near the Station exposing the following beds:- (Pl. V,2)

f.	Blown sand	
e.	Laminated sand, sometimes cross-bedded	2 ft.
d.	Brownish black sand full of decayed vegetable matter with a hard mineral crust on the top	3-5 ft.
c.	Laminated gray sand and silt	3 ft.
b.	Ferruginous sand	1 ft.
a.	Gravels	13 ft.

The lowest layer of bed 'd' is composed of a dark band of decayed vegetable matter about 5" to 1 foot thick, marking an ancient land surface which is now covered by blown sand, Within the bed e, four successive layers formed by decayed vegetable matter can be traced, each of which representing a halt in the growth of the sand dunes. The surface under each such layer is irregular.

Shell beds are reported to occur on the west bank of Garnock river a little north of Buckreddin House, Kilwinning, The river flows southward and a low cliff similar to that of the Irvine river is seen winding in harmony with the present meandering of the Garnock river. An abandoned ox-bow of the Garnock found in connection with this low cliff verifies the suggestion that the latter is a product of river erosion. This ox-bow is shown on the six-inch map about two-third of a mile south of Kilwinning.

From what has been said it appears that the deposits of the third raised shoreline can be grouped into three belts on the basis of differences corresponding to the different conditions of accumlation resulting from the relative distance of the belts from the margins of the former shore. The inner belt of gravel just below the shore cliff is a beach deposit. Seaward from this beach there is a zone of sands and clays with marine shells, and seaward of this again occurs a belt of sand dunes.

The submerged forest bed and the curious bend in the river Irvine just above its estuary are related phenomena subject to a single explanation. When the sea stood higher on the land than at present the area was an estuary, rather extensive and lengthy, receiving the waters of the Irvine and the Garnock. The shores of the estuary were high and ended in rocky promontaries at Troon and north of Irvine. Conditions were favourable to the development of an off-shore shingle bar, the existence of which is, of course, definitely hypothetical, but which may very probably have provided the foundation upon which there accumlated a belt of dunes as the level of the sea was depressed. The dune belt at least is not hypothetical: it extends from Troon northwards to Irvine and is backed by a sand plain of considerable extent and varying width. Before the completion of the dunes there had accumulated the beach gravels which extend seawards of the oldest belt of the third raised shoreline whose inner margin is marked by a sinuous line of low cliffs(fig. 15), associated with the lower courses both of the Garnock and of the Irvine.

The growth of the dunes led to a progressive deflection of the river mouths, that of the Garnock south-eastward from Saltcoats, that of the Irvine northwards, and enclosure of the estuary gave rise to a lagoon which became filled up be terrestrial deposits in the normal fashion. Shewalton Moss is a relic of this phase which indicates the landward extent of the lagoon. To the infilling,blown sand must have contributed considerably, and much of the area of lagoon deposit has been overrun by blown sand. The development of the dune belt must have been progressive. The earliest belt no doubt migrated inland. Its vestiges probably run along the motor road from Irvine to Troon and form Bogside Racecourse, and it, no doubt, contributed largely to the drift sand. The later additions constitute the present coastal sands extending from Troon by Fullarton to the present mouth of the Irvine and from the latter to Saltcoats. They finally united the mouths of the two rivers. The total result has been a considerable seaward displacement of the coastline and the gain of land to ... -

Ayrshire by the operation of coastal processes during the third raised shoreline period exceeds seven square miles.

The inner margin of the third raised shoreline, marked by the base of the inland low cliff which varies in elevation from 43 feet at Stevenston to 31 feet in Eglinton Park, is a depositional feature. The lagoon level was also probably something higher than the level of the sea, and the surface of the lagoon deposits must necessarily be higher still. Allowing a foot or two for the rather high indications given by the measurements it is suggested that the level of the sea at this time probably ranged from 30 to 40 feet O.D.

B. Region II (Fig. 17.)

This region comprises the coastal area from Troon southward to Ayr. The Pow Burn, though a comparatively small river affords good ground for the examination of the development of this region which is essentially similar to that described in Region I. Deposits seen in the inner parts are generally gravels like those exposed along the Pow Burn, SW of Aitkenbrae Bridge. In the outer belt, the gravel is covered by a layer of decayed vegetable matter which in turn is buried by three feet of sand on which blown sand has been deposited. This deposit is well exposed along the Rumbling Burn, a tributary to the Pow Burn. Inside the garden marked 'tank' on the six-inch map, north of Monkton Station, a forest bed similar to that occurring in the Irvine section, is seen overlain by 8 feet of sand which in turn is covered by 10 feet of

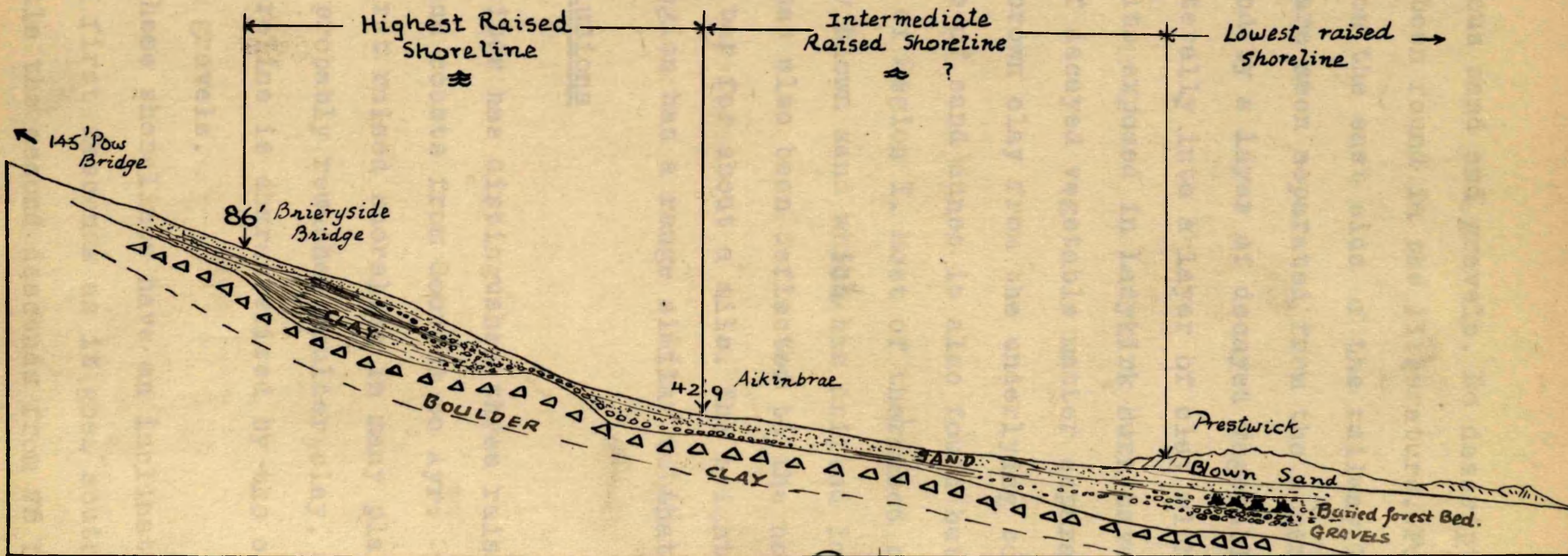

Fig. 17. Diagramatic section showing the deposits seen along the Banks of Pow Burn, Ayrshire.

ferruginuous sand and gravels. No description of this forest bed have been found in the literature. Further north in a sand pit on the east side of the railway line, coarse gravels and sand are seen separated from the upper brownish or ferruginous sand by a layer of decayed vegetable matter which passes laterally into a layer of clay with sand lenticles. The deposits exposed in Ladykirk Burn have the same sequence. A layer of decayed vegetable matter separated the overlying sand and brown clay from the underlying boulder clay. An outer zone of sand dunes is also found but with less extent than that of Region I. Most of the raised beach deposits are covered by blown sand which has drifted landwards and the mouth of the Pow Burn has also been deflected to the north by the growth of a sand bar for about a mile. The height of the shoreline in this region has a range similar to that of Region I.

IV. Conclusions

1. The writer has distingushed three raised shorelines on the mainland coasts from Gourock to Ayr.

2. The first raised shoreline in many places carries gravels which are probably rewashed boulder clay, while the second raised shoreline is characterised by the occurrence of true water worn gravels.

3. Both these shorelines have an inclination towards the south. The first descends as it goes south from 110 feet to 90 feet while the second descends from 75 feet to 60 feet.

4. The first shoreline is discontinuous in a section between Kilwinning and Drybridge where there occurs a thick glacifluvial deposit. It is therefore reasonable to conclude that during the first raised sea, shoreline formation here was interfered with by an inflow of glacial water from an adjacent ice tongue.

5. The Third raised shoreline has an uniform range of height between 30 and 40 feet, though it apparently becomes higher inland.

6. During the third raised sea, the coastal regions of Ayrshire were extended considerably by outward growth of the coast and by lagoon infillings. The lowest cliffs formerly suspected to indicate a still stand of the sea are explained as a local development of the River Irvine and Garnock.

7. It is found that the evidence collected in this region is in close harmony with that provided by Bute, Each of the shorelines has similar characteristics, history of development and shore features.

Chapter VIII

Glaci-fluvial Deposits and Raised Shorelines of Islay

Islay is known to have striking examples of raised beaches. Most of which are opened to interpretation as glaci-fluvial deposits laid down during the late glacial period of the last glaciation, though some of them are still regarded as indicating raised shoreline features.

The present chapter will begin with the discussion of the glaci-fluvial deposits under certain groups which distingush themselves from each other as regards origin, mode of occurrence and topographical forms.

I. Glaci-fluvial Deposits

Eskers, Kames and Drumlins.

The writer will not venture to discuss the most debatable question about the origin of eskers but it seems that the general belief points to englacial, or sub-glacial origin for such deposits. That they are formed within the margin of the ice is universally admitted in spite of the bulk of conflicting agruments regarding actual processes involved in the formation of such deposits.

Many of the glaci-fluvial deposits referred to below

Fig. 18. Map showing the Glaci-fluvial deposits of Islay.

Eskers, kames (extra thick lines), Sand and gravels (hatched). Marginal Delta (cross-hatched), Drumlins (circles), Arrows (glacial striae after Wilkinson) Contour interval: 250 feet.

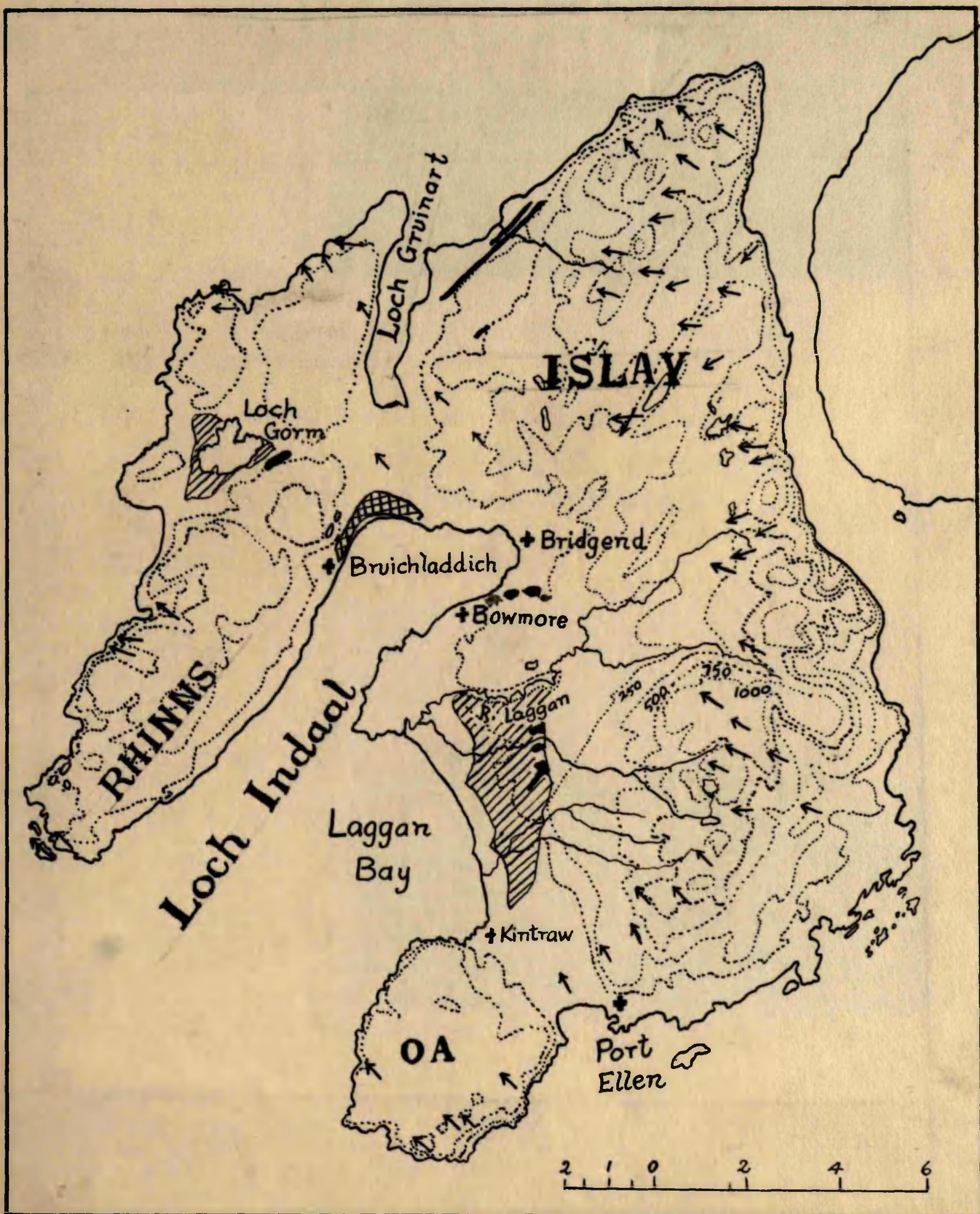

Fig. 1. Drumlins, looking north from Sunderland Farm, Loch Gorm.

Fig. 2 The eastern end of the Esker, Loch Gorm, Islay.

Plate VII.

Fig. 1 Esker Ridge of Loch Gorm.

Fig 2. Deposits of the Esker ridge.

do not appear to have been described. The occurrence of such deposits in Islay are few. They are shown in solid black on the accompanying map.(Fig.18)

South-east of Loch Gorm, beginning at the farm Aruadh, an esker ridge runs in a NE-SW direction for a distance about 1,200 yards. The ridge is flat-topped, nearly symmetrical, slightly steeper on the northern side with a height of twenty to twenty-five feet. (Pls.VI ,VII .) It stands just about the hundred-foot contour line. The ridge, however, is not continuous, but is divided into six portions with the crests at nearly the same level.

The deposits which composed the ridge are unstratified, but do have traces of a horizontal arrangement.(pl.VII ,2.) Gravels, coarse and angular, occur at both ends of the ridge. Judging from the appearance and character of the deposits, the sands seem to overlie the gravels. The gravels are derived from local rocks, mostly quartzite, with numerous igneous gravels chiefly dolerite and pebbles of Lewisian gneiss. These indicate a northward travel of the material, the Rhinns of Islay being composed of gneiss and transversed by quite a number af doleritic dykes. In discussing eskers, Flint(p. 410.) has pointed out that eskers are generally broken and discontinuous, composed of coarse material, the bedding of which is variable and irregular with semi-stratified and non-stratified inclusions. Hobbs is also of the same opinion. (.)

Plate VIII

Fig. 1 Material of a drumlin-like mound, 1,000 yards north of the Loch Gorm Esker.

Fig.

The steep sides of the present esker are probably due to the erosion of running water after deposition, as was the case in some eskers in Finland described by Tanner, (Tanner,I.)

The esker stands on a peat-covered flat which is over 70 feet above the present sea level. The ground slopes very gently to the north at the western end of the esker into a fan-like plain which is probably an outwash plain. No cuttings through the deposits of the plain are available to verify this suggestion. East of the fan-like plain, the ground which is almost flat, is drained by little streamlets.

About 1,000 yards N. of the esker ridge, the main road cuts through a mound of drumlin form. The mound is 15-20 feet high, composed of unstratified deposits varying from gravels to boulders. (Pl.VIII,1) The gravels are mostly angular, occasionally rounded, without striations. They are mostly local slates, quartzites with a number of doleritic boulders. The matrix of the whole deposit is sandy. North-eastward from this mound, there are numerous similar mounds running parallel with the esker ridge. They are probably drumlins.(pl. VII, fig 1) One of them is actually a rocky mound.

A ridge, starting from a point half a mile north of Bun-an-uillt, runs parellel with the course of Au Ruime, north-eastward for a distance of four miles to Doodilmore river north of Gortantoid.(Fig. 25, inset) It is amazing to see the continuity over such a long distance. The crest which at the south-west terminus is about 90 feet above sea level, rises occasionally up to 105 feet and drops down again to 90 feet at its northern end. There is a lesser discontinuous ridge between it and the sea, only conspicously seen across the Gortantoid river, west of Gortantoid Farm. At the rear of the main ridge, is a peat flat which probably is an old valley; through it flows the river An Ruime. The ridges are mapped as the highest raised beach on the one-inch geological map of 1896.

Though no exposures can be found along the ridges, it appears, from the outcast of rabbit burrows, to be composed of sand. The vegetation on the ridges are those commonly seen on sand dunes. These ridges, to the writer's opinion, are kame ridges formed in front of the ice. A kame-like ridge is also found across the peaty flat near the head of An Rumach at an elevation between 2-300 feet.

Two mounds running WNW-SSE at Grobolls, near Bridgend, standing above the 100-foot contour. They are probably the continuation of another group of rudely stratified gravel ridges to the E and NE of Bowmore. All these ridges are situated just above the 100-foot contour which may be taken to suggest that the hundred-foot contour marks the limit of the late glacial sea.

Following the high road from Bridgend to Port Ellen, a number of ridges or mounds may be seen to run across the road. Near Tallant Plantation there is one on both sides of the road with an axis ENE-WSW.

South of Torra Farm, such ridges are common, mostly composed of unstratified gravels with irregular sand lenticles. They run E-W and change into NE-SW when traced southwards. Near Torra Dubh, where a small river has cut a deep ravine into the deposits, there are exposed thick beds of fine sand overlain by gravels. The deposits here have a lobate form with a ridge-like tongue pointing to the SW on the lowlying plain. Southward of this locality, the ground gradually rises and only boulder clay is encountered along the main road.

Gravels, Sands and Terraces

Gravels and sands are the most abundant drift formation in Islay. Most of them show no definite topographic form and have probably been deposited as plains of gravel under the melting water.

Excellent exposures of deposits of this kind are found on the banks of the Laggan river on both sides of the Laggan Bridge, three miles SE of Bowmore. Three sections have been examined and they all present the same general sequence which is tabulated as follows:-

Section A	Section B	Section C
Peat Ferruginous gravels with distoreted sand lenticle	Peat Ferruginous gravels	Peat Distorted sands Ferruginous gravels
Boulder Clay	Stony boulder clay Coarse gravels	Red clay with sand bands. Boulder clay

Fig. a

Fig. b

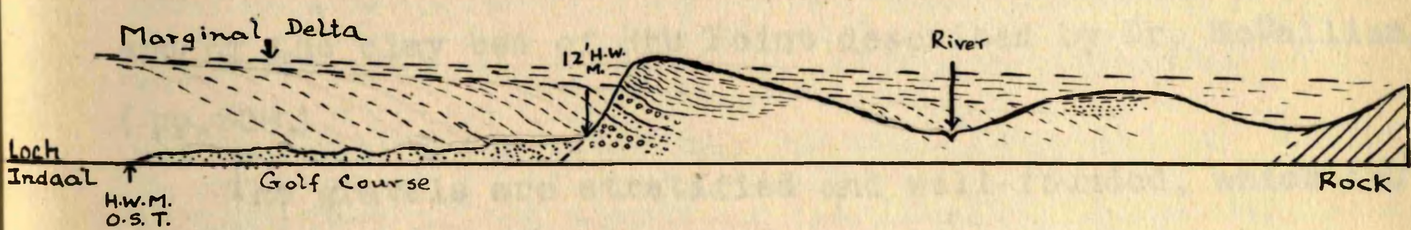

Fig. c.

Fig. 19.

a-b. Sections along the river Laggan, showing glaci-fluvial deposits. Not to scale.

c. Section across the deposits of a marginal delta, at the head of Loch Indaal. The broken lines indicate the reconstructed delta.

The boulder clay in all three cases is very hard, full of angular stones and dark red in colour. The overlying red clay is brighter in colour, stoneless and occasionally interbedded with sand bands. It is finely laminated. The contact between the red clay and the boulder clay is an 'unconformity'. (Fig. 19a-b) Overlying the clay of section C, is a bed of ferruginous gravels which in other sections lies directly on the boulder clay. This seem to indicate that the red clay is of a much earlier date than the gravels and there has probably been a gap in between the deposition of the red clay and the overlying gravels. No fossils are found, but the position and character of the clay resemble very closely to those of the glacial clay bed found along the shores of the Kyles of Bute and of the clay bed of Rhu Point described by Dr. McCallien. (pp.338.)

The gravels are stratified and well-rounded, which indicates sufficient water action. The whole bed is ferruginous sometimes stained probably by magnesium oxide. The gravels are in turn overlain by a thick sand bed which has been contorted into gentle folds, the cores of which are formed by the underlying gravels. It is important to point out that not only the lithological character, the sequence and the appearence of these deposits of sands and gravels are similar everywhere in Islay, but the contorted nature of the sand bed and its relation to the underlying gravels bed is also found in many other places.*

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* See appendix III

Remarking on these gravels and sands, Macculloch said: " The borders of the Laggan are formed by high banks of clay and gravel reaching even to twenty feet in altitute..... a consideration of the general disposition of the great alluvia, will be sufficient to show that these are not the effects of the streams, which have only ploughed their way through the yielding materials they have traversed. " (p.236)

Some other sections further down the Laggan river exposed a very interesting phenomenon. Boulder clay - the same red, stiff, stony clay as found in the upper course of the river -, is to be seen in two places overlying a thick bed of pure red clay. Whether the red clay is the equivalent to the bed overlying the boulder clay in the Laggan sections is still a question and there is no strong evidence suggesting an inter-glacial deposition. Although the Survey map has put the deposits of this part of the Laggan as the 100-foot raised beach, these sections of boulder clay, sands and gravels shows no marine characters: they are glaci-fluvial deposits, lying approximately between the contours of 90 and 110 feet.

The surface of these deposits is very even which at once suggests that they were deposited under water. Though derived from melting of ice, it is probably that this occurred when the sea stood at a higher level than it is now. Shall we call them raised beaches, which indicate their marine origin when they are actually materials derived from the ice, deposited as aprons in the melting ice water ?

South of the Laggan, many river sections tell the same story. Boulder clay is found occasionally with overlying sand and gravels and it is also found overlying stratified sand and clay north of Arirolchallum.

It is therefore legitimate to conclude that the flat ground from Bridgend to Port Ellen, lying between 150-70 feet, is almost filled up by glaci-fluvial sands and gravels and by boulder clay. This flat ground, morphologically speaking, is a composite sub-aquaeous plain built up at the confluence of the glacial waters which came from the glaciers then occupying the 1,500-foot high ground east of this region.

Apart from these plains built by gravels and sands, there are gravel deposits in which has been developed a terrace form. Such terraces are often mistaken for raised beaches, probably on account of the fact that they have been deposited within the range of the levels of recognised raised beaches. A number of these terraces are found on the west side of Loch Gorm. To the NE of Ballinaby, a gravel pit exposed thick series of ferruginous gravels dipping slightly towards the NE. The deposits have a terrace form, the inner margin of which rises to a height of 80 feet O.D. The gravels are similar to those seen in the Laggan sections, being well rounded, rudely stratified indicating glaci-fluvial origin. To the SW of Ballinaby, near Coulererach, another gravel pit exposes similar deposits slightly coarser at the top and dip towards the SSW. The inner margin of the terrace measured from the nearest bench mark is about 85 feet.

The terrace materials were probably deposited under melting water occupying the depression from Loch Gruinart to Loch Gorm. The water overflowed westward to Saligo Bay and northward to Sanaigmore. The northern valley now occupied by the small stream Leoig, has rock terraces on both sides evidently cut by a river once charged with a larger volume than the present.

South of Loch Gorm, at the foot of the hill, on which the Kilchoman Church stands, the river Allt Gleann na Ceardaich cuts into a deep ravine, exposing red boulder clay overlying gravels. Just north of that valley, another small stream has high banks of thick sand deposits resembling those recognized as glaci-fluvial in origin. The top of these deposits is flat and with the lack of ordinary cross-bedding characteristic in dune sand, they probably are of glaci-fluvial origin. The height of the boulder clay terrace is about 100 feet above sea level while that of the sands and the overlying gravels is about 70 feet.

It is apparent that in late glacial times, the Loch Gorm region was a shallow lake, the upper level of which did not exceed 90 feet O.D., and in this lake, glaci-fluvial sands and gravels were deposited in forms with deltaic structure. Some of them have later been eroded into terraces.

Marginal Deltas

A marginal delta is defined as a delta built in front of the ice margin. Practically all parts of the delta are under water except the head, which emerges slightly above the level of the water. At the rear of the delta, kettle plains and feeding eskers are common indicating the source of supply. When the delta is raised the head serves the purpose of indicating the former water level.(Nelson,) p.)

Sauramo, instead of using the name 'marginal delta' prefers the term 'marginal sand plains' which according to his description are actually deltas but have been built under a still-standing water body. Such a plain is built also in connection with the ice margin and it falls into the group of glaci-fluvial deposits. ( )

Along the main road about a mile north of Bruichladdich, a cliff, which is transversed by a small burn, exposes in its valley gravels overlying red clay. Further north along the same cliff, east of the farm Kentra, four feet of gravels are seen overlying a 10 feet bed of sand. Not far north of this locality a road side pit shows a thick deposit of gravels of deltaic structure, having top-set and fore-set beds well disposed. The frontal beds dip 25 degrees to the W.S.W.. (Fig. 19c)

Near the head of Loch Indaal, on the northern side of the main road, is a mile long continuous stretch of steep bank, running east to west. The face of the bank is very smooth, overgrown with bushes and in some places, grasses;(Fig.19,c.; pls.IX,fig.1) while the crest is uneven. The highest point being not more than 70 feet above the present sea. Two main

Plate IX

Fig. 1 A section across the marginal delta at the head of Loch Indaal. The cliff on the left side of the picture is the third raised cliff of the third raised shoreline period. The section cuts across gravels and sands, and on the top of which, gentle dipping clays. The character of the gravels can be seen at the right hand side of the picture.

Fig. 2 A road side pit, near School north of Bruichladdich, showing deposits of the marginal delta. The gravels and sands arrange in structures indicating both fore-set and top-set beds of a delta.

roads run across the cliff, the western one cuts across ferruginous gravel similar in charcater to those seen in the Laggan and that exposed in the near neighbourhood. After crossing the cliff the road follows the level ground for a few hundred feet and gradually slopes down to a peaty flat, beyond which it ascends again on to join another road which leads from Tynacoille farm to the north. Near the junction of the two roads, at about the 50 feet contour, deposits of sand occur. The sand bed is contorted. (Fig. 20.) The eastern main road leads up the cliff at the eastern end of the former golf course cutting across a steep dipping gravel bed over which, and on the level ground beyond the cliff crest, are laid gently sloping beds of clay. (pls.IX,fig.1) The roads descends and rises again and cross a gravel mound. Along the cliff face, not a single exposure of hard rock can be found, the whole cliff being cut into beds of gravel and sand and in some places, yellow clay, which is seen underlying the surface peat bed. It is interesting to see the change of surface vegetation, grasses grow on sand while bushes grow on clay. The cliff face has been cut into a once much more extensive deposit of gravels and clay with deltaic structure. (Fig. 19, c) The steep dipping gravels are the remanant of a series of foreset beds of the former delta, which were once marginal to an ice front, while the gentler sloping clay and sand beds are the top-set beds of the delta. The bottom-set beds have not yet been exposed.

This deposit has so far been described by two observers. Macculloch maintained that although these beds are popularily imagined to have been marine beaches, they are "obviously derived from other causes", for the deposits, though consisting in part of round gravel, contain perhaps an equal portion of either clay or vegetable matter, mixed throughout the whole mass. (II p.236) Anderson, the other observer who has expressed opinion on this deposit, believed that the cliff of "loose earth and angular stones" is similar in origin to the morainic heap at Corran, Jura.* He went on to say that the cliffs are nearly perpendicular, rise to about 100 feet, and are composed of materials easily washed away, and therefore "could hardly have remained as it is unless it had carried an ice foot." (p 321.) It is the impressiveness and the character of the deposits themselves which led both the observers to believe that they are of origin other than marine. Macculloch certainly has not used the term'glaci-fluvial', but he suggested an idea of deposition similar to glaci-fluvial. Anderson connected the deposit with an ice-foot. He certainly failed to realize that the steep cliffs are the product of later erosion as is shown by the uneveness of the crestline of the cliff and the discontinuity of the gravels in one or two localities where the cliff has retreated to such an extent that the gravels in some places have been completely removed.

Since a greater part of the original marginal delta has

*See appendix II.-

been removed by later erosion, many of the accessory characteristics have also been removed. There are no feeding eskers, no pitted plains; all being cut during the 25-foot submergence into a smooth level strand-plain in front of the cliff.

By connecting the evidence of the esker ridges found near Bowmore, with this marginal delta, the glacier to which the formation of this delta is due, seems to have come down from the high ridges of S.E. Islay, turning round the northern part of Bowmore and stood with its front along a line approximately NE-SW from Black Rock to Bruichladdich. The ice front was not a straight line but protruded in its middle portion and the delta was therefore built marginally to a curve convex to the north. Naturally the direction of the dip of the frontal beds of the delta would tend to change with the curve, running perpendicular to any point on the curve. That explains the W.S.W. dip of the gravels at the west end and the northern dip of the gravels at its middle portion.

About a mile north of this delta discussed above, another piece of flat-topped ground, over 70 feet, is seen stretching from east to west across the low peat flat of Loch Gruinart. Druim nah-Erasaid, as it is called, is bounded on the north and south sides by steep cliffs undoubtedly sea-cut. Examining the exposures along the cliff faces, it is clear that the whole deposit is composed of nothing but glaci-fluvial gravels and sands. This is probably another marginal delta.

Table I

Elevations of the First Raised Shoreline

Locality	Elevation in Feet (Inner margin)	Standard of Reference
Port Alsaig, N.Oa*.	85	H.W.M.
W.Port Alsaig.	67+	O.D.
Corrary, Laggan river.	67-77	O.D.
North of Loch Airidh Dhaibhaidh.*	65	O.D.
Bowmore.	65-	O.D.
Conisby, W.Loch Indaal.*	60	H.W.M.
S. of Bruichladdich.*	80	H.W.M.
Braibruich.*	70	H.W.M.
Damaoidh.*	67	H.W.M.
S.of Port Charlotte.* (1)	70	H.W.M.
(2)	72	H.W.M.
Torony.*	65	O.D.
Nerebolls.*	70	O.D.
Claddich.*	70	H.W.M.
Port-na-haven.*	62	O.D.
Ballinaby.*	60	O.D.
N.of Ballinaby.* (terrace top)	80	O.D.
Sanaigmore Bay.*	70	O.D.
Sanig.*	70	O.D.
An Diollaide, Sanig.*	60	H.W.M.
(gravel top.)**	65	H.W.M.
(bench on boulder clay)	98	H.W.M.
Cortle Bheag, Sanig.*	80	O.D.
Braigo - Sanig.*	80-85	O.D.
Toranore farm, Loch Gorm.* (gravel top)	93	O.D.
Ardnave Farm.*	75	O.D.
Leckgruinart.*	62	H.W.M.
Tynacoille.*	79	O.D.
Rudha na Faing, S.of the Rhinns.*	80	H.W.M.
Killinallan.*	65	O.D.
Gortantoid.*	70	H.W.M.
S.of Killinallan.*	65	H.W.M.

Heights indicated * have been measured by the writer. In the conditions under which the measurements were made and with the instruments and help available, it was not in most cases possible for the writer to base his measurements on bench marks. They were usually referred to a well-marked tide line.(H.W.M.) The tidal range is such that these measurements are not likely to differ from those based on O.D. by less than three or more than ten feet. For various reasons, measurements of the levels of pre-existing beaches are not likely to be consistent within much less than ten feet.

II. The Raised Shorelines

The writer has remarked on the eveness of the surface of the glaci-fluvial sands and gravels, and the terracing developed on these deposits, especially in the Loch Gorm region, The eveness of the surface may be original, for the sands and gravels have been laid down in water as aprons or as a sheet of outwash deposit. The terracing of these deposits may have been accomplished by downcutting of rivers flowing on the surface of the deposit, under whatever conditions the down-cutting may have taken place. The water in which sands and gravels were deposited may have been either marine or an ice-water lake. There is not sufficient evidence to show whether the deposits of Islay were accumulated in an impounded lake, for Islay is itself an island and the topography is such as to render the occurrence of a sufficiently extensive series of lakes impossible. The water in which the sands and gravels were deposited must be the open sea or a marine inlet. In either case there would be ample chances for marine planation of the surface of the deposits. There occurs around the shores of Loch Indaal, a terrace feature of the average height of about 70 feet and terraces occur at about the same level in the Loch Gorm region. This correlation indicate a general level of a raised shoreline in late glacial times, (Table I, [illegible]) and probably corresponds to the first raised shoreline of other parts of Scotland.

Apart from the terraces already been described, raised shorelines are well preserved in a few localities which have not been previously described.

Three terraces are seen in Port Alsaig, half a mile S.W. of Kintraw. The highest one is a terrace of gravels embedded in a red clayey matrix. Its inner margin is marked by a low cliff of boulder clay. A lower terrace is cut into the deposits and the underlying boulder clay having an inner margin of 55 feet above H.W.M. This is probably the second raised shoreline. The third raised shoreline is indicated by the lowest terrace whose inner margin is only 18 feet above H.W.M.. Sand is the deposit of this terrace. (Pl. X,fig.2)

At Rudha na Faing, (Fig.22,23) near Port-na-haven, deposits of well-rounded gravels are seen overlying a thick series of glaci-fluvial sands,clays and gravels. These glaci-fluvial deposits lie on a rock platform between 25 and 30 feet high above the sea, near the shore. They are seen to overlie boulder clay a short distance landwards. The raised sea level, presumably between 60 and 70 feet, has cut a shelf into the glaci-fluvial deposits and has deposited well-rounded gravels as a beach. It will be seen from figure 23, that the glaci-fluvial deposits formed a ridge-like mound, which is probably a drumlin. The third raised sea has removed a part of the second raised beach and the underlying glaci-fluvial deposits, and exposed the rocky bench below the deposits.

Fig. 1 'Pre-glacial' rock platform, on the northern coast of Oa peninsula, Islay.

Fig. 2 100-foot 'raised beach' north of Oa peninsula. The 'beach' is a bench cut in boulder clay.

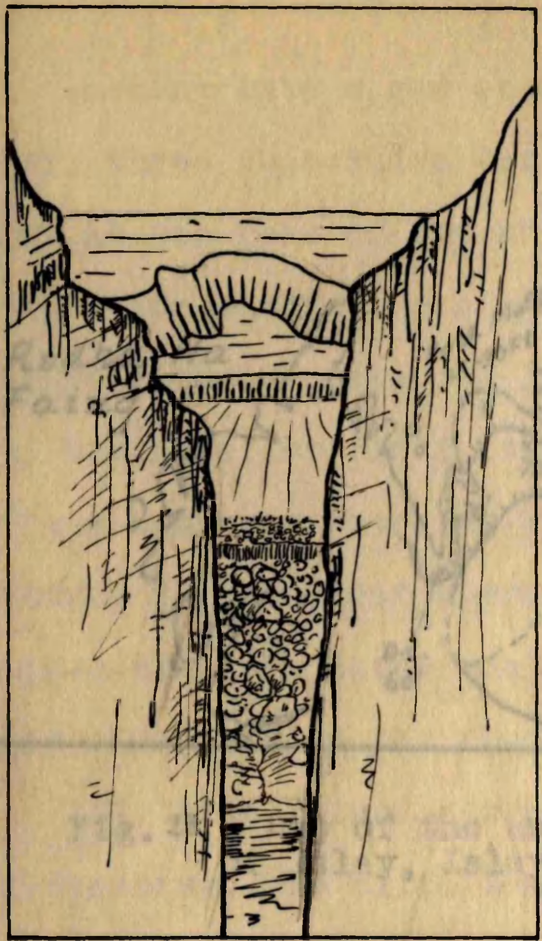
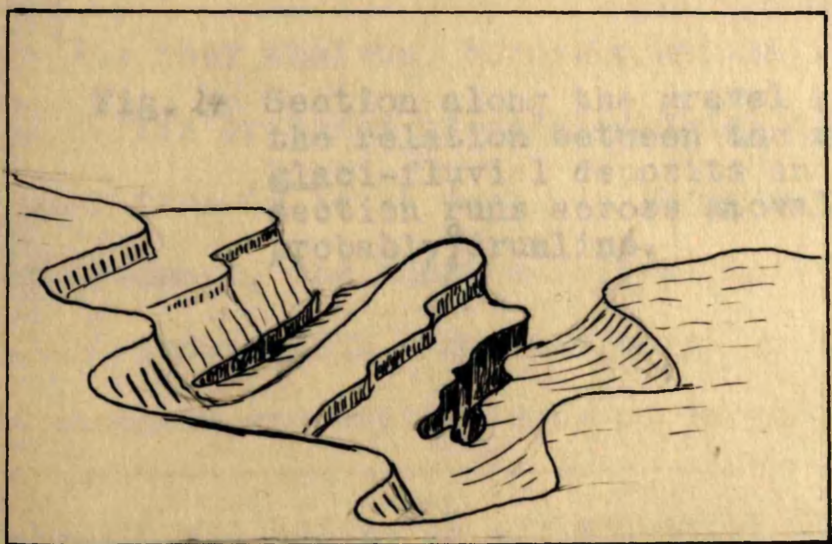


Fig. 21 View into one of the 'Geos' at Sanig Point, N. of Rhinns of Islay, showing three successive raised shorelines, the highest of which is cut into boulder clay.

Fig. 22 Looking seawards W. of Tobar Bunna Beirn, Rudha na Faing, Rhinns of Islay, showing two geos cut along two dikes and the intermediate ridge of well rounded gravels of the second raised shore period. The cliff surrounding it is composed of boulder clay and interbedded sand and gravels.



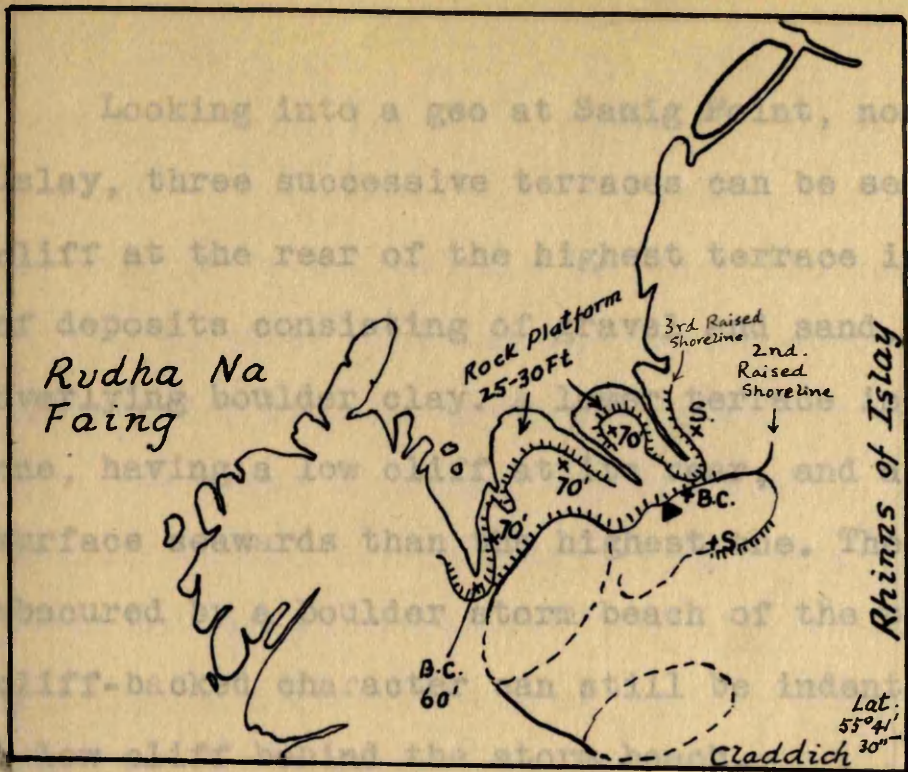


Fig. 23 Map of the Rudha Na Faing region, S.W. of Rhinns of Islay, Islay.

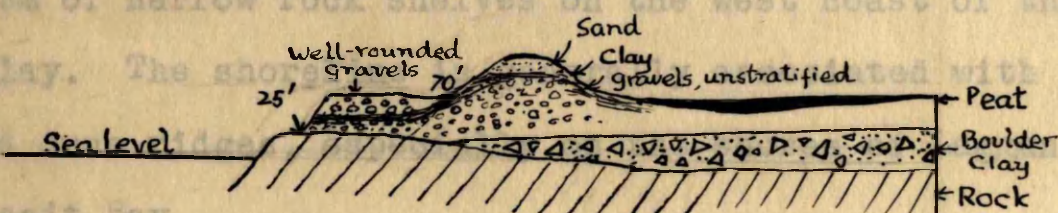


Fig. 24 Section along the gravel ridge in Fig. 23 showing the relation between the raised beach and the glaci-fluvial deposits and boulder clay. The section runs across an oval-shaped mound probably a drumlin.

Looking into a geo at Sanig Point, north of the Rhinns of Islay, three successive terraces can be seen. (Fig. 21.) The cliff at the rear of the highest terrace is cut into a series of deposits consisting of gravel and sand, with striated boulder, overlying boulder clay. A lower terrace is cut into the highest one, having a low cliff at its rear, and a steeper sloping surface seawards than the highest one. The lowest terrace is obscured by a boulder storm beach of the present day, but the cliff-backed character can still be indentified, as there is a low cliff behind the storm beach.

The third raised shoreline is well marked in Islay by two features. The cliff-backed bench of this shoreline occurs around the shores of Loch Gruinart and Loch Indaal and in the form of narrow rock shelves on the west coast of the Rhinns of Islay. The shoreline is generally associated with blown sand, and dune ridges, especially on the shores of Laggan Bay and Lossit Bay.

The rock shelves, bordered at its inner margin by either rock cliffs or banks of glaci-fluvial deposits, have heights ranging from 12 to 25 feet. On the shore of Loch Indaal and Loch Gruinart, the inner margin of this shoreline averages about 15 feet above H.W.M.* Benches occur in certain localities on the southern and western side of Oa and that of Kilnaughton Bay

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* The average height is arrived at by dividing the sum of the total heights with the number of heights measured by the writer. The writer has measured the elevation of the inner margin of the bench in more than forty localities on the island of Islay.

near Port Ellen has an inner margin of 22 feet above H.W.M. A stack is seen standing in a bench. The base of the stack is only 12 feet above H.W.M.. Rock shelves are absent on the N. and W. coast of Islay and on the west side of Oa, where, present day erosion has probably oblitered its traces.

The shore of Laggan Bay has a history of development similar to the Irvine coast of Ayrshire.* The westward sloping sheet of the glaci-fluvial deposits had been cut into by rivers, flowing in a direction down the slope and the remaining deposits are left as terraces between these rivers. River Laggan, flowing on the northern margin of the Laggan Bay, drains into the bay after making a hair-pin loop similar to that which occurs in the case of the Irvine. The river Duich has been deflected north-westward to join the Laggan instead of flowing straight on W.S.W. into the bay. This deflection is probably due to the vigorous growth of a shingle bar along the shore. Blown sand has now completely covered up the bar, but a section across the bar is visible at the mouth of the Laggan river. The section shows a core of shingle, mostly cobbles overlying boulder clay and overlain by blown sand. During the last submergence, which was probably 15 feet in this region, invasion by the sea extended inland about half a mile from the present shore where the effects of marine erosion are seen. The building of a shingle bar northwards from the Oa has converted the submerged area into a lagoon. Height was

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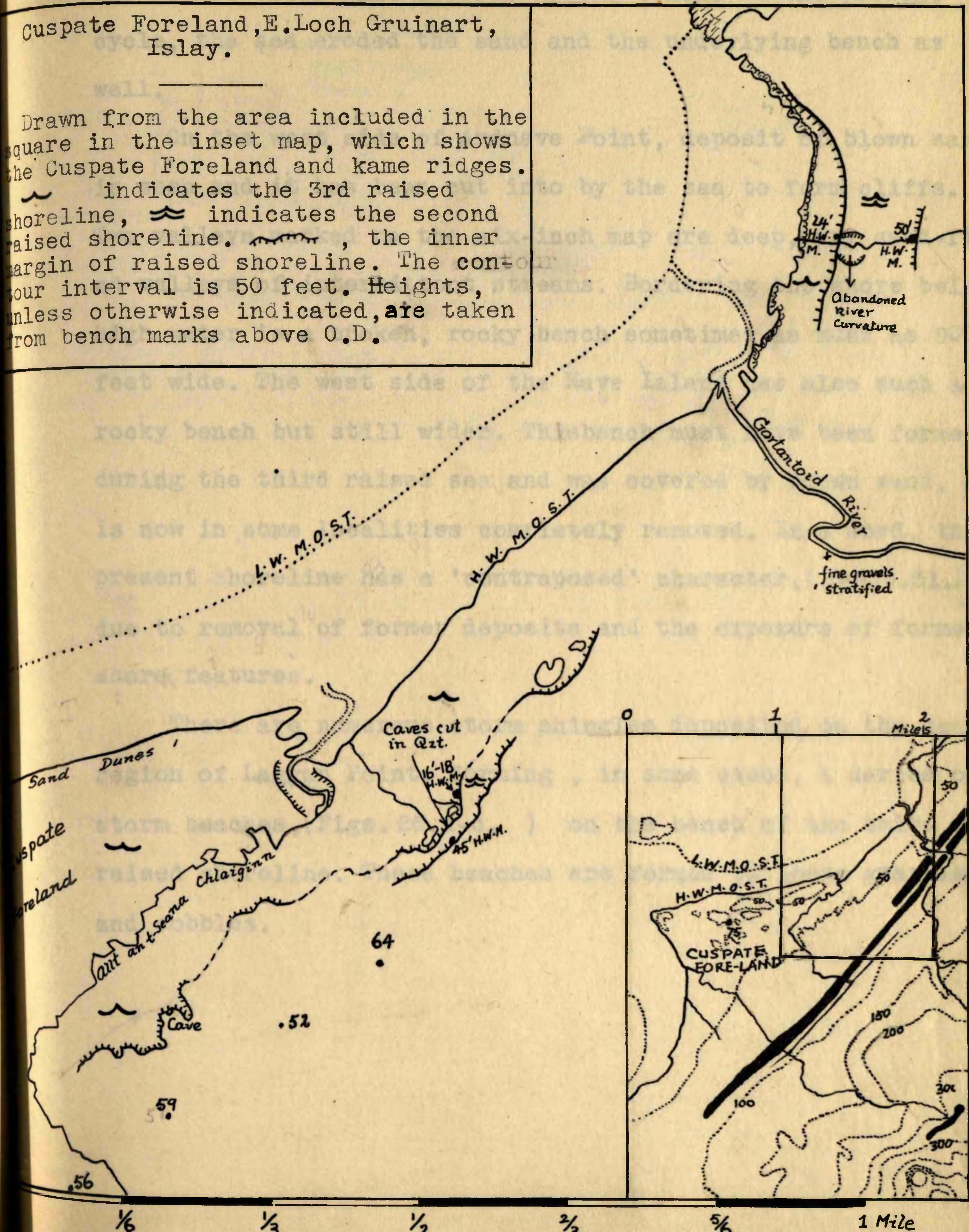
* See Chapter .

added to the shingle bar by a covering of blown sand and it succeeded holding back the sea.

On the eastern shore of Loch Gruinart, there occurs a cuspate foreland, formed entirely of blown sand. (Fig. 25.) The foreland is triangular in shape and its base stretches from the Gortantoid river south to Crois Mhor. Along the northern shore of the foreland, is a ridge of sand dunes at an average height of about 60 feet occasionally rising to 75 feet. The dune ridge has been eroded by the sea so as to form sand cliffs. The southern part of the foreland is low-lying and never rises above the fifty-foot contour. This indicates that the foreland owes its origin largely to the growth of the sand ridge on the northern shore. Sands drifting southward from the ridge must have formed irregular dunes and spread as a sand cover over a rocky bench. The southward extension of the sands is limited by the northward flow of the Gruinart river and a cuspate shape has resulted. Evidence showing the existence of a rocky bench below the sand cover is seen near the mouth of Allt an t-Seana Chlaiginn. A rock cliff with caves and stacks, which must have long been buried by blown sand are now exposed. These are undoubtedly marine features and must have been formed at a time when the sea stood some 16-18 feet above the present H.W.M. as is indicated by the elevation of the inner margin of the bench. The cliff can be traced southward by means of discontinuous exposures. It is very probable that the bench was formed during the last submergence, and at near the end of

FIG. 25.



Cuspate Foreland, E. Loch Gruinart, Islay.

Drawn from the area included in the square in the inset map, which shows the Cuspate Foreland and kame ridges. ⌣ indicates the 3rd raised shoreline, ≈ indicates the second raised shoreline. ⌒⌒⌒ , the inner margin of raised shoreline. The contour interval is 50 feet. Heights, unless otherwise indicated, are taken from bench marks above O.D.

the period blown sand covered up the bench. In the present cycle, the sea eroded the sand and the underlying bench as well.

On the west side of Ardnave Point, deposit of blown sand is seen and it has been cut into by the sea to form cliffs. Two valleys marked on the six-inch map are deep, dry sand-floored valleys of intermittent streams. Bordering the shore below high water is a broken, rocky bench sometimes as much as 800 feet wide. The west side of the Nave Island has also such a rocky bench but still wider. Thisbench must have been formed during the third raised sea and was covered by blown sand, which is now in some localities completely removed. In a word, the present shoreline has a 'contraposed' character,(See p.51.) due to removal of former deposits and the exposure of former shore features.

There are numerous storm shingles deposited on the headland region of Laggan Point, forming , in some cases, a series of storm beaches,(Figs. 26,a-c.) on the bench of the third raised shoreline. These beaches are formed by loose gravels and cobbles.

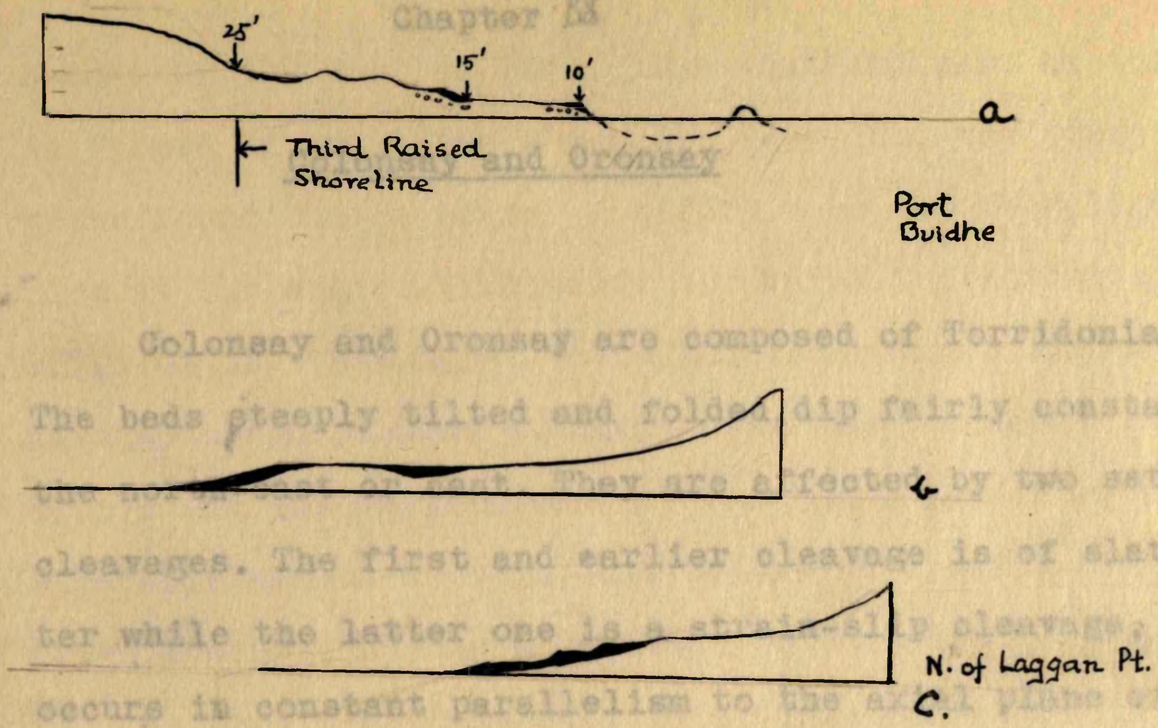


Fig. 26 Showing characters of storm shingle deposit on the third raised beach. Storm deposits are shown in solid black.

Chapter IX

Colonsay and Oronsay

Colonsay and Oronsay are composed of Torridonian rocks. The beds steeply tilted and folded,dip fairly constantly to the north-east or east. They are affected by two sets of cleavages. The first and earlier cleavage is of slaty character while the latter one is a strain-slip cleavage, which occurs in constant parallelism to the axial plane of the folds. Both the islands are standing on a ten-fathom submarine plateau which is more than twice the area of the present islands. Immediately east of Oronsay and south-east of Colonsay, there is a thirty-fathom deep trough which is believed to be the extension of the Great Glen Fault.

The topography of these islands is greatly influenced by the dip of the strata. The west side of the islands, from Kilchatten, Colonsay, to the south of Oronsay is low in relief but extremely irregular. Most part of the uneven surface has been covered by blown sand forming a sandy plain while the reminder forms a fringe of skerries along the shore. The dip of the rocks is generally oblique to or away from the shore, which gives rise to a stair-case phenomenon seen at Dun Ghallain.

The coast of the Kiloran section is bounded by a lofty cliff, steep and sometimes overhanging, often reaching the height of 400 feet or more. The southern part of this section is formed of phyllites which dip away from the shore. It is often found that a grassy platform some 200 feet high, beginning at the sea cliff extends landwards to another steep cliff of 150 feet high. Repeated escarpments due to successive outcrops produce a 'stair-case' appearance. The high cliffs and the straightness of the coast indicate the considerable amount of work done by marine erosion. The Uragaig coast, northern Kiloran, is bounded by overhanging cliffs. Here the coast runs in a direction at right angles to the general strike of the rocks. Uragaig, a remnant of the well-known 135-foot pre-glacial platform, (pl.XI,2.) is a headland region open to the attack of the waves. Many caves have been excavated along this part of the coast, some of which cut in opposite directions, almost connected with each other. In some cases it has happened that the roof of such a tunnel has sagged and formed a hollow. It is probable that the marine cliffs of the islands were cut when the sea stood higher than the present level and that they continue to be subjected to marine attack.

Balnahard, a region though crossed by stronger cleavages and severly folded rises to the highest in the island. This indicates that the cleavage of the rocks has little if any, influence on the topography.

Eastern Colonsay is a continuous belt of high ground, in which are represented nearly all the local Torridonian rocks. The coastal cliff is of 'hog-back' type* with rounded-off edges. Above the coastal cliff, the ground slopes gently seaward from the pre-glacial cliffs. This gentle sloping surface, described as a pre-glacial bench in the Memoir, seems to have adjusted itself in accordance with the dip of the rocks.

The hills of Colonsay and Oronsay are composed of a variety of rocks. They reach a general level between four and five hundred feet. The rivers are only small streams, the largest of which is probably the Abhainn a'Mhuilinn, which drains northward from Loch Fada into Kiloran Bay. Loch Fada, one and half mile long, occupies a narrow NE-SW depression between Bonaveh-Scalasaig and Kiloran-Kilchattan. Loch Sgoltaire, between Beinn a'Sgoltaire and A'Bheinn a'Tuath, forms the reservoir of the island. There are a few other lochs which are small and insignificant.

Shore deposits are extremely sparse on the islands. Storm shingle patches occur on the western coast, but none at all on the eastern coast of the island, where adjacent deep water probably cuts off shingle supply along the shore.

1. Pre-glacial and Glacial

Looking down from the top of Scaribh Hill at the north-eastern end of the island of Islay, Colonsay and Oronsay

Fig./The 4-500-foot platform of Ross of Mull, Mull.

Fig. 2 The 400-foot platform of Iona.

Plate XII

Fig. 1 -2 Pre-glacial platform of Colonsay appear to be a low-lying stretch of land, on which all hill-tops attain nearly a uniform level. This fact was noticed by Wright and Bailey and they have suggested that the level probably represents the remnant of an ancient plane of erosion, probably of marine origin. (The Geology of Colonsay and Oronsay, Mem.Geol.Surv. Sheet No.35,1911,p.2) The supposed marine platform now represented by the existing hill tops was cut irrespective of the difference of rock formations and structures. The general altitude of this plane is 400-500 feet which may be correlated with a similar plane of Ross of Mull, and that of Iona. (Pl.XI,1)

Nothing is known of the physiographic evolution after the formation of the platform until the time when the sea level stood 135 feet higher than the present. This sea level is recorded by the frequent occurrence of inland cliffs. No one can fail to remark the lofty cliffs and the even and gentle sloping platforms in front of them. (pl.XII, ,figs.1,2.) They have been ice-worn, beautifully moulded and striated and in places, covered with boulder clay. Thus it is believed that this platform at the general level of 135 feet above the present sea is of pre-glacial age. Although there is great resemblance between these cliffs and platforms and those of the present shore features, there are no other traces or evidences of undoubted marine origin, such as: caves, notches and shore deposits. The writer has searched for such evidences without success though some notches, notably that of of "The Shelter of the Miserable Woman" on the cliff-face above the 100-foot contour, north-east of Balnahard Farm, may be regarded as marine in origin.

Accepting the cliffs and platforms as shore features of pre-glacial age, the Memoir of the Geological Survey has included a map showing the distribution of these features. (Mem.Geol.Surv. No.35, fig.19, pp.64) The platform in many places is cut by a valley which itself is pre-glacial. The rivers Abhainn a'Ghlinne and Rioma Mhor have incised the platform, which appears as a terrace on both sides of the valleys. Roches moutonnees are beautifully preserved on the bottom of the valleys. The profile of the Abhainn a'Ghlinne is not in equilibrium at all. Being overdeepened in its lower part, it is narrower down stream and gives contrast to the wide open valley of the upper course. This shows that the land rose after the formation of the 135-foot pre-glacial platform, which has been dissected by rejuvenated rivers and still immature.

The next events of which there is evidence are connected with the on-coming of the Ice Age. During the maximum glaciation, the ice came from the east. It overrode the hills and valleys and smoothed out the 135-foot sea cliffs on the eastern coast. The valleys between Kilchattan and Uragaig presents a most striking appearance of a glacial valley in which irregularities have been planned down and the valley is but a very gentle and wide hollow. The valley of Abhainn A'Ghlinne referred above has been widened into the typical U-shape with a hanging tributary joining from the south-east.

The boulder clay deposited by the ice is seen at a few localities. It is mixed with angular boulders chiefly of local origin. The clay is poorly preserved in Colonsay except along the depression in which Loch Fada is situated. Without doubt ~~that~~ the depression was once filled up with glacial deposits and largely reopened by running water after the retreat of ice from the island. Thick boulder clay deposits can be seen on the northern slope of Loch Fada near Kilchattan. There are two ridges of glaci-fluvial gravels standing on the alluvial flat of Loch Fada south of Kiloran Farm. They are elongated in shape, round at both ends and run in a E-W direction. The gravels are water-worn though sub-angular. It is probable that the ridges were originally drumlins and were modified by later fluvial erosion.

Immediately after the retreat of the ice from the island, the Fada valley was excavated by a river which attained a stage of early maturity. This is shown by the sinuous course of the valley sides where they rise above the loch level. The reexcavated valley follows closely the margin of contact between the boulder clay and the rocky valley side. Reference to the impounding of Loch Fada will be made presently.

II. The Raised Shorelines

After the retreat of the ice, there was a period when sea level was very low during which the infilling of Loch Fada was eroded. The exact level of the sea during that period is not known but may be arrived at by estimating the depth of the down cutting of the valley. Although no soundings have been taken, the depth of the loch is about 25 feet half-way up the loch and probably considerably more at the lower end on the hypothesis of fluvial erosion. The surface of the loch was 77.9 feet in July of 1874,(Six-inch O.S.maps) thus giving a level of 50 feet or less for the bottom of the loch and the sea level may have stood anywhere below the 50-foot contour of the present land surface.

The Loch Fada river was supposed by the writers of the Memoir to have been dammed up at the western end by the 100-foot raised beach and a storm beach ridge rising to the height of 95 and 109 feet respectively at Kilchattan. If the river bottom is at or below 50 feet O.D. as suggested above, the 100-foot sea would submerge the whole river but could not possibly build a beach some 40-50 feet high. Unless the 100-foot gravels were accumulated on a feature of the type of a shingle bar, rising to a considerable height above the river bottom, the correlation of deposits at the west end of Loch Fada with the 100-foot beach is extremely doubtful. Loch Fada is cut off from the sea at its western end by a ridge standing at least some twenty feet above the present loch surface. Whatever the origin of this ridge, it cannot be attributed to the 100-foot sea.

Other indications of the 100-foot sea are mentioned. The low meadow in front of the Kiloran house is cited as a beach of that period. The gravels underlying it show characters of glaci-fluvial deposits and it should perhaps be regarded rather as a glaci-fluvial accumulation than as raised beach material.

Very poorly preserved gravel patches can be seen along the road from Scalasaig to Machrins. The origin of these gravels is very uncertain but they are believed to be 100-foot raised beach. The inner margin of the gravels attains a height of 90 feet O.D.. Spits of the 100-foot sea are mentioned in the Memoir but the 100-foot raised shoreline of Garvard is not at all convincing.

The Memoir seems to differentiate only two kinds of shore forms, namely: the beach and the storm beach, but the writer finds a considerable variety of forms among the deposits of the second raised shoreline. At Uragaig, according to the Memoir, storm shingle is found at the height of 77 feet above high water mark and estimates that sea level was at 70 feet. The writer, however, does not agree with such estimation, for storm shingle may be thrown to any height. The storm shingle of the twenty-five-foot raised shoreline of Jura is believed to have been thrown seventy-five feet higher than the sea level. (Ting II. pp.134.)

The bar running across from Meall na Monadh to Balnahard Farm (Fig.27.) has been described as a storm beach. The bar which is overgrown with vegetation, rises 60 feet above high water mark and is composed of gravels. It separates a low-lying basin on its north-east side from the raised beaches of Port Sgibinis. The basin must occupy the site of an enclosed lagoon which afterwards over-flowed through A on figure 27 , where, a long and narrow geo extends inwards and carries a small stream leading from the basin. In the later part of the second raised shoreline period, a gravel beach was built on the south-west side of the bar, which is at present overgrown with vegetation.

The second raised shoreline varies between 60 and 73 feet at Traigh Bhan, west of Umah Ur; between 60 and 70 feet at Machrins, 68 feet at Glassard and 50 feet at Garvard. The writers of the Memoir have endeavoured to reconcile the greatly varying levels of the second raised shoreline with a single stand of the sea. It seems possible that the difference in the height of the supposed second raised shore features is largely due to causes which have not yet been appreciated. It is possible that the sea never did stand at any definite level for a prolonged period but left marks here and there during its retreat from the 100-foot submergence. There may also be some deposits of the third raised sea remaining at levels considerably greater than twenty-five feet. Such deposits would certainly be confused with the definite raised beaches and indicate a variety of levels which might very possibly range between 40 feet and 70 feet.

The sea level stood during Mesolithic times, which are generally taken to coincide with the third raised shoreline times, higher than 25 feet. This sea represents the high w water period of the ocean immediately after the melting of the continental ice. The climate was much warmer than now and the sea appears to have exerted a maximum influence in erosion as well as deposition. Caves have been cut in cliffs in many localities. The island, in spite of the vigorous cutting, was not reduced much in extent by coastal erosion, for the land was rising during the erosion. Measurements show that the floors of all caves lie almost at a uniform level of 22 feet and indicate a general pause of the sea near that level. At Port Ban, the bottom of the arch below the Pig's Paradise has a height of 25 feet above high water mark. (pl. XIII , fig. 1.) Notches are often cut a foot or two above high water level such as the one below Dun Tealtaig cliff, Uragaig and some others seen in the south-west of the Rhinns of Islay, near Port-na-haven.

The period of the 25-foot sea may also have been an exceptionally stormy period. The quantity of shingles, beaches and sand dune ridges formed during that period seems considerable. This is true of Colonsay. For example, a

Fig. 1

Fig. 2.

Fig. 1. Natural Arch of the third raised shoreline period below Pig's Paradise, Colonsay. The floor of the Arch is 26 feet above H.W.M.. Notice the two bands on the right hand side of the arch. These two bands, resembling tide marks, are connected with a narrow rock shelf at the right edge of the picture. Are they really tide marks of a higher sea level ?

Fig. 2. The storm shingle and raised beach in Uragaig. The storm shingle is larger in size, and partly cover the small pebbles of the raised beach. Gravels on a grassy surface in the back-ground are of storm origin.

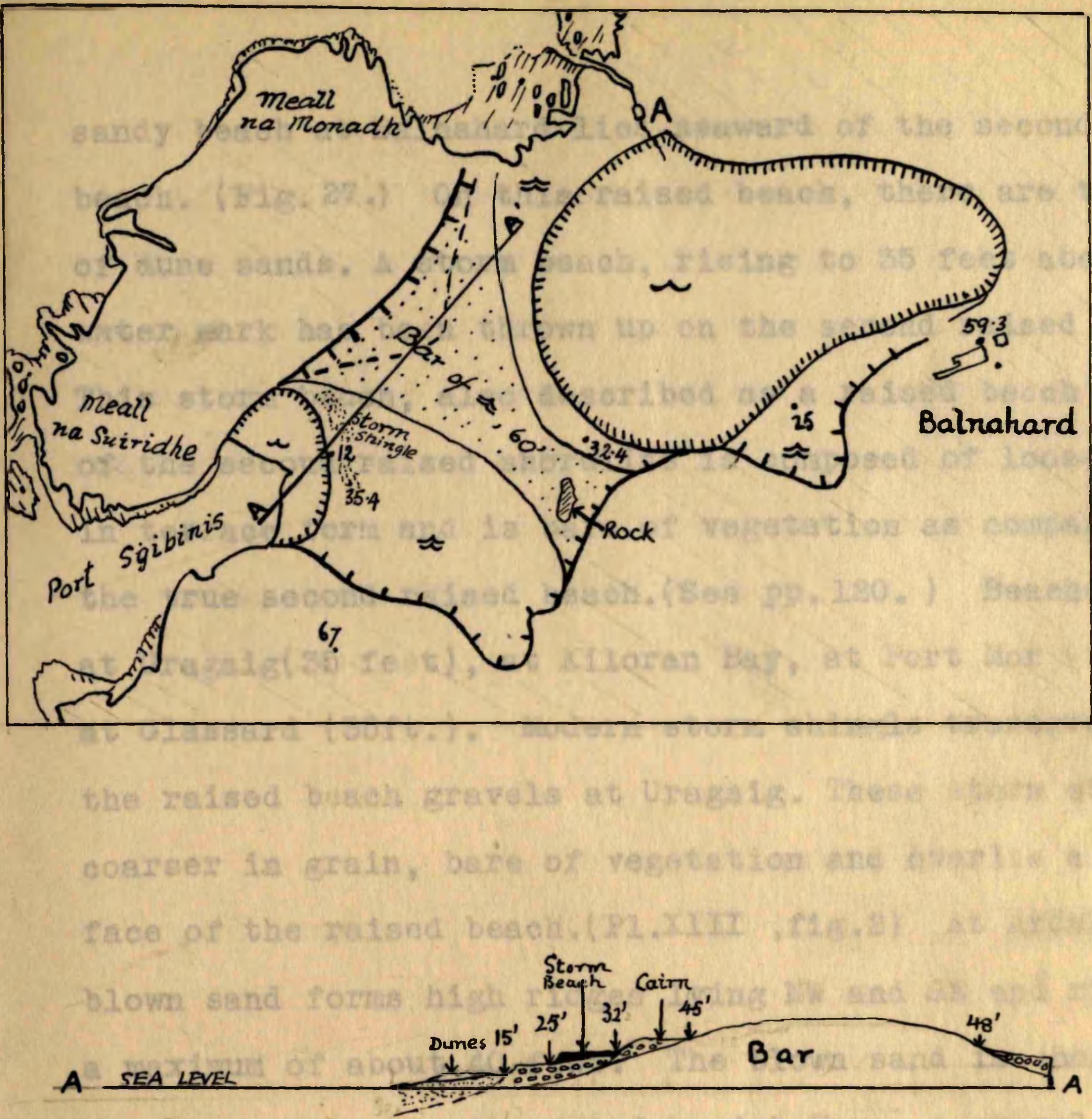


Fig.27 Map showing the Balnahard region and the shorelines. The section along A-A' is drawn in a scale 12" a mile. The Vertical scale is 6 times that of horixontal.

sandy beach at Balnahard lies seaward of the second raised beach. (Fig. 27.) On this raised beach, there are thin deposits of dune sands. A storm beach, rising to 35 feet above high water mark has been thrown up on the second raised beach. This storm beach, also described as a raised beach deposit of the second raised shoreline is composed of loose gravels in terrace form and is bare of vegetation as compare with the true second raised beach.(See pp. 120.) Beaches occur at Uragaig(35 feet), at Kiloran Bay, at Port Mor (26ft.) and at Glassard (35ft.). Modern storm shingle transgress upon the raised beach gravels at Uragaig. These storm shingle are coarser in grain, bare of vegetation and overlie a grassy surface of the raised beach.(Pl.XIII ,fig.2) At Ardskenish, blown sand forms high ridges lying NW and SE and rising to a maximum of about 40 feet. The blown sand is composed of broken shells. South of Ardskenish Farm, a gravel bar can be traced running along the present coast curving slightly at its terminus westward.

The whole of southern Oronsay is composed of sand dunes. They are superposed on a low platform, the exposed portion of which forms the skerries. The dunes probably initiated as a beach foreland for cuspate ridges belonging to this period can be seen around the south-most tip of the island. They occur with storm shingle. It is probable that the skerries represent a platform on which the sand dunes and the beach deposits of the 25-foot sea were deposited. The origin of the platform may be pre-glacial or it may have been cut by the third raised sea, or cut during the retreat of the sea from the level of the first raised shoreline. The present shoreline is of a contraposed character due to the removal of the loose covering of the platform.

The third raised shoreline period closed with the uplift of land to approximately the present level.

Part III

SHORE DEPOSITS OF THE PRESENT DAY

APPENDIX

REFERENCES

Chapter X

The Ayres of the Orkneys and their Origin

The Ayres of the Orkneys described as storm beaches in the Memoir of the Geological Survey, occur in a great variety of forms and situations. They are variously described as sickle-shaped or hook-shaped, as boulder bars jutting out into the open water to form headlands, as beaches fronting cliffs. They often pond back rivers into lakes; or enclose lagoons in which peat has been formed. Sometimes they connect two islands together or connect islands with the mainland. Such variety of forms and occurrences may perhaps be interpreted as representing different shore-forms of different origin.

The writer has examined many of the 'storm beaches' described in the Memoir, and has seen a few others which have not previously been described. A reexamination of the evidence may help towards an understanding of the origin of these shore features.

In the first place, the Ayres, being in most cases ridges of shore deposit, must not be taken for 'beaches' which are defined as shore deposits between high and low water mark in the form of a terrace. Secondly, many Ayres, being built above high water mark(H.W.M.) are probably of storm origin,* and must have been built by the waves approaching in the direction at right angles to that of the shore form. Thirdly, a number of these Ayres show traces which undoubtedly indicate beach drifting and transportation, and sometimes curvature, which marked the halt of the process during formation. Such features are not necessarily of storm origin.

A ridge of shore deposits, in most cases composed of shingle, built at levels higher than H.W.M., should be termed a 'beach ridge'. A beach ridge or a series of beach ridges can be built in various forms known as tombolos, spits, bars, etc. These terms are used to indicate the different mode of occurrence of beach ridges.

There is often a certain looseness in specifing the elevation of beach deposits. The writer will in each case state the condition of the tide when he has occasion to refer deposits to water level. He has calculated according to the Almanac of Kirkwall, the difference of rise of spring and neap tides. In some cases the measurements have been read at the hour of high water quoted on the Almanac, while to other readings, a correction is applied by noting

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* There is no sharp distinction between storm and normal waves. An artifical boundary may be drawn with reference to the velocity of the wind. Those waves generated by wind of over 27 miles per hour may be called 'storm waves'. But the strength of such waves varies according to the direction of the wind, the state of tide, the foreshore conditions and many other factors. In different circumstances waves generated by wind under 27 miles per hour may be even more '<u>stormy</u>' than those generated by wind over 27 miles.

the hours before or after high water and the probable height can be calculated. Thus a shore form 5 feet above H.W.M.N.T. in Kirkwall will be only 3 feet at spring tides, and will be only 1 foot above high water of extraordinary spring tides. With a breaking onshore wave of a height of 1 foot or more, which may occur when the wind is travelling at a velocity below the limit of 27 miles per hour, deposits may be heaped up without appealing to "Storm waves". It is therefore clear that such terms as storm waves, storm shingle, etc., are here used in the relative sense of the term.

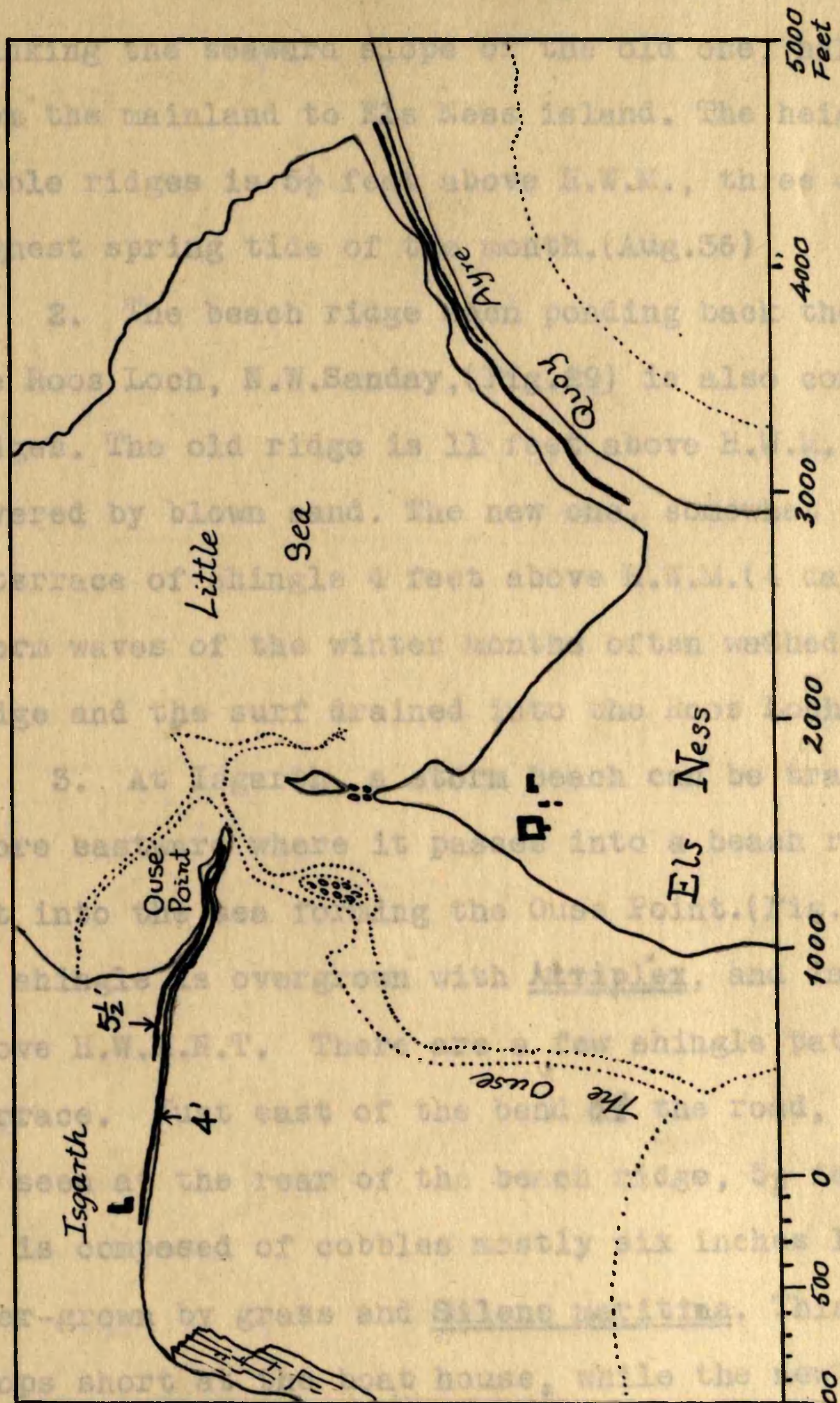
The writer will first discuss the beach ridges and their occurrences and will come to those forms which have a more composite origin and history.

I. Ayres that are simple beach ridges and storm beaches

That a beach ridge is shore deposit in ridge form while a beach is a terrace of shingle must be differentiated. We may now examine first some of the ayres which are regarded as simple beach ridges and storm beaches.

1. The Quoy Ayre, Sanday, (Fig. 28) separating the Little Sea from Sty Wick is a beach ridge taken the form of a tombolo. It is about half a mile long and is composed of two ridges of cobbles, mostly flat, derived from local flagstones. The ridges may be distingushed as old and new. The old ridge is covered with blown sand rising variously

Fig. 28 The Quoy Ayre and the Ouse Point, Sanday. Beach ridges are indicated by solid black lines.



from 13 to 16 feet above H.W.M., while the new one is seen flanking the seaward slope of the old one, half way across from the mainland to Els Ness island. The height of the cobble ridges is 5½ feet above H.W.M., three days after the highest spring tide of the month.(Aug.36)

2. The beach ridge seen ponding back the sea from the Roos Loch, N.W.Sanday,(Fig.29) is also composed of two ridges. The old ridge is 11 feet above H.W.M., and is covered by blown sand. The new one, somewhat eroded, is a terrace of shingle 4 feet above H.W.M.(4 days after S.T.) Storm waves of the winter months often washed over the ridge and the surf drained into the Roos Loch.

3. At Isgarth, a storm beach can be traced along the shore eastward where it passes into a beach ridge, and juts out into the sea forming the Ouse Point.(Fig.28) The terrace of shingle is overgrown with Atriplex, and is only 4 feet above H.W.M.N.T. There are a few shingle patches behind the terrace. Just east of the bend of the road, an older ridge is seen at the rear of the beach ridge, 5½ feet above H.W.M. It is composed of cobbles mostly six inches long and is over-grown by grass and Silene maritima. This old ridge stops short at the boat house, while the new ridge continues after a sharp bend. At the far end of the spit, a portion of the remanant of the old ridge is seen. It can be distingushed by its grass covering and the height it attained.

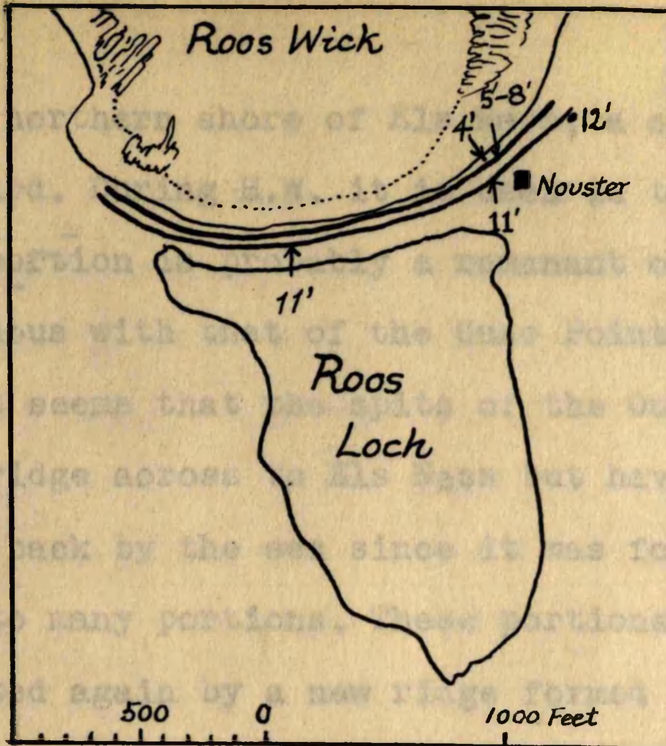
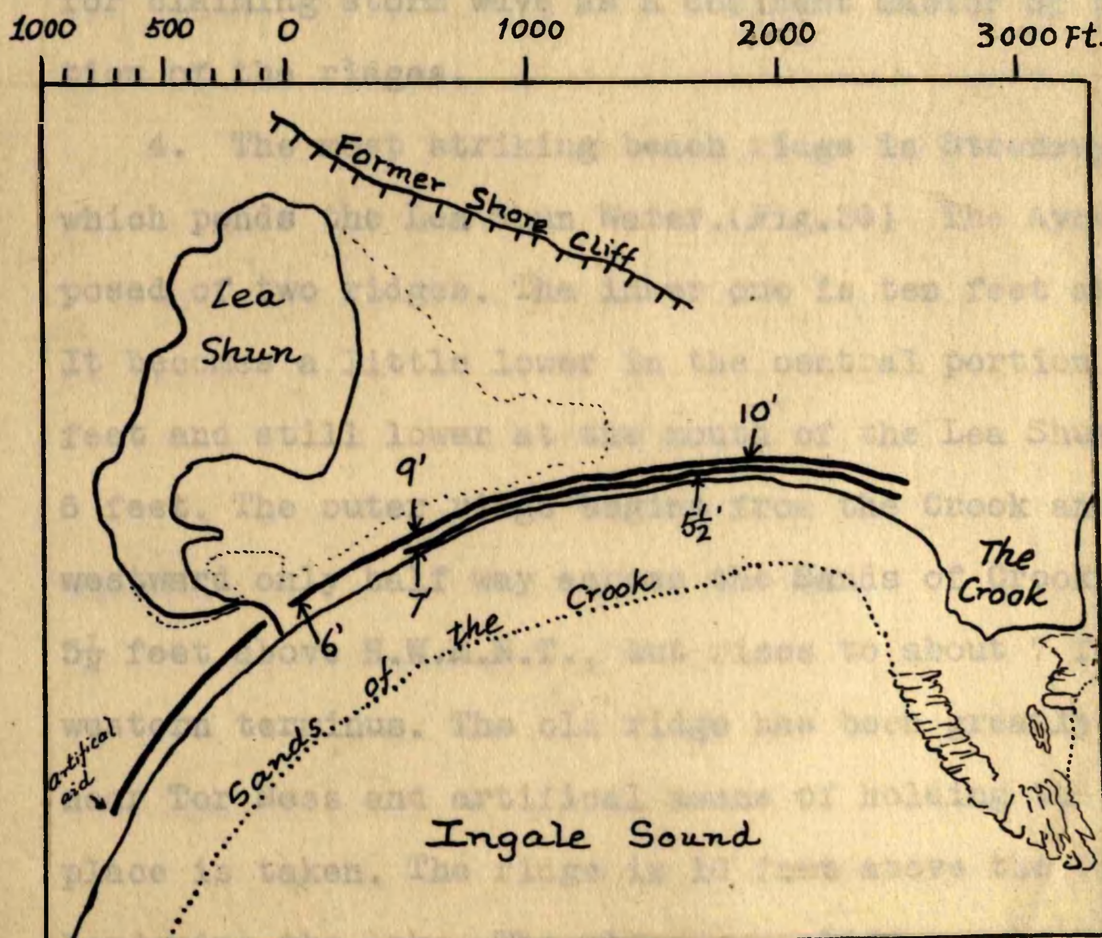


Fig. 29
The Roos Loch
Sanday.

Fig. 30 Lee Shun Water, S. Stronsay.



On the northern shore of Els Ness, a similar spit runs northward. During H.W. it is seen in two portions. The outer portion is probably a remanant of an old ridge once continuous with that of the Ouse Point.

It seems that the spits of the Ouse Point was once a beach ridge across to Els Ness but have been constantly pushed back by the sea since it was formed and later, cut off into many portions. These portions are now partly connected again by a new ridge formed in front of the old ridge. During spring tides the ridge would be only 1 or at most 2 feet above H.W.M.,which is a very small figure for claiming storm wave as a dominant factor of the formation of the ridges.

4. The most striking beach ridge in Stronsay is that which ponds the Lea Shun Water.(Fig.30) The Ayre is composed of two ridges. The inner one is ten feet above H.W.M. It becomes a little lower in the central portion giving 9 feet and still lower at the mouth of the Lea Shun giving 6 feet. The outer ridge begins from the Crook and runs westward only half way across the Sands of Crook. It is only 5½ feet above H.W.M.N.T., but rises to about 7 feet at its western terminus. The old ridge has been greatly destroyed near Tor Ness and artifical means of holding the ridge in place is taken. The ridge is 10 feet above the plain bordering the lake. The old shore cliff can be seen from the Crook southwards to Holland Farm.

5. On the western shore of Rothisholm, Stronsay, (Fig.31) a beach ridge is seen enclosing a lagoon known as the Straenia Water. It is between 6 and 7 feet above H. W.N.T. and is composed of small gravels. When traced northward it is found to be badly eroded at Peatworth where a section of peat* is exposed on the shore half covered with scattered shingle. The peat must have been formed in a basin because the base of the peat bed is seen at both ends resting on boulder clay while at the centre, the base has not been reached near sea level. The peat forms a platform or terrace lying between the eroded beach ridge and a boulder clay cliff which was once the shore cliff of the island. The peat is clearly an infilling of a former enclosed lagoon. North of Peatworth, the ridge reappears in its characteristic shape at the height of 7 feet above H.W.M.N. T. near Scaval, and 5 feet further north. When approaching Millgrip, the height is 9 feet. The size of the pebbles increase towards the north. (Pl. XIV 1,2)

It must be made clear that the measurements were taken actually at the hour of high water neap tides. An old line of dry seaweed perhaps marking the spring level of the sea, reached in recent times, is 5½ feet above the neap tide level. Such great variations in sea level must be taken into account before any storm origin is put to the Ayres.

6. The Guidmas Ayre, at the Bay of Franks, N. Stronsay, is an eroded beach ridge. It is almost completely

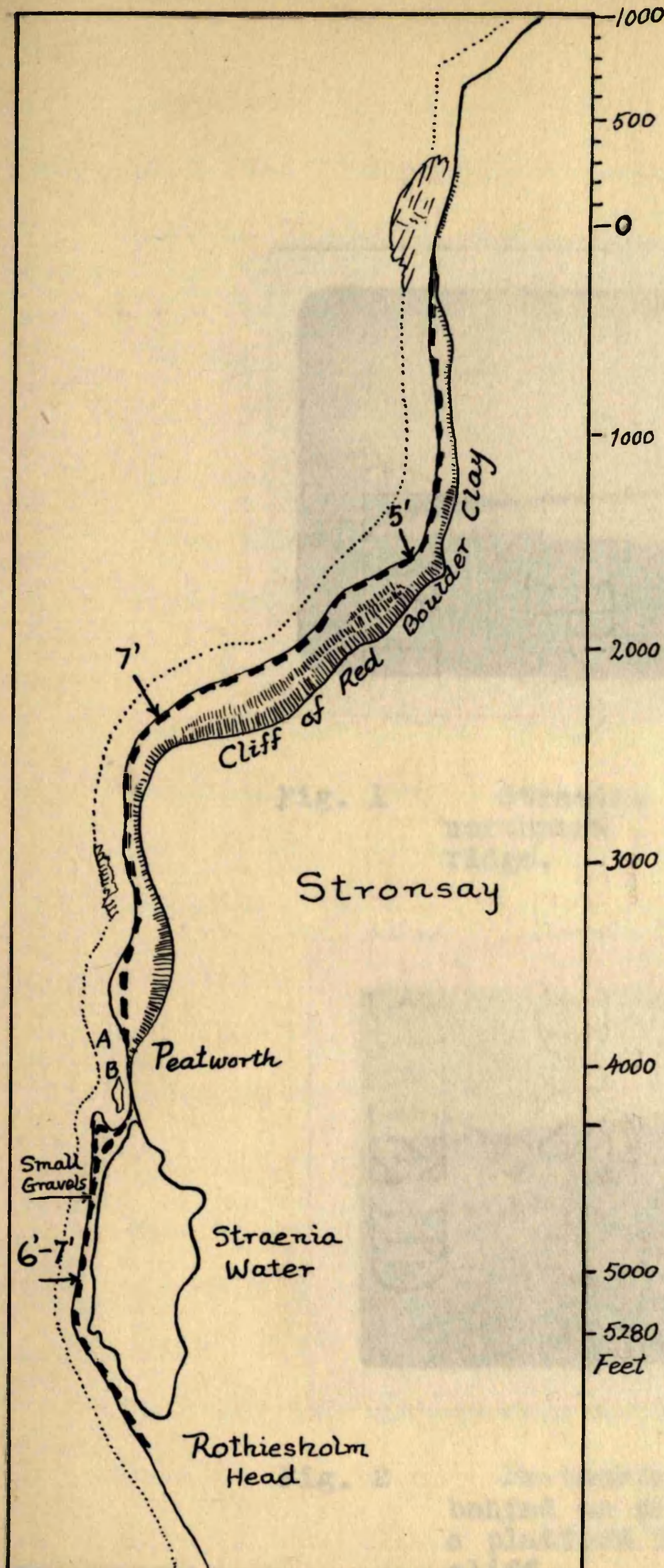


Fig. 31

Straenia Water, S. Stronsay.
Broken Lines indicate beach ridges
A and B indicate where peat samples have been collected for pollen analysis.

Fig. 1 Straenia Water, S.W. Stronsay, looking northward . On the left is the shingle ridge.

Fig. 2 Peatworth, W.Stronsay, showing peat behind an eroded beach ridge, forming a platform in front of a boulder clay cliff.

removed by the present sea. The cliff cut into the ridge is 3 feet high exposing small bedded gravels at most one inch in diameter. Storm origin seems to be very doubtful.

7. The shingle bank ponding back a lake, Mill Loch, on the east of Papa Stronsay is 11 feet high. (Fig.32) The ridge is composed of great boulders often 3 feet in diameter. The lake behind has been transformed into a swamp. An old level where the sea has left its mark is two feet higher than the H.W.M.N.T.

8. Similar beach ridges have been found on the shores westward from Point of Ayre, East Mainland. The older ridge, ~~is~~ grass-covered and in some places incompletely preserved, is 9 or 10 feet above H.W.M. while a new terrace, 5½ feet above sea level has been formed in front of it. There are shingle patches at about the same height near the Point.

9. On the shore of Rackwick, Hoy, boulders in a broad ridge at the northern end of the bay, are 16 feet above H.W.M., while at the southern end, ~~it~~ the ridge rises to about 20 feet but in a terrace form. The higher part of the terrace is composed of material of smaller size than that which forms the ridge, which is formed by boulders of 4 to 6 feet long.

10. An interesting double tombolo is seen tying up the Ness of Brough with the island of Sanday. (Fig.33) Both the arms of the tombolo are composed of beach ridges. The northern arm flanking the shore of North Bay has two ridges: the inner one 13 to 14 feet above H.W.M., the outer one ,11

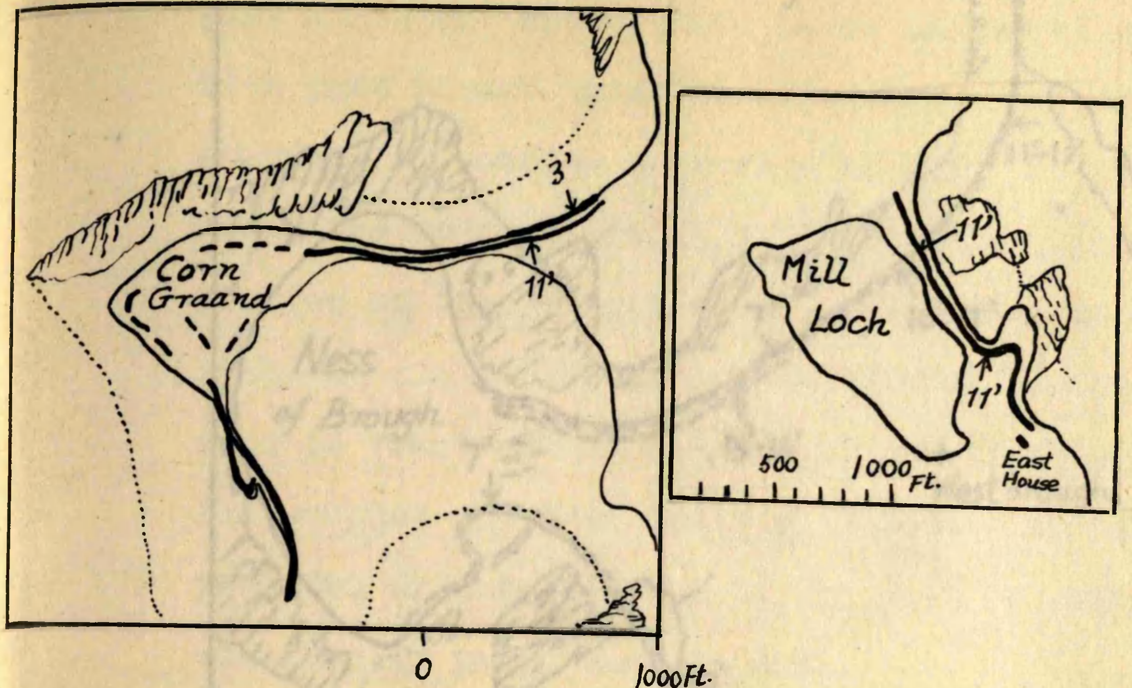
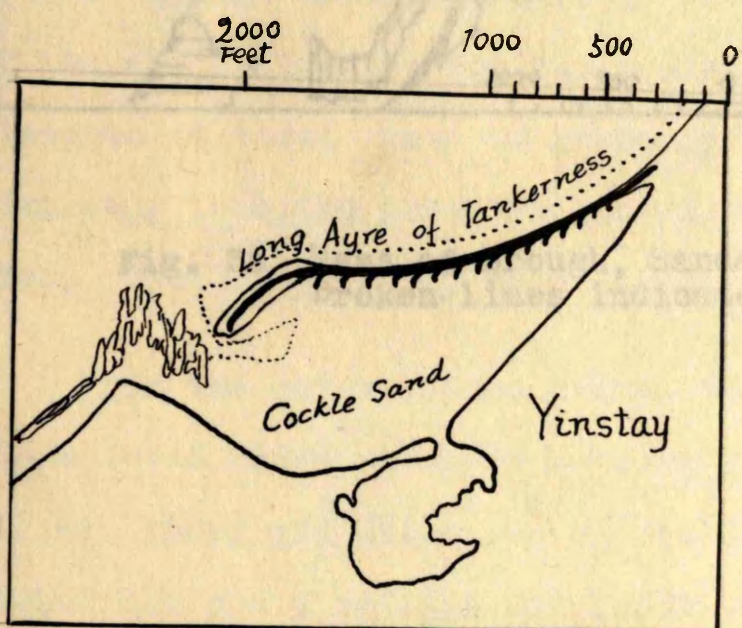


Fig. 32 Papa Stronsay and Shore Deposits

Fig. 34 The Long Ayre of Tankerness, Mainland, Orkneys.



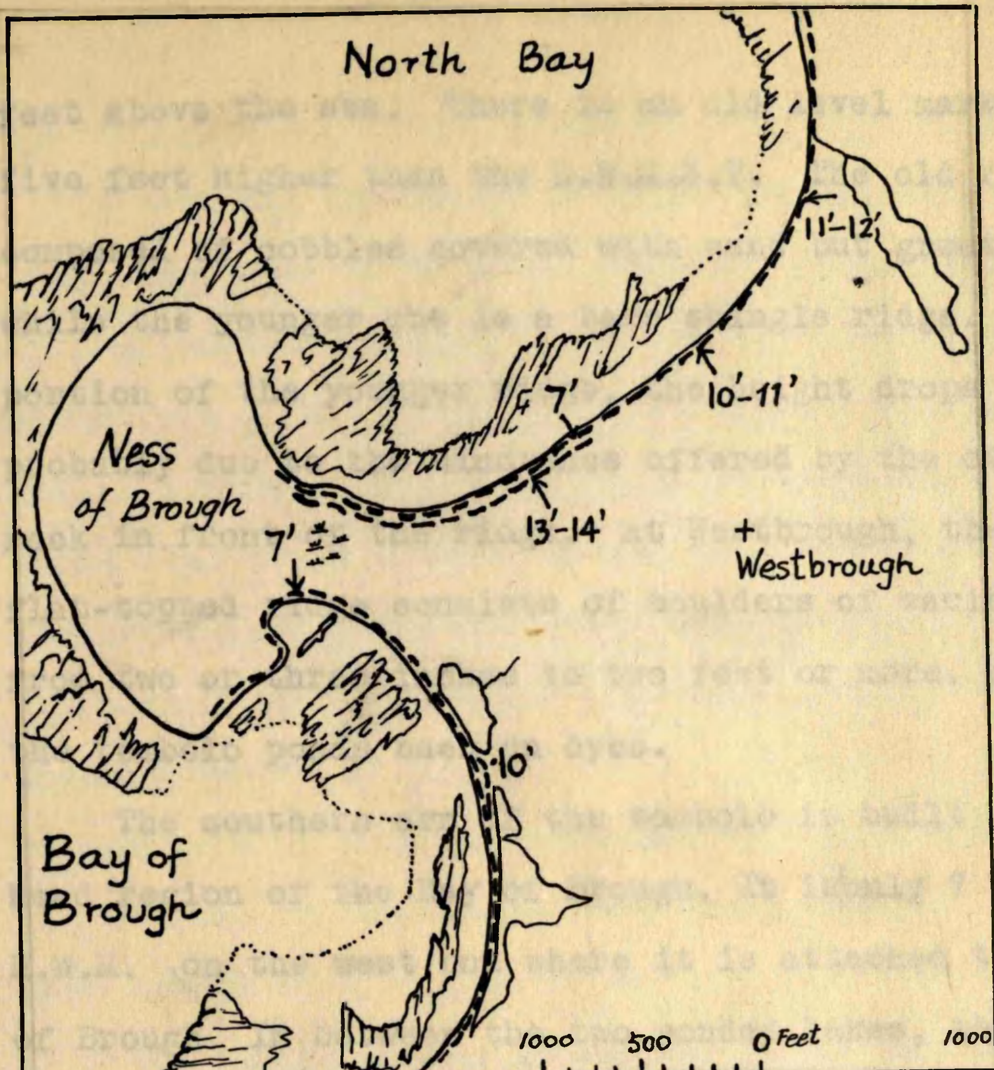


Fig. 33 Ness of Brough, Sanday.
Broken lines indicate beach ridges

feet above the sea. There is an old level marked by drifts five feet higher than the H.W.M.S.T. The old ridge is composed of cobbles covered with sand but greatly eroded while the younger one is a bare shingle ridge. At the middle portion of the younger ridge, the height drops to 7 feet probably due to the hindrance offered by the outcrop of rock in front of the ridge. At Westbrough, the younger flat-topped ridge consists of boulders of various in size from two or three inches to two feet or more. This arm of the tombolo ponds back an oyce.

The southern arm of the tombolo is built at the bay-head region of the Bay of Brough. It is only 7 feet above H.W.M. on the west end where it is attached to the Ness of Brough. In between the two ponded lakes, the height rises to 10 feet. This is probably due to the more exposed situation than the northern end which is sheltered by the Ness. This ridge has a steeper landward slope.

From the descriptions above, it is apparent that the shore forms known as Ayres involve a number of simple beach ridges. There are often two ridges in combination, an old and higher one and a younger and lower one. The reasons for believing that the landward ridge is older are firstly, it is built invariably higher than the outer ridge; secondly, the shingle has been exposed for sufficeint length of time so as to be coated with weathered colour, and thirdly, the ridge is generally overgrown with vegetation.

There are no traces of longshore growth and the ridges would therefore be regarded as being formed by waves coming in a direction at right angles to the general trend of the shore form. The old ridge which always the highest, must be formed during stormy or heavy seas, and is later covered by blown sand or by a thick growth of shingle vegetation. The seaward ridge, recently formed, never attains a height equal to that of the old. This may indicate that the subsequent waves, by which these new shingle ridges were built, were of smaller magnitude in comparison with the old storms. In some instances, the ridge has subsquently been eroded to a very great extent.

The height of the beach ridges, in most cases, is about 5½ feet above H.W.M. This does not necessarily imply the formation by storms. Many possibilities can account for such elevation, amony these the oscillation of the tidal levels seems to be the dominant factor, especially when the situation of the Orkney islands is concerned. It has already been mentioned that the difference between spring and neap rise is from 2 to 3 feet. Some old lines of sea level marked by drift of seaweed have been observed and the highest of them reaches 5 or 5½ feet above H.W.M.N.T. It is perhaps worthwhile to make detail investigation regarding these drifted materials and the heights in relation to the tidal level.

II. Ayres that have a composite origin

We now come to consider some more complicated shore forms in Orkneys. These are called Ayres, because of their apparent similarity to the beach ridges described above, but in fact, they possess some remarkable evidences which tell against the storm origin of this ayres.

11. The Long Ayre of Tankerness, Mainland (fig.34), (Pl.XV 1,2) is a ridge of cobbles about 580 yards long. It is only 5 feet above H.W.M. It has a steep seaward face and shelves fairly steeply below the sea, thus permitting strong waves to reach the base of the ridge during heavy seas. The lagoon side is less steep and during low water, one would never fail to see the perforating edge of the embankment, being formed by cusps of cobbles of no systematic spacing. These cusps when looking from the mainland shore, appear to be many spits jutting out into the enclosed lagoon. Undoubtedly these recurvatures indicate the successive terminal position of the growth of the embankment. The ayre takes the shape of a mid-bay bar, growing by the supply of longshore drift and finally reach a small skerry which was buried and formed the head of the Ayre. The general trend of the Ayre is not a straight line but concave in the centre towards the direction of the open sea. It is probable that during the formation and growth of the bar,

Plate XV

Fig. 1 The Long Ayre of Tankerness. Notice the drift line marked by seaweeds which were probably washed up by the sea during high water.

Fig. 2 The Lagoon shore of the Ayre of Tankerness, showing successive recurvatures forming during the growth of the bar.

waves at right angles to the direction of its growth had been able to push back the terminal end into a recurvature and by repetition of such process, successive recurvatures were formed on a curved line concave towards the direction of stronger wave action.(Pl. XV, 2)

Its height above sea level gives no particular favour to storm wave origin for reasons mentioned in the above discussion of beach ridges. It is however possible that a small quantity of cobbles has been thrown up on the bar during and after its growth. Such material being added by occassional storms contribute no significance to the origin of the shore form.

12. The Ayre of Tresness is very interesting (Fig.35). It is a tombolo about two miles in length connecting the island Tresness with Sanday. At high tide the Cata Sand is completely covered, forming an enclosed lagoon. At low tide, the sand is exposed and a tidal channel, the Clogg, forms the outlet of the ebbing tide. The tombolo first grew from north in a direction almost due south. It gradually shifts towards the west and reaches the present position, making a turn of about 40 degrees. The presence of gravel ridges (Pl. XVI,1) mostly covered by blown sand in directions progressively varies from south to parallel with the main ridge strongly suggests the westward migration of the tombolo. Such migration is similar to that of Cape Cod, described by Davis. By extending the original

gravel ridges, it is found that they must have once aiming directly at Ness Garth,Tresness. Then the whole tombolo had been pushed back by waves from the open sea and transformed into a bar with one end free from any connection with land. The head of this old bar is seen as four gravel ridges branching from the present main ridge and lying on the Cata Sand. Later longshore transportation has been able to refill the place where the tombolo was breached and finally attain the present state. The extreme southern portion of the tombolo is very narrow and low lying indicating the refilled portion referred above. The basal gravels and shingle ridges are only 5 feet above H.W.M. while the blown sand adds considerably to its present height of 15 to 20 feet.

There must have been attempts of the waves to built a bar across the bay of Tresness, connecting the island with the mainland. But the tidal channel prevents a complete tombolo being formed. On the west side of the Clogg a spit juts out into the bay and is composed of gravels. This spit has been eroded considerably.

The Tresness tombolo and the spits on both sides of the ebb tide outlet are typical of the composite shore forms seen in the Orkneys. Undoubtedly such complicated forms cannot be that of a simple storm wave formation. They can neither be explained as the product of a series of storm waves, unless the angle of approach of such waves vari~~ous~~es

Fig. 1 The Tresness Tombolo, showing former beach ridges on the Cata Sand. A remnant of an once dune-covered ridge is seen near the right(arrow).

Fig. 2 The Spit of Papa Stronsay.

regularily.

13. The Lama Ness, Otter Wick,Sanday,(Fig. 36) is a compound recurved spit. It is composed of cobbles ridges juts out into the bay. The ridge are 5 feet above H.W.M. On the northern side of the spit erosion has half excavated the sand dunes, exposing the structure of the ridge. The southern side, being sheltered from strong waves is composed of a sandy flat the sands of which were held up by the recurvatures of the spit. On the eastern end of the spit new recurvatures of gravels ridges have been formed recently and are only one or two feet above H.W.M. The successive recurvatures are indicated in the figure.

14. In Papa Stronsay, (fig.32; Pl.XVI,1) a spit was formed on the western tip of the island. It runs westward and turns sharply towards the south. The terminal point of the spit is composed of cobbles of one foot or more and covered with blown sand. The ridge itself is on the brink of being breached through by the sea and a groyne is erected to hold the shingle in place. The ridge is 11 feet high above H.W.M.N.T. Tracing eastward, a layer of decayed sea weed is found below a thin veneer of blown sand 6 feet lower than the ridge. It represents a higher stand of the sea and reducing the height of the ridge to about 6 feet above the highest level of the sea known.

The N-S portion of the spit is lowlying, the highest point being only two feet above H.W.M.N.T. This part must

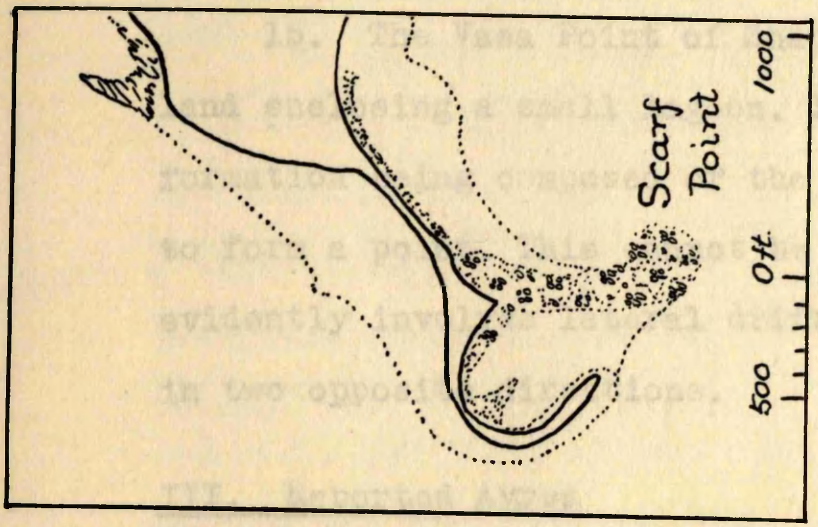


Fig. 37
The Scarf Point,
Mainland, Orkney.

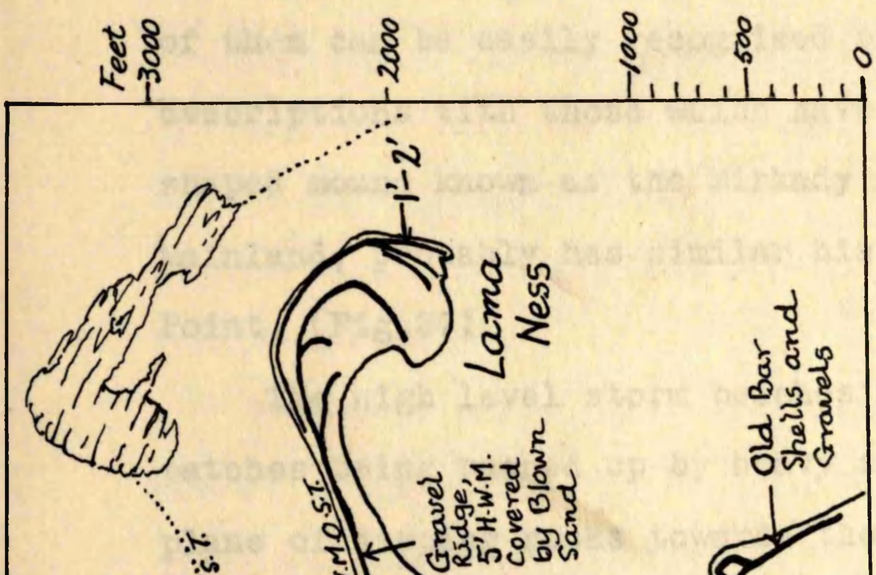


Fig. 36
Lama Ness, Sanday.
Solid lines indicate
beach ridges.

be of recent origin and is perhaps formed by the balance of the inward drift of shore material from the north with the waves coming from the east.

15. The Vasa Point of Shapinsay is a cuspate foreland enclosing a small lagoon. It is a relatively simple formation being composed of the two beach ridges converged to form a point. This cannot be of storm origin as it evidently involves lateral drift of material and growth in two opposite directions.

III. Reported Ayres

The present writer has not been able to visit all the localities where Ayres are reported to occur, but a number of them can be easily recognised by comparing the shape and descriptions with those which have been studied. The sickle shaped mound known as the Mirkady Point, East of Deer Sound, Mainland, probably has similar history to that of Ouse Point. (Fig.37)

The high level storm beaches are actually shingle patches being pushed up by heavy sea along the bedding plane of dipping rocks towards the sea. In Stronsay, a huge boulder of many tons is reported to have been thrown on the cliff top during storms.

The Memoir states that the Aith Hope tombolo, which connects Hoy with South Walls, "most probably represents the last stage in submergence before a peninsula becomes "an island".(Mem.Geol.Surv.,Orkneys,1935,pp.9) It appears to the writer that such features do not indicate submergence of the features themselves for such features are formed <u>after</u> the land has been submerged. They are formed to connect islands together, the latter being the products of submergence. The Memoir further states that " evidence of recent subsidence is afforded by the presence below high-water mark of beds of peat and of features that appear to be eroded and submerged storm beaches or ayres"(pp.33) Regarding the peat, it is possible that it does prove submergence provided that other possibilities are fully considered, while the feature that appear to be submerged storm beaches is doubtful. If such submerged storm beaches are true storm deposits as what has been suggested by the Memoir, submergence must account for its presence under high water mark. But if such deposit are formed under ordinary conditions,as most of the Ayres do, and to a lesser extent 'decorated' by storm shingles, there has no necessity for introducing submergence to account for their occurrence under highwater mark as many such forms do occur below that level. e.g. the tombolo of Campbeltown,Kintyre.

IV. Conclusions

The origin of the Ayres involve two processess. Those which are composed of simple beach ridges must have bee n formed by waves coming in a direction at right angles to the general trend of the shore ridge. They may or may not involve storm conditions which itself has no definite distinction with normal conditions. Heights alone do not prove the storm origin as there are many other factors to account for them. Those which show composite origin indicate not only the transverse direction of approaching waves but also longshore drift. Spits, tombolos are known to have been initiated, developed and modified by these processess. Though eddy currents apparently coincide with the direction of the drift in most cases they do not responsible for the drift of materials for the velocity of the currents is not strong and the period which the current can work on shingle is short. Simple beach ridges or storm shingles may have been thrown on these forms but it is essential that the forms should be classified under their original form they took and the processess from which they owe their origin and development.

WITH THE AUTHOR'S COMPLIMENTS

To ______________________________

Chapter XI

Storm Waves and Shore-forms of South-Western Scotland.

BY

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Storm Waves and Shore-forms of South-Western Scotland.

By S. TING, Glasgow University.

THE effect of waves on a shore depends largely on the angle of approach, for the energy of the advancing waves tends to erode the headlands and drift the products of erosion into the bays. Wave refraction [1] applies to waves approaching the shore in any direction, but is only ideally developed in ordinary weather conditions or by approaching waves caused by distant storms. Locally developed storm waves usually approach the shore at an oblique

[1] Johnson, D. W., *Shore Processes and Shoreline Development*, 1919, 74.

angle to its general trend, owing to the failure of wave refraction and are the most effective where locally they meet the shore at right angles. Beach drifting will be in operation along the section of the shore which happens to be at an angle oblique to the direction of the approaching waves.

Storm waves have the power of lifting as is shown by the lifting of concrete blocks by wave pressure transmitted through crevices below the mass.[1] But there is another way of lifting materials which is seldom referred to in the literature, though well known to coastal engineers. When the waves approaching the shore impinge against a sloping wall or a cliff the wave is deflected vertically upwards to very high levels. The upward rush of surf charged with debris will carry the latter up to considerable heights and drop it at that level. Great damage may be done by the falling of the mass of water and the debris, because they acquire considerable energy when descending with accelerating velocity. This lifting power is important in connection with the discussion of the storm-built forms.

The islands of Islay, Jura, Colonsay, and Oronsay, of South-West Scotland, are exposed to the west and south-west, and afford interesting examples of storm wave deposits. The Clyde Estuary is protected by Kintyre and presents many shore-forms other than those of storm origin. The writer wishes to record some of the depositional features due to storm waves, and attempts to demonstrate the relative importance of these waves in the production of shore-forms.

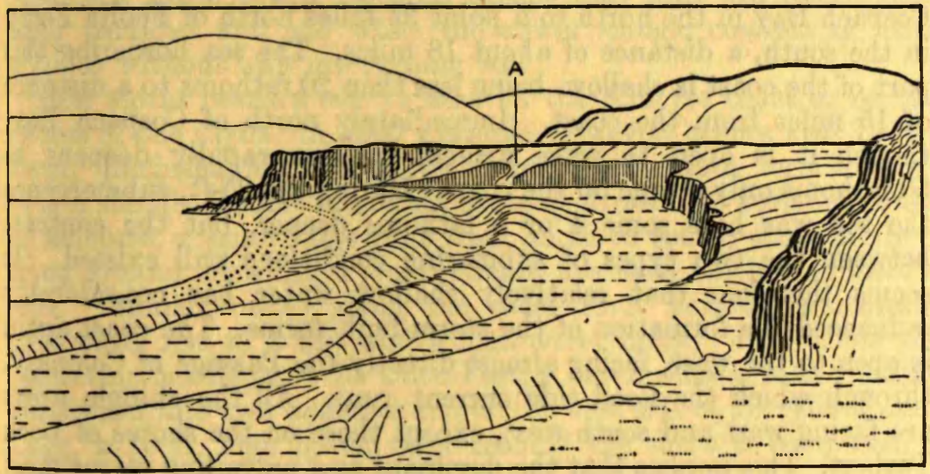
Storm Shingle.

In an earlier paper,[2] the writer has classified storm shingle into storm beaches, storm shingle patches, and beach ridges. These three types are found in many places, at various heights above the present high-water mark. Storm beaches have a terrace form often with a slight landward slope. Shingle thrown into a ridge is called a beach ridge. Shingle having no definite shape and occurring only in patches at various heights belongs to the group of shingle patches. The writer has encountered such deposits in many places, notably on the western coast of Jura, where there are widespread areas of shingle, many of which are in ridge form, arranged in two or three terraces up to the height of more than 100 feet. Text-fig. 1 shows the shingle area found on the southern side of Loch Tarbert, Jura. The highest shingle patch is here a terrace rising only to about 30 feet above sea-level, while the lower shingle consists of two sweeping beach ridges. These deposits have blocked up a river to form a lake. They have been mistaken for raised beaches because of their height, but it is easily seen, especially in the case of the lower ridges, that they are built on a pre-existing cliff-backed marine platform of the third raised shoreline period. In places

[1] Ibid., p. 66.
[2] S. Ting, "Beach Ridges of S.W. Jura," *Scot. Geogr. Mag.*, 52, 1936, 182–7

(A, Text-fig. 1) the highest shingle is seen masking the face of the cliff. It is evident that the shingle has been laid down after the formation of the cliff and that it is not a part of the raised beach deposit.

Some other features also confirm their storm origin. The shingle consists mainly of ridges of asymmetrical section, being steeper at their rear slopes, which indicate the angle of repose when the materials were being thrown up into ridge form. This is a common feature in shore forms above ordinary high-water mark. Genuine beach deposits do not usually attain ridge form, and will not have the steeper rear slope, since they are not thrown up but rolled up by the waves. The Jura shingle consists of partially rounded cobbles which are scarred with concussion bulbs,[1] due to their beating one against another during deposition, while ordinary beach shingle



TEXT-FIG. 1.—Shingle beaches and ridges, southern shore of Loch Tarbert, western Jura. Drawn by W. J. McCallien from a sketch by the author.

is well-rounded and does not show such scars because it has suffered considerable wear by water action when rolling up and down a fairly steep foreshore slope. On a gentle slope similar waves may not be able to move the coarser elements, but storm waves will tend to throw rather than roll the materials and will thus transport them to higher levels. Another point is that much of the high shingle is found overlying hard rock in the form of a platform, which has no sign whatever of marine origin. On the landward side of this higher platform there is no marine cliff, a feature always associated with a wave-cut bench.

The beach ridges found 2½ miles north of Feolin Ferry, south-west Jura, began to form at the close of the 25-ft. submergence, and continued to prograde during the rise of the land. Many of the low level

[1] "The Geology of Jura, Knapdale, and N. Kintyre," *Mem. Geol. Surv. Scotland*, 1911, 127.

shingle deposits are therefore interpreted as raised shingle, formed during the last emergence. The writer also believes that the higher shingle was also formed by the 25-ft. sea. The validity of the suggestion that shingle materials were thown up by a sea 25 feet higher than the present to a height of 70 or 80 feet above it may be doubted. But present-day records show that the surf of storm waves has frequently broken the windows of a lighthouse, 200 feet above the sea, at Unst, Shetland. Geikie also mentioned the broken windows of the Dunnet Head Lighthouse by stones swept with the 300-ft. rise of the storm surf.[1] Boulders 10 feet long are reported to have been thrown up into a mound 15 feet high on the top of a cliff 60 feet above the sea in the Orkneys.[2] It is therefore not at all surprising to suggest the throwing of much smaller cobbles to a height of 80 feet above the sea-level.

Bare shingle occurs all along the western coast of Jura from Cospach Bay in the north to a point 2½ miles north of Feolin Ferry in the south, a distance of about 18 miles. The sea bordering this part of the coast is shallow, being less than 20 fathoms to a distance of 15 miles from the coast. Immediately north of Cospach Bay, though it is open to wave attack, the sea rapidly deepens to 50 fathoms only a mile off the coast. During the 25-ft. submergence the sea was here some 4 or 5 fathoms deeper, but the contrast between the two types of submarine conditions still existed. It seems therefore that relatively shallow water has considerably influenced the formation of the storm-built forms. The coast again is open to the west, facing almost directly the Passage of Colonsay, through which the flood tide current runs. All the shingle areas are facing west and south-west, except those on the shores of Loch Tarbert. This implies that the dominant and prevailing waves most frequently came from the south-west, as happens at the present day. Loch Tarbert, however, is a sheltered loch and the explanation of its shingled beach is probably that the waves passing into the loch, which narrows rapidly, have had to force their way into the passage. Their speed has been increased, and they developed sufficient power to throw materials up to high levels.

To the west of Jura, on the islands of Colonsay and Oronsay, storm beaches and ridges are less frequent while sand dunes are abundant. The dunes, which are sometimes formed on a beach ridge foundation, often preserve the trend of the ridges. Such dune ridges on Ardskenish, South-West Colonsay, having a fairly regular trend normal to the south-west direction and, rising to uniform heights of about 40 feet, are probably formed on beach ridges. The central part of Oronsay is thickly covered with sand dunes, while on the southern part of the island grass-covered shingle areas are seen below a thin layer of blown sand. Storm shingle patches are, nevertheless,

[1] Geikie, A., *Text-book of Geology*, 3rd ed., Macmillan, 1893.
[2] "The Geology of the Orkneys," *Mem. Geol. Surv. Scotland*, 1934, 10.

very abundant. They have no regular shape, vary in dimensions and height, and are occasionally mistaken for raised beaches. They have been brought up by waves and dropped on the ground above the reach of high water. Where the shingle is dropped, the ground, if composed of loose and soft material and especially dry blown sand, would probably be depressed slightly by the force and weight of the falling water and shingle. Later deposits would therefore fall on a cushion of shingle and be scarred and heaped up into patches, the middle part of which is presumably thicker than its outer margin. Most of these patches are present-day formations.

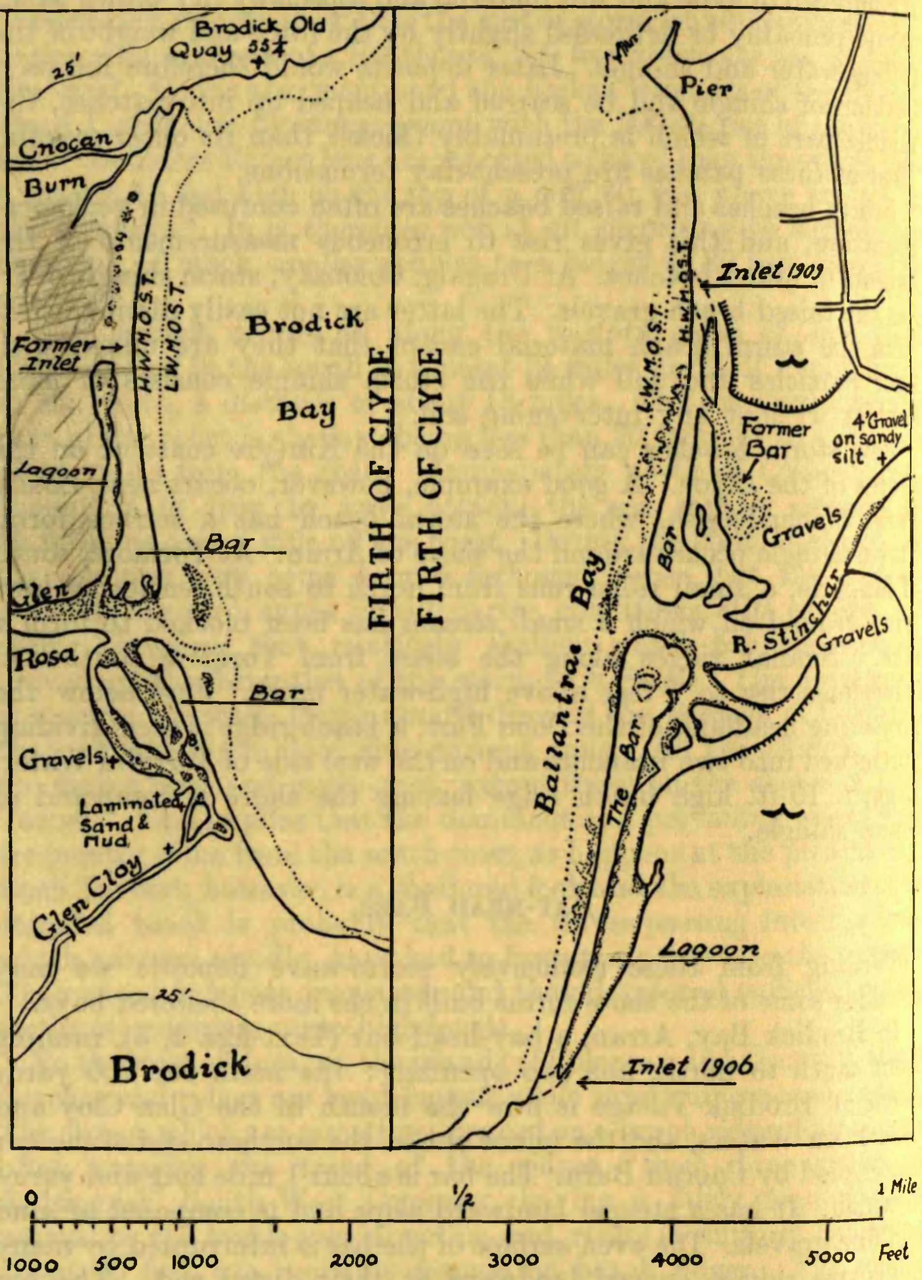
Storm beaches and raised beaches are often confused in geological literature, and this gives rise to erroneous measurements of the heights of raised beaches. At Uragaig, Colonsay, storm shingle overlies the raised beach gravels. The latter are not easily distinguished from the storm beach material except that they are mixed with finer particles and soil while the storm shingle consists of loose cobbles without any intervening soil.

Few storm beaches can be seen on the Kintyre coast or on the shores of the Clyde. A good example, however, occurs near Losset Park, Machrihanish, where the storm beach has a terrace form. Storm shingle occurs around the shore of Arran. At Tormore, south of Machrie, a small ridge runs from north to south, enclosing low-lying ground on which a small stream has been blocked to form a lake. Similar ridges along the coast from Tormore southward sometimes rise to 7 feet above high-water mark. Just below the projecting headland of the Doon Fort, a beach ridge is seen dividing northward into two branches and on the west side of Torrylin Water, Lagg, a 10 ft. high beach ridge fencing the shore is composed of coarse shingle.

Bay-head Bars.

Turning from these exclusively storm-wave deposits we may consider some of the shore-forms built in the more sheltered bays.

In Brodick Bay, Arran, a bay-head bar (Text-figs. 2, 3), running from south to north, has two openings: the main one 700 yards north of Brodick Village is now the mouth of the Glen Cloy and Glen Rosa Waters, and the minor one at the northern end of the bar is occupied by Cnocan Burn. The bar is about 1 mile long and varies in width. It has a steeper landward slope and is composed of sand and fine gravels. The even surface of the bar is interrupted by many miniature ridges, curved landward at their distal end. The bar encloses an elongated lagoon. The southern portion of the lagoon is actually the course of the Glen Cloy Water, while the northern portion is a former river course. The bar has undergone many changes since it was initiated. Early in the nineteenth century it had its present appearance. In 1859 the southern portion was breached in three places, which were afterwards used by the Glen Cloy Water as outlets.[1] These temporary openings have later been silted up and both the Glen Cloy and the Glen Rosa Waters were deflected some 700 yards north of the present opening. Early in the present

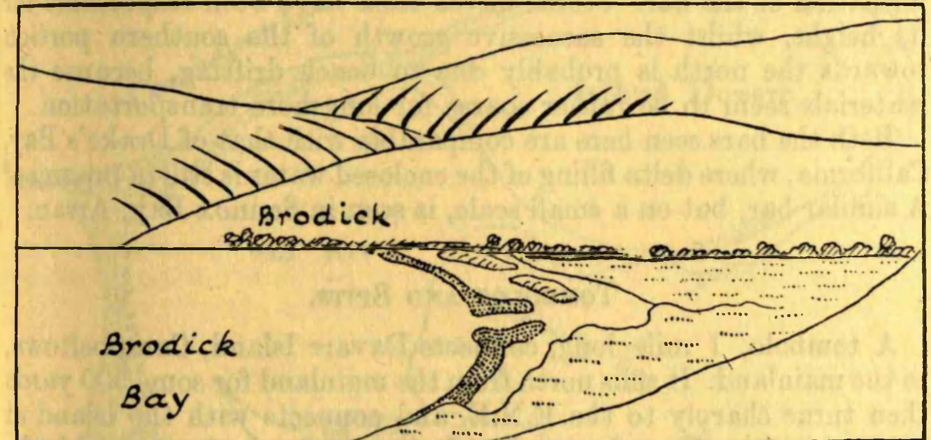


TEXT-FIG. 2.—The Bay-head Bars of Brodick and Ballantrae.

[1] The term " outlet " is equivalent to the term " inlet ". The former term is used with reference to rivers draining into the sea through an opening in an off-shore form, while the latter is preferred in cases when the tidal currents or waves are considered.

century the opening shifted back to the present locality and left the northern course as an elongated lagoon. The minor opening has undergone few changes. The former Cnocan Burn originally had a strongly meandering course, which was artificially straightened, thus perhaps enabling it to maintain its outlet.

The bar is connected with the heavy deltaic deposition of the confluent rivers, which gave rise to the plain behind the lagoon, erroneously mapped by the Geological Survey as 15 ft. raised beach, and at the same time shallowed the water. The waves then broke on shallow water and had ample opportunity to throw the material up into a bar. Deposits examined in a few exposures along the river banks show that the plain is built of coarse gravels with carbonaceous inclusions. The difference between the grade of the materials which build the bar and that of the plain suggests that



TEXT-FIG. 3.—Brodick bar (dotted) looking south from the lower slopes of Goatfell.

the features are of different origin. The sand composing the bar must have been derived from longshore transportation, though part of it may have resulted from the slow but continuous grinding of the deltaic gravels by the waves. Waves responsible for the formation of this bar came from the north-east and the materials being drifted along with the wave into the zone of perpendicular wave action were heaped up into the bar. Waves approaching from other directions would tend to fill the inlet and cause shifting of the latter either northward or southward.

A similar bar is found at the mouth of Stinchar Water, Ballantrae, South Ayrshire (Text-fig. 2). This bar is about a mile long, running southward from the Ballantrae Pier. The Stinchar Water maintains an outlet near the middle of the bar, which, however, appears to have been largely silted up, a crescent-shaped mound being seen across the mouth during low water. The bar faces W.N.W., and is composed of cobbles with ridges similar to those seen on the Brodick

Bar. On the northern portion of the bar and on the plain behind there are traces of a former ridge, truncated by the present bar, facing S.S.W. The southern portion of the bar is growing northward, as is indicated by the many successive recurvatures. Study of the old maps shows that early in the nineteenth century the mouth of the Stinchar Water was an estuary.[1] The 6 in. map of 1855 showed a well-developed bar with an opening approximately at the present site, but the northern portion was overlapping the southern part. Groome's map [2] (1884) showed openings at both ends of the bar, which was an island. On the 1 in. map of 1906 the northern opening was closed and a lagoon occurred behind it, while the Stinchar drained into the sea from the south. Three years later the southern opening was closed and a northern was opened. By 1912 the bar had attained its present configuration. It is clear that the Stinchar estuary has been silted up by coarse deltaic deposits due to the formation of the bar. Storm waves must have been responsible for its height, whilst the successive growth of the southern portion towards the north is probably due to beach drifting, because the materials seem to be rather coarse for longshore transportation.

Both the bars seen here are comparable with that of Drake's Bay, California, where delta filling of the enclosed water is still in progress.[3] A similar bar, but on a small scale, is seen in Sannox Bay, Arran.

Tombolos and Spits.

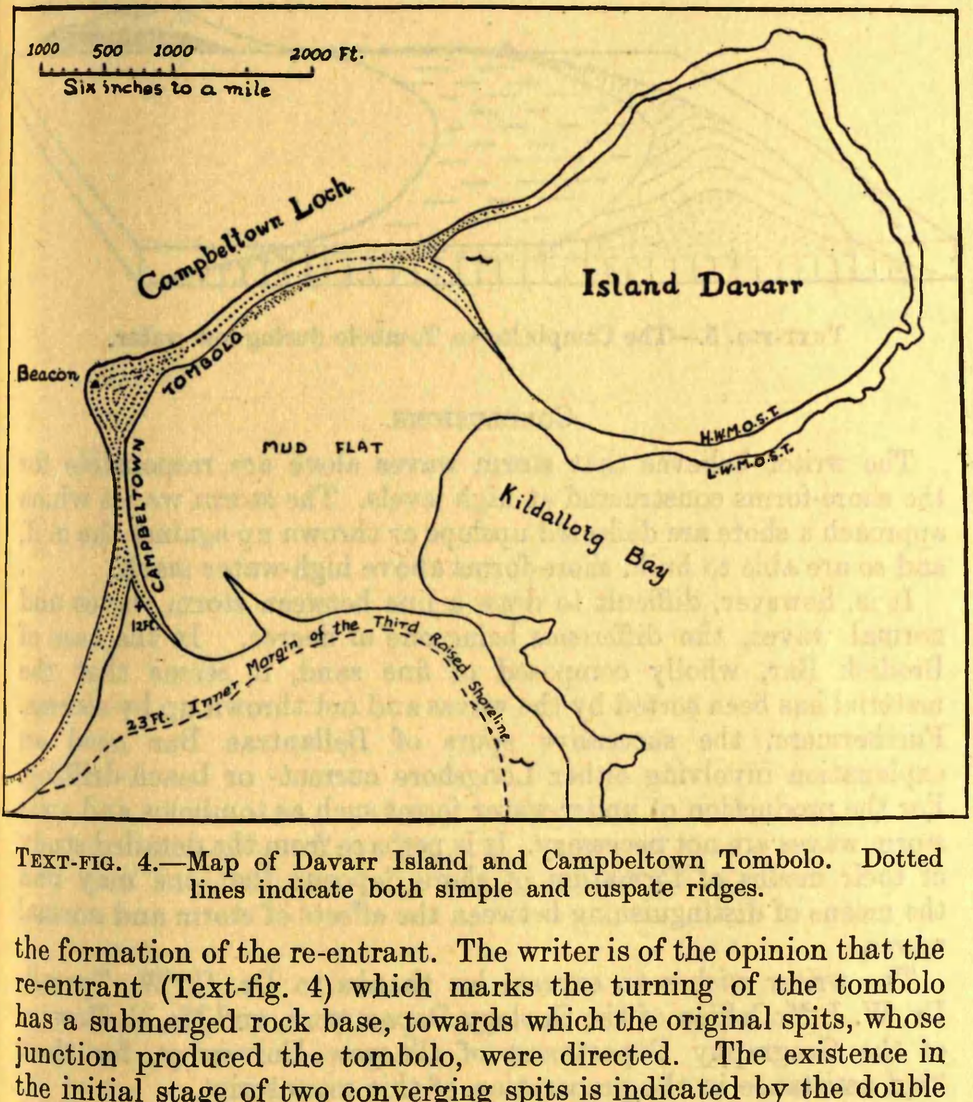
A tombolo, 1 mile long, connects Davarr Island, Campbeltown, to the mainland. It runs north from the mainland for some 500 yards then turns sharply to the E.N.E. and connects with the island at its western tip (Text-figs. 4, 5). It is composed of coarse shingle, lying on the northern and western edges of a mud flat, which, together with most of the tombolo, is submerged during high tide. The unsubmerged parts of the tombolo, only a few feet above the high-water mark, consists of the cuspate ends and the central re-entrant. The latter is made up of a succession of rings of ridges. The material of the tombolo is, in the writer's opinion, derived from the raised beach shingle on the southern coast of the island and the neighbouring northern coast of the mainland. In both localities the raised beaches are eroded into a low cliff. The waves come from the south-east, erode the raised beaches, and carry the debris northward until they encounter the eddy currents in Campbeltown Loch. The unequal development of the arms of the cuspate ridges points to a more vigorous action from the south-east. There is no indication of storm wave action, and the tombolo itself is the product of a delicate balance between the stronger inward drift over a former rock

[1] Chambers, *Gazetteer of Scotland*, 1832, map.

[2] Groome, *Ordnance Gazetteer of Scotland*, 1884, map.

[3] Gulliver, F. P., "Shoreline Topography," *Proc. Acad. Art. and Sci.*, 34, 1898–9, pp. 208–209, 227, 232, figs. 21, 31.

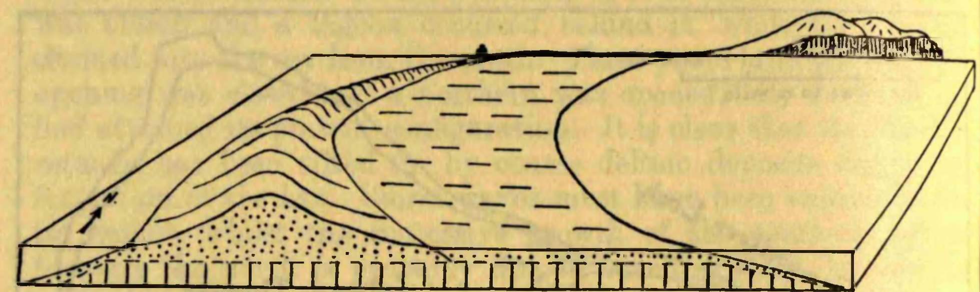
platform of shallow depth and the weak eddy currents in Campbeltown Loch. The shallowness of the water on the platform has considerable influence in diminishing the power and velocity of the inward drift, and the tombolo has been formed where the drift is checked by the eddy currents. The mud, as a result of the overflow of the eddy current during flood, accumulates on the platform. While accepting the formation of the tombolo as it is discussed above, Dr. McCallien, with whom the writer has discussed the above features in the field, differed from the writer in the explanation of



TEXT-FIG. 4.—Map of Davarr Island and Campbeltown Tombolo. Dotted lines indicate both simple and cuspate ridges.

the formation of the re-entrant. The writer is of the opinion that the re-entrant (Text-fig. 4) which marks the turning of the tombolo has a submerged rock base, towards which the original spits, whose junction produced the tombolo, were directed. The existence in the initial stage of two converging spits is indicated by the double Y formation of the cuspate ridges, each portion of the present tombolo being a former double Y-tombolo. Dr. McCallien doubts this hypothesis and suggests that the concrete foundation of the beacon is responsible for the greater accumulation of shingle around it. The northern portion of the tombolo shows traces of recent changes in shape. The telegraph poles, presumably planted on the crest-line of the shingle, are now situated on the sides of the ridge and some even on the mud flat.

A typical spit occurs in the head of Loch Indaal, Islay, pointing to the south. It is known to have existed a long time with no appreciable changes. Another spit occurs behind a dyke, just south of Kildonan Hotel, South Arran. The dyke stretches out into the sea and collects shingle on its leeward side. On the crest of the ridges the shells are arranged in lines with many short branches pointing to the north.



TEXT-FIG. 5.—The Campbeltown Tombolo during low water.

CONCLUSIONS.

The writer believes that storm waves alone are responsible for the shore-forms constructed at high levels. The storm waves which approach a shore are deflected upslope or thrown up against the cliff, and so are able to build shore-forms above high-water mark.

It is, however, difficult to draw a line between storm waves and normal waves, the difference being one of degree. In the case of Brodick Bar, wholly composed of fine sand, it seems that the material has been sorted by the waves and not thrown up by storms. Furthermore, the successive spurs of Ballantrae Bar need an explanation involving either Longshore current- or beach-drifting. For the production of under-water forms such as tombolos and spits storm waves are not necessary. It is perhaps from the detailed study of their modes of formation of shore deposits that one may find the means of distinguishing between the effects of storm and normal waves.

The writer wishes to express his thanks to Dr. G. W. Tyrrell, Dr. W. J. McCallien of the Geology Department, and Mr. G. Bowen, of the Geography Department of Glasgow University, for their kind assistance in the preparation of this manuscript.

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BEACH RIDGES AND OTHER SHORE DEPOSITS IN SOUTH-WEST JURA

By S. Ting, B.Sc., Research Student at the Department of Geography, Glasgow University

(*With Maps, Diagrams and Illustrations*)

Location and Description.

An interesting series of beach ridges occurs on the east coast of the Sound of Islay, about two-and-a-half miles north of Feolin Ferry. From the opposite side of the Sound they appear as a wide spread of shingle with an undulating surface, bare of vegetation. The ridges are chiefly composed of well-rounded, quartzite cobbles of more or less uniform size, ranging from four to six inches in their long axes. The cobbles have been derived from local rock, as the greater part of Jura is composed of quartzite. There are about twenty parallel ridges running in a NE.-SW. direction and slightly convex toward the land. The ridges are uniformly spaced and well defined by the alternation of bands of large and small cobbles. Six lines of white cobbles, sometimes forming the crests of the ridges and sometimes the intervening valleys, are striking features of which the origins are still obscure. The beach ridges decrease in height

* For all references see list at end of article.

as one approaches the shore. The innermost ridge rises to twenty-nine feet above sea-level, while the outermost merges into the present beach (see Figs. 1 and 2 and Plate 1).

The beach ridges have been built up in a NNW.-SSE. hollow which is bounded on the north-east and south-west by low cliffs not more than fifty feet high, and on the south-east by a low gravel ridge. This ridge, which limits the series of bare beach ridges on the landward side, is clearly distinguished from them by its greater height and breadth, and by its covering of grass. Behind the grass-covered ridge, the river Abhuinn na h-Uanaire drains a small plain overlain with peat. The river, rising in Loch A'Chnuic Bhric, flows southward through a narrow valley till it reaches the plain, which it crosses in a NE.-SW. direction, parallel to the trend of the grass-covered ridge. The river leaves the plain by a gorge

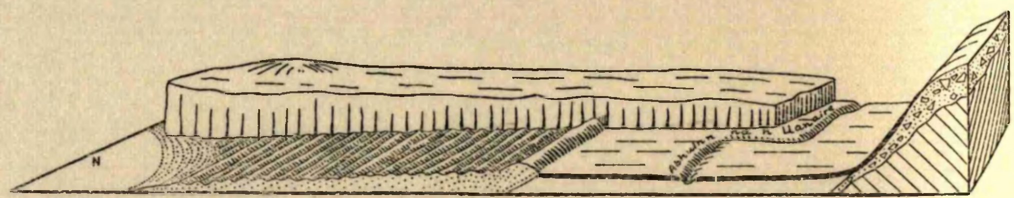


FIG. 1. Block-Diagram of Beach Ridges in South-West Jura.

and drains out by Inver Cottage into Whitefarland Bay, where it has built up a small delta (see Fig. 2).

The Formation of the Beach Ridges.

In discussing the origin of beach ridges, D. W. Johnson[1] has sought to establish three main principles :—

1. That beach ridges are built by storm waves, which are capable of throwing up coarse shingles to a considerable height.

2. The ridges are formed in the first place in front of an existing bar or embankment in shallow water. The bar may itself be a product of storm-wave action.

3. They are built of materials supplied by longshore transportation.

The application of these principles to the beach ridges of Jura necessitates some consideration of the marine conditions off the coast. The Sound of Islay is a N.-S. trough of deep water lying between the islands of Jura and Islay. Islay, on the west side, rises steeply from the sea to a height of over a thousand feet, and forms a shelter for the low western shore of Jura against the west wind. The promontory of McArthur's Head on Islay protects the Sound from any serious attack by storm waves generated by south-west winds. It is from the north that the coast of Jura is most open to wave attack : here the Sound is wider, and there are no head-

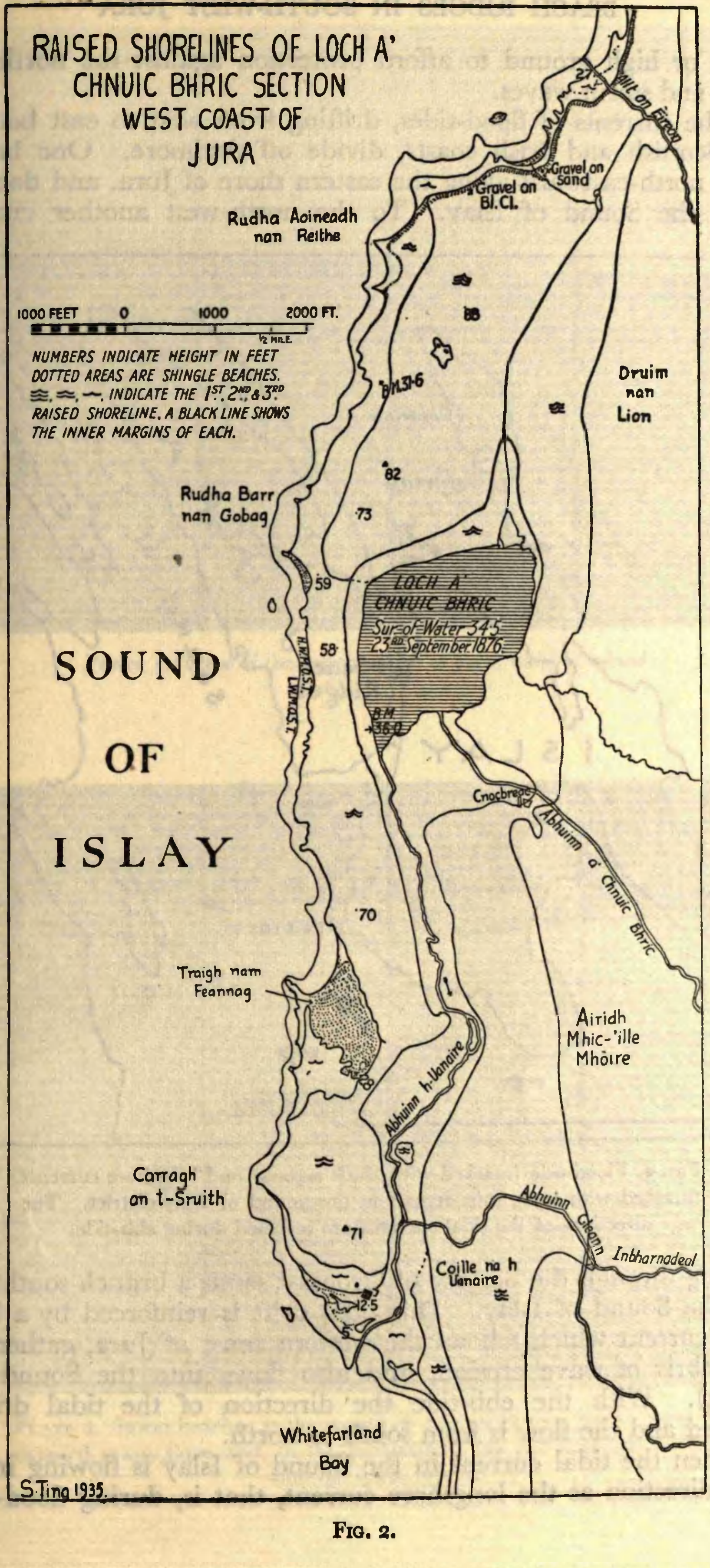

RAISED SHORELINES OF LOCH A' CHNUIC BHRIC SECTION WEST COAST OF JURA
Rudha Aoineadh nan Reithe
1000 FEET 0 1000 2000 FT.
½ MILE
NUMBERS INDICATE HEIGHT IN FEET
DOTTED AREAS ARE SHINGLE BEACHES.
INDICATE THE 1ST, 2ND & 3RD RAISED SHORELINE. A BLACK LINE SHOWS THE INNER MARGINS OF EACH.
Gravel on Bl. Cl.
Gravel on Sand
Druim nan Lion
Rudha Barr nan Gobag
LOCH A' CHNUIC BHRIC
Sur. of Water 34.5
23RD September 1876
SOUND OF ISLAY
Cnocbreac
Abhuinn a' Chnuic Bhric
Traigh nam Feannag
Airidh Mhic-'ille Mhòire
Abhuinn h-Uanaire
Carragh an t-Sruith
Abhuinn Gleann
Inbharnadeal
Coille na h Uanaire
Whitefarland Bay
S. Ting 1935.

FIG. 2.

lands or high ground to afford protection against the north-west wind and storm waves.

The currents of flood-tides, drifting from west to east between the Scottish and Irish coasts, divide off Ardmore. One branch flows north-eastward along the eastern shore of Jura, and does not enter the Sound of Islay. To the north-west another current,

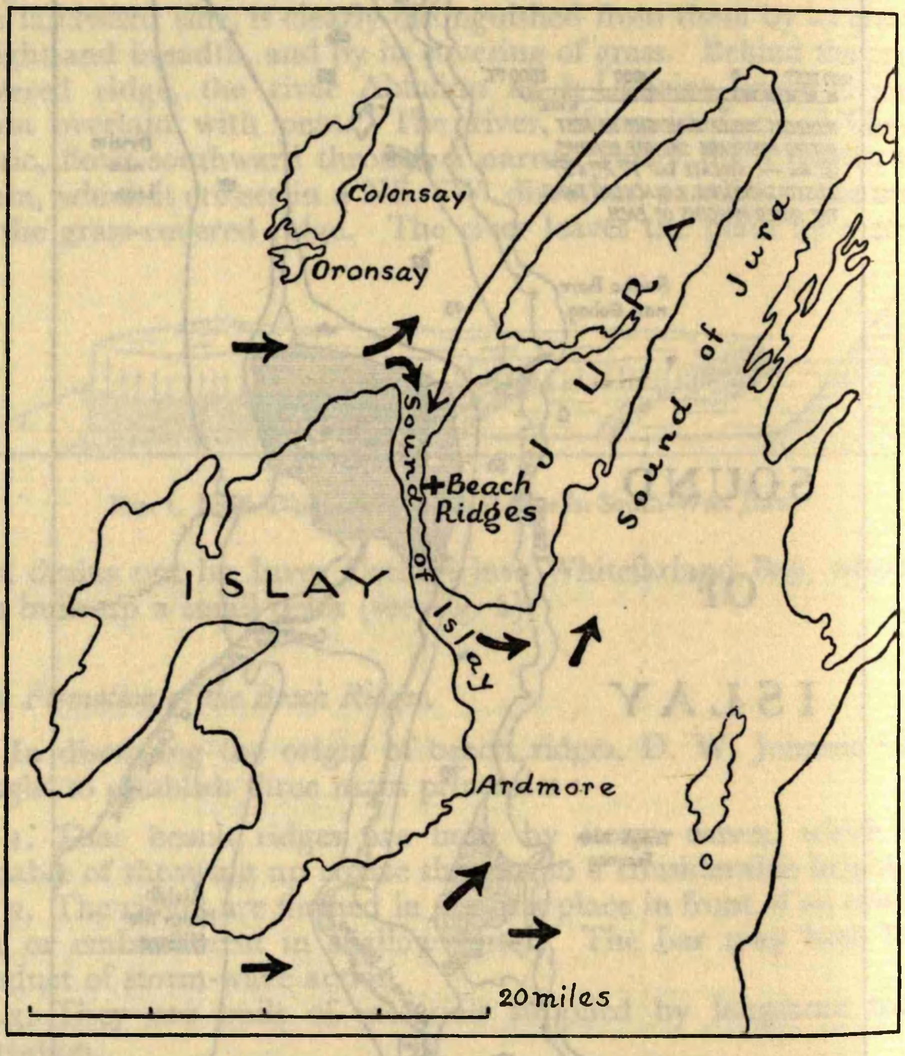


FIG. 3. Flood-tide (marked with thick arrows) and longshore currents (marked with long, thin arrow) in the Sound of Islay district. The directions of the tidal currents are reversed during ebb-tide.

running through the passage of Oronsay, sends a branch southward into the Sound of Islay. This tidal drift is reinforced by a longshore current which follows the western coast of Jura, gathers up the debris of wave erosion, and also flows into the Sound (see Fig. 3). With the ebb-tide the direction of the tidal drift is reversed and the flow is from south to north.

When the tidal current in the Sound of Islay is flowing in the same direction as the longshore current, that is, during flood-tide,

PLATE 1. View of the beach ridges of Jura, looking inland.

PLATE 2. Storm beaches at the mouth of Allt an Eirean, Jura. Note the exposed grassy slope and, in the background, the cut made by the river into the storm beach.

and especially during a high sea, it will transport abundant debris into the Sound. Part of this may be deposited in sheltered coves, but most of it is carried through the Sound. During the ebb, however, when the tidal current, which is stronger, flows in the opposite direction to the longshore drift, it checks the latter and gives rise to heavy deposition at the point where they meet. It is here that the beach ridges are found. The abundance of shore deposition to the north of these ridges indicates the active work of the longshore current, but southward from the meeting place of the ebb-tide and the longshore current, shore deposition is rare, on account of the diminution in the power of the latter current during ebb-tide.

In addition to the phenomenal current discussed above, the formation and development of the beach ridges have been influenced by river deposition. The river Abhuinn na h-Uanaire has cut its valley through a series of easily eroded deposits, probably raised beach materials and boulder clay. Originally, it entered the sea in the small bay in which the beach ridges are now found. Accumulating a great load of gravels and sands from its upper course, the river built up an alluvial plain, marginal to the former shoreline. On the seaward side this deltaic debris was heaped up by storm waves to form the grass-covered ridge which now bounds the beach ridges on the landward side. This gravel ridge temporarily blocked the outflow of the river, which was forced to cut a valley southward through the raised beach deposits, thus reaching the sea in Whitefarland Bay.

In front of the gravel ridge the deposition of material by the longshore current continued, and this marine debris was heaped up by storm waves to form the first of the beach ridges. The process has been repeated until there are now about twenty ridges of cobbles.

The first of the beach ridges developed at the end of the third raised shoreline period (twenty-five-foot submergence), the ridges being built between the cliffs which had been cut in the raised beach during the submergence. With the continued elevation of the land the beach ridges have continued to advance. The progressively decreasing height of the ridges, from twenty-nine feet to sea-level, can be explained by this gradual emergence of the land. The regular spacing and the alternation of large and small cobbles indicated the uniformity and continuity of the forces which have been responsible for their formation.

Other Shore Deposits.

It has been mentioned that north of the beach ridges discussed above, deposition is abundant. Here, storm-built forms predominate and may be classified under three heads, (*a*) storm beaches, (*b*) storm shingle patches and (*c*) beach ridges. The term "storm beach " has been vaguely used in Scotland to denote any shore-form that is wholly or partly built by storm waves. It is here restricted to storm shingles which have a terrace form. Those which have no definite form but are higher than the beach will be included under the term "storm shingle patches." Beach ridges have already been discussed.

A very good example of a storm beach occurs at the mouth of

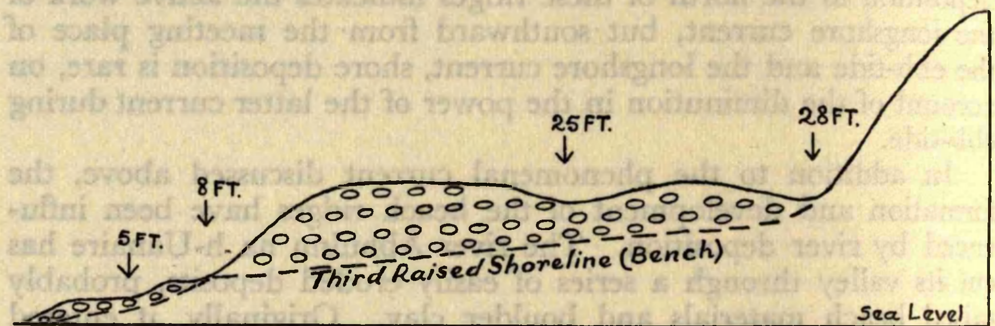


FIG. 4. Storm beaches at the mouth of Allt an Eirean, South-West Jura.

Allt an Eirean (see Fig. 4). It here consists of three terraces at the heights of five, eight and thirty feet above high-water mark respectively. All three are interpreted by the writer as being of storm origin (see Plate 2).

Storm shingles are very common. They vary in height according to the nature of the forces responsible for their formation. Some are found twelve feet above high-water mark, blocking the entrance of former caves. Some, scattered without any definite pattern, lie on the rocky shore, half-covering the rock platform. One of them is banked up against a cliff forty feet high.

REFERENCE

[1] D. W. Johnson, *Shore Processes and Shoreline Development*, pp. 404-407. London, Chapman and Hall Ltd., 1919.

The writer wishes to express his thanks to Mr. G. Bowen of the Department of Geography, Glasgow University, for revising the manuscript, and to Dr. W. J. McCallien of the Department of Geology, for re-drawing some of the illustrations for this paper.

Appendix I

Pollen Analysis of Peat from Ettrick Bay, Bute.

Read before the Geological
Society of Glasgow on April 8th.,1937.

The peat samples are treated according to the method recently described by G. Erdtman. (Svensk.Bot.Tid.,Bd.,30, pp.154-164,1936) This method has two advantages. In the first place it gives a good concentration of pollen grains from the peat samples and the concentration is, in general, sufficient to give the minimum quantity required for representative results. Secondly, the treatment causes the grains to swell slightly, rendered easier examination of the pores, ex-exines and in-exines under the microscope. The differentiate expansion of pollen grains, on the other hand, causes difference in the size of some grains and renders identification by means of measurement impractisable. Other morphological features are much more useful for the identification of a grain. The chemical treatment may be too strong for some specific grains, for instance, the spores of Sphagnum moss are considerably affected and their number is diminished in the finished sample. Sphagnum, though important in regional studies of vegetation, is however, not a very important factor for geological pruposes.

The peat samples were collected from sections exposed along the St. Colmac Burn. (Fig. 12) The land surface here is an even slope from a height of 75 feet down to sea level, except where it is interrupted by the occurrence of two parallel beach ridges (Figs 11,12,) running in a direction from NW to SE. These ridges were probably built as s successive bars across the bay and enclosed a lagoon behind, during the 25-foot submergence.

Samples A and B are taken from a layer of peat about 20 inches thick between 55 and 60 feet above the sea. The peat bed can be traced land and seawards into a layer of silt, and overlies gravels which presumably are the 50-foot raised beach deposits. That the peat was formed in a hollow is clearly shown by the lie of the ground. The hollow is elongated and probably pepresents a former river course now abandoned.

Samples C and D were taken very close to the inner margin of the beach ridges. The peat occurs in very thin layers (15 cm.) or sometimes in lenticles alternating with thicker beds of clay and silt. A thin band of greenish clay is often found below each layer of peat. Tree roots and other rootlets sometimes penetrated two or three such layers. In the layer from which sample C is taken, there is imbedded in the peat a tree trunk. It is a drift log and examination of thin sections roughly prepared show that it is the trunk of a broad-leaved tree. Between the localities where A,B and C,D are taken, there are many layers and lenticles of peat interbedded with sediments. These beds have not been analysized, and it is advisable to study these layers before drawing any definite conclusions in regard to age. The interpretations put forward in the present paper, must therefore be regarded as open to further investigations.

Samples A and B. (Fig 38)

These samples taken from the same layer of peat show similarities in their pollen content. Both are remarkable for an extraordinarily high *Alnus* percentage, ranging from 75 to 96%. No doubt this considerably over-represents the alder as a member of the plant community: in no previous case has the genus been found to obtain such an overwhelming percentage. It is to be explained by the fact that the alder specially frequents the banks of rivers and lakes and the dropping of the inflorescences into rapidly accumulating peat would naturally lead to a very strictly local excessive accumulation of alder pollen. Especially in sample A aggregates of *Alnus* pollen in tetrads or even more complex combinations were frequently met with under the microscope. Besides *Alnus*, genera like *Betula*, *Quercus* and *Corylus* are represented with increasing frequency towards the upper layers of the peat bed but in the case of none of them does the pollen percentage exceed 16%. *Ulmus* occurs in both samples(0-4%). *Fagus* pollen grains were noted thrice in sample B, *Carpinus* once in sample A. Myrica occurs in A2, A3 and B1. Salix is sporadic.

It has been shown by Erdtman that Alnus comes in later than Quercus and that its immigration marks the late-Boreal or possibly the Early Atlantic period. The abundance of Alnus in these samples, though partly due to over-representation, must in part, indicate a period of luxurious growth following immigration and the period of these beds must anyhow be post-Boreal.

Peat beds under sand of the 25-foot raised beach at West Strand, S of Portrush, Antrim were analysized by Erdtman. They show a dominant Alnus component, followed by Corlyus, Betula, Ulmus, Quercus and Pinus in the uppermost part of the peat bed. Comparing this analysis with the average of samples A and B, it seems that they agree in general, though the orders of frequency of Betula, and Corlyus and of Quercus and Ulmus pollens are reversed in the latter.(Table I) Erdtman considers that the Antrim beds are of Atlantic age and ~~Ettr~~ Ettrick Bay deposits must be of the same age in correlation. If such dating be accepted at present, the higher altitude above the sea and the greater thickness of the peat bed as compared to samples C and D, indicate that ~~they were~~ it was formed close to the shore of the 25-foot raised beach.

Table I

Sample	Order of frequency			
A.	A	B,Co,	U,Q,	P
B.	A	B,Co,	U,Q,	P
Antrim	A	Co,B,	Q,U,	P

Samples C and D (Fig. 38.)

Sample C is distingushed from A and B by its conspicuously higher Pinus content. The Pinus percentage is not any more than 2% in A and B but in C it rises to about 12%. Alnus is still the most important tree while pollen of Quercus, Betula, Ulmus is more frequent than in A and B. The percentage of Corylus also rises to as much as 42% in C4. In C1 and C5, Myrica is seen. Two Fraxinus pollen grains were counted in C1 and C2. There are traces of Acer.

Sample D has a still greater percentage of Pinus which in the lowest layer dominates over Alnus. Quercus, Betula, and Ulmus have a greater percentage of the total tree pollen. One beech pollen grain was found in D3.

Though evidence from C and D is not sufficient here to draw conclusion with greater assurance, it seems highly probable that the peat is a later formation than A and B, for it shows a tendency towards Pinus maximum, which is an out-standing character of the sub-Boreal period.

It has been mentioned that two ridges were built across the bay during the 25-foot submergence and enclosing a lagoon on their landward side. The lagoon has been filled up by sediments and altered into marshy ground at the later part of the submergence. Peat growing on the marsh under these conditions was buried by sediment washed into the lagoon during seasonal floods, and high seas. The drifted tree trunk and the tree remnants, mostly twigs, found in C indicated this . By the repetition of this process, alternate layers of silt and peat were therefore built up.

Local Vegetation

These analysis, though insufficient to prove beyond doubt the age of the peat, have supplied some data with regard to the general vegetation of the region. The Non-tree Pollen Curve (NTPC.) on the pollen spectra (Fig.38) indicates the general distribution and density of herbaceous elements in connection with forest trees. The NTPC of samples A and B are closely correlated. It also strikes the eye that the curve runs complimentary to the Alnus curve. Frequency curves of vegetation for the various non-forest elements together with curves for total tree pollen show that the Gramineae in all samples occur complimentary to forests in a very remarkable manner and constitute by far the most important element in the NTP of samples A and B. (Table III) In samples C and D, the place of the Gramineae is taken by ferns, the curve of which corresponding closely to that of Gramineae, is comlimentary to that of the forest trees. In D3 a Salix-fern growth is indicated by the rise of Salix percentage to as high as 4.

As has already been sug ested the samples A and B are peat from the shore of the Atlantic standing at a former high level while C and D represent a marsh peat formation. The difference of the dominant non-tree component in the peat

Table II

Non-forest Trees, Shrubs, etc.,

Plant Sample	A	B		C	D
Corylus	64	130		209	242
Salix...............	14	7		11	16
Myrica..............	3	4		1	1
Fraxinus............	-	-		2	-
Acer................	-	-		2 ?	-
Ilex................	-	6	?	-	-
Total Forest Pollen	1600	1400		860	655

Table III

Important NTP Elements

Plant Sample	A	B	C	D
Cyperaceae	158	265	85	110
Gramineae	702	541	77	229
Fern	124	153	155	392
Ericaceae	38	73	7	14
Sphagnum	19	90	10	31
Comarum	9	-	3	2
Marsh Plants:-				
Alisma-Plantago	1	-	-	-
Typha	2	-	-	3
Statice	1	-	-	1
Nuphar	-	-	1	5
Lysimachia	-	-	-	1
Chenopodium	-	-	1	1
Other Plants:-				
Rumex	22	13	-	1
Plantago	32	10	-	1
Umbelliferae	27	62	5	4
Caryophyllaceae	3	10	-	-
Compositae	13	-	-	8
Scabiosa	2	-	-	-
Total NTP pollen	1147	1283	346	813

confirms this suggestion. The grass component is the most important in A and B and indicated moisture was sufficiently abundant but not to such an extent as to produce marshy conditions, while C and D contain a majority of ferns many species of which enjoy a wet habitat.(Table III) Further analysis shows that the C and D samples contain many pollen grains of marsh plants notably the pollen of Nuphar, and Chenpodium. On the other hand, samples A and B contain far more pollen of plants which are not marsh plants at all. This can be seen in Table III which shows that the genera Rumex, Plantago, and the families of Umbelliferae, Caryphyllaceae and Compositae are by far most abundant in A and B and are very much less numerous in samples C and D. Hence the peat represented by C and D is very probably of marsh origin and it supports the interpretation of the history of the coastal changes of this region during the last rise of the sea.

Appendix II

Note on the Esker Ridge and Sand Plain of Corran, E. Jura

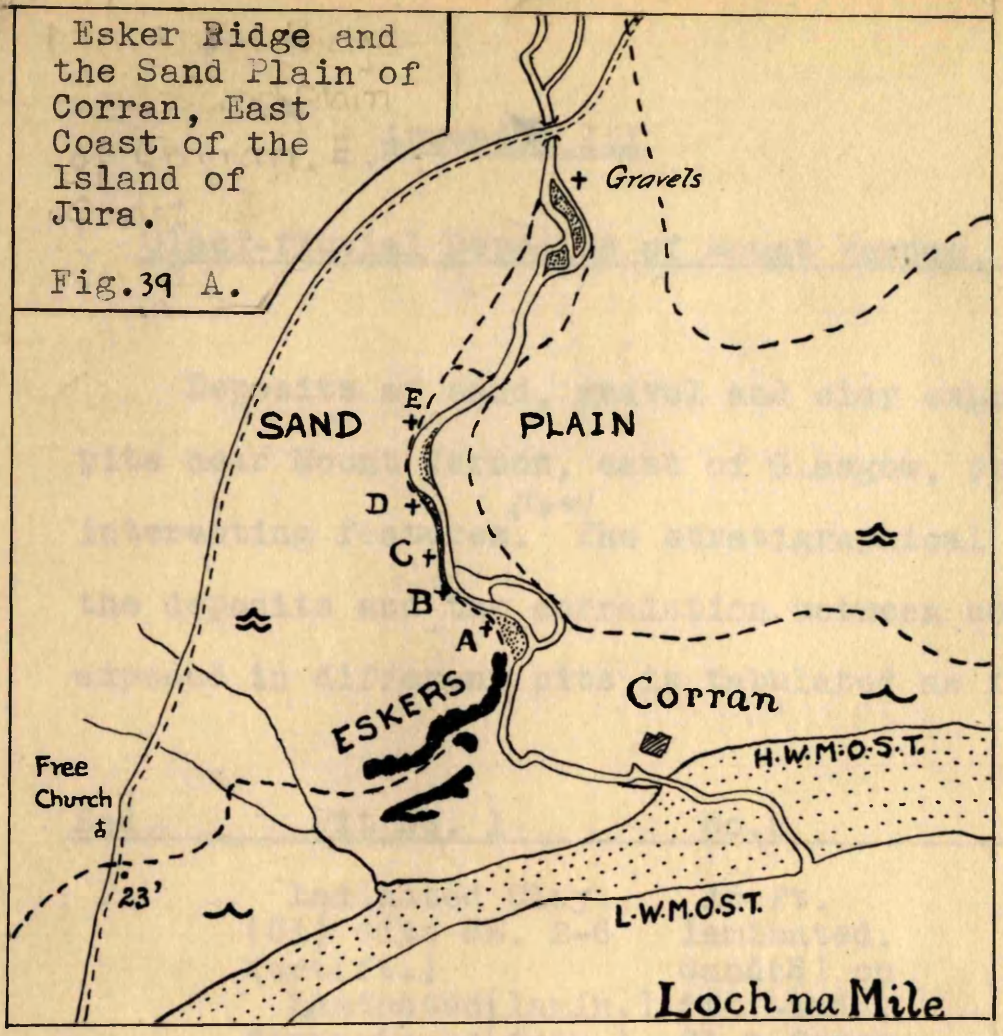
Corran river, which derives its name from the village Corran, three miles north-east of Craighouse, east Jura, has its source in Loch an-t-Siob', a lake probably of glacial origin. The lower course of the river has cut a deep gorge and descends on to a plain before it reaches the sea. The plain is covered with peat and on its edge stand two ridges. The inner or landward ridge, about fifteen feet high above the plain is symmetrical and very well preserved. The crest rises to its highest in the middle portion. The seaward ridge is poorly preserved but shows traces of former branch-like sub-ridges. Both of the ridges are composed of hummock-like mounds.

It is only on the west bank of the Corran river that the deposits of the inner ridge can be examined. There a section of the eastern end of the ridge and the sand plain behind is exposed on the river bank. At locality A, figure the section shows a deposit of sand twelve feet thick. The sand is inter-bedded with pebble layers and can be traced upstream where it is false-bedded. Underlying the sand there are always gravels, usually sub-angular, but at locality C, figure 39 B , the gravels are well-rounded. There is another sand bed exposed below. The tentative sequence is as follows:-

4. The ridge, probably sand.
3. Thick sand bed with intercalated gravels layers, sometimes false-bedded.

2. Gravels mostly sub-angular, sometimes rounded.
1. Sand.

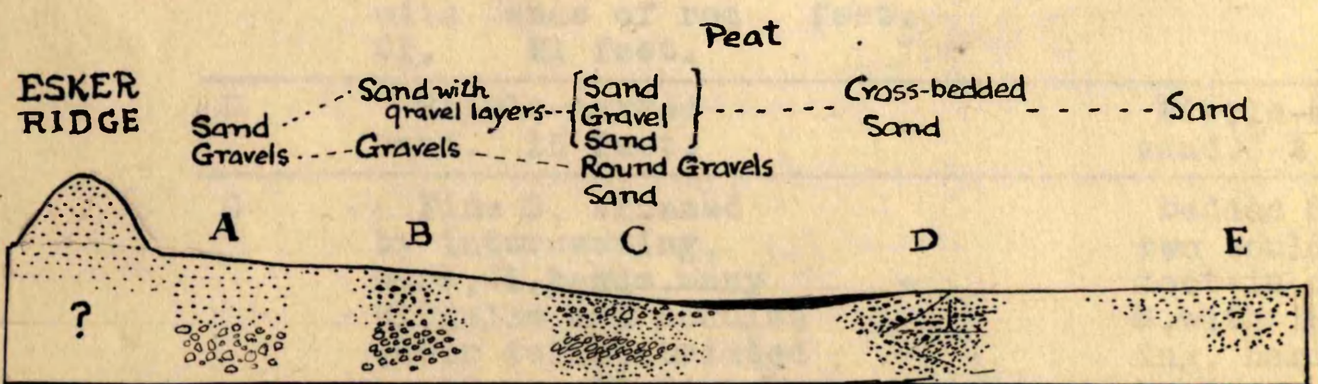
The ridges have been briefly described by Anderson (p.321) who suggests that they are morainic accumulations of the Corran glacier. Judging from the material that composes the ridges and the plain behind them, the deposits appear to be glaci-fluvial rather than purely glacial. The ridges seem to have been laid down in the form of eskers during the final retreat of the glacier which at one time occupied the Corran valley. At the same time, ice water flooded all over this region and a sand plain was formed. Most probably the plain had an original gentle and smooth surface and it is possible that a later rise of the sea has further levelled the sand plain. The seaward ridge, situated within the reach of the third raised sea shows signs of great erosion, while the inner ridge is very well preserved.



Esker Ridge and the Sand Plain of Corran, East Coast of the Island of Jura.

Fig.39 A.

Fig.39 B. Section along the Corran river, showing the deposits of the sand plain and the esker.
Not true to scale.



Appendix III

Glaci-fluvial Deposits of Mount Vernon, E. Glasgow

Deposits of sand, gravel and clay exposed in the sand pits near Mount Vernon, east of Glasgow, presents some interesting features. (Fig 40.) The stratigraphical sequence of the deposits and the correlation between such deposits exposed in different pits is tabulated as follows:-

Bed	Pit No. 1	No.5	No.6
F	Laminated Clay (Cl) dips SE. 2-6 feet(ft.) Laminated(lamin.) ferruginous(ferr.) sand on eroded surface. 3-8 ft. (Pl. XVII, 1.)	15 ft. laminated. Sand(S) on 5ft. Lamin. Cl.& ferruginous S, dips ENE. (Pl. XVII, 2.)	4 ft. Purple Cl. 3 ft. gray Cl. 2 ft. Lamin. Cl. with sharp folds (Fig 41)
E	Hard, compact, S, with imbedded Cl. blocks, dips ESE. with Bands of red Cl. 21 feet.	Hard, gray & yellow sand, 10 feet.	Cross-bedded S, 3 feet. Gray S. 2 feet.
D	Ripple-marked sand. 15 feet.	-	Ripple-marked sand. 2 feet.
C	Fine S, crossed by intersecting, hard, Cl. bands. Many Cl. galls and nodules Queer folds, striated boulder. 15 feet. (Fig. 41)	-	Bedded S. 15 ft. two boulders, 1 foot in diameters S. with intersecting, hard Cl. bands
B	Fine S, exposed 5 feet. Black shale and coal debris in lenticles.		3-4 feet pebble sand with black shale and coal debris.

(Continued)

Bed	Pit No.1	No.5.	No.6
A	-	Alternate beds of gravels(gr.) & S. Gr.increases in size downwards.Large sub-angular, striated stones. Minature Faults.	Coarse Gr.,smaller in size,cross-bedded with fine S.Large Gr. in lower parts ferr.matrix. The whole bed is hard, some parts cemented by Manganese oxide. The contact with bed B is not conformable and assumed a ridge-form.

Pit No. 2 exposes bed E which is here represented by 20 feet false-bedded, ferruginous sand with a slight dip to the west but fades out shortly in that direction. The same bed is seen in Pit No. 3 as bedded sand about 20 feet thick. Pit. No. 4 has exposed 7 feet of sand with coal debris as that which characterizes bed B in other pits.

According to the Geological Memoir of Glasgow District, these deposits are believed to have been formed in a sheet of water impounded by ice then occupying the region NE of the locality. The gravels were the accumulation at the mouths of the sub-glacial rivers while the sands,which lie to a large extent though not always on the gravel, were deposited a short distance from the mouth. The clay overlying the sands seems to have been attributed to marine deposition. The fact that the gravels were originally deposited in a ridge-form(pit No.6 bed A) suggests their relation with sub-glacial river channels. They may have been fommed within the channel of the sub-glacial river. The axis of the gravel ridge is approximately E-W which coincides with the direction of the retreating ice. The gravels must therefore be sub-glacial origin.

The melting water was then impounded to a depth well over 50 feet because the overlying sands has in localities attained a total thickness of 40 feet or more. The sand accumulated between the gravel ridges to great thickness.

The fine sands with derived boulder clay blocks and sometimes striated boulders indicate the melting of ice bergs on this impounded sheet of water. The higher sand beds have developed ripple marks indicating that the impounded water was of sufficient depth. The sands are disturbed into curious folds but all have their 'anticlinal' tops pointing to the east indicating the slight oscillation of the ice front. (Fig. 41.)

The laminated sand and clay were deposited on an eroded surface. The clay is disturbed on Pit No. 6. Elsewhere, it is not horizontal but has a mark inclination. Is it a ill-developed facies of varve clay ?

Fig. 40. Map of Mount Vernon, showing the positions of the sand pits.

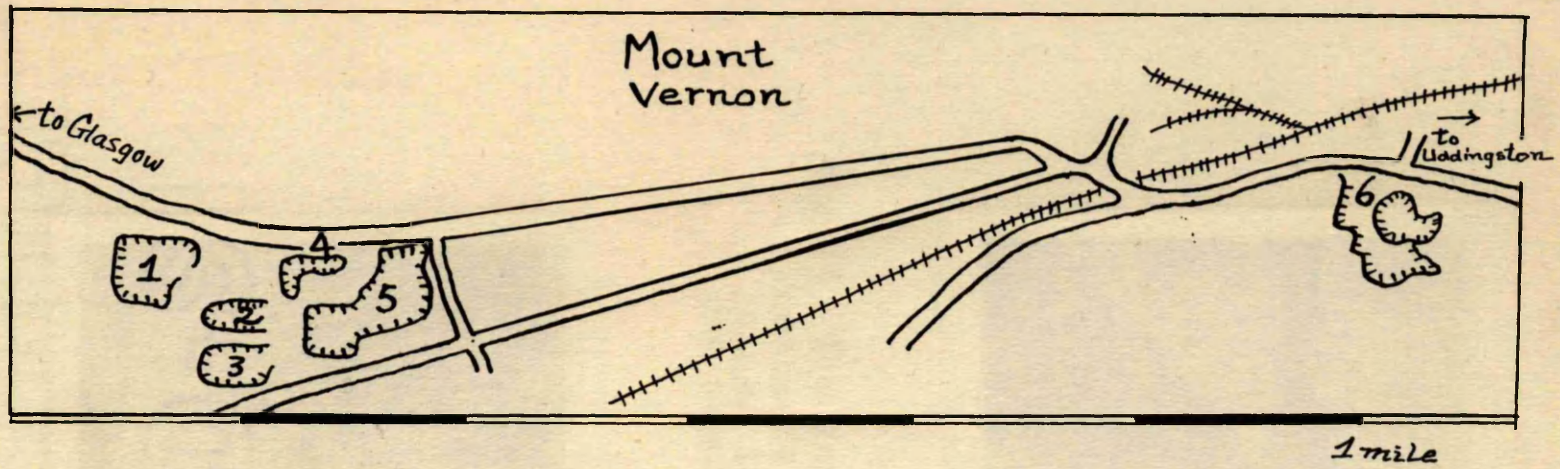


Fig 41 Some 'structures' of the deposits

Fig. 1 The laminated sand and clay on the southern wall of pit No. I. The hammer indicates the junction between the deposits with bed E.

Fig. 2 The laminated sand and clay of pit No. 5. looking north-east.

Fig. 1. Bed C of pit No. 1, showing cross-bedding, and the hard, inter-secting clay bands.

Fig. 2 Bed C in pit No. 2, after exposed for a long time.

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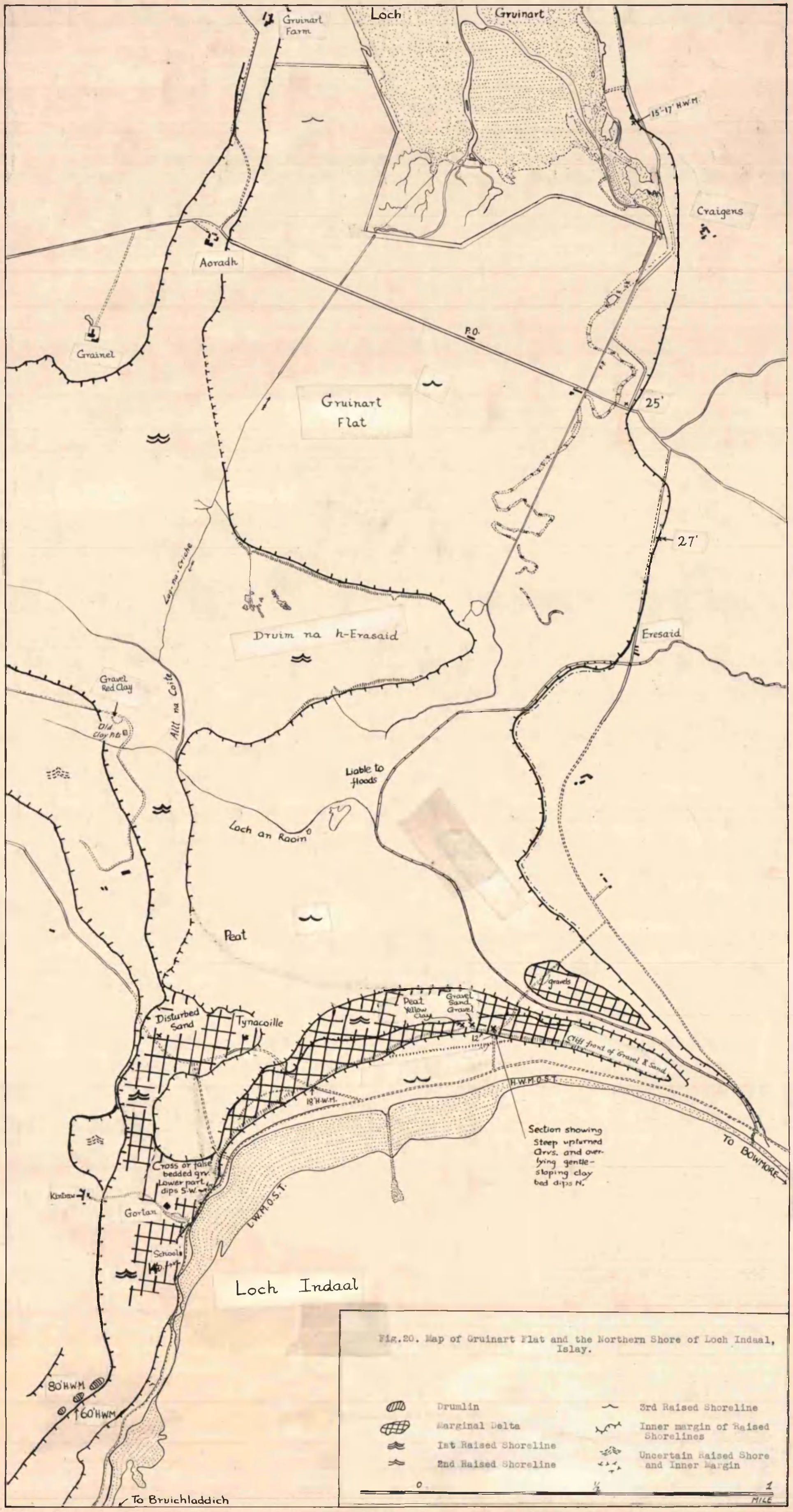

Fig.20. Map of Gruinart Flat and the Northern Shore of Loch Indaal, Islay.

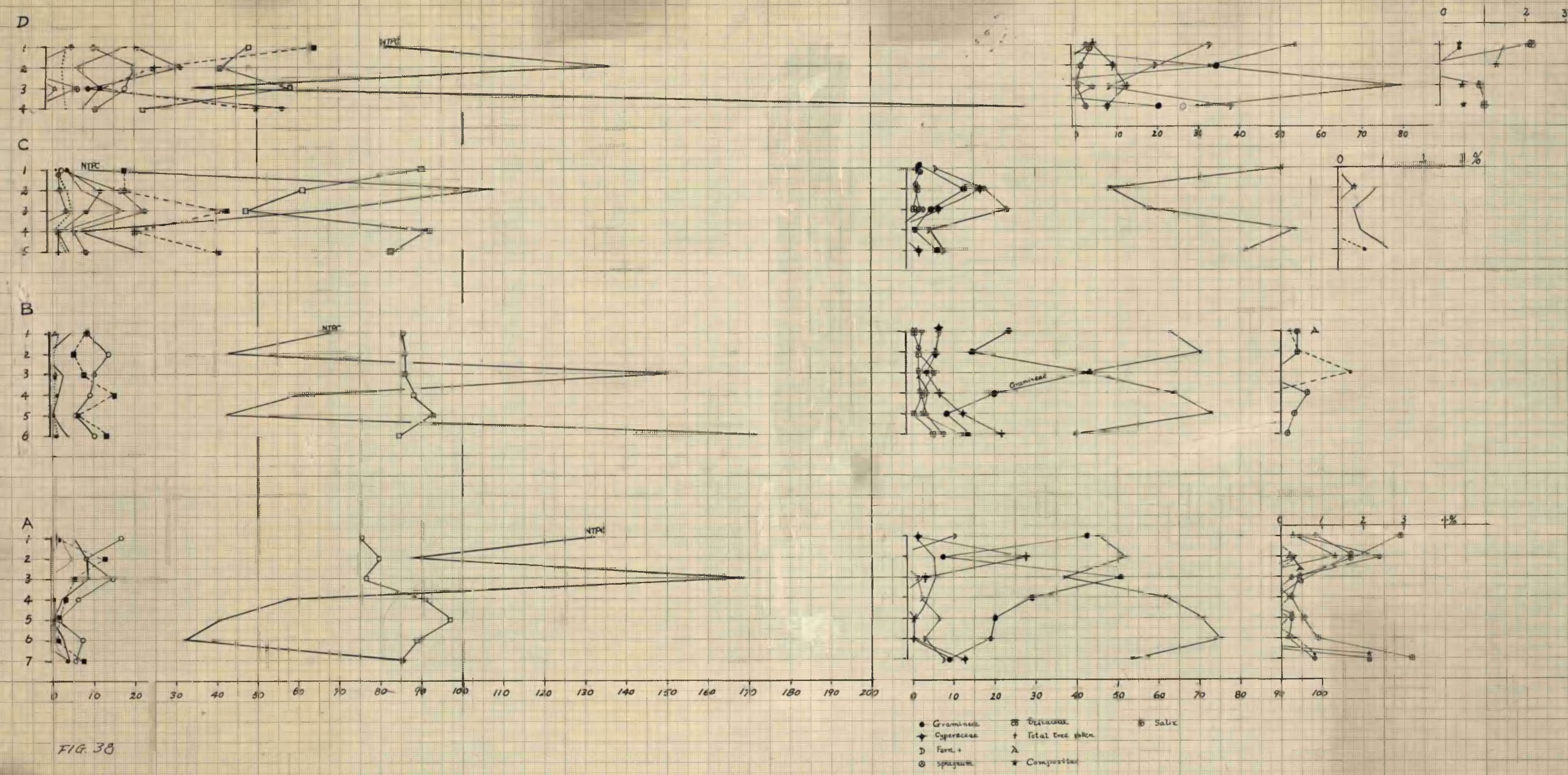
D
C
B
A
NTPC
Gramineae
Gramineae
Cyperaceae
Fern +
Sphagnum
Ericaceae
Total tree pollen
Compositae
Salix
3%
%
%

FIG. 3B