Chapter 12 Quaternary

After the cessation of volcanic activity and before the onset of glaciation there appears to have been a period of intensive weathering. It was during this period too that extensive landslipping seems to have taken place. A sheltered pocket in Coire na Banachdich in the western Cuillins has escaped glacial erosion. Here the gabbro is weathered to a considerable depth which contrasts with its hard smooth and striated appearance elsewhere, indicative of negligible erosion since glaciation.

In northern Skye little of the material produced by this late-Tertiary weathering has escaped subsequent removal by ice. Evidence for this period of weathering lies chiefly in the dolerite dykes, many of which are decayed to a considerable depth.

Glaciation. The evidence of glaciation in Skye are best seen in the central and southern half of the island where the hard gabbro of the Cuillins, the quartzite of the Cambrian and the hard Torridonian sandstone show scratched and polished surfaces in abundance. In the north, evidence for glacier movement is carried largely by the dolerite sills and dykes and by the moulding of the Jurassic outcrops. The lavas which form the land surface over most of northern Skye rarely show much direct evidence of glacial erosion.

Thaeglacial action has played an important role in the shaping of the present landscape of Skye is evident, but it is equally clear that the general configuration was determined by aqueous erosion during the latter part of the Tertiary period. The subject of glacial erosion will be dealt with more fully below but it is necessary to' realise at this point that prior to the advent of glaciation the rocks had been deeply weathered and the major features of the topography were already in existence.

In the early part of the Pleistocene, before Skye was reached by ice from the mainland, a local glaciation must have developed. This resulted in the formation of an ice-cap in the Cuillin area from which glaciers radiated in all directions. In the north, valley glaciers may have developed along the Trottemish ridge and in this respect it must be remembered that the neve field of The Storr-Quirang range prior to post-glacial landslipping (p. 6) would have had an area almost twice that of the present day. To the east of it there was the pre-glacial landslip (p. 6); to the west, valley glaciers flowed down to the sea. It is possible that smaller mountain groups like that of Healaval Bheag and Healaval Mhor in Duirinish and the Beinn Bhreac-Beinn na Caillich ridge in Sleat also gave rise to independent glacier systems. That part of the mainland ice-sheet which impinged on Skye and Raasay was built up of five major glaciers (Figure 19). In the south, ice from Loch Hourn, Glenelg and Loch Alsh, moved westwards and over-rode Sleat. Beinn na Caillich. (2403 ft), Ben Aslak (1984 ft) and Beinn na Seamraig (1839 ft), all Torridonian hills, though later over-ridden, must have at first caused a slight diversion, but to the south of them the ice movement was almost due west and practically at right angles to the Cuillin glaciers which were diverted by the greater pressure of the Highland ice. The Loch Slapin ice was forced to travel across Strathaird and Soay whilst the Loch Scavaig ice moved down Soay Sound. There is no evidence that Highland ice extended so far north as Strathaird and Soay.

The Loch Alsh glacier was split by Beinn na Caillich (2403 ft) at Broadford, into a southern stream which travelled in a south-westerly direction to join the Glenelg glacier in Loch Eishort, and a northern stream which effectively dammed the north-easterly flowing Cuillin ice and was itself diverted to the north-west.

The distribution of erratics suggest that this Glenelg ice was forced to keep to a north-westerly direction by the pressure of the Cuillin ice from Sligachan at least as far as Mugeary, after which it turned again westwards only to meet ice from Macleod's Tables, against which it split to form a southern stream down the Bracadale valley and a northern travelling north-westwards down Loch Dunvegan and Loch Bay. There is no evidence that the area between Loch Bracadale and Loch Dunvegan was ever overridden by Highland ice. The eastern part of this north-westerly Glenelg glacier passed to the north of Cruachan Beinn a' Chearcaill (888 ft) and Ben Uigshader into Loch Snizort, joined by ice which came by way of Glen Varragill and by a stream diverted by Ben Lee (1456 ft) over the Braes, Ollach and Portree to Loch Snizort Beag.

Judging by the intense erosion which resulted, the eastern half of the Loch Alsh ice, joined as it was by ice from Loch Carron and further north by the Loch Torridon glacier, formed the thickest and most powerful of the ice-flows which affected Skye. With the possible exception of the Dun Caan ridge (maximum 1456 ft), Raasay was completely over-ridden. Much of the Inner Sound and the Sound of Raasay is over 50 fm deep so that, assuming the ice-sheet remained grounded, it is not likely to have been less than 1700 ft or much more than 2000 ft thick. Thus the bulk of the ice flow was diverted to the north by the eastern coast of Skye, which is a cliff made up of Jurassic sediments and Tertiary dolerite sills. In the south at Ben Tianavaig it is capped by lavas and reaches 1352 ft, north of Portree at Sithean Bhealaich Chumhaing it is 1286 ft and descends gradually to sea-level at Staffin. Behind this is a second barrier, the Trotternish lava scarp, much of which exceeds 2000 ft. Once free of the Cuillin ice therefore, the Loch Alsh–Loch Carron stream met a north-south barrier to its westerly progress which in places exceeded 2600 ft. Thus at Rubha na h'Airde Glaise the lower 1300 ft of ice could not have moved westwards. Some came ashore south of it and meeting the barrier of Beinn a'Chearcaill (1812 ft) was forced to continue northwards over Loch Fada and Loch Leathan and back to join the main stream at Tottrome. Even if the ice thrust against the Trotternish ridge reached a higher level than in the open Sound and even if at its maximum it overrode the ridge at say 2500 ft, the greater bulk must still have been confined to the east of the Trotternish ridge with only the upper layers over-spilling through the bhealach into the Haultin, Lon Mor, Romesdal, Hinnisdal, Glen Uig and Rha valleys which lead westwards into Loch Snizort. It is notable that all the bhealachs between The Storr and Beinn Edra are at more or less the same level i.e. 1650 ft O.D. Since no evidence of northerly ice movement has been found above this level, it is thought that during most of the main glaciation the ice-level stood at about 1700 ft O.D. against the east of the scarp and thrust small piedmont glaciers through the gaps in the ridge into the western valleys.

This would mean that an ice stream passed south of The Storr, travelled northwards on the west of the scarp and joined the main stream again at Bealach Uige north of Beinn Edra. Thus the Storr-Beinn Edra ridge was for much of this time a nunatak. Charlesworth (1956, p. 874) in his account of the late glacial history of Northern Scotland came to a similar conclusion.

North of Meall nan Suireamach where the sea-cliff is low, the westward pressure of the Highland ice began to take effect and the ice-stream swung round to the north-west over the low ground between Kilmaluag and Duntulm. Here the full weight of the ice-sheet had its effects and deep grooves were cut like that between Kilmaluag Bay and Lub Stac nam Meann, reminiscent of those seen in Raasay.

Here in the north and again south of the Cuillins the ice-sheet may have extended as far as the Outer Hebrides but the resistance to westward flow offered by most of Skye must have so reduced the pressure that it is unlikely that the ice margin extended far beyond the west coast.

Retreat of the Highland Ice. With cessation of the main glaciation the pressure of the Highland ice on Skye was relaxed and by stages the ice retreated from the island. Some evidence of these retreat stages is to be found on the west side of the Trotternish ridge. Four main pauses, designated the 1450-ft, 1300-ft 1100-ft and 500-ft stages, from the approximate levels of the ice edge of the Loch Snizort Glacier in Western Trotternish during the cutting of the glacial drainage channels, are shown in (Figure 20). Indications of a still higher stage at about 1650 ft, marked by the spilling over of ice on the main ridge from east to west, are indicated on the 1450-ft diagram. On the east side of this ridge landslipping seems to have occurred pari passu with the withdrawal of the stabilizing effect of the ice and all signs of retreat stages destroyed.

Whether the ridge was ever completely submerged or not (p. 179) there is on the western side evidence of a period of stasis at about 1450 ft (Figure 20). As has already been suggested, the heights of the cols in this ridge are uniformly at about 1650 ft, which level is also believed to mark the maximum height (to within say 50 ft) of the ice-level on the eastern side. On the west, where the direct pressure of Highland ice was not felt, the ice probably stood at a lower level which may have been marked by the overflow channel of Beinn an Laoigh at 1450 ft. Ice or water was dammed in the Fuar, Iomhair and Chaiplin corries but in these it was confluent. The Beinn an Laoigh ridge however, formed a barrier to drainage towards the north and a channel was cut to allow access to Coire Amadal.

A second stage in the retreat is marked at about 1300 ft, (Figure 20). By this time the ice-level on the eastern side had probably fallen below 1650 ft and the ice-lakes in the western corries cut off from their source of supply. With the western ice-stream at 1300 ft lakes were formed in the valleys the exits of which were still closed. The lake in Romesdal drained by way of two channels in the Beinn a'Sga ridge, both at about 1300 ft, into Hinnisdal and from thence by a channel in Beinn Fhuar (1300 ft) to Glen Uig.

Evidence for a pause at about 1100 ft is more complete (Figure 20). A lake held up in Eskidal drained northwards through Bealach a'Chaol-reidh at about 1100 ft into the valleys of the River Haultin and Lon Mor and thence by way of two channels in the Beinn a'Chapuill-Beinn an Righ ridge, both at about 1050 ft, into Romesdal. Drainage appears to have been lateral into Hinnisdal, by this time containing a large body of water and from here one of the best examples of a drainage channel, i.e. that east of Creag Chargach at 950 ft, leads into Glen Uig. From here drainage was lateral into the Rha valley lake, from which water escaped northwards through a channel in Beinn a'Sga at 850 ft. This series of chonels indicates a uniform thinning of the western glacier northwards from about 1100 ft at Portree to a little over 800 ft at the point where it joined the eastern glacier south and east of Duntulm.

Retreat next appears to have taken place more rapidly and except for one or two rather dubious channels at about 700 ft there is little evidence for another pause until the ice-level had dropped to about 550 ft, and then to 500 ft (Figure 20). At the south-western end of the Haultin valley are channels at 550 and 500 ft and again between Romesdal and Hinnisdal at Creag an Locha and Creag Madragil. Between Hinnisdal and Glen Uig at Beinn Bheag only the higher channel is present whereas at Creag Moine, between Romesdal and Haultin valley, only the 500 ft channel is seen. The best developed of all is just west of Creag na Cuthaige at about 450 ft.

Evidence that the main flow of Highland ice east of the Trotternish ridge was standing at a higher level than that in the Chracaig valley and, by inference, that to the west of the ridge during at least one of the retreat stages is clearly shown by the terminal and lateral moraines of a short lobe of ice thrust westwards into the head of Lon Druiseach 3 miles N.N.E. of Portree. The Sound of Raasay ice must have been standing at a little over 1100ft when it spilled through a gap in the cliff-top north of Sithean Bhealaich Chumhaing to form this small glacier.

Away from the Trotternish ridge evidence for the retreat stages is not easily found. Channels at about 950 ft are to be seen on the east side of Beinn na Greine, S.W. of Portree, at the 450–500 ft level east of the Vaternish ridge and east of the Healaval Mhor–Healaval Bheag massif.

One of the most interesting areas is that lying between Loch Harport ice on the west and the Sligachan–Mugeary ice on the east. This, at the 500 ft retreat stage, was apparently clear of ice and probably formed an area of tundra topography with numerous lakes and a complex series of drainage channels, here referred to as the Bracadale-Edinbain lake system (Figure 21).

Late-Glacial Re-advance. Following the final decay of the main ice-sheet and a period of milder climate came a renewal of glacial conditions represented in Scotland by the development of valley glaciers.

In Skye a small ice-cap was re-established in the Cuillins together with a radial glacier system. The Trotternish ridge developed small glaciers on both slopes, those on the eastern side flowing for the most part over the landslip which had become established after the retreat of the main ice sheet (p. 190).

The Cuillin ice had two main outlets i.e. southwards into Loch Scavaig and northwards into Glen Sligachan. Subsidiary glaciers from Blaven and Beinn na Cailleach flowed down Loch Slapin and southwards across the Strath to Sleat. From Marsco, Beinn Dearg and Glamaig the flow was north-eastwards down Loch Ainort and north-westwards to join the main Cuillin ice from Glen Sligachan and so north down Glen Varragill and the Chracaig Valley to Bearreraig, and down Glenmore to Mugeary, whilst a westerly branch flowed down Glen Drynoch to Loch Harport. Four small glaciers combined on the western Cuillins to feed ice into Glen Brittle.

The Trotternish ridge appears to have nourished at least seven small glaciers. On the eastern side the Lealt glacier was fed from corries between Carn Liath and Sgurr Ruaidh, the Kilmartin glacier originated in Coire Cuither and probably became confluent in Staffin Bay with the Brogaig glacier from Druim na Coille. Probably also a small glacier originated in

Coire Scamadal and flowed down the valley of Rigg Burn.

On the western slopes ice from The Storr and Beinn a'Chearcaill gathering ground became confluent in the Haultin river valley and flowed westwards into Loch Eyre. The Romesdal valley carried ice from Hartaval. Glen Hinnisdal, a magnificent example of a glaciated valley, was occupied by a glacier formed by three confluent streams from Coire Fuar, Coire Iomhair and Coire Chaiplin. In Glen Uig the topography is complicated by extensive landslip in the middle section of the valley but in the higher reaches shows typically glaciated features caused by ice from Coire Amadal and Bealach Uige.

Valley Glacier Retreat stages. In the valleys of three of the eastern glaciers a deeply cut gorge commences at the seaward end at about 200 ft, i.e. in the Rigg, Lealt and to a less extent in the Kilmartin Rivers and again less conspicuously in the western valleys. These may indicate the maximum extent of the glaciers, or, more likely, an early resting stage in their retreat.

Another break in the valley profile occurs between 400 and 500 ft, perhaps representing a later retreat stage. Certainly above this level the ice became stagnant and produced, on melting, typical hummocky moraine. Terminal moraines are very rare but the later stages of the Kilmartin glacier left both lateral and terminal moraines in the area round Loch Cuithir at about 600 ft. The longer glaciers from the Cuillin ice-cap in Glen Varragill and Glenmore must have decayed more or less in situ leaving hummocky moraines along the whole length of both these valleys.

Glacial Erosion. The resistance offered by Skye to the westerly progress of the Highland ice-sheet led to the building up of enormous ice-pressures. Consequently glacial erosion on the eastern side of the Trotternish ridge was very considerable. Coming directly under the sole of the ice, Raasay was considerably and typically eroded. Deep parallel grooves were cut in the felsite sill which covered much of the area of the central and southern parts of that island. In Skye this type of erosion is only found where the full thickness of the Highland ice came to bear on the island, i.e. south of the Cuillins, especially in Sleat where the Torridonian rocks are deeply scoured and north of the Trotternish ridge between Flodigarry and Duntulm.

Along the whole of the east coast from Sligachan to Flodigarry the ice was moving northwards and bringing to bear very considerable lateral pressure on the coastal cliff and the lava-escarpment behind. Thus from Portree to Staffin the sea-cliff forms a gentle curve virtually unbroken by indentations or promontaries.

The less resistant Jurassic sediments have been cut back to form ledges whilst the harder dolerite sills stand as vertical faces. Wherever a prominence does break the even curve of the coast-line it is due to an outcrop of igneous rock—the Balmeanach promontary is a felsite sill, Holm Island, Rubha nam Brathairean, Rubha Garbhaig, Staffin Island, Eilean Flodigarry, Sgeir Eirin and The Aird are all dolerite sills. The re-entrants are all due to the presence of sediments—Tianavaig Bay is in Jurassic rocks and Palagonite Tuffs, Portree Bay is in Palagonite Tuffs, Staffin and Kilmaluag bays are in Jurassic sediments.

Inland the erosive effect of the ice was more spectacular. If, as is argued on p. 190 pre-Glacial landslips covered the low ground between Portree and Bearreraig Bay, it was entirely cleared away, as was that fronting the scarp between The Storr and Sron Vourlinn. Thus conditions were created which were favourable for the formation of a new landslip once the ice had retreated. The strath between Portree and Loch Snizort was one of the few places where Highland ice had a relatively uninterrupted passage across Skye to the west. Here, though on a smaller scale than in Raasay, longitudinal grooving can be observed. Numerous rock knobs show a north-north-westerly alignment, e.g. Dun Sgalair, Ben Tote, Skerinish Duns, Creag nam Meann.

Erosion by the re-advance valley glaciers was far less intense and nothing like the characteristic steep-sided U-shaped valleys of the Cuillins is to be found in northern Skye.

The valleys on the west of the Trotternish peninsula however, such as Glen Uig, Hinnisdal and Romesdal have typical corries at their heads, below which they broaden rapidly into a wide flattened U-shape.

There are examples of typical semi-circular corries on the eastern scarp also like that west of Cam Liath, Coir 'an t-Seasgaich and Cuither, but in the tumbled masses of the landslip the valleys soon lose their regular glacial form.

Glacial Deposits. Boulder clay, though usually thin and stony, is widely distributed throughout Skye.

Occasionally however, in valleys such as Glen Varragill and the upper reaches of the River Rha, quite considerable thicknesses are to be found. In the upper part of the Lealt River 15 ft of blue boulder clay has been recorded and in the River Brogaig at Staffin, it is between 12 and 18 ft thick. The Abhainn nan Cnoc, north-east of Loch Cuither, and outside the landslip margin, runs in a gorge 30 ft deep in which can be seen two boulder clays separated by banded silts, in all about 25 ft thick.

Thin boulder clay was produced by some of the re-advance glaciers and in places must rest on boulder clays of the main glaciation, but it is only where they are separated by landslip that any distinction can be made between them (p. 193).

Erratic Boulders. Rocks foreign to Skye introduced by Highland ice are rare. The erratics found on the western side of the Cuillins are all local basalts, gabbros and granite. East of Sligachan, though granites predominate, there are some Moine and Torridonian boulders. This distribution supports the suggestion that the Cuillin ice-cap excluded mainland ice from its western side.

Boulders of Torridonian sandstone have been found in Loch Vatten and the Lampay Islands along the line where the western margin of the Loch Dunvegan glacier was in contact with the local ice from Healaval Bheag and Healaval Mohr.

Elsewhere the only erratics recorded are local igneous and sedimentary rocks. Some of these are very large, e.g. Clach Chraigisgean, a mile west of Balgown in Trotternish, is an enormous block of dolerite which must have been brought by the north-easterly ice-stream from a more southerly exposure of the sill on the ice-smoothed surface of which it now rests. In the Kilmaluag River, west of Druim Fada is a large mass of Kimmeridge clay which appears to have been moved a mile or so from the outcrop to the south-east.

Moraines. None of the morainic deposits seen in northern Skye can match in size and perfection of form those seen in the Cuillin area. Small lateral moraines are present in some of the valleys on the eastern side of the Trotternish ridge especially in the upper reaches of the Lealt River but terminal moraines are rare. West of Loch Cuither and at the head of Lon Druiseach are both lateral and terminal moraines but these are small.

By far the most common type of morainic deposit in northern Skye is 'hummocky drift' or 'kettle-moraine'. This, the characteristic deposit of stagnant ice is excellently developed in Glen Varragill, Glen Drynoch and Glen More. Hummocky moraine is also found in Glen Varkasaig, once occupied by a glacier from Healaval Bheag; in the strath between Portree and Loch Snizort Beag especially round Borve and Achacork; and in the valleys on the western slopes of the Trotternish ridge i.e. Lon Mor, Romesdal and Hinnisdal.

Sands and Gravels. Except for a small patch at Fasach in the Hamra River, Duirinish, sands and gravels have not been recorded.

Raised Beaches. There is abundant evidence in northern Skye for the previous existence of sea-levels higher than that of the present day. Since Tertiary times however, the coast of Skye must have been, as it now is, for the most part rocky and precipitous. Consequently the coastal features were mainly formed by erosion and not by deposition and do not indicate actual sea-level with any accuracy. Thus the oldest, the 100-ft Beach-level is marked by rock platforms at various levels between 75 and 90 ft O.D., the 50-ft Beach level by features at about 35 to 45 ft O.D. and the 25-ft level by platforms between 10 and 20 ft O.D. This lowest beach-level may fall within the limits of present beach development and is in places partly covered by more recent storm-beach.

At the present time deposition of beach material is taking place primarily in embayments and inlets such as the bays of Staffin, Lub Score, Uig, Portree, Ardmore and Dunvegan and it is in these same areas that deposits were formed at times of higher sea-levels. The 100-ft Beach deposits in Cairidh Ghlumaig (Lub Score) and near Monkstadt contain sea-worn shells as do the 25-ft Beach deposits in Loch Caroy between the mouth of Ose River and Ose Point (Loch Bracadale) but this is unusual.

The 50-ft sea-level is marked by a rock-ledgel ■ mile S. of Cairidh nan Ob. Such features are not uncommon but it is difficult to identify them with any certainty since the basalts and dolerites which form so much of the coast of N. Skye are not marked by mollusc borings which in limestone country give an infallible and accurate datum line.

All three raised beaches are present and well seen on the south side of Staffin Bay, from Kilmaluag Bay westwards to Solitote, in Lub Score, Skeabost and Loch Bay. The highest beach-flat is the best developed and most extensive, covering a considerable area both at Stenscholl and Kilmaluag and probably extended southwards from Camas Mor almost to Totscore, an area later occupied by Loch Chaluim Chile.

The 50-ft Beach is usually found associated with the higher one and is not always clearly separable especially when, as is frequently the case, both are peat-covered. The lowest (25-ft) platform is only seen as narrow coastal strips except in places like Ardmore Bay in Vaternish, and Balmeanach Bay south of Portree, where the beach flat links a rocky island with the shore, and Isay Island in Loch Dunvegan where the whole island except for a small rock knob consists of 25-ft Beach-flat.

Landslip: Definition. So many varied phenomena have been described under the heading of landslip that some definition of what is, in this instance, meant by the term, is necessary. Only those movements which exhibit the following characteristics are here regarded as true landslip:

1. In vertical section the glide-plane is a curved surface on which the overlying material moves downwards and outwards. A rotational element in this movement is an essential feature of landslipping.
2. In horizontal section the glide-plane is also a curved surface so that the inner margin of the slipped mass is always a curve.

Other related phenomena are:

a) Rock Falls (including Scree) in which fragments of rock have broken away from the parent mass and fallen to a lower level. Characteristically, the individual blocks are orientated in a disorderly fashion and the whole has the form of a cone of talus.

b) Rock-Slides in which masses of rock have slid along an inclined bedding plane away from the parent mass. Individual blocks tend to be inclined towards the direction of movement because of deceleration at the base.

c) Creep, the material of which, usually already unconsolidated, moves by gravitational pull down an incline without the formation of a controlling glide-plane. As in landslip, but unlike rock-slides, the material is forced into ridges and hollows at right angles to the direction of movement. The mechanics is, however, different from both in that the movement appears to consist of small asymmetric folds which become underthrust from behind.

Mechanics of Landslip. The basic principles affecting the formation of landslip are relatively simple. The essential requirements are a plastic or semi-plastic material capable of deformation by shear, sufficient load to overcome the internal resistance of the material to shear and a unilateral release of pressure allowing the development of shear-planes. The operational force is gravity.

The mechanics of landslipping have been investigated largely by civil engineers who are concerned with the practical problems involved. An empirical formula has been proposed—Coulomb's equation, primarily intended to apply to small scale slipping in embankments etc. But with certain reservations the general principle appears to apply to slip of any size (see Petterson 1955).

The basic assumption is that the form of the shear-plane is cylindrical and, therefore, the movement of the slipping mass is rotational. There is ample evidence for this in most landslips. The equation is :

$\mu = \rho \tan \theta$

where μ = shearing resistance per unit area

ρ = normal compressive stress

θ = angle of shearing resistance (angle of internal friction)

The glide plan is in fact a logarithmic spiral having the equation r = r0εθ tanO (see Terzaghi and Peck 1948) but the simpler equation above suffices for all practical purposes.

For clays, which are the most common contributing factor in landslip the equation should be written :

$\mu = c + \rho \tan \theta$ where c is the cohesion.

θ for clay is generally about 15°. The coefficient of friction in clay is largely dependent on the amount of included water which reduces the resistance to shear (see Skempton 1953).

Though this equation appears to apply reasonably well to the relatively simple case of a single slip it is clearly inadequate in the case of the larger compound slips in Skye.

These show that the mechanics of a compound landslip are extremely complex. Nevertheless, certain general principles can be deduced and the more important factors affecting the slip can be determined with sufficient accuracy to predict the future behaviour of a slip.

What is not usually appreciated is the fact that the lateral extent of a slip is relatively small and that all large landslips are compound. The eastern face of the Trotternish ridge is formed by a series of intersecting arcs—as is the back of any large slip e.g. Blackgang in the south-west of the Isle of Wight, Herne Bay in Kent, the coast east of Redcliff Point in Dorset, and Walton Naze in Suffolk. But these are in reasonably homogeneous material. In Trotternish, however, the scarp is capped by basalt lavas and the arcuate back of the slip, which may be a segment of a circle at the top of the sediments, is modified by the non-plastic nature of the overburden and the proximity of joints. In addition there are several arcs of much larger radius which are the backs of corries and post-date the landslip. It is probable that the presence of a vertical joint plane in the lavas has determined the position of a glide-plane in the underlying sediments primarily because it would allow water to percolate and so help to reduce the coefficient of friction at this point. Apart from this the lavas are of little significance except that their weight supplies some of the motive force which activates the slip.

The glide-plane along which the slip moves is formed entirely in the sediments, in the beginning, at the base of the lavas, at the angle of shear, but immediately curving away to form by the integration of an infinite series of thrust-planes the characteristic curved back which is the trace of a logarithmic spiral.

All the factors involved are variables. The pressure (p) exerted by the overlying mass of rock is initially vertical and downwards but as the slipped material slips outwards the tilting of the moving block increases the horizontal component until at 45° this is at its maximum of $\rho/2$. As gliding continues the horizontal pressure falls to zero and the mass becomes stationary. Another variable is the angle of shear (θ). In dry clay this may be very small, i.e. the internal friction may be very high and the resultant fracture is then virtually parallel to the direction of maximum pressure. The addition of water, however, has the effect of reducing the internal friction. Theoretically, the angle of shear could vary between 0° and 45° which is the maximum possible in material such as paraffin wax where the internal friction is zero. E. M. Anderson (1951) has shown that for sedimentary rocks in general θ is about 20°. The fact that the sediments involved do not consist entirely of clay but may include beds of limestone, or even sheets of igneous rocks, does not seriously affect the issue provided they are strictly subordinate in thickness and are so placed that the glide-plane approaches them at a fairly obtuse angle.

Eventually the glide-plane approaches the horizontal and at about the same place the horizontal component of pressure is at its maximum. The slide from then on behaves as a thrust, the horizontal pressure usually at this stage being reinforced by pressure from the succeeding wedge. At the same time the forward elements are approaching the position of rest and there is an increasing resistance to forward movement which will in time entirely inhibit any further slip.

Most of the landslip in Skye appears to have reached a position of equilibrium, though examples of active landslip are to be found at Ben Tianavaig south of Portree and on the east side of Dun Caan in the neighbouring island of Raasay, outside the area of the present memoir.

The Quirang landslip (Plate 4); (Figure 22) is still a little unstable because the toe of the slip reaches the sea in Staffin Bay and is being constantly removed by marine erosion.

It remains to discover how many of the operative factors can be determined or calculated and how the principles of landslipping can be applied to individual examples in Skye.

The height of the operative free face (h^1) can in most cases be calculated with reasonable accuracy. In almost all the known landslips in Skye this is the thickness of sediment lying between the base of the lava-flows above and a major dolerite sill below. The total height of the free face (h^2) is the operative thickness of the sediments below, plus the thickness of the lava overburden. The distance from the free face to the margin of the slip (d) can be measured, as can the angle of rest (a) of the slip.

The angle of shear (θ) is theoretically variable from 0 to 45° and almost directly proportional to log it (it = shear strength). The relationship between 0 and p is expressed by the formula:

2θ = I 1/μor

θ = ±450 ± ω/2 where tan ω = μ (Anderson 1951)

Thus when μ is very large, in practice ± 10, θ is virtually 0° and shear cannot take place. When there is no shear strength i.e. when μ = 0, θ is 45°. Anderson (1951) has shown that the inclination of faults is on the average between 18° and 22.5°; i.e. μ for average sedimentary strata must range from 1.0 to F38. The value of μ for the Skye sediments is taken to be ± 1.2 (θ ± 20°). If this is so then the glide-plane is a logarithmic spiral of 20° and the relationship between the horizontal and vertical radii is r^1/r^2 = 1.3 and it follows that the higher the free face, i.e. the greater the plane of minimum pressure, the greater the radii of curvature of the glide-plane.

The curvature of the back face is a segment of a circle of radius equal to that of the logarithmic spiral at the top of the free face, thus its radius of curvature (r^3) will be the same as r^1.

Examination of the landslip east of Trotternish lava scarp and south of the Quirang reveals that the generalized slope of the stabilized landslip is about 15° (β) which corresponds to a stable angle of 6° (α), i.e. the angle subtended by the plastic medium to the margin of the slip. The relations are d (distance of margin from scarp) = $h^1/\sin \alpha$ or $h^2/\sin \beta$. The latter is the more easily measured. When these angles reach these minimum values forward progress of the slip is halted. It follows that if the angles are greater the slip is unstable and further slipping may be expected.

Landslipping in Skye and Raasay. In late Tertiary times the lava plateau was tilted slightly to the west and considerably broken up by faulting. As a result of these dislocations the eastern sea-board from Portree to Kilmaluag must have been a cliff of remarkable dimensions probably reaching a height in places of at least 2000 ft. The lower half of this cliff would have been composed of Jurassic sediments and dolerite sills, whilst above stood a great thickness of lava-flows. Such an arrangement is obviously unstable and from the moment of its inception the sediments must have tended to slide under the weight of the super-incumbent lavas. Almost identical conditions to those in north Skye obtain in the Cascade Mountains in northern Washington, U.S.A., where the Columbia lavas in sheets 400 to 500 ft or more thick, rest on clays and sands, or on deposits of volcanic lapilli, and the series has been eroded so as to form steep escarpments. The type of landslip described from the Lookout Mountain in this area is very similar to that found in northern Skye (Sharpe 1938).

The Storr Landslip. The best known and most spectacular of the Skye landslip areas stretches from The Storr (2360 ft) across the glaciated trough partly occupied by Lochs Leathan and Fada and reaches out 5000 ft almost to the coast (Plate 1), (Figure 23). This is a mature stable slip with an angle of rest (β) of 15°. It is clear that the present slip is entirely post-glacial, its volume and extent being consistent with the existence of a pre-slip escarpment about 2000 ft east of its present position. The back face is in places over 2000 feet but is variable. The base of the lavas is, however, consistently at about 900 ft O.D. (The palagonite tuffs at the base of the lavas which may be of the order of 100 ft thick are included with the Jurassic sediments).

Thus 1000 ft of sediments lie between the thick Armishader sill and the lava-base, but included in them is the thinner Creag Langall sill, the top of which is 500 ft below the base of the lavas. Sills as thick as the Armishader intrusion appear to inhibit landslip. Thinner sills of which the Creag Langall sill is one, act as a base to the slip when approached obliquely by the glide-plane, but where this intersects the sill at a high angle it behaves as the base of a rigid block. These complications are well illustrated by The Storr Landslip (Figure 23). The effective thickness (h^1) of incompetent strata in the present Storr slip has been always between 400 and 500 ft. Thus h^1 (500 ft), d (5000 ft) and a (6°) form a series of standard values which can be compared with those of other slips.

Though there is no evidence of present movement in The Storr landslip its stability can be only temporary since removal of the toe of the slip by erosion will probably lead to some compensatory forward movement. That such is the case is evidenced by the development of a fissure back from the escarpment edge marking the position of a future slip. The process will be, however, extremely slow.

In the upper part of the landslip the component segments are clearly visible and show the characteristic tilt of the vertical axis towards the back, but older blocks have been reduced by movement and weathering to chaotic heaps of rubble. The dimensions of the segments involved in any one slip appear to be partly controlled by the thickness of the plastic medium. In general the thicker the sediments the bulkier the moving block. Speed of movement is probablypartly dependent on the mass of the lava-block above and the stage of maturity reached by the slip.

The Quirang Landslip. Situated west of Staffin Bay the Quirang Landslip (Figure 22) is more extensive though less spectacular than that of The Storr. It is the greatest landslip in Skye and for that matter, in Britain, extending 7000 ft from the scarp of Meall nan Suireamach to the coast of Staffin Bay. This too is a mature slip, stable for the most part, though in the north near Flodigarry where the toe is being actively removed by the sea there is continuous though not extensive movement. The main road near Flodigarry is frequently dislocated. This same road provides a good section through the lower part of the slip showing tumbled masses of basalt lava in a gravelly rubble consisting largely of bole and decomposed lava.

The forward thrust of the toe has profoundly disturbed the underlying Jurassic sediments in Staffin Bay and beach sections of strata ranging from the upper beds of the Great Estuarine Series to the Kimmeridge Clay show beds dipping westwards at very high angles with the development of considerable overthrusts, the most evident being that which repeats the hard sandstone of the Belemnite Sands. The normal dip of these sediments is rarely more than 15°.

The basement of this slip is formed by the thick dolerite sill which composes Staffin and Flodigarry Islands. This is faulted and stepped so that although the dip is westwards the amount of sediment intervening between the sill and the base of the lavas remains fairly constant at about 700 ft. The stable angle (a) is 6°, the angle of slope 0) almost 15° so that the limit of slip (d) should be about 7000 ft as indeed in the stable portions it is. The height of the lava column is here much the same as at The Storr, being a little over 1000 ft. Since h^1 is greater here the slipped blocks are larger, some being almost 500 ft across, e.g. The Table.

Here the backward tilt of the constituent blocks towards the scarp is seen more clearly than to the south.

The pre-glacial slip which must have extended seawards from a scarp 3000 ft east of the present position and have had an altitude of at least 2500 ft was removed by the Highland ice which came ashore north of Rigg. The toe of this slip must have extended eastwards as far as Flodigarry and Staffin Islands.

Between The Storr and the Quirang the landslip fronting the lava-scarp is mature and stable. In places additional evidence as to the date of the slip is to be found. On the east side of Loch Cuithir are moraines belonging to a small glacier which flowed in a north-easterly direction from Creag a'Lain. Farther north a small local glacier in the Smearal River has almost removed the landslip. Patches of boulder clay are to be seen here and there on the landslip, particularly south of Beinn Edra, whilst erosion of the landslip margin by streams, in particular the tributaries of Abhainn Gremiscaig, shows that it is resting for the most part on boulder clay. The greater part of this section of landslip therefore was formed after the main glaciation and prior to the late-glacial readvance.

Mature landslips like those at Loch Losait in Vatemish are cut by the 100-ft Beach. On the other hand the toe of the Quirang landslip in places overrides the 25-ft Beach.

The Ben Tianavaig Landslip. The area on the east side of Ben Tianavaig on the south side of Portree Bay affords an example of an immature and unstable landslip.

At the close of the main glaciation the eastern face of this mountain must have presented a cliff face of about 500 ft largely determined by small faults.

The lower part consisted of Jurassic sediments (Lias, Inferior Oolite and the basal part of the Great Estuarine Series).

In the present slip 1000 ft of sediments separate a thick dolerite sill from the base of the lavas. Thus the margin of the slip should be almost 10 000 ft from the cliff face. It is in fact about 3500 ft to sea-level and the toe of the slip is being actively eroded. The slope (6) is about 21° and the slip unstable and land-slipping may be expected to continue until the greater part of the mountain is removed. The radius of curvature of the slip plane (r^1) is about 1250 ft so that very large masses are involved in each sector of the slip; the most recent block to move is a rectangular mass exceeding 1000 x 1500 x 3000 ft, i.e. more than 16 million cubic yards.

The Dunn Caan (Raasay) Landslip. Although Raasay is outside the area of this Memoir the landslip east of Dunn Caan must be referred to since it is a unique example not only of a highly unstable slip but one which is known to have moved in recent times.

Compared with the Skye landslips this at Dunn Caan presents several unusual features. Firstly the cliff consists almost entirely of Jurassic sediments indicating that a lava overburden is not an essential feature of this phenomenon.

The back face comprises about 2000 ft of sediments in the middle of which is the competent Middle Lias sandstone. The history of this slip appears to have been firstly that of the beds overlying the Middle Lias (h^1 = 1000 ft), secondly slip of the L. Lias (h^1 = 1200 ft) with the Middle Lias acting as overburden, thirdly, of the Great Estuarine Series and overlying lavas (h^1 = 500 ft). The angle of slip is over 20°, and the sole extends only 3000 ft to sea-level where the toe is being actively eroded.

Thus the slip is highly unstable. On 7 August 1934 the local newspapers reported that twice within a period of six weeks a volcanic eruption had taken place in Raasay. Rising steam and smoke, showers of stones and loud rumbling noise were reported by local inhabitants. Professor A. D. Peacock, who visited Raasay shortly after the last reported occurrence, considered that the phenomena were due to stones falling down one of the very extensive fissures backing the latest slipped mass. But it seems more probable that such a spectacular disturbance was due to movement on a larger scale i.e. to renewed slipping of the unstable mass. The present author visited the locality almost 20 years later to find many new fissures and evidence of considerable and recent movement.

Other Landslips in Skye. There are several localities in northern Skye where the known presence of Jurassic rocks beneath the lavas has resulted in landslip and others where landslip suggests the existence of completely hidden sediments. For example on the north side of Loch Losait in Vaternish and on the west side of Dunvegan Head in Duirinish are typical slips but no sediments are exposed. On the other hand the landslip west of Waterstein Head in Moonen Bay contains fragments of Jurassic rocks though the outcrop is entirely covered by scree and slip.

The Conon inlier east of Uig is an amphitheatre of Corallian and Kimmeridge Clay shales surrounded by a wall of lava. Landslip has taken place all round the margin although the lava-base cannot anywhere be more than 20 ft or so above the floor of the inlier.

Rockfalls and Scree. Everywhere the lava-scarp and sill outcrops produce extensive scree. This is too commonplace to remark except that in two localities i.e. at The Storr and below Ben Essie, 1½ miles N.E. of Portree, the scree has become famous for its zeolites. In both places extensive suites of minerals have been obtained. Heddle (1901) records apophyllite, stilbite, natrolite, mesolite, thomsonite (variety fareolite), chabazite, levynite, laumontite and gyrolite.

Rockfalls are less common and are mainly formed by debris from the scarp of a columnar dolerite sill. Two outstanding examples are ½-mile S. of Rubha Garbhaig, Staffin, where the sea-cliff at the back of the 25-ft Raised Beach is a dolerite sill composed of large regular columns. These on breaking off have formed a rockfall composed of more or less cubical blocks many feet across which have accumulated as a loose aggregate and containing large cavities. This rockfall is later than the 25-ft Beach which it covers from cliff to coast.

The fall resembles landslip in that it is due to the presence of Jurassic sediments separating it from the underlying non-columnar dolerite sill which forms the present sea-cliff. But the blocks composing the fall lie entirely at random and there is no sign of the underlying pattern of a landslip.

A similar fall has developed under Cnoc Roll just south of Duntulm and is also formed by rocks from a columnar basalt sill resting on Great Estuarine sandstones and shales. This fall is much fresher in appearance than that of Rubha Garbhaig and is in continual movement. The Uig–Kilmaluag road which crosses it is frequently shifted and broken.

Diatomite. Diatomite (Kieselguhr), a fresh-water lake deposit consisting largely of the remains of microscopic unicellular plants, is found in many places in Skye. Mixed with the siliceous skeletons of the diatoms is a varying amount of clay and peaty matter. The deposit is usually greenish in colour when wet but almost pure white and is very fine-grained and uniform in texture. All the occurrences seen suggest that this is not a deposit being formed at the present time for they are all covered with clayey or peaty soil.

At Loch Cuither, the most extensive deposit known in Skye, the diatomite, rests on moraine which is itself on landslip. The deposit is thus later than the latest glaciation and earlier than the peat.

The earliest post-glacial period (Pollen Zone I) was apparently wet and one of extensive solifluxion. In Skye this was probably the period of landslipping immediately following the retreat of the Highland ice. Pollen Zone II, with a dryer milder climate (Allerød) left no recognizable deposits in Skye, but Pollen Zone III, showing a return of a colder, wetter climate and a second period of solifluxion, is perhaps the period of the Scottish Re-advance and the development of valley glaciers.

Later came a climatic optimum during which it is suggested that diatomites were laid down. This may also be the period during which the Chara Marls which are found scattered all over Britain in a similar stratigraphical position to the diatomites but in a calcareous environment, were formed. Certainly a warmer climate than that at present obtaining is suggested.

Return to a less mild and wetter climate put an end to the diatomite-rich pools and instead peat formation began.

Diatomite is first recorded in Skye by Wilson and Macadam in 1886, but had been found earlier in Mull (Gregory 1853, 1854) and Lewis (Burgess 1882, Rattray 1887).

The diatom flora is rich in species; Wilson and Macadam (1888) recorded 78 species belonging to 23 genera from Loch Quire (Cuithir), Sartil (west of Stenscholl), Loch Snuisdale (Sneosdal) and Uig (Loch Chaluim Chille). Almost half the known Quaternary genera are represented. The Raphidae are represented by the genera *Amphora*, *Cymbella*, *Stauroneis*, *Pleurosigma*, *Navicula*, *Gomphonema*, *Rhoicosphenia*, *Achnanthes*, and *Cocconeis* ; the Pseudo-Raphidae by *Epithema*, *Eunodia*, *Synedra*, *Fragularia*, *Diatoma*, *Denticula*, *Cymatopleura*, *Surirella*, *Campylodiscus* and *Nitzschia*; and the Crypto-Raphidae by *Cyclotella*, *Melosira* and *Euodia*. For a full list of species and their distribution Wilson and Macadams's account should be consulted.

Sartil is ¾-mile W. of Brogaig on the north side of Staffin-Uig road. Loch Cuithir is about 1 mile N.E. of Creag a'Lain, Loch Sneosdal is 1½ miles due E. and Loch Chaluim Chille ¾-mile W. of Balgown, all in Trottemish. Other localities where diatomite has been recorded are Loch Beannichte and a nearby dry pond on the Score Horan landslip, Loch Mealt, and Loch Cleat ¼-mile E. of Duntulm.

The composition of diatomite is discussed on p. 200.

Alluvium. Freshwater alluvium occurs chiefly as narrow strips along stream courses and the silted-up basins of lochans. The largest tract is that on the site of the old Loch Chaluim Chille, north of Uig in Trottemish. This Loch originally over one mile long and 90 ft above sea-level, occupied a glacially scoured hollow in dolerite sill which probably was once part of the 100-ft Beach, from which it is separated by a ridge of boulder clay now breached by the outlet stream and by artificial drainage channels. After unsuccessful attempts in 1715 and 1763 the loch was finally drained in 1824.

Additional channels were dug in 1947. The soil is peaty but nevertheless many acres of valuable pasture have been recovered.

Blown Sand. At An Corran, the promontory bounding Staffin Bay on the east, are large accumulations of sand both on the beach and heaped up against the cliff.

As a result of south-easterly gales the north-face on the eastern side of the promontory has been thoroughly sand-blasted. The dolerite of the cliff is highly polished and pebbles having a typical dreikanter shape are not uncommon on the beach.

Olivine Sand. The Tertiary basalt lavas and dolerite sills are frequently olivine-rich. In areas where these form part of the coast dark-green olivine and augite sands occur. Probably the best example in Skye is that described by Walker (1932) in Lub Score, Duntulm.

Musical Sands. The oil-shale which is found at the base of the Great Estuarine Series in the Portree area is replaced further north by a black sandstone composed of quartz grains unusually uniform in size and shape. This sandstone forms the north and north-eastern shore of Loch Leathan, the most northerly of the two lochs south-east of The Storr. The rock has been bleached by the overlying peat and weathers to a clean white sand which emits a musical note when struck. It is thought that the uniformity of grain-size causes sympathetic resonance to be set up so that the small vibrations caused by walking on the sand are amplified to audible volume.

Nullipore 'Sands'. In certain areas round the west coast of Skye the calcareous alga Lithothamnion calcareum Aresch flourishes in great abundance and broken fragments of the thallus form dazzling, creamy-white beaches which are composed almost exclusively of this material.

In Vaternish, Haldane (1937, p. 79; 1939, p. 442) has recorded beaches of Lithothamnion debris (commonly known as 'Coral Sands') from three bays, the largest known as Camas Ban, which lie north of Rubha na Gairbhe on the east side of Loch Dunvegan. At the most northerly of these is a small spit of sand and pebbles which connects the Lampey Islands with the mainland and which is uncovered at lowest tides. On it the unbroken algal colonies grow in clusters up to a few inches in diameter.

This kind of environment appears to favour the growth of Lithothamnion since another rich colony, that ½-mile N. of Ord in Sleat is found in a similar position—a spit of sand joining a small unnamed island to the mainland. Colonies of L. calcareum are not uncommon on the west coasts of England, Ireland and Scotland in the upper and lower sub-littoral zone. In places they have been dug for agricultural lime, Skye occurrences are known in Loch Bracadale at Camas Ban and Colbost Point.

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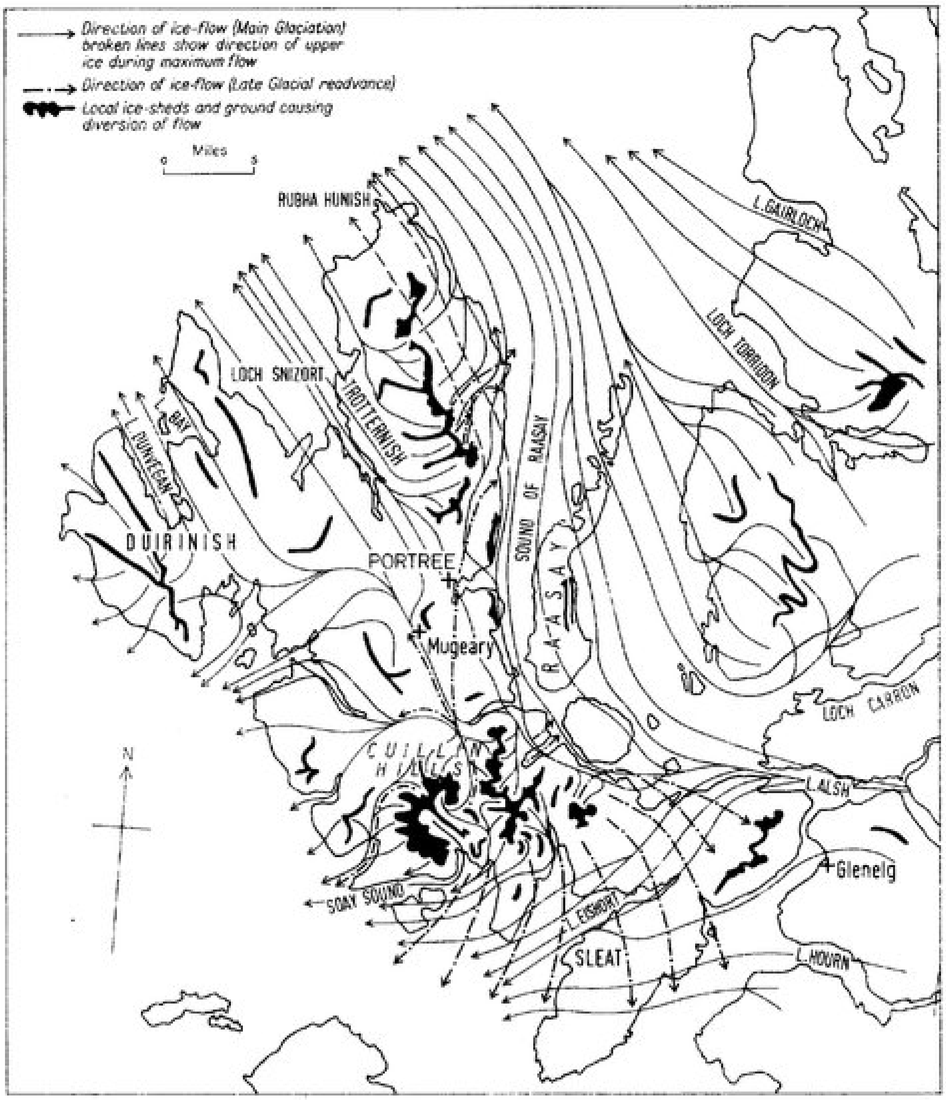


FIG. 19. *Sketch-map showing movement of ice and other glacial features in Skye*

(Figure 19) Sketch-map showing movement of ice and other glacial features in Skye.

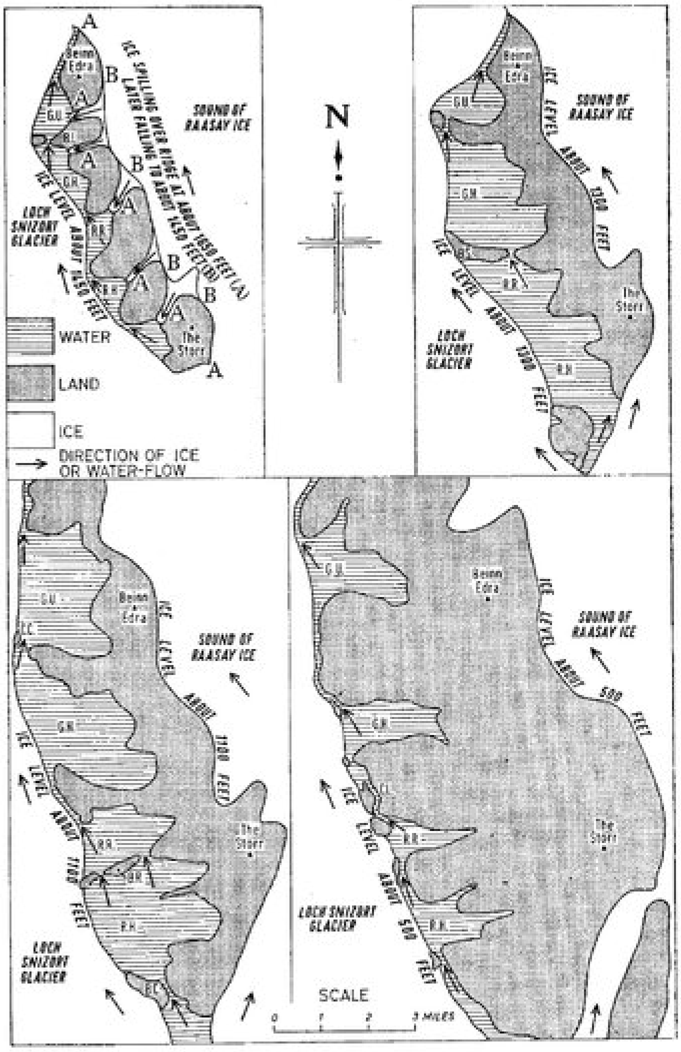


FIG. 20. *Glacial retreat stages in Trotternish, Isle of Skye*
BC, Bealach a'Chaol-reidh; BL, Beinn an Laoigh; BR, Beinn an Righ; BS, Beinn a'Sga; CC, Creag Chragach; CL, Creag an Locha; GH, Glen Hinnisdal; GU, Glen Uig; RH, River Haultin; RR River Romesdal

(Figure 20) Glacial retreat stages in Trotternish, Isle of Skye. BC, Bealach a'Chaol-reidh; BL, Beinn an Laoigh; BR, Beinn an Righ; BS, Beinn a'Sga; CC, Creag Chragach; CL, Creag an Locha; Gil, Glen Hinnisdal; GU, Glen Uig; RH, River Haultin; RR River Romesdal.

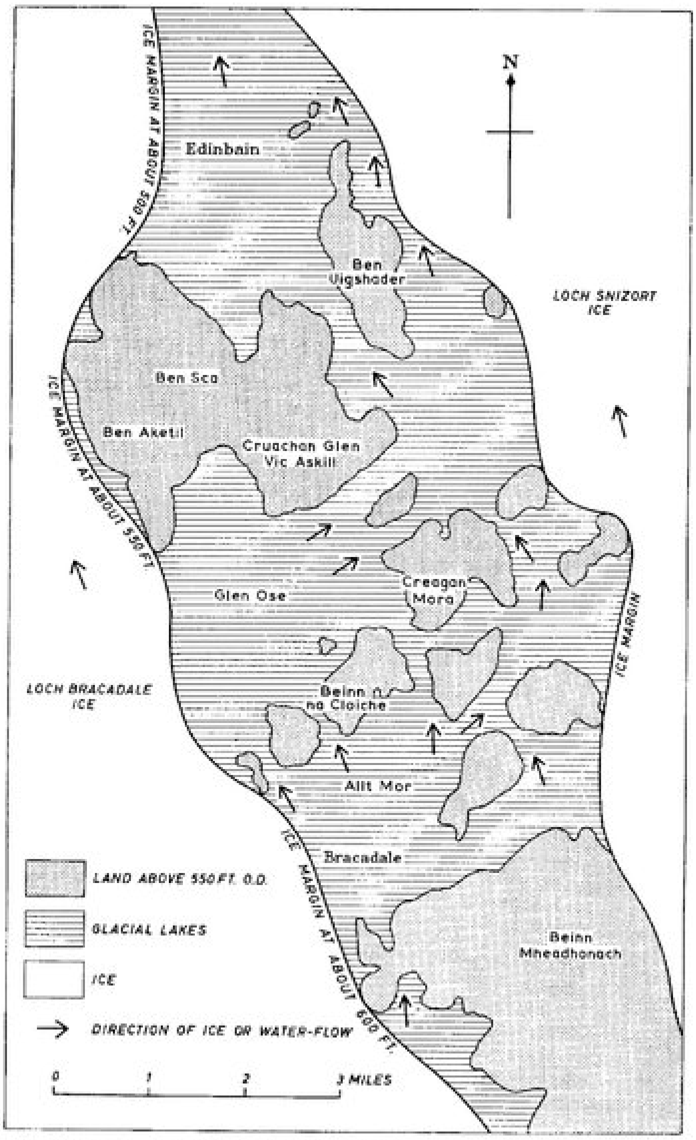
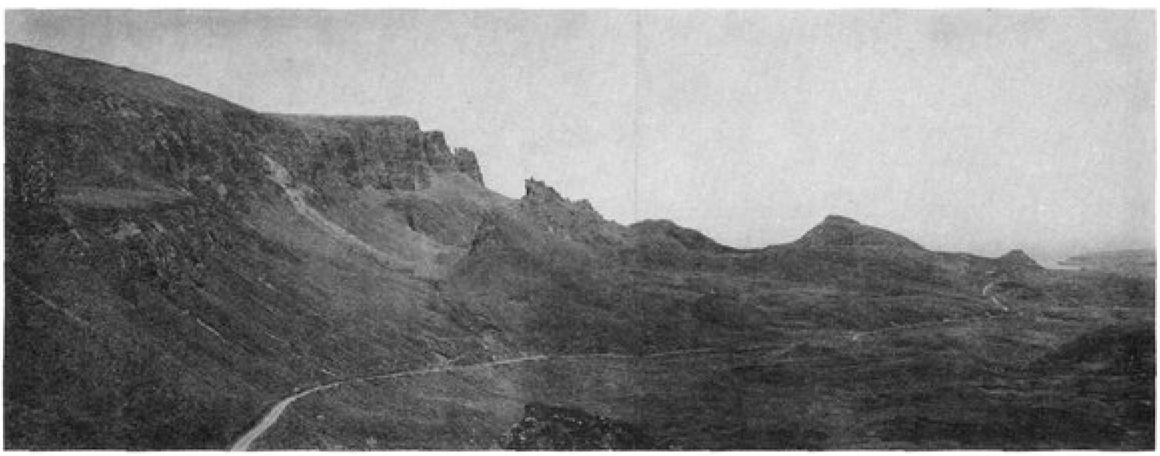


FIG. 21. *The Bracadale-Edinbain late-Glacial lake system at the 550-ft retreat stage*

(Figure 21) The Bracadale–Edinbain late-Glacial lake system at the 550-ft retreat stage.

Geology of Northern Skye (Mem. Geol. Surv.) PLATE IV



(C3899-3900)

THE QUIRANG, LOOKING NORTH-EAST FROM UIG ROAD

Escarpment of Tertiary lavas with extensive area of landslipped masses of Tertiary volcanic material. Staffin is on the extreme right

(Plate 4) The Quirang, looking north-east from Tug road. Escarpment of Tertiary lavas with extensive area of landslipped masses of Tertiary volcanic material. Staffin is on the extreme right. (C3899–3900).

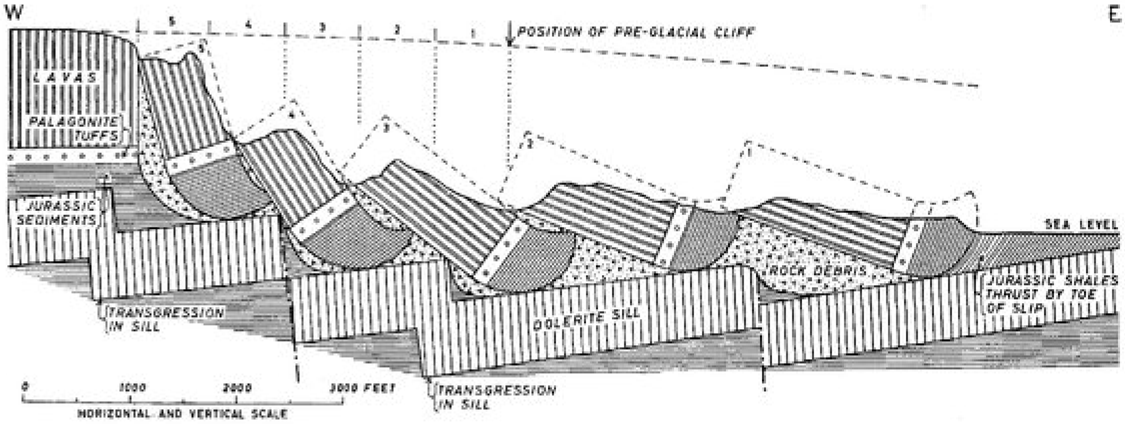
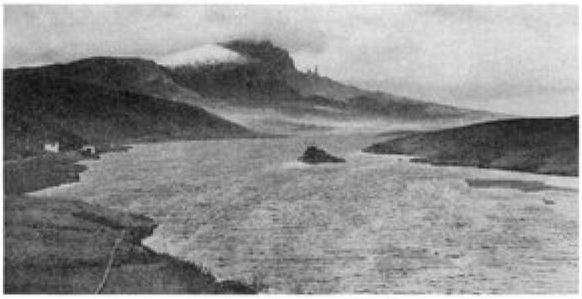


FIG. 22. *Section of the Quirang Landslip*

(Figure 22) Section of the Quirang Landslip.

Geology of Northern Skye (Mem. Geol. Surv.) PLATE I (*Frontispiece*)



(D3173)

A. THE STORR FROM THE SOUTH; PART OF THE TROTTERNISH LAVA-SCARP

(D3172)

B. LANDSLIP TOPOGRAPHY SOUTH OF FLODIGARRY HOTEL

(D3171)

C. STAFFIN BAY FROM THE NORTH

(Plate 1) A. The Storr from the south;. part of the Trotternish lava-scarp. Landslipped lavas and Jurassic sediments form the ground to the right of the escarpment. In the foreground a glacially eroded hollow in Jurassic sediments is occupied by the two lochs Fada and Leathan, which supply water for the Bearreraig Hydro-electric Station. (D3173, replaces MN20706); B. Landslip topography south of Flodigarry Hotel. In the foreground slipped masses of Tertiary lava and Jurassic sediments. In the distance the headland of Rubha Garbhaig is of Tertiary dolerite sills in Jurassic

sediments.(D3172, replaces MN20704); C. Staffin Bay from the north. On the foreshore are upper Jurassic sediments. In the middle distance Staffin Point (An Corran) is formed by two dolerite sills with Jurassic sediments between them. Behind the storm beach the 25-ft and 50-ft beach flats are well seen and correspond with the rock notches seen in An Corran. (D3171, replaces MN20705) Frontispiece.

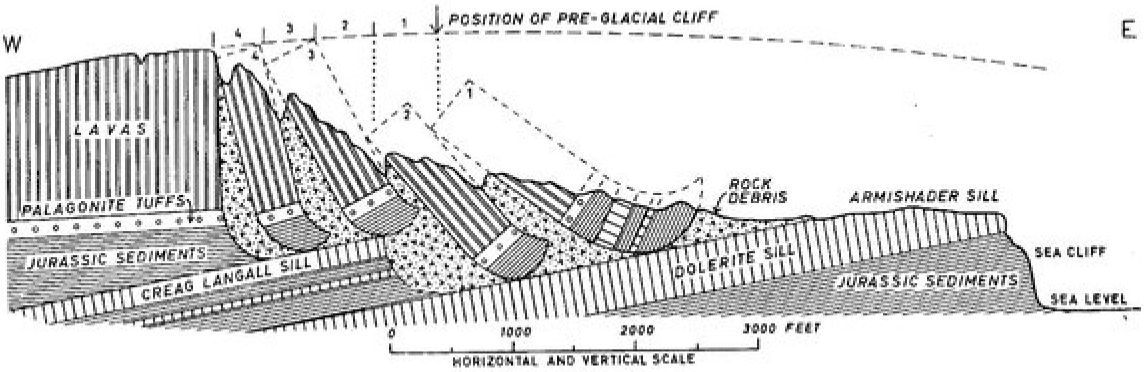


FIG. 23. *Section of The Storr Landslip*

(Figure 23) Section of The Storr Landslip.