Glaciations and stadials, Palaeogene volcanic districts of Scotland

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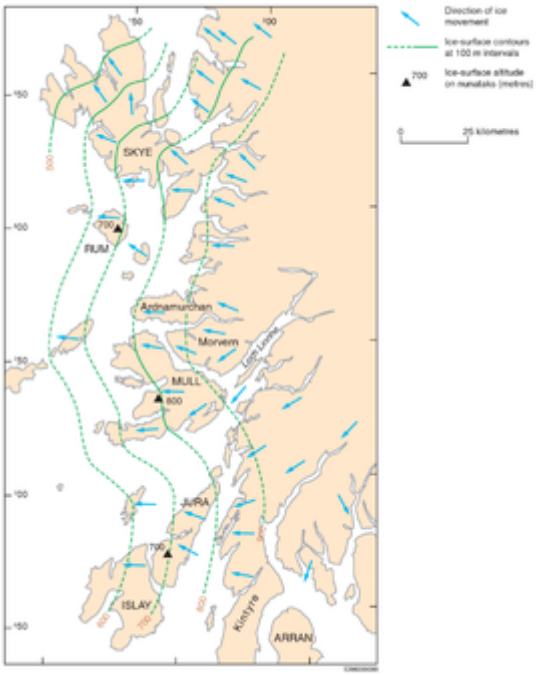

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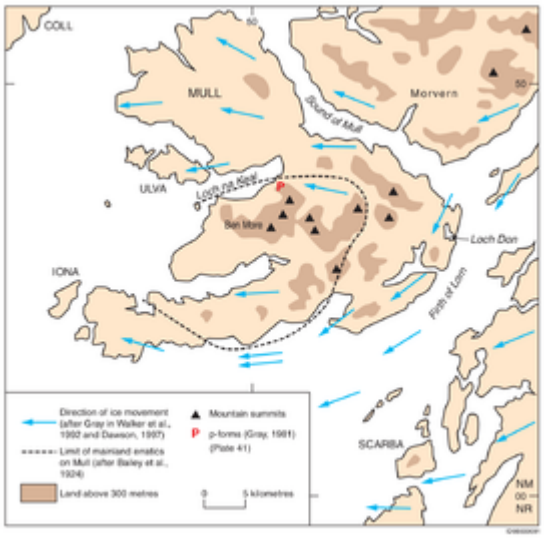

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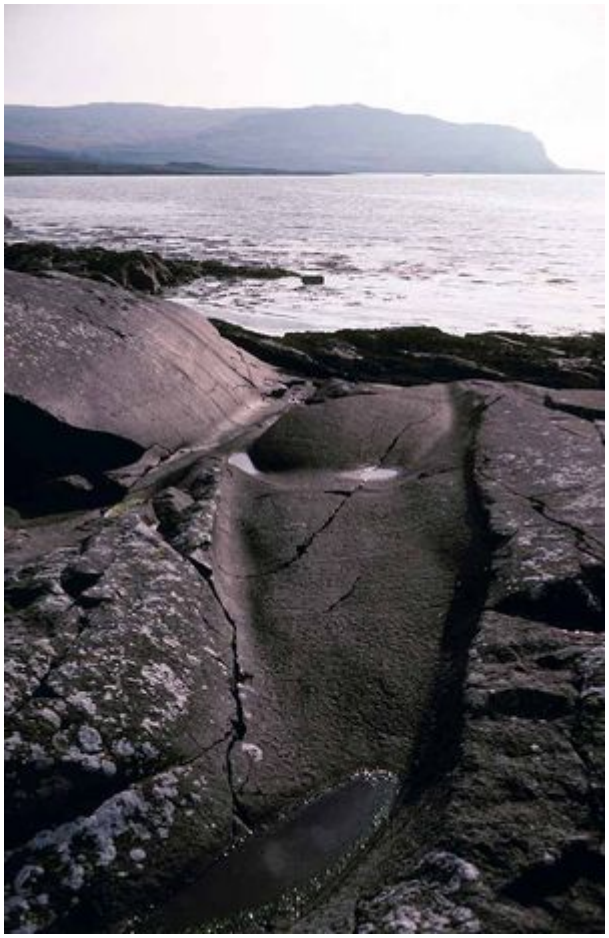

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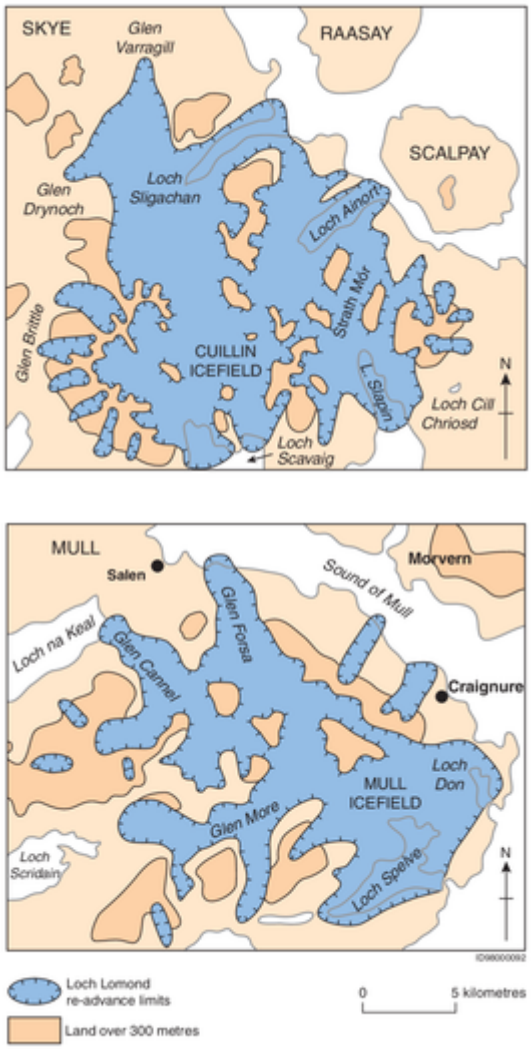

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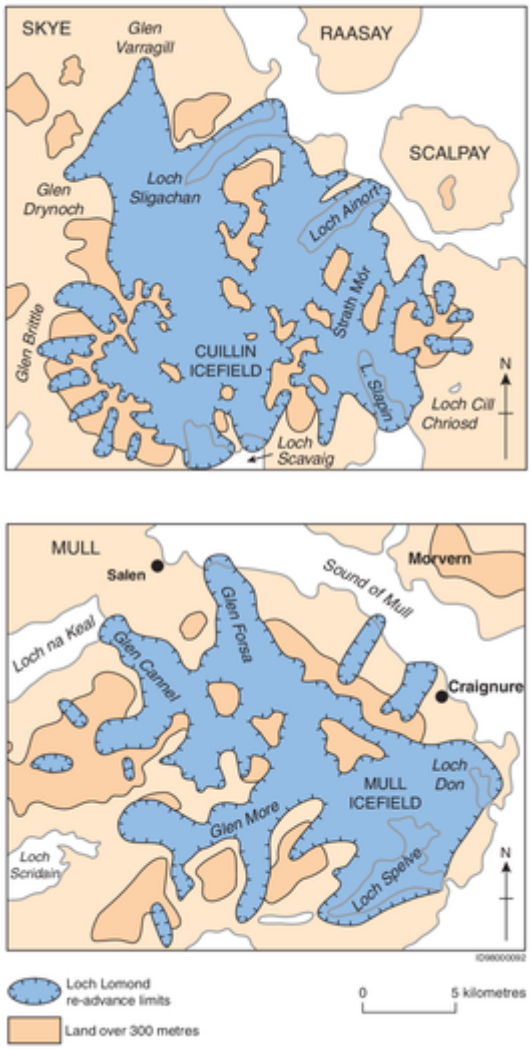

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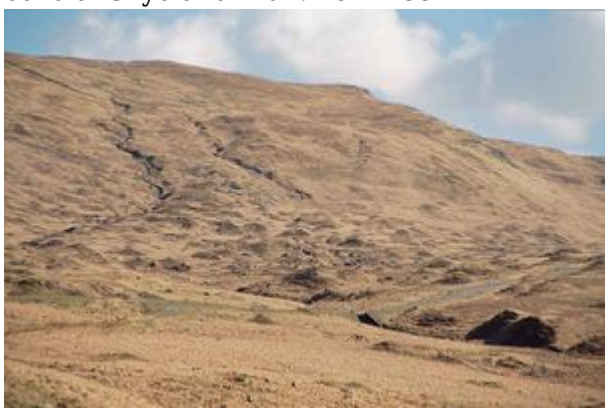

Hummocky morainic drift, Glen More, Mull. P580488

An indication of some of the glaciations that occurred prior to the Main Late Devensian Glaciation is provided by high-level, marine-cut platforms and notches in clifflines covered by glacial deposits of supposed Late Devensian age, for example on Skye and Rum (see below). These features must have formed while the land was substantially depressed relative to sea level, suggesting that an extensive ice sheet existed prior to the Late Devensian (Sutherland and Gordon, 1993). Support for this suggestion comes from St Kilda, where there is evidence of four cold periods (Sutherland et al., 1982). The oldest till on St Kilda is the well-consolidated Ruaival Drift which is up to about 14 m

thick. This is overlain by the Abhain Ruavail sandy deposits, which are less than 55 cm thick but contain organic remains that show interstadial characteristics. A minimum radiocarbon date obtained from these deposits indicates that they predate the Late Devensian glacial maximum. Exotic erratics in the till on St Kilda are limited to rare, small fragments of red feldspathic sandstone. However, rounded iron-stained quartz grains and assemblages of minerals that are characteristic of contact and regionally metamorphosed rocks have been recovered from stream sediments (Harding et al., 1984). These exotic erratics, minerals and quartz grains most likely came from Mesozoic or older (possibly Torridonian) sedimentary rocks; some possibly came from rocks contact-metamorphosed by the central complex and now concealed beneath the sea east of St Kilda. The erratics were incorporated in a till that formed during an earlier glaciation, pre-Ruaival Drift, when mainland ice covered the islands. After reworking during two later valley glaciations, these materials were finally released into stream sediments during the Holocene.

The scale of some of the erosional landforms that are attributed to glaciation also provide compelling evidence for a pre-Late Devensian glaciation. The likely rates of erosion beneath an ice sheet are estimated at about 1 mm/year. Thus, it is clear that some large corries could not have formed entirely during the Main Late Devensian and Loch Lomond Stadial glaciations, because the volume of moraines associated with the later glaciation are considerably less than the volume of the corries from which the debris was derived.

Dimlington Stadial

Main Late Devensian Glaciation

The extent of former glaciers has been deciphered by establishing the source of glacial erratics in the tills and moraines, and by recognising glacial trimlines. Trimlines define the highest levels to which glacier ice has actively eroded, or trimmed, frost-shattered bedrock and debris on protruding peaks (nunataks). Above the trimline, frost-shattered bedrock will persist but on the lower slopes, below the trimline, the bedrock will be glacially moulded and striated (P580489). Glacially transported boulders will be present below the trimline but otherwise most of the loose material that characterises nunataks will have been removed. The mineralogy of weathered materials may differ; gibbsite is common in the clay fraction of debris on former nunataks but it is rare, or absent, below the trimlines. Subsequent events may obscure or eliminate the evidence of trimlines, for example the downslope movement of scree debris (Ballantyne, 1997, 1999).

The Inner Hebrides and Arran were almost entirely covered by a thick regional ice sheet during the early part of the Late Devensian (P914157). The ice sheet extended west of the Inner Hebrides, but probably not as far as St Kilda, which supported local glaciers. Later, as the ice sheet diminished, independent ice domes formed over the Outer Hebrides, and the islands of Skye, Mull, Arran and probably Rum.

Skye was an important centre for ice sheet glaciation and the Cuillin is an outstanding area for the study of glacial geomorphology (e.g. Gordon and Sutherland, 1993). The distribution of glacial striae, ice-moulded rocks and erratics all indicate that the Cuillin and the Red Hills were not over-ridden by ice from the Scottish mainland during the Main Late Devensian glaciation. Instead, independent ice caps developed and these deflected the ice that flowed westward from the mainland. The distribution of glacial erratics from the mainland over a range of altitudes on Raasay and Scalpay to the north, and on Soay to the south, and their absence from upland areas of central Skye, defines the area unaffected by mainland ice (Harker, 1904, but see also Ballantyne, 1990).

The former height of the Main Late Devensian ice cap has been established by the mapping of glacial trimlines around mountains that stood above the ice as nunataks in central and northern Skye (Ballantyne, 1990). High-level, Main Late Devensian trimlines have been recognised on the higher peaks of the Cuillin and Blà Bheinn, on certain of the high peaks in the Red Hills and on Healabhal Bheag in western Skye (Dahl et al., 1996). On the Trotternish peninsula, the Main Late Devensian trimline descends from 580 to 610 m OD in the south to 440 to 470 m OD in the north, within a distance of about 24 km. Frost-weathered bedrock (regolith) is common above the trimlines in the summit regions of the Cuillin and the Red Hills. In these areas relict solifluction sheets and lobes of Late Devensian (Main Late Devensian and/or Loch Lomond Stadial) age are also preserved, for example on Druim na Ruaige, on the west side of Beinn Dearg in the western Red Hills. Talus slopes of similar age are preserved on the Strathaird peninsula, on Ben Méabost and An Càrnach. These features are identified by their relatively complete vegetation cover when compared with features forming at the present day. Some of the extensive landslips on the Trotternish peninsula also predate the Holocene (see below). In the later stages of the Main Late Devensian Glaciation, as the pressure of the mainland ice decreased, the ice cap over the Cuillin and the Red Hills was able to spread outwards. Supporting evidence comes from the Allt Beinn Deirge area, south-east of Beinn na Caillich, where unconsolidated deposits outside the limit of the later, Loch Lomond Stadial glaciation have been deformed by ice moving in an easterly direction (Le Coeur and Kuzucuoglu, 1992).

The mountains of south-central Rum may have supported an independent ice dome during the Main Late Devensian Glaciation. However, the distribution of striae and erratics on the lower ground, and on all the adjacent islands, show that the other Small Isles were over-ridden by mainland ice which was diverted around the mountains of Rum. On Eigg, striae indicate westward movement of ice, with possible diversion around An Sgùrr. There are no convincing striae on Muck, but on Canna and Sanday striae indicate ice flow towards the north-west and west, respectively. Amongst the distinctive erratics found in the Small Isles are:

- Moine gneiss on Rum
- gneiss, limestone of both Cambro-Ordovician and Jurassic age, and Torridon Group sandstone on Canna and Sanday
- gabbro, basalt, gneiss, mica-schist, quartzite, Torridonian and Mesozoic sandstone on Oigh-sgeir (suggestive of derivation from the mainland, Rum and the surrounding sea bed)
- Moine gneiss on Eigg and Muck

Mainland erratics have not, however, been found on the high ground in northern Eigg. Till deposits attributable to the Main Late Devensian Glaciation are common on Rum and small patches of till occur on the other islands, but glaciofluvial deposits are everywhere rare. There are two prominent north-east-trending morainic ridges in north-east Eigg. The eastern ridge is most likely part of a large crag-and-tail structure produced by ice flowing around the north end of Eigg, whereas the western ridge is a lateral moraine formed as the same ice mass decayed. Good examples of kettleholes occur in Cleadale, on Eigg.

The glaciation of Mull during the Loch Lomond Stadial (see below) removed much of the evidence for earlier glaciations from the central parts of the island. A local ice dome was established over the hills of central Mull during the Main Late Devensian Glaciation, diverting the mainland ice down Glen Forsa and south-west along Glen More and Loch na Keal (Bailey et al., 1924; P914158). Ben More and other high peaks probably formed nunataks (Ballantyne, 1999).

On the south side of Loch na Keal, for some distance either side of the outlet of the Scarisdale River, bare basalt slabs on the shoreface have been moulded into a striking assemblage of smoothed, fluted, channel-like forms a metre of so in depth and a few metres in length (P580490). These are

termed 'p-forms', and are excellent examples of structures that probably originated by a combination of erosion by glacial meltwaters and overlying ice (Gray, 1981; Walker et al., 1992). At the northern end of Loch Don, deltaic sands and gravels were deposited where south- and south-east-flowing meltwater streams entered the sea, to form the lower levels of the 'Loch Don Sand-Moraine' (Bailey et al., 1924; Benn and Evans, 1993; see below).

The Ardnamurchan peninsula was completely over-ridden by mainland ice during the Main Late Devensian Glaciation but apparently escaped renewed glaciation during the Loch Lomond Stadial. Evidence for ice movement from the south-east is provided by numerous striae and by the distribution and character of glacial erratics, including many derived from the Strontian Granite Pluton which occur, for example, on Ben Hiant. Much ice sculpting of the bare rocks has occurred and the hills formed by the gabbroic ring-intrusions now provide numerous examples of roches moutonnées.

The mainland ice sheet centred over the Highlands extended across Arran for most of the Main Late Devensian Glaciation. However, by about 13000 yearsBP, the southern limit of the ice sheet on Arran lay along a line from Imachar to Corrie, with a detached remnant over the high ground to the south. By 12 400 years BP, the island was free of mainland ice, although a local ice cap may have persisted on the northern hills. The south of Arran escaped glaciation during the Loch Lomond Stadial and, consequently, deposits of an earlier glacial episode are widely preserved in that area. Reddish till, coloured by debris from the New Red Sandstone, is commonly exposed in river and stream sections, and in the Sliddery Water and Kilmory Water a clay bed near the base of the till contains a perfectly preserved shelly fauna (Tyrrell, 1928). Enigmatically, this fauna exhibits both Arctic and temperate characteristics (Sutherland, 1981). A large variety of features associated with the decay of the Main Late Devensian ice are preserved in the low ground of south-west Arran (Gemmell, 1972), including a succession of kame terraces north-east of Shiskine and drumlins near Blackwaterfoot. South-west-draining meltwater channels occur on the western slopes of Beinn Tarsuinn (near Blackwaterfoot) and south of Glen Iorsa. Moraines in Benlister Glen are probably of comparable age, recording the retreat of the Main Late Devensian ice. At the head of Glen Cloy, a raised shoreline estimated to date from about 12 000 BP cuts outwash from moraines in the glen. Deposits of gravelly till derived from readily weathered granite are restricted to the northern hills and the mouths of the valleys draining the granites. These deposits, which are up to 15 m thick, probably formed as the local ice decayed, after Arran became isolated from the mainland ice.

Ailsa Craig, 20 km south of Arran, lay in the path of a south-flowing stream of mainland ice that helped mould it into its present steep-sided dome shape. The distinctive blue-grey Ailsa Craig microgranite is widely distributed as glacial erratics and ice-rafted stones on coasts bordering the southern Firth of Clyde, in the north of County Antrim and on both sides of the Irish Sea as far south as Cork and Pembroke (Harrison et al., 1987). The distinctive pebbles and cobbles are also found on beaches in western Arran, where they may have been carried by drifting icebergs during the decay of the Firth of Clyde ice sheet.

On St Kilda, the Village Bay Till postdates the Abhainn Ruaival organic sand, from which it is separated by up to 3 m of detritus of periglacial origin (the Ruavail Head). The till is generally less than 4 m thick and the upper part lacks a true matrix, consisting only of closely packed angular boulders and smaller fragments, all of local origin.

Windermere Interstadial

Deposits relating to the warm Windermere (Late-glacial) Interstadial (13 000 to 11 000 years BP; Table 17) are of limited occurrence in the district. Sediments at the base of a succession sampled from Loch an t-Suidhe on the Ross of Mull, yielded a 14C age of 13 100 years BP, while clays with a molluscan fauna of interstadial affinities have been found in a few localities, for example on the floor of Loch Arienas north of Loch Aline in Morvern. Sedimentary deposits from this period are also found on the south shore of Loch Spelve, Mull (Walker et al., 1985), and at Kinlochspelve, where shells have been dated at 11 330 ± 170 years BP. The latter deposits were subsequently disturbed by a glacier. In general, these beds may correlate with the Late-glacial Clyde Bedsof the Midland Valley of Scotland (e.g. Peacock, 1981).

Loch Lomond Stadial

During the Loch Lomond Stadial (11 000 to 10 000 years BP; Table 17), small ice fields and glaciers became re-established in the mountainous areas of the district, leading to renewed valley and corrie glaciation, and to the modification or erosion of older glacial deposits; a distinctive suite of deposits is associated with this glaciation.

In Skye, glacial activity was centred over the Cuillin and the western Red Hills (P914159a). In addition, there were two small glaciers in north-east-facing valleys on the Trotternish escarpment and glaciers in Kylerhea Glen and Glen Arroch in eastern Skye. The extent of the Cuillin ice field has been defined by the distribution and orientation of glacial striae, roches moutonnées and moraines, and by the lithologies and distribution patterns of glacial erratics. Outlet glaciers flowed northwards down Glen Sligachan into glens Drynoch and Varragill, and into Loch Sligachan;others were located along the north sides of the western and eastern Red Hills. To the south, a large glacier flowed into Loch Slapin and outlet glaciers formed in Srath na Creitheach and from Loch Coruisk into Loch Scavaig. Nunataks protruding through the icefield included the main ridge of the Cuillin together with Sgùrr na Stri and Blà Bheinn, and Marsco and Glamaig in the western Red Hills.

Corries such as Coir' a' Ghrunnda, Coire Lagan, An Garbh-choire and Coir'-uisg, with their precipitous sides, rock falls and striated, ice-scoured rock in the corrie floors, provide some of the most spectacular glacial landforms in the district (P521672, P580489). Moraines and glacial trimlines generally help to define the extent and thickness of the corrie glaciers, although in the Red Hills this evidence is generally obscured by scree. Tills are common, and typically have a sheet-like geometry within topographical depressions, although more-linear deposits are also present in the form of moraine ridges, as in the area around Sligachan. Excellent examples of moraines formed at glacier margins occur at the mouth of Coir' a' Ghrunnda in the Cuillin and at Coire Fearchair in the eastern Red Hills. Hummocky moraine is common, containing material supplied from both subglacial and supraglacial environments. In Gleann Torra-mhichaig, east of Glamaig, chains of hummocks oblique to the valley floor are attributed to intermittent bulldozing by advancing ice during the 'overall decay' of the valley glacier. In Coire Choinnich at the head of Loch Ainort, a chaotic assemblage of hummocks, non-aligned ridges and fluvial terrace accumulations resulted from the in-situ decay of less-active glacier ice.

Depositional features from the Loch Lomond Stadial are abundant in the mountains in the southern half of Rum, where there is evidence that twelve local glaciers formed. One occupied Coire nan Gruund and, at the lower end of the corrie, the Kinloch—Dibidil Path crosses a well-defined moraine made of ultrabasic blocks derived from the east side of Hallival and Askival. Rock slabs north of the

moraine show north-north-east-directed glacial striae from the Loch Lomond Stadial glaciation cutting across north-west-directed striae from the earlier, Main Late Devensian Glaciation. In upper Glen Harris, linear moraine ridges parallel to the direction of ice movement are strikingly developed in Atlantic Corrie.

A wealth of glacial erosional and depositional features is preserved on the Western Granite hills of Rum, including a fine arcuate terminal moraine composed of microgranite blocks north of Sron an t-Saighdeir. There is also a superb blockfield, of supposed Loch Lomond Stadial age on the southern slopes of Orval and Sròn an t-Saighdeir (Ballantyne and Wain-Hobson, 1980). This has been modified by later solifluction processes, with the development of stone stripes on the lower, steeper slopes.

During the Loch Lomond Stadial, Mull supported an ice sheet that extended from Loch Bà to Loch Spelve, with Beinn Talaidh and other high hills in central Mull forming nunataks (P914159b). The most striking scenic features of Mull attributable to glacial processes date from this episode. Glaciers from the main area of ice reached the sea at several points, as did local glaciers flowing north-north-east off the hills into the Sound of Mull in the vicinity of Craignure. Outwash deposits formed at the foot of Loch Bà and Glen Forsa. Terminal moraines are present at Kinlochspelve and at the northern end of Loch Don, where Late-glacial deltaic deposits of the Loch Don Sand Moraine (see above) are partly covered by till from the Loch Lomond Stadial glaciation (Benn and Evans, 1993). Inland, there are widespread deposits of hummocky morainic drift, for example east of Craig in Glen More (P580488). Linear drift deposits, or fluted moraines, occur at several localities; well-defined examples on the north-west shoulder of Sgurr Dearg were formed by glaciers converging to the north-west.

The northern hills of Arran supported valley glaciers during the Loch Lomond Stadial and the till formed at this stage augmented earlier till (see above). Valley glaciers from a small ice field centred on the head of Glen Iorsa extended down glens Catacol, Easan Biorach and Iorsa. Glaciers also occupied North Glen Sannox and the upper parts of glens Rosa and Sannox. Small corrie glaciers formed on the eastern side of the Goat Fell ridge and north-west and north of Beinn Bharrain. There are two generations of moraine in the northern hills. One group of fairly well defined moraines occurs at low levels throughout the area and is covered with grass and heather, for example in lower Glen Rosa. The second group is formed of fresh moraine ridges, studded with boulders and relatively free of vegetation. The latter moraines generally occur above 450 m OD, and are almost entirely restricted to corries in the east of the northern hills, for example at the head of Glen Rosa, on the north side of Casteal Abhail, and to the south-east of Beinn Tarsuinn. Substantial corrie glaciers evidently persisted in the eastern part of the northern hills after most of the ground to the west had become free of ice.

Periglacial deposits are widespread on St Kilda. Hill slopes are mantled by frost-shattered debris, together with inactive solifluction lobes. Two major protalus ramparts north and west of Village Bay overlie the youngest till. On the basis of the relative freshness of the clasts and their stratigraphical relationships, the protalus ramparts are thought to have developed during the Loch Lomond Stadial, the last time that severe cold affected St Kilda.

References

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