The Geology of the Region about Preservation and Chalky Inlets, Southern Fiordland, N.Z.

PART II.

THE EVOLUTION OF THE MODERN TOPOGRAPHY.

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Advance Summary.

The development of the present land forms presents a complex problem which requires detailed analysis and consideration of alternative explanations. To clarify the statement of the various lines of evidence, the following general conclusions are given in advance:—

1. The whole Fiordland region was reduced to a peneplain surface either in Cretaceous times, as usually held, or, as now seems more probable, during the later part of the Tertiary period. In its present elevated position the surface then formed is hereinafter termed the Fiordland Peneplain.

2. Before the peneplanation, if it occurred in Tertiary times, but after it if in the Cretaceous, the region was raised early in the Tertiary period with a marginal seaward downwarp. Dissection and marine erosion took place, followed by subsidence, resulting in the deposition of coarse arkosic sediments succeeded by finer and more or less calcareous beds.

3. Renewed elevation was accompanied by marginal corrugation along north-west–south-east axes and development of north-east–south-west undulations. The synclinal axes of the two series cross one another at the sites of the present Preservation and Chalky Inlets.

4. Consequent drainage systems developed in the north-east–south-west synclines, and eroding headward into the rising Fiordland region tended to become adjusted to the structures therein. The controlling structures were the faults, shatter-zones, or joints in the slates, schists, and plutonic rocks. On the hypothesis of the late Tertiary origin of the Fiordland Peneplain, the major planation occurred at this stage and was followed by further uplift. On the hypothesis of the Cretaceous age of the Fiordland Peneplain, the uplift and dissection of the region after the deposition and folding of the Tertiary sediments was a continuous process.

5. While dissection of the uplifted peneplain progressed in the headward portions of the main valleys, the intervening coastward slopes of the peneplain were considerably reduced, with the production of a relatively low and undulating strip of land extending ten miles or more back from the shore, a foothill region in front of the residual promontories of the peneplain. Slow and moderate subsidence then followed, permitting the planing of this lowland region by wave-action during the transgression of the sea over it. Accompanying this there was necessarily much deposition of detritus in the submerged valleys. Such subsidence continued until the original surface of the peneplain in the region discussed in this paper had been lowered to within about 2000 feet of the sea-level, and remained in that position long enough to permit the destruction and disappearance of nearly all of the sea-cliffs cut by the advancing sea, while the main valleys became matured for a long distance inland.

6. Then a movement of elevation commenced which raised the inner margin of this wave-planed strip to a height of about 1500 feet above the sea. It may indeed have been a gentle arching, for the surface of the plateau is convex east of Puysegur Point, though this is possibly better explained by decrease in the rate of submergence towards the end of the previous phase of movement, and, consequently, the more nearly horizontal extension of the wave-planed surface, which is visible in some though not in all parts of it. The smoothed raised surface thus laid bare will hereinafter be termed the "Coastal Plateau." It is perhaps possible that its uplift was accompanied or followed by a revival of old lines of fracture and the subsidence of certain crust-blocks, which may have taken a part in the formation of the present broad depressions in the coastal plateau, namely Preservation Inlet, with Otago's Retreat, and the Western and Eastern parts of Chalky Inlet, with Southport. If that were the case, the two larger islands and Gulches Peninsula remained as horsts between these depressions. It does not appear clear, however, that such differential crust-movements occurred.

7. As the uplift began, streams leaving the margin of the Fiordland Peneplain extended their courses over the emerging coastal plateau. The major streams re-occupied their earlier recently-infilled valleys, from which they speedily removed the detritus, thus bringing about a rejuvenation that finally led to a perfecting of earlier adjustment to structure, which may perhaps have been favoured by the accompanying revival of movement along the early lines of fracture. The intervening minor streams entrenched their consequent extended courses in deep canyons across the plateau, discharging into the open sea.

8. At the commencement of the Pleistocene period glaciers moved down the main valleys, overwhelmed the islands in the inlets, and overflowed on to the coastal plateau on which there were deposited sheets of morainic and outwashed material. It is difficult to estimate how much of the lowering of the land surface should be assigned to preglacial erosion and how much to glaciation or to crustal movement. At all events, at the retreat of the ice the removal of detritus from the valleys was completed and benches along their sides were much modified. Further, the Sounds had a depth comparable with their present depth, whilst masses of moraine lay plastered on the sides of the inlets and probably also formed much of the thresholds at their mouths, and together with some outwash material covered portions of the coastal plateau.

9. Post-glacial activities have been:—

(a) A very small amount of stream erosion within the Sounds and much dissection of the morainic sheet on the coastal plateau. Delta-accumulation is well displayed in some of the Sounds.

(b) Cliff-recession under wave attack with the transport of detritus and morainic material and further growth of the thresholds, building of spits, tying of islands, and levelling of the sea-floor.

(c) Depression of the coast to some extent.

(d) A rather smaller elevation with brief still-stand intervals about fifteen and forty feet above the present sea-level. It is not possible at present to determine the sequence of events in (c) and (d).

THE FIORDLAND PENEPLAIN.

The most striking feature of Fiordland topography is the accordance of summit-levels. There has been a general acceptance of Andrews' (1905) view that " from Milford Sound to Preservation Inlet the even topped ridges . . . appear to represent the survivals of a former huge plateau decreasing from a height of 6000 feet at Te Anau and Milford " as it is traced towards Preservation Inlet. Daly (1912) has argued that accordance of summit-level in the Cordillera of British Columbia, a region analogous climatically and structurally to Fiordland, may result from a complex process of " equiplanation " in which the isostatic depression of salient masses, the concentration of weathering and erosive activities on the higher peaks, and the checking of such activities beneath the tree-line, together with the compound processes of river-spacing and slope-gradation play the chief rôles, but this view has not many supporters. The development of accordant summit-levels during the present geographical cycle by the equiplanation of a region of highly irregular relief would demand an equality of result in spite of diversities of structure and stream-spacing that seems beyond the bounds of probability. Gilbert's (1904) account of a similar region in Alaska is most apposite in its application to Fiordland. " The approximation of summit-heights to uniformity is too close to be accounted for without the hypothesis of an uplifted plain, but the departures from uniformity indicate that little if any of the original plain survives." The dissection of the Fiordland Peneplain about Preservation Inlet (and, indeed, in general) is complete. Nevertheless, the thick-line profile (Plate 2 D), taken from Windsor Point north-eastwards along the crest-line east of Long Sound and Longburn, illustrates the degree of uniformity of summit-levels in the higher parts. Plotted against this is the thin-line profile along the crest-line south of Dusky Sound together with two other profiles parallel thereto between Dusky and Breaksea Sounds along the lines shown in Text-fig. 2, Part I. These three profiles have been based on Preston's (1929) unpublished topographic map of Dusky Sound made available through the courtesy of the Surveyor-General. The accordance of summit-levels is very marked, and their continuity with the general level of the Fiordland Peneplain as far north-east as Milford Sound and Lake Wakatipu is demonstrated by Plate 2, figures B and C. Thus the acceptance of Andrews' general conclusion by Marshall (1905), Park (1909), Speight (1910), and Gregory (1913) seems to have been well founded. As will appear, however, Andrews' first impression that the peneplain descended to an elevation of only 1000 feet at Preservation Inlet cannot be supported. Its south-western limits are in the Bald Peaks, Treble Mountain, Mount

Bradshaw, and Resolution Island at a level of a little over 3000 feet, and between it and the sea lies the coastal plateau, commencing at the foot of the above-named points at an elevation of over 1500 feet and descending smoothly towards the sea, ending abruptly in a line of cliffs. The higher and more extensive level has been termed the Fiordland Peneplain, a descriptive term free from any implication which may be involved in the use of Park's (1921) term " Tahora."

It should be noted, however, that the term " Fiordland Peneplain " has here been employed for the sake of brevity and in deference to previous usage (Andrews 1911, Park 1921). But unless it be qualified by the words " thoroughly dissected," it fails to describe the land-surface to which it refers. Indeed, the former existence of a peneplain is only an inference from the marked accordance of summit-levels, which apparently was all that Andrews (1906) had in mind when speaking of " numerous sub-horizontal masses," though he also spoke of the survival of " ridges *and mesas.*" So far as has been gathered from a study of many photographs obtained by alpinists in various parts of northern Fiordland and north-western Otago, only very rarely is there any hint of the presence of flattish areas near the summit-levels which might be considered to be residuals of an original peneplain surface. Such exceptional residual surfaces may be represented by the Bryneira Range, immediately east of the middle portion of the Hollyford River, which range Professor Park has described (1921) as " flat-topped." But though the summit-level of the Barrier Range at the head of the Dart River is remarkably uniform, panoramic views of it obtained from two different directions do not reveal any noteworthy area of sub-horizontal surface. There is, therefore, insufficient evidence to indicate precisely the form of the original surface, and it might be better to substitute for the word " peneplain " Willis' (1928, p. 493) new term " matureland," with the qualifying adjective " subdued " to denote its approximation to a peneplain. " A subdued matureland, thoroughly dissected and subsequently heavily glaciated " would thus be perhaps the nearest approach that can be made at present to an exact explanatory descriptive term for the land-surface to which for the sake of simplicity we here refer as the " Fiordland Peneplain."

The age of this surface demands discussion. It has been customary to consider it of Late Cretaceous age, following the views of Speight (1915), Cotton (1916), and others, though Park (1921) has argued that the planation was complete in Middle Cretaceous times. On this surface, it is held, were deposited Cretaceous and Tertiary sediments, portions of which still remain as outliers, especially where they have been warped and faulted down into low-lying situations. Nevertheless, Marshall (1918) briefly indicated that peneplanation of the schists of eastern Otago had been accomplished in Late Tertiary times, and that the surface so formed has since been locally warped. Benson's unpublished studies of the Dunedin district have revealed two distinct peneplain surfaces. The dissected lava-flows of this region rest on a peneplain-surface cut obliquely across a series of Middle and Lower Tertiary marine sediments which in turn rest on a Cretaceous peneplain cut in schist. The warping of the Late Tertiary peneplain is here very considerable, but diminishes when traced into north-eastern Otago, where the two peneplain surfaces have been recently described by Service (1933). In North Taranaki (Grange 1927), in the region near East Cape (Ongley and Macpherson 1928), and in North Auckland (Cotton 1922), the peneplanation of the soft Tertiary sediments is now recognised, and in all these districts the Late Tertiary peneplain has been dislocated by warping or faulting. It is therefore difficult to prove in most cases whether the exposed surface of the oldermass is merely the ancient pre-Tertiary surface stripped of its cover, as is commonly assumed, or a new erosion surface cut in the older rocks during the planation of the Tertiary beds, which intersect the pre-Tertiary surface with varying degrees of obliquity, as in the conception of intersecting peneplains implied in the explanatory descriptive term "morvan" introduced by Davis (1912).

It is obvious that planation of soft Tertiary sediments might be accomplished within a period too short to permit of the complete reduction of more resistant formations, but there is weighty, though not unanimous, opinion that extensive planation of hard formations has been produced within Late Tertiary times under climatic conditions not greatly different from those which existed in Fiordland. Thus Smith and Willis (1903) held that the accordance of summit-levels on the Cascade Mountains of the north-west of the United States gave evidence of a peneplain cut in Pliocene times in a complex of granites, schists, Palaeozoic (?), Cretaceous, and even early Tertiary folded sediments and lavas. This surface was then elevated and warped, the consequent streams were very maturely developed, and an early mature topography was superinduced by rejuvenescence following on further uplift. R. T. Chamberlin (1919) arrived at a like conclusion concerning the age of the rather imperfect peneplain cut out of the granites, etc., forming the Rocky Mountains of Colorado. This peneplain had been recognised by Davis (1911) and referred by Finlay (1916) to an Oligocene age. Daly (1912) argued that comparison with the Appalachian region made it improbable that its reduction to the present general summit-level could have been accomplished as late as Pliocene time, but Johnson's recent interpretation of Appalachian topography greatly weakens this argument. "During the Tertiary came the . . . long cycle or cycles of erosion ending in the production of the remarkable, well-developed, and widespread Schooley Peneplain which bevels both the ancient crystallines and the (Cretaceous) coastal plain deposits," and three successive elevations have since lead to the development of two lower peneplains on the weaker formations and the final entrenchment of streams (Johnson 1931). Atwood and Mather (1932) have concluded that in Colorado the peneplanation of a complex of crystalline rocks, Palaeozoic and Mesozoic sediments, and Tertiary volcanic rocks was accomplished during the Pliocene period (monadnocks of the harder rocks being left), and that there followed after a gentle doming a long complex history of profound dissection during the Quaternary period. In Europe, Brückner (Penck and Brückner 1909, pp. 476-9) describes the Pliocene planation of the Jura Mountains.

Much other literature on this topic might be cited, from which it would appear that Late Tertiary peneplanation of the Fiordland region is at least worthy of discussion. Two direct lines of evidence bearing thereon may, therefore, be considered.

In the neighbourhood of Preservation Inlet the Coastal Plateau has obviously been cut across the folded Mid-Tertiary strata and into the slates and granites (see Plate 2 E). The basal Tertiary beds, dipping at angles of 20° or 30°, approach within five miles of the summit of Bald Peaks, whence there extends away to the north-east the even, gently ascending summit-level of the Fiordland Peneplain. The conventional hypothesis would regard that summit-level as representing the surface on which the Tertiary beds were deposited, but unless the corrugation of the pre-Tertiary surface died out completely in the intervening five miles, the Fiordland summit-level would seem to truncate the pre-Tertiary land-surface (see Part I, Plate 43, Section; and Plate 3 E). Moreover it has been shown (Part I, p. 428) that the surface on which the basal Tertiary beds rested could not have been a peneplain, but possessed considerable relief.

More striking is the occurrence of a long, steeply-dipping strip of marine Tertiary rocks infaulted among the semi-schistose Palaeozoic (?) sediments at Bob's Cove on Lake Wakatipu and extending for at least fifteen miles northward (McKay 1880, Park 1909).* The age of these rocks has not been ascertained precisely, but they belong to the Oamaruian system of approximately Oligocene-Miocene age. Originally resting on the schist, they have been dragged down to a depth of about five thousand feet along a fault-plane. The general relations, topographic and geologic, are shown in Plate 2, A, C, and F. The last figure is copied in part from Professor Park's (1909) section, but has been modified to indicate the hypothetical former position of the Tertiary beds. Whatever may have been the original disposition of the various formations, it would seem that the faulting that could bring the Tertiary beds into their present position could not have been accomplished without a relative displacement of the formations on either side of the fault-plane that would have had a vertical component amounting to several thousand feet. Nevertheless, the accordance of summit-level continues unchanged across the fault-line, and the infaulted strip crosses the flanks of the mountains, and does not follow any valley or fault-angle depression. The suggestion seems very strong that the Fiordland Peneplain truncates the faulted Tertiary rocks, and was, therefore, formed after a considerable crust-movement involving Mid-Tertiary formations. Further, the occurrence of major earth-blocks such as the Remarkables or Cromwell Flat, elevated or depressed in relation to the general summit-level, appears to indicate

* This region is now being examined in detail by Mr C. O. Hutton.

that block-faulting of the Fiordland Peneplain occurred in very late Tertiary or even Pleistocene times. In this connection it may be suggested that the development of Tertiary sediments at Bob's Cove, so much wider than elsewhere even at higher elevations along the fault-line, lends support to the suggestion that the rocks here have been let down by transverse W.-E. trough-faulting, which may have been responsible for the initial formation of the middle portion of Lake Wakatipu itself and the Arrow Basin, both of which have later been modified by erosive processes (cf. Andrews 1911, pp. 135-6).

In putting forward this hypothesis of the Late Tertiary age of the Fiordland Peneplain, it should be noted that Bell and Fraser (1906) suggested that the Wainihinihi Peneplain cut in the schists and early Tertiary (?) rocks of South Westland, was a continuation of the Fiordland Peneplain. This view was at first supported by Morgan (1908), though later he assumed, without very detailed discussion, the pre-Tertiary age of the peneplain (Morgan and Bartrum 1915). Obviously definite conclusions cannot be based only on the facts that are here cited, though it would appear there is a case for the critical revision of the conventional hypothesis concerning the Fiordland Peneplain. The proof of its Late Tertiary age, if obtainable, would have far-reaching effects on the study of the Cainozoic history of the South Island of New Zealand.

On the conventional hypothesis of the pre-Tertiary age of this peneplain, the sequence of events during Tertiary times near Preservation Inlet might be as follows:—The peneplain was uplifted in early Tertiary times with strong marginal downwarpings, but no other dislocation. The marginal slopes were dissected and coarse sediments accumulated at their base. The region now subsided and finer sediments were deposited in a sea which transgressed widely over the peneplain. Uplift again took place, with strong N.W.-S.E. corrugation sharply limited to a narrow strip reaching not more than five miles inland from the present outer coast-line near Puysegur Point. This was crossed almost perpendicularly by a gentle undulation, which was more sharply folded when it reached the site of the present outer coast-line. The induced consequent drainage resulted in the formation of the valleys which debouched where Preservation and Chalky Inlets now open, and stripped the Tertiary sediments from those portions of the area above the then existing base-level (rather more than 1000 feet above the present sea-level).

On the alternative (and preferred) hypothesis of the Tertiary age of the Fiordland Peneplain, the record of Tertiary times might be thus:—In early Tertiary times basal arkosic breccias were deposited around a surface of considerable relief, which became lessened both by subaërial erosion and subsidence or marine transgression in Mid-Tertiary times. Uplift followed associated with marked corrugation on N.W.–S.E. axes in the Preservation Inlet district, together with extensive faulting which lead to the involution of the Tertiary beds among the older formations in the Wakatipu region. The development of the great peneplain then ensued, the erosion surface being formed at a considerable depth below the former level of the base of the Tertiary beds except in the regions marginal to Fiordland, and adjacent to the infaulted beds. Then renewed uplift occurred, producing a broadly-arched surface gently inclined to the south-west. In the Preservation region a slight almost longitudinal undulation, perhaps on N.E.–S.W. lines determined by the previous undulation, caused the development of consequent drainage-systems where are now the two main valley-systems. On either side of these was formed a narrow partially planated lowland about fifteen hundred feet below the level of the Fiordland peneplain and possibly perfected in its planation by marine erosion.

Whether the Pre-Tertiary age or the Tertiary age of the Fiordland Peneplain be accepted, the Chalky and Preservation drainage-systems may reasonably be considered as consequent on the warped margin of the peneplain. As the drainage-systems became mature, their valleys would tend to adjust themselves to the structures of the rocks that they traversed. As already shown, these rocks had been broken by several systems of shatter-belts, faults, well-marked joint-planes, and other fractures. It is, therefore, desirable to consider whether there be any evidence of such adjustment, which will be done in the following section.

THE RELATIONS BETWEEN TOPOGRAPHY AND STRUCTURE.

The major correlation between the synclinal structure and topography of Chalky and Preservation Inlets has just been noted, whilst the anticlinal character of Gulches Head and the existence of several well-marked series of fractures have been discussed in Part I. The minor relations between structure and topography may be indicated by the following parallelisms:—

1. Parallel to those fracture-lines that trend nearly east and west are the following: The upper portion of Gray River, and the shore of Preservation Inlet westward of the same; Dawson Burn, Narrow Bend, and the central trough of Preservation Inlet as shown by the 50 fathom isobath; the ridge of the Cording Islets; Blacklock Stream and the low col leading into the head of Useless Bay opposite thereto; the middle reach of Long Sound; the narrow inlets opening from Cliff Cove, and, as a major feature, Cunaris Sound; the eastern part of Northport and the valleys immediately to the north thereof; probably also the strait between Passage and Chalky Islands. Gregory (1913) indicates that this lineament is seen throughout the south-western portion of Fiordland. Thus the coast-line eastwards from Windsor Point follows this direction, also Dusky Sound and the islands therein, Wet Jacket Arm and Breaksea Sound and streams adjacent thereto. (See Part I, Text-fig. 2.)

2. Parallel to those fracture lines trending approximately north-east–south-west are the following: The western portion of Northport; Edwardson Sound and the eastern entrance to Chalky Inlet; Isthmus Sound, the northern portion of Long Sound and Useless Bay. With these also are to be grouped the three main valleys, Longburn, Carrick River, and the Oho Valley. On the south coast, Lake

Hakapoua and the Upper Kiwi Valley beyond the present district follow this direction, but the apparent parallelism therewith seen in the streams between Kiwi Burn and Otago's Retreat, and on Coal Island, which traverse the Tertiary rocks, may result merely from their consequent courses. Nevertheless, the Tertiary rocks are sharply cut off by Otago's Retreat, which it will be shown is probably a rift.

Beyond the area under study, Cascade Cove entering Dusky Sound and several small streams adjacent thereto, which do not follow the lines of quickest descent, are probably influenced by fractures along this trend line. The Five Fingers Peninsula is most strikingly parallel therewith. The major feature parallel to this line is, however, the general course of the coast from Dusky to Milford Sound, an almost rectilinear coast broken only by the entrances of the various Sounds. It plunges steeply down into deep water, soundings of 188 fathoms and of over 300 fathoms being recorded within a mile of the coast between Daggs and Thompson Sounds. Hector (1863) records that off Nancy Sound the mountains rise from the water's edge with a slope that is rarely less than 25° and often 50° to 60°, but not forming sheer precipices.

Andrews (1907), Park (1910), and Morgan (1929) considered this to be a fault-coast, recency of movement along which may be indicated by the occurrence of earthquakes (Taylor 1855). Its fault-origin has not, however, been accepted without question, and Hutton (1875) gained the impression that its slope was terraced rather than an abrupt scarp. This may not, however, be inconsistent with an origin by repeated movement. On the whole, this north-eastern–south-western direction is the most marked trend in the topography of the region herein considered and is, of course, that of the axis of the South Island of New Zealand.

3. Parallel to the fractures running to the west of north may be noted first the western side of Southport, which clearly follows the Southport Fault and is, as will appear, a fault-line scarp resulting from revival of movement. Again, the southern end of Long Sound and Revolver Bay are enclosed between steep shores parallel to the same direction, whilst Long Island is similarly oriented. Lumaluma Creek entering the head of Edwardson Sound, Duck Cove, and especially Acheron Passage in Dusky Sound are parallel to this group of fractures, and the direction of the coast from Cape Providence to West Cape may also be determined to some extent by structural features following this direction.

4. The most striking topographic feature trending north-west–south-east is the deep through valley between Last Cove, in Long Sound, and Cliff Cove (near the head of Cunaris Sound) on the western side of which is the Last Cove fault. The shores of Last Cove are drift covered, and those of Cliff Cove do not display any marked shatter-zones in this direction, but it seems hardly likely that the association of so low a col with so definite a fault-line can be wholly fortuitous. Again, the south-east trend of the lower part

of West Branch, or Lumaluma Creek, which enters the head of Edwardson Sound, has perhaps been influenced by the strongly developed north-west jointing in that region. The same direction appears, beyond the area mapped, in the trend of the majority of the Sounds, notably Daggs, Doubtful, Nancy, Charles, George, Bligh, Sutherland, and Milford Sounds, and of the north and middle fiords of Lake Te Anau, Clinton River, and Esk River entering South Fiord.

5. Few marked topographic features follow an east-south-east direction within the area mapped, unless the course of Richard Burn entering the head of Long Sound be reckoned as such. In Chalky Inlet the southern coasts of Passage and Great Islands and the adjacent isobathic lines seem to follow this direction, to which also is parallel the shatter-belt nearest to Stripe Head.

Reviewing the statements above, it may be concluded that there are a large number of facts indicative of structural influences in the development of the topography, and of some adjustment of streams to structures.

THE COASTAL PLATEAU.

General Description.

The stereogram (Part I, Plate 41) and profiles (Plate I; Plate 2, B, D, E) of the region under consideration show that the edge of the elevated Fiordland Peneplain is separated from the sea by a lower sloping coastal plateau, a striking feature, which has been described by Hector and McKay. Thus Hector (1863) states concerning the coast between Dusky Sound and Cape Providence, " The shore is bounded by rocky cliffs a few hundred feet in height, from the summit of which there is a gentle slope for a distance of six miles to an elevation of fifteen hundred feet backed by smooth wooded ridges, the summits of which are three thousand feet above the sea. This slope is divided by a stream which comes down to the sea at West Cape . . . and its uniformity is broken by a few sharp cones." Similar features continue east of Preservation Inlet. McKay (1896) notes that " the south coast from Puysegur Point to the Big River presents between the granite mountains and the shore an area five to ten miles in breadth which declines gradually or in terrace-like steps from twelve hundred feet to within two hundred feet of sea-level, the land as a rule terminating in a line of cliffs. Above the general level stands a line of rocky projections which have received the name of hummocks, but which are really hills of considerable size. . . . The passage across it of the several small streams and lesser rivers has been the means of cutting deep gorges and canyon-like valleys, or, in the case of larger streams, broader valleys, the sides of which are sculptured into gullies and ridges." The terraces are, however, evident only in the south-eastern portion of the region, between Wilson's and Big Rivers, where attention was drawn to them by Hutton in 1875, but the present writers had no opportunity of studying them at close quarters.

At Puysegur Point the surface of the plateau is apparently unbroken by terracing, but is convex, its slope near the shore being nearly 6°, but becoming almost horizontal further from the sea (see Plate 2 E). The inner margin of the plateau has the line of "hummocks"* referred to by McKay running near and parallel to it, but is not marked by any abrupt cliffs. There is instead a pronounced change of slope around the base of the Bald Peaks, which may be traced from their south-east to their north-west aspect, and continues to the base of Arnett Peak overlooking the sharp bend in Long Sound, thus leaving a strip of the Coastal Plateau to the east of Revolver Bay which probably reaches over 1500 feet above the sea. It is not possible to recognise any systematic break of slope along the sides of Long Sound that would indicate the continuation therein of this coastal bench, though it seems to be represented on the southern flanks of Treble Mountain by the sloping shelf upon which lie the lagoons shown in the map. The shelf is, however, vaguely defined and becomes visible from Preservation Inlet only when the illumination of the mountain slopes comes from an appropriate angle. It is well defined on the south-western spurs of Treble Mountain and is sharply distinct where interrupted by Southport and Preservation Inlet, though its landward limits are very indefinite, owing to the gentle slope of the mountain. It may be traced northwards along the eastern coast of Chalky Inlet, continuing with increasing elevation into the prominent spur above its junction with Cunaris Sound. No clear indication of remnants of this coastal bench can be seen along the sides of the upper part of Edwardson and Cunaris Sounds, though there are hints of it to the north-east of Northport, where a gently sloping mammilated bench averaging about a thousand feet in height above the sea appears to have resulted from the glacial scouring of the remnants of the Coastal Plateau to a depth of several hundred feet. The western slopes of the Brothers and the Kakapo Mountains slope gradually down into the Coastal Plateau to the north of Cape Providence, and it is apparent from the topographic map of Dusky Sound that the change of slope is fairly abrupt at the base of Mount Bradshaw, and is continued by the western slopes of Resolution Island, the low Five Fingers Peninsula being also a portion of the Coastal Plateau. The broken ridge constituted by Gulches Peninsula and Passage and Great Islands lies mostly below the summit level of the Coastal Plateau, but the outer seaward slopes of Chalky and Coal Islands continue its level from north of Cape Providence to the south-east of Puysegur Point (Plate 3 D; and Map, Text-fig. 4).

Hypotheses of Origin.

The Coastal Plateau may conceivably have originated in one of several ways.

Hypothesis No. 1.—Andrews (1911) was of the opinion that it represents the downwarped continuation of the Fiordland Peneplain.

* A notable instance is the "Knob" near the head of the Wilson River, a rocky peak rising abruptly over 100 feet above the general plateau level. (See distant view, centre of Plate 3 A.)

Thus he says, " Earth forces raised *a* peneplain here in recent times to form *two* high plateaus." The grounds for this conclusion are comprised within the following sentences taken from the same paper. " Whenever two peneplain or old age surfaces are found associated in resistant rock structures . . . and the two such surfaces are situated the one above the other, and the two are separated by a youthful or mature topography, it may be considered that they were formerly continuous, but are now discontinuous, owing to earth processes other than those due to erosive activities. Such earth processes may be either warping or faulting."

In Andrew's view, therefore, the steep western rise in the profiles traced in Plate 2, D, E, would be the result of a pronounced local dislocation. That this view is inadequate seems probable for two reasons. The first is that the higher plateau has been so highly dissected that it is represented only by sharp-cut, narrow divides separated by huge valleys, but wide interfluves remain between the early mature or youthful valleys that traverse the lower plateau, even where it is cut in comparatively yielding Tertiary sediments. This absolute difference in degree of dissection is strong if not conclusive evidence that the two surfaces are not coëval. Secondly, the inner margin of the lower surface is strongly sinuous, for it enters for some distance into the major embayments of the upper surface; this makes difficult of acceptance the view that the two were separated merely by a line of warping.

Hypothesis No. 2.—A second possible explanation is that the Coastal Plateau resulted from partial peneplanation of a coastal strip of the Fiordland Peneplain consequent upon uplift and warping subsequent to its formation. Professor Speight has kindly drawn the writers' attention to Gilbert's (1904, pp. 129-134) account of low-level peneplains along a portion of the Alaskan shore-line which rise on their landward margin to a height of three or four hundred feet above the sea. They have been cut in relatively weak slates and mica-schists lying between the shore and more resistant granites and quartzites further inland, which form an older high-level plateau, from which mature valleys open out on the lower peneplains. The greater part of the Coastal Plateau near Preservation Inlet is considerably higher than the Alaskan low-level peneplain, and there is no relation between its limits and those of the various geological formations. Granites, as well as schists, slates, quartzites, and Tertiary sediments are in turn truncated by its surface. But though there is an abrupt rise from the Coastal Plateau to the level of the Fiordland Peneplain at the Bald Peaks and Mount Bradshaw (Plate 2 D), the long slightly concave slope rising from the plateau remnant above Southport up to the level of the Fiordland Peneplain in Treble Mountain may well have formed during a partial peneplanation such as Gilbert envisaged (Plate 43, Section; Plate 3 D; Plate 4).

Hypothesis No. 3.—The Coastal Plateau, though now uplifted, may be deemed comparable in origin with the strand-flats of Norway. The Fiordland Peneplain, it may be assumed, after elevation was dissected by many small valleys, as well as the few large inlets, so that on partial submergence it had an exceedingly indented shore-line. At a time of considerable refrigeration, preceding, however, the last expansion of the ice, this very broken coast-line was so eroded by wave-action fortified by excessive frost-work that the many promontories and islets were consumed and a wide platform or strand-flat was produced. The detritus was washed into the valleys and fiords that traversed the area and was later removed from these by the normal marine, fluviatile, and glacial processes which were active during and after the subsequent uplift.

The formation of fiords and the coastal dissection generally before the cutting of the strand-flat in this manner are strongly urged by several Norwegian writers such as Nansen (1922, pp. 46-7). Holtedahl (1927, pp. 146-167) believes that this process, though probably effective, is not always of dominant importance. He supposes instead that, after some marine planation, the low shelves thus formed may become covered with a coastal ice-sheet and broadened by the headward cutting of its feeding cirques. As the hemicycle of glaciation advanced to its maximum, continental glaciers descending the great fiord valleys would overflow the coastal lowland, plane its surface, and smooth away the minor irregularities left by the cirque-heads in its landward bounding slopes. Comparison between the Fiordland Coastal Plateau and the Norwegian strand-flat fails, however, in several respects. The maximum elevation of the former is about ten times that of the strand-flat described by Nansen, and, in place of being nearly horizontal, its surface slopes sometimes with increasing declivity seaward. It is not best developed near the mouths of the main inlets, but between them, and its planation cannot have been conditioned by the " preceding splitting up of the land-mass into peninsulas and islands," as is necessary for the Norwegian strand-flat. It might be held that the " hummocks " and " conical hills " are analogous to the cliffed islands which make the Norwegian " skjaergaard," but this cannot be discussed, as the writers were unable closely to examine the residuals in question.

The absence or obliteration of anything corresponding to a sea-cliff on the landward side of the plateau and its deep dissection by extended and consequent streams do not accord at all well with the idea of the origin of the surface in glacial times in the manner described, nor does there seem in Nansen's and Holtedahl's accounts to be any Norwegian analogy for the merging of the coastal platform into several flights of terraces, prominent on its seaward face as well as on the sides of the valleys, such as seem to occur near Big River (but of these only distant views were obtained).

Hypothesis No. 4.—The Coastal Plateau may be an uplifted surface which has had a twofold origin. It may be supposed that after a moderate elevation of the Fiordland Peneplain a low partially planed surface was produced subaërially in the manner described by Gilbert (See 2 above). Slow subsidence then permitted the sea to transgress across it, and to plane the gently undulating surface truncating alike the Tertiary and Ordovician sediments and the granites, a process which must have been slow enough to permit the obliteration of nearly all traces of the small coastal cliffs that were formed. The " hummocks " and " conical hills " may then represent wave-cliffed residuals of the higher portions of this lowland which formed off-shore islets at the time of greatest submergence when the Fiordland Peneplain had been lowered to within two thousand feet of sea-level (See middle of Plate 3 A). Coastal detritus and river-alluvium accumulated in the drowned river valleys or was exported seawards. Then re-elevation of such character occurred that the wave-cut surface was raised to form the present Coastal Plateau rising from near modern sea level to a height of over fifteen hundred feet. It was more or less completely stripped of its cover of unconsolidated detritus as it rose through the littoral zone, and, in consequence of irregular rate of uplift, under favourable conditions developed terraces which modified its even slope. Streams that had extended across this plateau from the adjoining former coast and the new consequent streams cut deep canyons, with re-excavation of old valleys buried under unconsolidated detritus, this process being aided by the betrunking of the streams as the sea-cliffs receded before the attacking waves. Even the huge accumulations of detritus in the valleys of the former major streams were removed, and, thus rejuvenated, these latter proceeded further in the adjustment of their headwaters to the structures that they traversed.

Later, as the climate changed, glaciers advanced down the main valleys, scouring them out to their present depths, which are very great within the narrow parts of the valleys, though not so great near their mouths, where the flow, diminished by melting and ablation, deployed over wider channels. Within the region of maximum glaciation erosion upon the valley-sides removed the last remnants of the pre-glacial high-level bench. Thus, it may be supposed, there were developed the raised Coastal Plateau, the deep sounds, and broad shallow inlets.

So far as it refers to the effects of glaciation, the hypothesis accords more or less with Andrews' earlier views (1905; 1906) and gives, moreover, a hint as to the origin of the " double slope," to which he directed attention as occurring in many of the New Zealand Sounds (Andrews 1906) and which may represent residuals of the high-level bench.

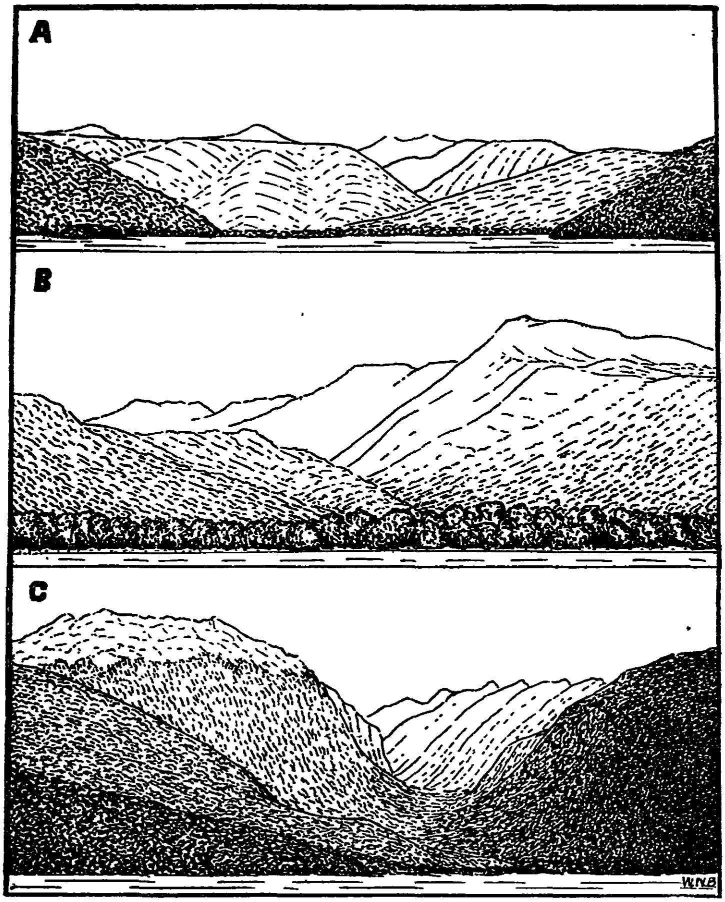
On either side of the outlets of the major valleys the Coastal Plateau was covered by a thin piedmont ice-sheet, creeping slowly seaward and depositing ground moraine and outwash-gravels. These would temporarily protect the plateau from dissection by rivers, though such erosion would become active again as soon as the ice retreated.

The assumption that débris-filled valleys were completely scoured out after the Coastal Plateau had been elevated suggests that some valleys might occur in which this process was not carried to completion. An instance appears to be afforded by the Cascade Valley, two hundred miles further north. According to Turner (1930a), the valley was cut along a fault-zone in the Fiordland Peneplain;

and, during a period of subsidence, became partly filled by coarse gravel which spread out into a broad delta-fan. Uplift followed to such an extent that the landward margin of the fan was raised to 1800 feet above the sea. The gravel, however, had become strongly cemented. The revived Cascade River cut a deep broad valley across only the southern flank of its former delta-fan. Though it has since been truncated by coastal recession, notched by consequent streams, and partly covered by a thin sheet of ice (an overflow from the Cascade Glacier), a broad quadrangular block of the delta-fan still remains to form the Cascade Plateau, and residual masses of the cemented gravel, resting on the sides of the Cascade Valley, extend for some miles upstream.

It is not yet clear what evidence exists for the continuation of the Coastal Plateau between Cascade River and Dusky Sound. Park (1887) spoke of terraces from 100 to 300 feet high extending southwards to Martin's Bay, and, according to the verbal statements of Mr E. James, a strip of relatively low land runs between the high mountains and the coast almost as far south as Milford Sound. Yates Point, five miles north of the entrance to Milford Sound, as noted by one of us (Benson), has a form very suggestive of the existence there of a feature comparable with the Coastal Plateau (See Text-fig. 5). Further south, Hutton (1875, p. 80) noted a series of narrow terraces on either side of the entrance to Doubtful Sound, the highest being at an elevation of about 800 feet.

The degree of maturity attained in the main Preservation and Chalky valleys after the uplift of the plateau, but prior to the glaciation, demands attention. The existence at the present time of remnants of the Coastal Plateau level, represented by the benches on the slopes high above the entrances to Long, Cunaris, and Edwardson Sounds, and the rarity of small tributaries deeply incised into the sides of the Sounds, shows that the tributaries could not have been developed to such an extent that their dividing ridges survived the lateral scouring-action of the great glaciers. The major tributary valleys, namely, Richard Burn and Lumaluma Creek, which were clearly important prior to the uplift, were thereafter deepened by subaërial and glacial erosion to an extent almost comparable with the development of the main valleys. Between the extremes furnished by the small tributaries and these last are several streams draining catchment areas of moderate size each containing portions of the marginal slope of the Fiordland Peneplain and of the Coastal Plateau at its foot. In all instances the general course of the stream runs a little south of west parallel to a series of joints and fractures; valley-development may consequently have been favoured, even though the rock traversed is granite in all but one case. The upper portions of the valleys of Blacklock Stream and Dawson Burn, the only two which have been observed by us, have obviously been glaciated. Blacklock Stream, with a catchment of five square miles, has had its lower portion so cut back that it now hangs several hundred feet above Long Sound. The adjacent valley of Dawson Burn (See Text-fig. 6 B), with a catchment of ten square



TEXT-FIGURE 6.—Views of three valleys cut in granite.

A. Valley of Gray River seen from off Kisbee Beach: a pre-glacial valley cutting a V-gorge 1400 feet deep through the edge of the Coastal Plateau and draining about eight square miles of westward-facing catchment. Bald Peaks (3500 feet) in background. Ice coming south from Revolver Bay (behind the hill in the left) divided above the low ground in the middle distance, part of it flowing towards the observer into Preservation Inlet, and part continuing southwards, rising on to the Coastal Plateau, and depositing thick masses of moraine on the slopes rising to the right.

B. Valley of Dawson Burn entering the southern end of Long Sound, draining from Caton Peak (3784 feet) with a westward-facing catchment of 10 square miles. Glacially modified in its upper portion; an open V-gorge in the lower portion. Remnant of Coastal Plateau on right. Main ice-flow from left to right. Traced from photograph.

C. Unnamed valley entering Edwardson Sound near its head. Eastward sloping catchment of about four square miles area, rising behind Inaccessible Peak (3600 feet). Main ice-flow from right to left. Traced from photograph.

miles, is so much more deeply recessed that its enclosing spurs have escaped complete truncation even though the valley opened on to the convex side of a right-angle bend in the course of the main ice stream. The same may be remarked concerning the Gray River valley (See Text-fig. 6 A), which has a catchment of eight square miles and enters the south-eastern angle of the Preservation Inlet depression through an open gorge cut to a depth of over 1400 feet in the edge of the Coastal Plateau. In both these cases the lower valleys are V-shaped, show little or no sign of glacial modification and appear to have been formed subaërially and adjusted to a base-level rather below the present sea-level.* At the time of their formation, therefore, the floor of the main valley, now occupied by Long Sound, must have been excavated to a depth below the present sea-level at least as far from the coast as the mouth of Dawson Burn, and, thereafter the crust movements amounted in all to moderate subsidence. The increasing body of evidence that in New Zealand, as well as in other countries, there was more than one epoch of Pleistocene glaciation (cf. Willis 1932) raises the question as to whether such a deepening of the main Long Sound valley was accomplished in pre-glacial times, or whether it could have resulted in part from the excavation performed during an early epoch of the glaciation. This involves the decision as to whether such deep gorges could be cut in inter-glacial times. On the views of Garwood (1910; 1932) this might be affirmed, and attention might be drawn to the contrast between the forms of these westward-facing tributary valleys and that of the small glaciated valley discharging eastward into Edwardson Sound near its head (Text-fig. 6 C). It is difficult to obtain quantitative conceptions from the available literature, but though a considerable amount of subaërial gorge-cutting in riegels and valley-steps and benches during inter-glacial times is recognised by Penck and Brückner (1909), De Martonne (1910-11), Nussbaum (1910) and others, there is little to indicate in the works cited that streams with such small catchments as the Gray and Dawson could excavate in granites such large valleys during inter-glacial times.† Moreover, the even slopes of the sides of these valleys lend no support to an hypothesis of multicycle origin.

The extent of development of Kohe Creek is even greater than that of these other streams. Possessing a catchment of eight square miles, this stream rises on the west of Treble Mountain. It is not

* Gilbert (1904, pp. 151-6) describes V-shaped valleys slightly modified by ice and more or less truncated at their mouths entering the upper portions of the Lynn Canal almost at grade and concludes that "there was a pre-glacial, comparatively narrow valley through the Lynn Canal, the floor of the valley being below present sea-level. Lateral V-gorges were tributary to it, and were largely adjusted to it at grade. The Pleistocene glacier broadened the river valley, truncated the side spurs and the tributary gorges, and at the same time materially deepened the valley for the whole breadth of the trough." Capps (1931) holds that here "faulting had much to do with the establishment of the pre-glacial drainage lines."

† Atwood and Mather (1932, pp. 58-9, Plate 17 C) described the gorge of a large stream which has been cut into schist and granite to a depth of about 2000 feet since the earliest Pleistocene glaciation.

noticeably glaciated in its upper portions and is deeply incised into the gently sloping flanks of this mountain and into the Coastal Plateau, whilst it enters Southport in a widely open early mature valley which has received a number of tributaries apparently entering it at grade. A flat delta extends a short distance into its valley. It also must be considered to have been formed in pre-glacial times adjusted to a sea-level rather lower than at present existing.

The absence of deep valleys dissecting the southern slopes of Treble Mountain indicates that during the same time the tributaries of the main valley through the Preservation Inlet area can have had only short valleys dissecting the surface of the Coastal Plateau and adjusted to the shatter-zones of which Isthmus Sound, with Revolver and Useless Bays may be the evidence. These valleys did not extend back into the higher slopes of Treble Mountain. Gray River possibly found an outlet at this time through a valley ancestral to Otago's Retreat, though the fact that it was adjusted to the same base-level as Dawson Burn, which entered a much more powerful stream, renders this unlikely. The seaward slope of the Coastal Plateau is sufficient reason for the lack of noteworthy northward-flowing tributaries.

Similar tributaries to the main Chalky Valley may have been developed along fracture-zones in the neighbourhood of Northport, but were not incised to any great extent in the flanks of the Kakapo Range, say, near Mount Inaccessible (Text-fig. 6 C). Traces of the old plateau level appear as a glacially scoured bench extending a couple of miles north-east of Northport, while on the eastern side of the Inlet the Coastal Plateau, which is well developed south of Kohe Creek, passes northwards into a faintly-marked bench above the mouth of Cunaris Sound. It is noteworthy that whether or not the eastern opening of Chalky Inlet was in existence in pre-glacial times, the pre-glacial maturing of Kohe Creek betokens a pre-glacial origin for the Southport depression, though not necessarily the existence of an outlet valley there.

Hypothesis No. 4, now under discussion, thus leads to the conclusion that at the commencement of glacial times sea-level stood rather lower than at present. The main streams, and a few of their tributaries draining remnants of the Fiordland Peneplain and rejuvenated by the uplift of the Coastal Plateau, had cut deep valleys extending far up their courses, but their minor tributaries had formed only short youthful gorges, dissecting their old valley floors and guided largely by fracture zones, and had seldom become recessed into the higher slopes. They had, however, cleared out most of the detritus that had accumulated in their former valleys. It follows, however, that the plexus of small gorges formed in the Preservation Inlet area must have taken a large share in the total excavation that had been accomplished in that area.* Accordingly, when the glaciers advanced down the main valleys and spread over

* Apart from a moderate degree of glacial modification the present features of Kiwi Burn Valley (see Plate 2 A), especially in its lower portion, afford a small-scale analogy with the inferred form of the Preservation Valley immediately prior to glaciation.

the Coastal Plateau, they occupied in the latter not only their main outlet channels, but also a plexus of small valleys which greatly facilitated the work of erosion.

On the assumption that erosion is competent completely to account for the present land forms, it should first be observed that the glacier discharging from Long Sound rose high above the level of the remnants of the Coastal Plateau. The scoured form of the promontory by Arnett's Peak, and of the plateau remnant above the mouth of Dawson Burn, and the broad channel of high-level flow from the end of Long Sound into the Gray River catchment which McKay had seen, afford evidence of this. There would consequently have been a vigorous discharge into the Isthmus, Useless, and Revolver valleys cutting down the divides at their heads, so that in the case of the last the ice crossed the divide to reinforce the flow in the Gray River valley. As the ice advanced thus on to the dissected coastal plateau with its greatest force concentrated at three points, conditions were propitious for the development of a wide terminal basin, even though the glacier became considerable deployed. Excavation was further facilitated by the fact that the formations on to which the glaciers emerged from the rather sparsely jointed granites were the abundantly jointed Ordovician quartzites and argillites, more susceptible to glacial plucking than any other formation in the region. It is significant that the eastern boundary of the depression occupied by Preservation Inlet almost coincides with that of the sedimentary rocks, while its southern shore, and its northern possibly, coincide with the heads of the small pre-glacial insequent gorges, for there are no important recesses made by large tributaries streams crossing these boundaries. The channels in the floor of the inlet follow the lines that might have been expected for the outlet streams, so that the various islands may be considered to be incompletely consumed resistant residuals of the former secondary divides. They consist chiefly of massive quartzite rather than argillite. Their small size compared with the granitic isthmus to the east betokens the greater resistance to glacial plucking and scouring offered by the latter.

The features of Otago's Retreat need special consideration. It is enclosed between steep almost rectilinear walls truncating obliquely the strike of the Ordovician and Tertiary sediments. Great bluffs of quartzite project from the eastern wall near the middle and at the northern end of the channel, and these bands of resistant rock are continued into Coal and Crayfish Islands. In a shallow recess between them lies Te Oneroa Beach, in which the rocks are largely argillites as at the Morning Star Mine. Immediately opposite this is the deepest part of the inlet, but the depth decreases rapidly near the quartzite bar on the southern side. The channel narrows seaward, and is half closed by a promontory composed of Tertiary arkosic sandstone. That the top of this promontory is the same height as the coastal plateau on either side of the channel seems to indicate that it has not been over-ridden by any effectively eroding mass of ice.

Certainly, the widespread morainic matter on the plateau on either side of Otago's Retreat may indicate a temporary extension of the ice-sheet over it, but the presence thereon of more or less stratified gravels shows that the conditions were often those of an outwash apron. Holtedahl (1929, p. 141) comments: "If there is any tendency for the ice to dig deeper in one sort of rock than another . . . conditions do not at any rate point in favour of the looser rocks; one would rather say that hard but jointed rocks give a more angular and complicated design to a fiord . . . so there is a greater chance of getting in these rocks an uneven irregular profile with very great depth. Evidently the plucking effect of a glacier is of paramount importance." Matthes (1930, pp. 89-103) also emphasises (and, according to von Englen, 1933, pp. 590-592, possibly over-emphasises) the importance of close-spaced jointing for the promotion of glacial erosion.* Matthes holds that in the Yosemite region cross-walls, glacier-stairways, and roches moutonnées are all the products of selective glacial erosion at points where monolithic, hence obdurate, granite masses are interposed between much jointed, hence quarriable, rock. Hence in our region there is no reason to suppose that a relatively thin sheet of ice over-flowing from the main mass in Otago's Retreat should have on the Tertiary sediments as strong an effect as the thicker mass had on the harder but more jointed Ordovician sediments. At the same time, the seaward constriction of the "Retreat" suggests that it may have been formed by a lobe of the main glacier in the Inlet which had overflowed through a low saddle at the head of a small consequent stream traversing the seaward slope of the Coastal Plateau. The valley of this stream, possibly, was the outlet of Gray River at some stage of its history. The glacial lobe scoured out a small terminal basin, and did not extend beyond the promontory. As the tidal Big River fifteen miles east of the "Retreat" discharges from Lake Hakapoua through a valley cut in Tertiary sediments, so it may be that there was never any discharge of ice from the Inlet into the sea through Otago's Retreat. If this were so, the present opening of the latter would have to be explained by river-erosion and cliff-recession under wave-attack, together with some regional subsidence. Any terminal moraine must then have been removed in the formation of the outwash apron. Alternatively, it may be suggested that a terminal basin may have been formed by an ice-lobe in an early glacial period, the opening into the sea being made in the manner mentioned, but during an interglacial period, and enlarged by ice-action during a later glacial epoch. There is no need, however, for such an hypothesis. The small notch at the base of the promontory through which the lighthouse road has been made could easily have been cut by a small stream escaping from the ice-front.

* In Yosemite this holds within a single lithological unit. "Where the rock (granite) is massive or only sparsely divided by fractures, the glacier . . . can reduce it only by abrasion, a slow and relatively feeble process; on the other hand, where the rock is abundantly divided by natural partings the glacier will quarry out entire blocks and excavate at a relative rapid rate." (Matthes 1930.) The writers have not yet had access to Ljunger's (1930) paper on the morphological significance of fractures.

If either of these views as to the origin of Otago's Retreat be accepted, the implied wasting away of the main Long Sound ice so near the coast may explain the failure of the main ice-stream in the Inlet to broaden the opening between the resistant masses of Crayfish Island and Cavern Head, though there is no reason to doubt that there was a considerable discharge of ice into the sea through it.

Hypothesis No. 5.—Though the hypothesis last discussed seems adequate to explain the present topography of the region, it is desirable to consider Andrews' (1911) final conclusion concerning the region: "The earth forces raised a peneplain here in recent times . . . and dropped a centre block to form the (Preservation) Inlet which has since been modified by glacial erosion." At one stage in these studies this view seemed to the writers to be inescapable. The narrow rectilinear channel of Otago's Retreat, half-closed by a promontory of weak rocks, and parallel to well-known lines of fracturing and perhaps faulting (the hypothetical fault along the west coast of Fiordland), seemed best explained as the result of trough-faulting, though the need to suppose that the fault-strip did not extend the whole length, but left a "bridge," subsequently reduced by erosion, at the southern end, imports a special feature which, though not fatal, lessens the probability of this hypothesis. Again, the rectilinearity of the boundaries of Preservation Inlet itself and in particular of the long wall extending from Revolver Bay southwards, together with the need of explaining the early development of a base below the present sea-level to which the Gray and Dawson valleys could become adjusted before the glacial period, offers support for the hypothesis that this broad depression resulted in part from a pre-glacial subsidence of fractured crust-blocks, such as has occurred on a large scale in many of the intermontane basins of the South Island of New Zealand. It still remains possible that such movements may have been instrumental in the dismemberment of the coastal plateau in pre-glacial times, but the features of Preservation Inlet alone seem inconclusive as evidence of recent subsidence of this character.

Further, the western side of Southport coincides with the most strongly marked fault in the district studied, and in topographic form is either a fault-scarp or fault-line-scarp. The eastern side has a much gentler slope, and north of the mouth of Kohe Creek rises gradually up to the level of the Coastal Plateau. The section (Part I, Plate 43) suggests this may indicate the stripping away of Tertiary rocks involved in a fault-angle depression during the pre-glacial dissection of the Coastal Plateau. If such a fault continued across to join the fracture-zone along the western shore of Edwardson Sound (thus outlining the granite massif), it is conceivable that for a time the outlet of the Chalky drainage may have been through here. This suggestion need not assume any dislocation of the Coastal Plateau, but an explanation of the maturity of Kohe Creek involving the pre-glacial subsidence of narrow crust-blocks in Southport and Chalky Inlet would require such movements. Once more, however, the evidence is inconclusive.

The glacier in Chalky Inlet had probably a greater catchment than that in Long Sound (though the exact position of the divide between them is yet unknown). Moreover, it received by the through valley at Last Cove about a third of the total stream of ice moving down Long Sound (estimated by a comparison of approximate cross-sections), and there is such abundant proof of intense glacial scouring as far down as the junction of Edwardson and Cunaris Sounds that the overdeepening of these Sounds requires no further explanation. Overflow into a valley draining the Coastal Plateau between Chalky Island and Gulches Head, and its subsequent enlargement would seem a sufficient explanation of the eastern outlet of Chalky Sound, even if the main pre-glacial stream discharged through Southport (which need not have been the case). The glacial enlargement of Southport to its present form (Plate 3 F) would, however, follow only if there were maintained a significant difference of surface-levels between the Chalky and Preservation glaciers, which the abundant opportunity for westward discharge of the former would tend to prevent, though McKay cites evidence of a noteworthy flow of ice through this opening at one stage. If his description of the locality be correctly interpreted, the edge of the Coastal Plateau nearest to the Seek Cove-Southport neck bears a covering of morainic matter, indicating that the thickness of the ice here was for a time over 1500 feet.

There is sufficient analogy between the conditions in Preservation Inlet and those which must have obtained in the western part of Chalky Inlet to render it unnecessary to assume extensive block-faulting for the explanation of this western depression. Though there was here some deploying of the wasting glacier, three main streams must have come through Northport, Return Passage, and Bad Passage respectively, in each case through channels developed in granitic rocks. They passed out on to an area of normal, well jointed Ordovician sediments lying between Cape Providence and Chalky Island, which would have been very susceptible to plucking. The total volume of rock that was removed would have been comparable with that excavated from Preservation Inlet. The retention of a remnant of the Tertiary rocks now forming Chalky Island may be explained by Holtedahl's (1929) comment cited above.

General Conclusion.—The amount of topographical and geological detail available in this region of varied features has invited an attempt to make a fairly comprehensive application of the method of multiple working hypotheses to the elucidation of its geomorphogeny, in the light of the latest accessible discussions of the origin of the Norwegian fiords and American glacial topography. It has lead to the conclusion that in general the glacial excavation of a series of pre-glacial valleys adjusted to a more or less fractured series of diversified rock formations, together with small submergence of the region, is competent to account for the bulk of the features observed. And, further, though there are a number of facts suggesting that the differential subsidence of relatively small fractured crust-blocks may have influenced the pre-glacial relief, the evidence that this was the case is not complete. Nevertheless, there is considerable probability that a major fault-plane determining the west coast of Fiordland obliquely truncates the coastal plateau in the region of Dusky Sound (See Part I, Text-fig. 2).

The Pleistocene Glaciation.

Distribution and Erosive Activities of the Glaciers.

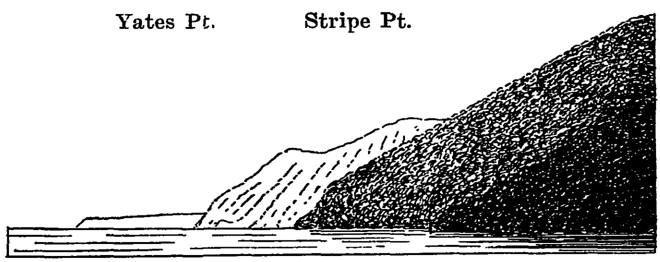
McKay's detailed account of this period here and the above discussion need but little supplementing. During its maximum the ice must have risen to a height of over two thousand feet above present sea-level in the regions about the heads of Long, Cunaris, and Edwardson Sounds, whence it diminished westward to a thickness that just enabled it to overflow on to the Coastal Plateau as a thin sheet extending for some miles on either side of the main glacier-streams. The following particulars concerning the individual streams are noteworthy. The main Longburn glacier entered Long Sound over a riegel north of Houseroof Hill (Plate 3 E), on the north side of which it scooped out an overdeepened lake-basin. It was joined by a tributary glacier moving down Richard Burn, and continuing down the valley scoured and plucked the rocks to a depth of over fifty fathoms below modern sea-level, leaving sides of the valley shorn smooth save for a few truncated spur remnants. High plunging cliffs with gentler upper slopes mark the granite areas; more even and smoothed but less steep slopes (about 27°) occur on the mica schists. About a third of the ice overflowed through the gap from Last Cove to Cunaris Sound, the sides of which are intensely shorn and the base reduced almost to sea-level. The main flow, however, discharged over and through a granite barrier, dividing into several channels, and enlarging pre-glacial valleys that were probably controlled by fractures. The most direct flow passed over Jane Cove to Isthmus Sound, and a smaller one over a low col into Useless Bay. The chief flow meanwhile was deflected twice at right angles and passed through Narrow Bend, shearing off the lower portion of Blacklock Valley, which thus hangs above the Sound.

The lower portion of Dawson Burn Valley was protected, owing to its recessed situation at a bend of the main glacier, and was little modified by the ice, though the upper part was glaciated in common with that of Blacklock Stream. A thick sheet of ice flowed over the edge of the Coastal Plateau above Revolver Bay and, merged with the stronger stream that followed this latter depression, thrust against the south-eastern angle of the Preservation Inlet depression, though a thin apron extended over the plateau towards Wilson River. The main underflow, however, deflected westwards, scoured the southern wall of the depression, and entered Otago's Retreat. As in similar cases, there was but little modification of the Gray River Gorge, which was protected by its situation in a recess. The channels of the principal ice-streams outflowing across the floor of Preservation Inlet are clearly indicated by the bathymetric contour lines; between them there rise island-capped ridges.

TEXT-FIGURE 4.—Topographic and bathymetric map of Preservation and Chalky Inlets based on the Admiralty and Lands and Survey charts for coastline, depths, and spot elevations, and on numerous photographs and sketches as regards the form-lines, which are therefore approximations only. Numerous depths in Isthmus and Long Sounds are recorded merely as exceeding 54 fathoms; probably much of Long Sound is more than 100 fathoms deep.

The Cunaris Glacier, fed by ice from Carrick River, was thrust to the north by the ice, already noted, coming through the gap from Long Sound, which caused the coastal slopes that received the thrust to be recessed and ice shorn (See Text-fig. 4). For a short time there was probably some southward flow of ice from Edwardson Sound moving across the smoothed col between Tower Hills and The Lump. The southward direction of the ice sweeping out of the recess is proved by the striation of the promontory at its western end. The Sound itself was scoured to a depth of more than 130 fathoms, and a narrow channel was cut almost against Divide Head. Beyond the shelter of this spur, on receiving the full thrust of the Edwardson ice, the Cunaris ice cut off more than a mile from the end of a southern promontory enclosing Cunaris Sound, the intensely plucked and abraded Cunaris Islands and the broad shallow submerged platform to the south of them remaining as residuals of this former spur.

The Edwardson Glacier received its main supply from the Oho Valley, in which Carrick (1895) noted a series of lakes* above the large Freshwater Lake, which is shown on the Admiralty chart and lies 80 feet above sea-level, so that the ice probably descended over a succession of rock basins and low riegels. It scoured out a broad hummocky lowland, nearly a thousand acres in extent, between Saddle Hill and the Sound. The main western flow into the Sound came down Lumaluma Creek, a normally glaciated valley, but a minor tributary glacier descended from the northern end of the Kakapo Range in a valley, which recalls the familiar "text-book" diagram of staircase valleys with U-shaped cross sections (Text-fig. 6 C). Between the Stopper and Mount Inaccessible, a mile to the north-east of the former, there is a tarn-filled cirque which now discharges into the Sound by an unrecessed stream following a granite slope



TEXT-FIGURE 5.—View from the entrance to Milford Sound, looking towards Yates Point, five miles to the north, showing the presence there of a coastal plateau. Traced from a photograph.

which, as Hector noted, is for the most part inclined at an angle of 40° and continues beneath the water to a depth of over 100 fathoms. This south-east slope has been worn to a plane surface, with intensely scoured and striated minor irregularities, which passes here and there into plunging cliffs. Across the Sound the opposing slopes facing north-west have been cut in mica-hornfels and schists and are less steep. Pre-glacial valleys moderately recessed in these slopes have been almost planed away. Towards the southern end of the Kakapo Range the higher slopes are concave instead of convex and somewhat mammillated or terraced, apparently the result of glacial modification of an earlier bench associated in origin with the Coastal Plateau. Lakes Rimmer and Caesar are probably recessed in the landward margin of this bench. The scouring of this bench, which lies about three or four hundred feet below the height of the Coastal Plateau appropriate for this situation, must have been influenced by the thrust of the Cunaris Glacier. There must have been a

* Preston's (1929) map of Dusky Sound shows some of these and suggests that Carrick's sketch-map exaggerates their size.

vigorous westward flow across Northport, to which may be assigned the responsibility for the enlargement of the main channel and perhaps also of that of the parallel tributary valleys, which seem to have been developed in pre-glacial times along a shatter-zone. Great Island would have been overridden, for its surface is mammillated and bears two small lakes. The spreading of the ice through Return Channel and Bad Passage may also have been effective in the excavation of those straits, and Passage Island would probably also have been overridden. It is not so clear to what extent Chalky Island may have been overwhelmed; its covering of detritus, so far as it exists, may have been in part fluvio-glacial. Between this and Cape Providence there would doubtless have been a series of Ordovician sediments, which would have been exposed to erosion by ice moving on to it from Chalky Inlet through three channels cut in granite. To some extent, therefore, the conditions of Preservation Inlet may have been repeated, and the glacial excavation of the western portion of Chalky Inlet seems a reasonable hypothesis. The main flow from Chalky Inlet, however, discharged east of Chalky Island, scouring out a terminal basin which even adjacent to the northern end of Chalky Island is over fifty fathoms deeper than any recorded sounding in the open sea within a radius of five miles, and is probably considerably deeper nearer Northport.

The effects of the ice that descended westwards from Kakapo Range are scarcely known. Lake Hector seems to be in a rock-bound basin some 600 to 800 feet below the level of the Coastal Plateau, and discharges by a short stream at first broad and swampy, which, after passing the remnant of a terminal moraine, becomes narrower and steeper and falls in all about 200 feet into a valley, which turns sharply and discharges through a short gorge into the sea instead of following what would appear to be its natural route along a broad, gently-sloping through valley, which runs to the north-east almost parallel with Northport. Apparently there has been here considerable erosion along intersecting shatter-belts and perhaps subsequent glacial modification, but the details have not been determined. Lake Thomas also discharges by a stream which follows a mature valley in the plateau until it suddenly descends by a steep youthful gorge about 700 feet to Landing Bay.

The Glacial Deposits.

No special attention was paid to the glacial deposits by the present writers, and reference must be made to McKay's (1896) detailed account of them, which, however, seems to require modification in some respects. McKay found that they extended over the Coastal Plateau forming outlying patches, and that they cover three-quarters of the surface of Coal Island, the western margin of the plateau east of Southport and part of the peninsula to the west thereof, whilst he correctly inferred that they would also occur on the gentle slope from the Kakapo Range to the West Coast. Neither he nor the present writers, however, ascertained whether these deposits occur on Chalky Island. Clearly, they were formed beneath a piedmont ice-sheet which overflowed from the main ice-streams on to the enclosing sloping plateau. On " the height of land " near the head of the Wilson River ". . . they reach an elevation of 950 feet. At places the glacier-drifts appear as deposited, but usually the upper portion has been modified, at higher levels but slightly, but in the middle and lower parts of the slope the material has been separated into coarse bouldery wash and beds of finer sand. Below these re-sorted drifts there is usually an unascertained thickness of unmodified glacier deposits, readily distinguished from the former by the angular character of the material and the presence of clayey material giving the lower deposit the appearance of a till. . . . Between the landing at Otago's Retreat and the Puysegur Point lighthouse there appears on the flat-topped spurs on each side of the road a very coarse but well-rounded gravel, and a small creek cutting through this has its bed choked by granite boulders of large size. This is, therefore, a glacier deposit, first re-assorted by the sea and afterwards cut through by the creek, so that the shingle in the creek is much concentrated, and, being auriferous, has, to a limited extent, been worked for gold " (McKay 1896). A like explanation is given of the concentration of gold in other valleys.

" The action of the sea " has been traced up to a height of 800 feet, but no other evidence than the rounding and re-assortment of the gravel is offered for the rise of the sea to this level. The alternative explanation that this re-assortment was the work of outwash streams descending the sloping plateau from the piedmont ice-sheet is supported by the presence of lignitic and swamp material on the flat-topped spur leading to Puysegur Point.* McKay held that on the southern slopes leading to Preservation Inlet between Kisbee Beach and Otago's Retreat, similar " evidences of marine action " are abundant. This can hardly be due to re-sorting of an outwash apron, but conceivably may be the work of streams at the margin of the glacier. Stratified drift on a shelf at an elevation of 150 to 200 feet behind Te Oneroa Beach (Berg's claim) contains masses of scarcely-lignified wood. At Price's Beach, east of Gulches Head, " the action of the sea breaking up and re-assorting the tough underlying boulder clay has led to the formation of about thirty feet of thick auriferous gravels " (McKay). These gravels form a terrace with a slight slope to the south and west, and, like the others, may possibly have been re-assorted by a stream marginal to the ice-sheet. On their flank there is a narrower lower terrace of fine auriferous black sand. (See Plate 3 F.)

The subsidence of the land and its subsequent rise to an amount of eight hundred feet since the end of the glacial period, as postulated by McKay, might be expected to have left many more indications of raised beaches than the few that have been noted. Doubt is,

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* Comparison is suggested with the peaty shales, sands, and shingle of the outwash gravel forming the great terraces near Strahan in western Tasmania described by Sir Edgeworth David (1924) in a paper which may have considerable bearing on the history of Pleistocene glaciation in New Zealand.

therefore, felt concerning the correctness of this conclusion of McKay's, though indications of minor post-glacial movements of sea-level are noted in the next Section.

Among other glacial deposits worthy of note are " the vast accumulation of morainic matter " plastered against the hill-slopes east and south of Kisbee Beach as the ice retreated, and a large deposit of the same material recorded by McKay as laid down upon the spur above Southport Isthmus at the confluence of two glaciers. West of Kakapo Range fluvio-glacial gravels cap the cliffs near Cape Providence, forming a layer some ten feet in thickness and eighty feet above sea-level at the Cape, but rising to two hundred feet or more in elevation further north. The presence of " varve " rocks was noted *en passant* on the slope about 100 feet above the north-western angle of Landing Bay. They show a face about ten feet high of horizontal, rhythmically-banded silts, with layers from two to ten millimetres in thickness which probably represent seasonal deposits in a lakelet at the side of the receding ice-sheet. An arcuate ridge of boulders which crosses the adjacent bay marks probably a temporary marginal moraine.

McKay declares that there are no glacial deposits on the south-eastern slopes of Treble Mountain. Were this not so, it would be natural to consider that the " lagoons " there were held in glacial deposits on a remnant of the Coastal Plateau. As a further feature of the glacial deposits, mention may be made of erratics, often of huge size, which litter the shores of the Sounds and occur in profusion on all the islands in Preservation Inlet.

The huge thresholds at the entrance to Chalky and Preservation Inlets, though probably in large measure composed of solid rock, are also likely to be covered with massive terminal moraine, and wave-distributed material. The smaller inner threshold at the entrance to Isthmus and Long Sounds are more likely to consist mostly of terminal moraine marking a retreat-stage of the main glacier.

POST-GLACIAL FEATURES.

1. *Erosional Features.*

(a) Fluviatile Erosion:

As elsewhere in New Zealand, there has been little post-glacial stream erosion, as is indicated by the many unrecessed streams and waterfalls " flaunting their whitened waters " on the slopes leading down into the Sounds. A marked exception to this is a steep-walled gorge cut on the northern slope of Cunaris at the back of the great ice-shorn recess facing Cliff Cove (Part I, Plate 41). It may be that the stream occupying it is cutting through a thick mass of readily excavated morainic material plastered against the valley-wall. The great fall over which Longburn enters the head of Long Sound has receded two hundred yards or more into the face of a high riegel, which here crosses the valley (Plate 3 E); but this may very largely have been the work of a sub-glacial stream or of inter-glacial stream-activities. Recession of the low falls at the outlet of Freshwater Lake into the head of Edwardson Sound is much less marked; Hector (1863) remarked upon the depth of the pool below the fall.

(b) Coastal Erosion:

Recession of the sea-cliffs of the region may have been in progress during, as well as after, glacial times. It is evident in the cliffing and removal of all traces of glacial scouring and striation from all portions of the shores within a few miles of the sea, though further within the Sounds these features abound. In the more exposed locations, sea-cliffs more than three hundred feet high occur, and reach nearly six hundred feet in height on the western coasts of Coal Island and especially of Chalky Island. The projection of the surface of the Coastal Plateau from Puysegur or Long Reef Points would intersect sea-level less than half a mile from the present shore, indicating that coastal recession has been limited to this distance, but reefs and skerries which extend out nearly a mile from Cape Providence suggest that wave attack has there been particularly active in the recent past.

2. *Constructional Features.*

(a) Terrestrial Slope Deposits:

These do not require special comment. Hector (1863) remarked on the abundance of frost-riven rock-fragments forming a talus on the lower slopes of the loftier and steeper hills.

(b) Deltas.

Longburn and Oho Creek as effluents of overdeepened rock basins bring no heavy detritus into the heads of the Sounds into which they flow. Carrick River makes a large delta at the head of Cunaris Sound, while Richard Burn and the stream opposite it have nearly filled the top of Long Sound. The lowest reaches of Lumaluma Creek entering Edwardson Sound are alluviated, and noteworthy deltas have been built by a stream a mile to the south of the last-mentioned creek by Kohe Creek and by Dawson Burn. Gray River may have discharged at one time into Kisbee Bay, but, after building a broad flat largely from re-sorted morainic material, now discharges into Revolver Bay. Here it may be recalled that Hector (1863) emphasised how steep was the outer slope of the smallest deltas within the Sounds. This is certainly true of the Gray River delta.

(c) Wave-deposited Material:

Examples include:—

1. The filling of Northport by sand coming in through Blind Entrance and choking the mouth of Shallow River.
2. The tombolos represented by the isthmus at Southport and Te Whara Spit, the beach behind this latter, and many small pocket beaches.

3. Redistributed detritus worn from the outer sea-cliffs and from moraine naturally occurs in huge amounts; its extent may be judged partly by the fairly even slope of the sea floor indicated by the few soundings. In sheltered waters sand continues to accumulate. Thus Otago's Retreat has a sandy floor and is crossed by a bar only a fathom deep, whilst the relatively shallow thresholds of Preservation and Chalky Inlets probably are partly built of wave-borne detritus. In more exposed portions of the coast, where the longshore currents are rapid, the finer material has been removed to a considerable depth, for a rocky bottom occurs down to about twenty-five fathoms as far offshore as four miles west of Cape Providence. The Balleny Reefs and possibly Table Rock are perhaps the remains of moraine deposited between the Chalky and Preservation Glaciers.

3. *Features Indicating Minor Oscillations of Sea-level.*

(a) Subsidence:

In addition to the already-described features of the Gray, Dawson, and Kohe valleys, which indicate that there has been a moderate subsidence of the region since the commencement of glacial times, the embayed character of the shores of Northport, Great and Passage Islands, and the fact that Wilson's River is tidal for a mile and a-half from the sea (Gordon 1893), and that Big River and Lake Hakapoua are also tidal, show that the evidence for such submergence extends throughout the whole area, though it is not yet possible to infer exactly whether the movement was in continuous progression or was limited to a definite period. The features about the mouth of Big River, where there seem to be a number of terraces visible from the sea, will probably be of most critical value in determining the precise history of glacial and post-glacial times in this district. Hutton (1875) was probably justified in rejecting as inconclusive other evidence of subsidence brought forward by Hector (1863).

(b) Elevation:

Hector (1863) noted on Crayfish Island a wave-cut cave, the floor of which was about ten feet above sea-level, and other caves elsewhere with floors up to twenty feet above the sea. From Cape Providence stretching towards West Cape there appears to be a narrow uplifted strand, at about the same elevation, at the base of the ancient sea-cliffs. Much of it consists of storm beach, but near the group of huge stacks three miles from Cape Providence, a raised rock-platform is also in evidence. In the sheltered parts of the Inlets, McKay recognised as raised beaches several other deposits, including the broad flat between Gray River and Kisbee Bay, a small beach at the north-eastern point of Coal Island, and another just east of Te Oneroa at Price's Beach, the isthmus at Southport, and the wide flat on either side of the mouth of Kohe Creek. In each case the surfaces are only a few feet above sea-level, and it is difficult to be sure that uplift is actually indicated, since the level of the storm-beach of earlier times was certainly higher than that of to-day, when deposition has shallowed the near-shore waters in these bay-heads.

Higher terraces are indicated by a small cemented-gravel terrace at the north-east of Coal Island, which is exposed in a cliff about forty feet high, whilst McKay notes, but does not estimate, the height of gravel terraces on the east side of Southport. Hutton (1875) drew attention to a pierced rock at Green Islets, south-east of Preservation Inlet, which was surrounded by a wave-cut terrace forty feet above the sea. Finally, there are the higher terrace already mentioned between Price's Beach and Seek Cove, which present a cliffed margin nearly a hundred feet in height, and another small terrace of somewhere about the same height above Te Oneroa Beach. It has been suggested above that these were formed by streams at the margins of the glaciers. If so, they would have no necessary relation in elevation to each other. It is noteworthy, however, that in the case of the former, the streams draining from the central peak of Gulches Peninsula, now extended across the terrace, have been so rejuvenated by the disappearance of the ice or raising of the terrace that they have notched deep V-gorges in its seaward front (See Plate 3, Fig. F). As these gorges seem rather too large to have been cut in the massive Tertiary sediments in post-glacial times only (especially considering the amount of cliff recession that may have occurred), the suggestion may be advanced that they were developed during an inter-glacial period, and escaped subsequent obliteration, as the latest glacier was here almost at its termination, and in place of actively eroding its sides, was nearly stagnant.

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LIST AND DESCRIPTIONS OF ILLUSTRATIONS ACCOMPANYING PART II.

PLATE 2.—Features of the Fiordland Peneplain and Coastal Plateau.

A. Panorama from the summit of Ben Lomond, Lake Wakatipu, traced from a series of photographs, showing the accordance of summit-levels. Except for the narrow strip of infaulted Tertiary marine sediments shown in solid black, the whole region consists of more or less altered Palaeozoic (?) sediments, greywackes, and argillites to the west, semi-schists in middle distance, schists in foreground, north-west, and north. Geology after McKay (1880) and Park (1909).

B. Profile along S.W.-N.E. axis of Fiordland Peneplain.

C. Profile W.-E. across the gently arched Fiordland Peneplain showing the major departures from the general summit-level made by the elevated block of the Remarkables and the Cromwell depression (and Lake Wakatipu?); also the situation of the infaulted Tertiary marine beds.

D. Profile S.W.-N.E. from Windsor Point along the south-eastern margin of the Long Sound catchment, the southern end of profile B. This is drawn in a thick black line. Against it are plotted three profiles (thin lines) running W.S.W.-E.N.E. adjacent to Dusky Sound based on Preston's topographic map (1929), and showing the continuity of the Fiordland Peneplain and the Coastal Plateau respectively in the two regions.

E. Profile from Windsor Point to Bald Peak showing geological structure. (After McKay, 1896).

F. Profile across the infaulted Tertiary sediments near Ben Lomond to natural scale, showing the hypothetical former position of the now-removed Tertiary sediments and its relation to the summit-level. Drawn to natural scale, and based with modifications on Park's section (1909).

PLATE 3.—Sketches of coastal topography between West Cape and the Green Islets, N.W. and S.E. respectively of the entrances to Chalky and Preservation Inlets. Also views of the head of Long Sound and of the Solander Rocks.

PLATE 4.—Preservation Inlet, taken from Morning Star Mine, Te Oneroa, Treble Mountain in the distance. (Bartrum photo.)

TEXT FIGURES.

TEXT-FIGURE 4.—Topographic and bathymetric map of Preservation and Chalky Inlets based on the Admiralty and Lands and Survey charts for coastline, depths, and spot elevations, and on numerous photographs and sketches as regards the form-lines, which are therefore approximations only. Numerous depths in Isthmus and Long Sounds are recorded merely as exceeding 54 fathoms; probably much of Long Sound is more than 100 fathoms deep.

TEXT-FIGURE 5.—View from the entrance to Milford Sound, looking towards Yates Point, five miles to the north, showing the presence there of a coastal plateau. Traced from a photograph.

TEXT-FIGURE 6.—Views of three valleys cut in granite.

A. Valley of Gray River seen from off Kisbee Beach: a pre-glacial valley cutting a V-gorge 1400 feet deep through the edge of the Coastal Plateau and draining about eight square miles of westward-facing catchment. Bald Peaks (3500 feet) in background. Ice coming south from Revolver Bay (behind the hill in the left) divided above the low ground in the middle distance, part of it flowing towards the observer into Preservation Inlet, and part continuing southwards, rising on to the Coastal Plateau, and depositing thick masses of moraine on the slopes rising to the right.

B. Valley of Dawson Burn entering the southern end of Long Sound, draining from Caton Peak (3784 feet) with a westward-facing catchment of 10 square miles. Glacially modified in its upper portion; an open V-gorge in the lower portion. Remnant of Coastal Plateau on right. Main ice-flow from left to right. Traced from photograph.

C. Unnamed valley entering Edwardson Sound near its head. Eastward sloping catchment of about four squares miles area, rising behind Inaccessible Peak (3600 feet). Main ice-flow from right to left. Traced from photograph.

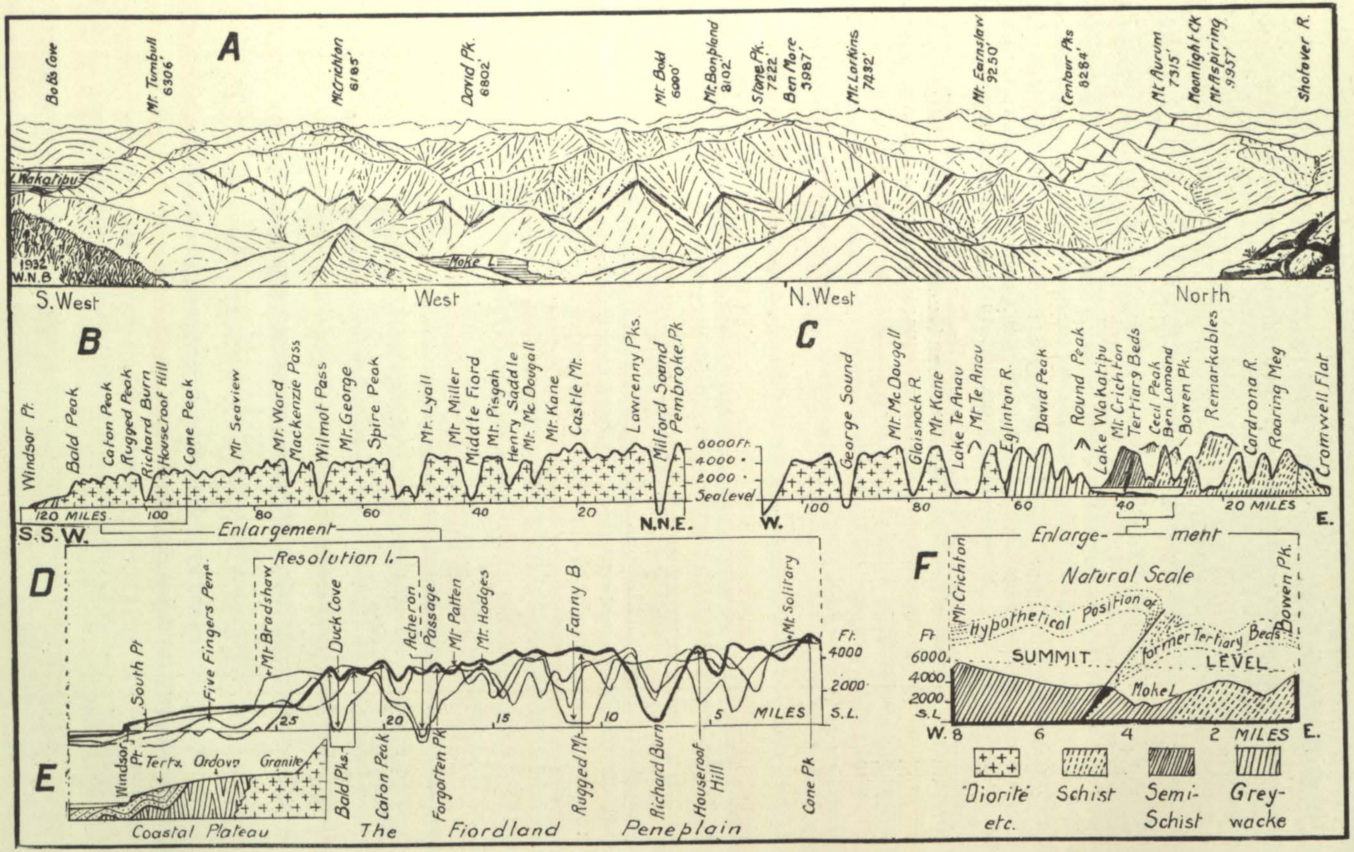


Fig. A.—Panorama traced from photographs taken from the summit of Ben Lomond (5747ft), showing position in solid black of fossiliferous Oligocene (?) marine sediments infaulted among the more or less altered Palaeozonic sediments which here rise to an accordant summit-level, the Fiordland Peneplain. Geology according to Park (1909).

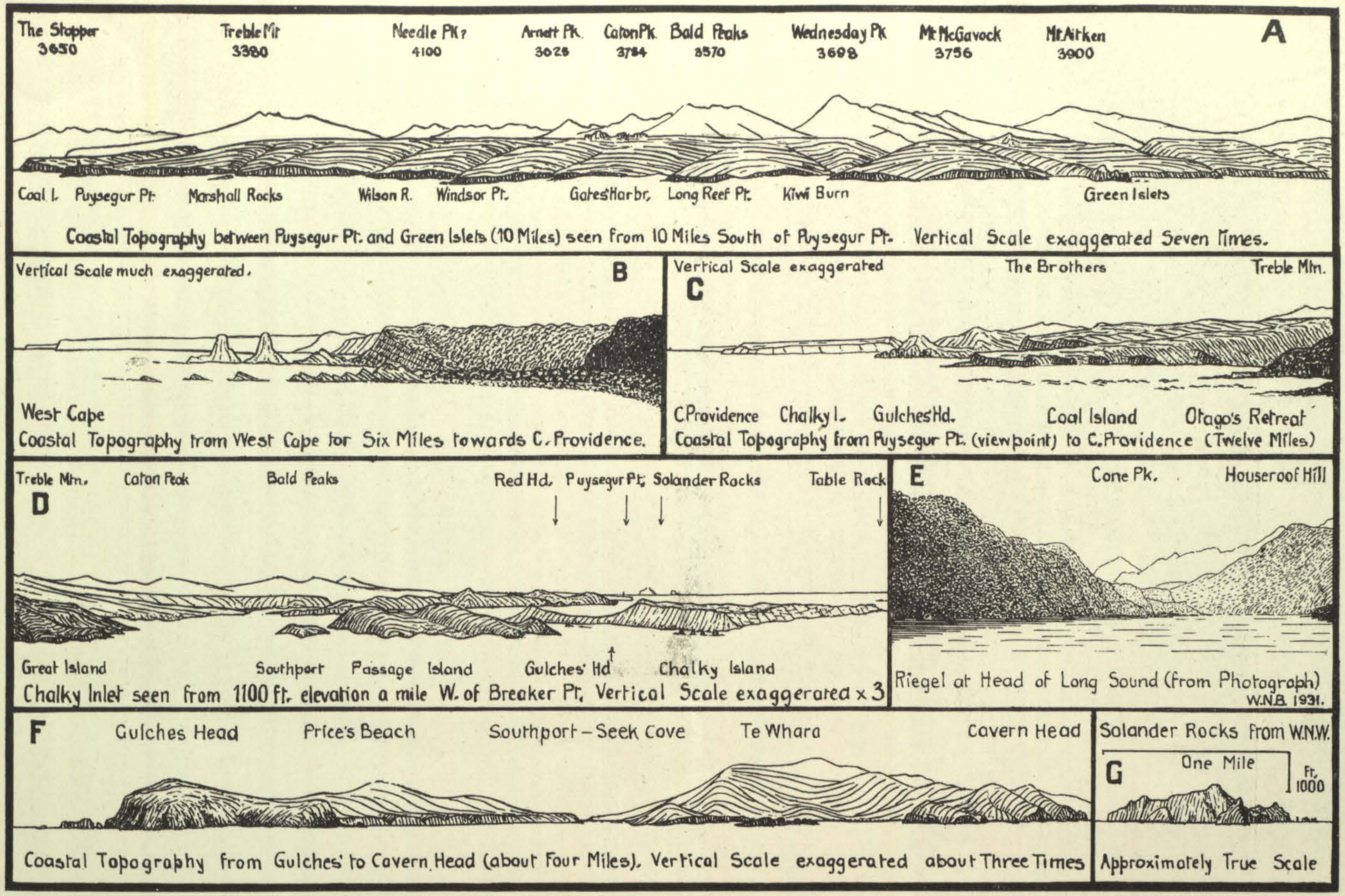
Fig. B.—Profile of the Fiordland Peneplain traced nearly along its axis descending from the head of Milford Sound southwards towards Preservation Inlet, where it is cut off by the narrow Coastal Plateau.

Fig. C.—Profile across the Fiordland Peneplain showing its slight arching and the presence of major departures from the general summit-level probably resulting from the displacement of crust-blocks in Pleistocene times.

Fig. D.—Profile (in thick line) drawn along the south-eastern crest bounding the watershed of Preservation Inlet and Long Sound, plotted against three (thin lines) profiles W.S.W.-E.N.E. across the Dusky Sound area, based on Preston's topographic map (1929). Shows the continuity in all four profiles of the distinction between the Coastal Plateau and the Fiordland Peneplain.

Fig. E.—Geological Structure of the Coastal Plateau near Preservation Inlet.

Fig. F.—Section across the Moke Lake Valley near the view point of Fig. A, showing the possibility that the Fiordland Peneplain was cut after the infaulting of the Tertiary sediments.



Sketches of coastal topography between West Cape and the Green Islets, N.W. and S.E. respectively of the entrances to Chalky and Preservation Inlets. Also views of the head of Long Sound and of the Solander Rocks.

Preservation Inlet, taken from Morning Star Mine, Te Oneroa, Treble Mountain in the distance.
(Bartrum photo.)