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# The Quaternary deposits and glacial history of the area around Inchnadamph, Sutherland

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BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/03/120

# The Quaternary deposits and glacial history of the area around Inchnadamph, Sutherland

Tom Bradwell

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# Foreword

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The Assynt Estate are thanked for allowing unrestricted land access.

# Contents

# Summary

This report describes the Quaternary geology of the 1:25,000 sheet NC22, covering the area around Inchnadamph, Sutherland. The extent and distribution of glacial deposits shed light on the glacial evolution of the Assynt district. Consequently, a new model of Late Devensian deglaciation is proposed.

# 1 Introduction

Assynt possesses some of the most dramatic glacial scenery in Scotland. The high ground around Ben More Assynt and Beinn Uidhe would have been ice accumulation areas during the last glaciation; whilst the Lewisian Gneiss landscape is classic 'cnoc and lochan' terrain, scoured by an ice sheet flowing from east to west.

NC22 includes the ground from near the summit of Conival in the east to the Quinag ridge in the west. Inchnadamph is the only settlement. The map sheet includes the eastern half of Loch Assynt, an overdeepened lake basin. The sea protrudes into the fjord Loch Beag on the northern edge of the sheet.

The area is covered by the six-inch county series maps *Sutherland 60* and *71* and was originally mapped by Officers of the Geological Survey between 1886-1900 (BGS, 1904, 1907). Since 1923 the area has appeared on the Assynt Special Sheet (solid and drift). However, the Quaternary geology of the area has never been comprehensively mapped or described in a geological memoir. The glacial history of the area has been studied, in whole or in part, by Charlesworth (1955), Sissons (1977), Lawson (1983, 1986, 1990), McCarroll *et al*., (1995) and Ballantyne *et al*. (1998). These authors' findings are summarized in section 4 of this report.

# 2 Quaternary Deposits

The following Quaternary deposits were identified during field mapping in 2002.

## 2.1 TILL

Till – a primary glacigenic deposit – is relatively restricted in the Assynt district. Interestingly, there appears to be a general relationship between till occurrence, or at least till thickness, and the underlying geology. Till, as opposed to morainic deposits, chiefly occurs on the Durness limestone, in the Tralligill valley around Achmore Farm, and immediately W of Glas Bheinn. Till also occurs around Loch na Gainmhich and in Coire a' Baic to the N. A further arm of till lies on Cambrian Quartzite in the Allt Poll an Droighinn valley. Two other small till deposits were mapped – one at Lochan Allt a' Chalda Mor [2270 9240] and another overlying Lewisian Gneiss on the shore of Loch Assynt [2234 9231]. No other mappable till deposits were identified on NC22. The relationship between till occurrence and underlying geology is not well documented in the literature. It is clear from geological mapping in the complicated Moine Thrust Zone that till sequences are only common on certain rock types. For example, the Lewisian gneiss landscape – which stretches for over 15 km from Loch Assynt to the Atlantic Coast – is almost completely devoid of glacial deposits. However, sandstone of the Stoer and Torridon Groups on the Stoer Peninsula [NC 03] is covered by a thin cap of till (mapped by Peach and Horne in 1892 (Sheet 107W, BGS 2000)). The correspondence between the change in lithology and the re-appearance of glacial deposits is striking. A similar situation occurs in Coigach, where sandstone is till-covered whilst Lewisian gneiss is apparently till-free.

The till encountered in Assynt is highly variable in sedimentology depending on the underlying lithology, the topographic setting, and the distance the material has been carried. Locally it can be up to 4 m thick, as in the Loch Lurgain trough and Loanan Valley. However, most deposits of till in the Inchnadamph area are spatially restricted and thin (<1 m thick).

### 2.1.1 Subglacial till

True subglacial tills are relatively rare within the largely mountainous area bounded by NC22. Where exposed, on low ground, they are well consolidated matrix-supported massive diamictons with a clay/silt/sand matrix. Clasts are scattered throughout the sediment and are normally subangular to subrounded (*sensu* Benn and Ballantyne, 1994) often with striated surfaces. Clast lithologies range greatly. Clast lithologies in the tills of the Assynt district largely represent the geology on which the deposits are found, with a component of clasts derived from the bedrock over which the ice has travelled. No till-fabric analysis was conducted but the majority of the deposits observed were massive and structureless – *Dmm* under the Miall classification scheme.

The best exposures of subglacial till were found outside NC22 in the Loch Lurgainn trough, SW of Stac Pollaidh [eg. 2080 9103] (Fig. 2.1.1.1, below). A brown-grey well consolidated, matrix-supported sandy diamicton containing subangular to subrounded clasts of predominantly Torridonian sandstone occurs in several roadside sections N of Loch Bad a' Ghaill and Loch Lurgainn. This unsorted structureless deposit typifies the tills of the area, formed beneath a mobile ice mass, and is named here as the *Loch Lurgainn till* of the *North-West Highlands Glacigenic Subgroup*.

Figure 2.1.1.1. Subglacial till at Loch Bad a' Ghaill [NC21], 2 km W of Stac Pollaidh [2080 9103], referred to by Hambrey (1995: 122). Dr M Krabbendam for scale. BGS registered photograph P513050.

Occasionally, structures can be identified within subglacial tills. A crude clast fabric is displayed within the clay-sand diamicton near Loch Bad a' Ghaill [2070 9111] (Fig. 2.1.1.2). These weak structures and aligned clasts dip at an angle of 20-30 to the E. Orientated stones may be the result of shear stresses within the deposit set up as the ice overrode the unconsolidated sediment. The sense of movement would therefore have been from E to W, down the pre-existing valley. No shear planes were observed in the till, indicating that the sediment was viscous, possibly even water saturated, upon deposition.

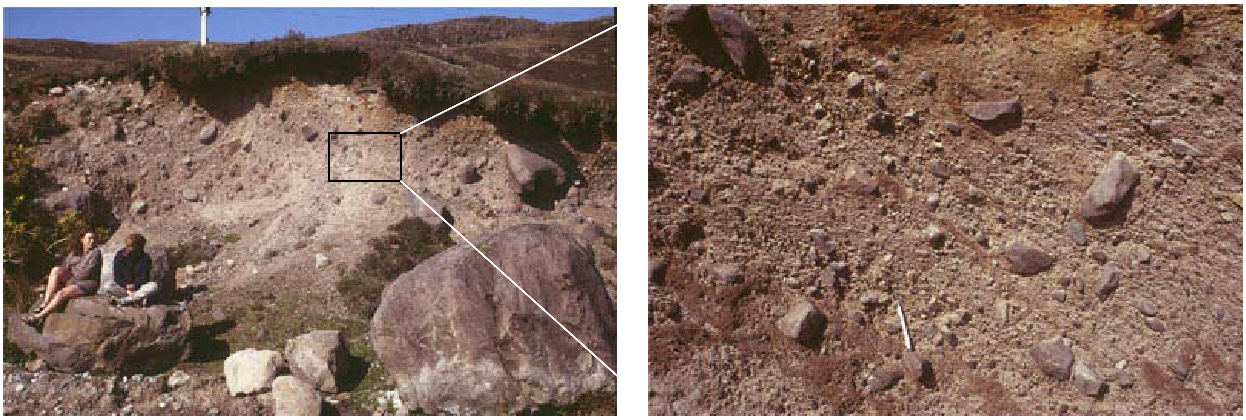

Figure 2.1.1.2. Subglacial till at Loch Bad a Ghaill [2070 9111], Drs K Goodenough and E Pickett for scale. Note the clast orientation within the diamicton (right), probably indicating a sense of shear from west to east. Pencil for scale (0.10 m). Registered photographs P513421 (left) and P513423 (right.)

Subglacial till is strangely uncommon on the Lewisian gneiss bedrock of the Assynt area. Where identified, the deposits are localised with thicknesses probably not exceeding 1-2 m. Exposures are rare. One good section was observed in a man-made cutting by the track leading to Ardvar farm [2175 9328] (Figure 2.1.1.3). A small area of till (250 x 200 m) accumulated in the lee of a large bedrock knoll or *cnoc*. The till, exposed for c. 100 m, proved to be at least 2.5 m thick. This well consolidated poorly sorted diamicton contains subrounded to well-rounded clasts supported within a clay-rich sandy matrix. Most of the clasts are of either Torridonian sandstone or Lewisian gneiss. Many are bullet shaped and display clear striae (Fig. 2.1.1.3). No structures were observed within the diamicton. The deposit is a lodgement till. No other Quaternary units were observed above or below the till.

Figure 2.1.1.3. Lodgement till overlying Lewisian gneiss near Loch Ardbhair [2175 9328]. Note the massive unsorted nature of the deposit and well rounded striated clast within (right). 56-mm lens cap for scale. Registered photographs P513408 (left) and P513407 (right).

## 2.1.2 Supraglacial till

Although not distinguished on the map face, a second type of till was clearly recognised on NC22. The deposit consists of a poorly to moderately consolidated, unsorted, matrix-supported (locally clast-supported) sandy diamicton. Clasts show a broad range of characteristics, but are dominated by angular, non-spherical, cobbles and boulders. The diamicton has a low clay/silt content with the bulk of the matrix being sand fraction. Structures and clast fabrics are rare. However, where developed they are unrelated to ice-flow and may relate to local meltwater reworking or syn-depositional slumping. This deposit is probably largely a product of debris on the surface of the glacier being laid down as the ice melts. The term *ablation till* has been used to describe this deposit (Boulton, 1971). *Supraglacial melt-out till* is more appropriate and is currently the preferred terminology (Benn & Evans, 1998).

Figure 2.1.2.1. Exposure of supraglacial till, near Allt Chrunulah [2241 9296], resulting from melt-out of debris on the glacier surface. Note the angular nature of the clasts and the unsorted structure. This sediment may form part of a medial moraine complex. Registered photograph P513482.

Exposures of supraglacial till are restricted. Where observed it often overlies a well consolidated, massive, clay-rich diamicton – interpreted as subglacial till. The best example of this occurs in a roadside section near Unapool [2237 9326], just N of NC22. Other exposures of supraglacial till are seen near Loch na Gainmhich [2241 9296] (Fig. 2.1.2.1.), and around Achmore Farm [2241 9253]. The supraglacial till and moundy glacial deposits in the vicinity of Unapool Burn, trending NNW, could constitute a large palaeo-medial moraine complex.

Supraglacial melt-out till is often the primary constituent of morainic landforms. However, moraines may contain other sediments such as glaciofluvial gravels, debris flow deposits and subglacial till squeezed or thrust up from the glacier sole. It has been accepted for mapping purposes that constructional glacial landforms with surface expression, even when comprised of till, should be mapped as moraines (hummocky [moundy] glacial deposits), although this system is not entirely satisfactory. By means of illustration, moderately consolidated, unsorted, matrix-supported sandy diamicton in the Loanan valley [224 920] is mapped as hummocky [moundy] glacial deposits even though the ground is probably comprised of supraglacial melt-out till (Fig. 2.1.2.2). In this area the till forms large mounds, ridges and sheets deposited at the margins of a valley glacier (see 2.2, below).

Figure 2.1.2.2 Morainic deposits near Leathad Lianach, Loanan Valley [2243 9211]. Note the pale colour of the diamicton, angular nature of the clasts, and the lack of internal structure. The sediment is primarily supraglacial melt-out (ablation) till derived from locally sourced ice-contact debris (ie quartzite, limestone). Registered photograph P513455.

## 2.2 MORAINES

Morainic deposits with topographic expression [hummocky (moundy) glacial deposits] occur in several localities on NC22. Their distribution is greater than previously mapped by Sissons, (1977) or Lawson (1981, 1986) and they occur on all bedrock lithologies. The main areas of morainic deposits are described below:

### 2.2.1 The southern 'corrie' on Quinag [221 928]

A superficial veneer of unsorted, subrounded to subangular gravel, cobbles and boulders set in a silty sandy matrix covers much of the ground around Lochan Bealach Cornaidh. The matrix is grey-brown coloured and moderately well consolidated. The deposit, although areally extensive, probably does not exceed 1 m in vertical thickness. In places, only a thin lag (<0.2 m thick) of gravel and cobbles with no topographic expression overlies sandstone bedrock. The southeastern extent of the lochan is dammed by a low ridge (2-3 m) of this morainic debris [2211 9280], which arcs around to meet the backwall of the corrie beneath Spidean Coininch. The feature teminates at a bouldery debris-flow deposit, emanating from a deep gulley [2208 9279].

The morainic deposit continues around the eastern shore of the loch where it forms a broad boulder spread [2212 9282] (Fig. 2.2.1.1.). A bank of sediment lies to the N of Lochan Bealach Cornaidh, which in places can be seen to overlie *in-situ* bedrock [2206 9284]. This deposit is probably glacigenic, although may have a talus or mass movement component, and marks the lateral extent of a small former corrie glacier.

Figure 2.2.1.1. Typical composition of the bouldery morainic deposit found around Lochan Bealach Cornaidh seen in the foreground. Cambrian Quartzite (40%) and Torridonian sandstone (60%) clasts suggest a local origin for the debris. The dashed line on the hillside indicates the upper limit of this morainic deposit, and probably represents the former margin of a small corrie glacier. BGS Registered photographs P513498 & P513499.

A more enigmatic deposit occurs at 550 m OD in the Bealach a' Chornaidh [2203 9285](Fig. 2.2.1.2). Consisting of a loose, openwork, accumulation of angular Torridonian sandstone boulders this ridge is approximately 100 m long and 3-4 m high. The size, angularity and sorting of the boulders suggests that they have not been deposited directly by glacier ice but probably as rockfall debris onto or against the margin of a glacier.

Figure 2.2.1.2. Looking S towards Spidean Coinich (764 m). Arrow points to rockfall 'moraine' ridge, in Bealach a' Chornaidh, Quinag [2203 9285]. BGS Registered photograph P513697.

Further east at an elevation of 300-350 m OD is another area of morainic deposits [2224 9281]. Forming a chaotic assemblage of low mounds on sandstone bedding planes, this deposit covers much of the ground between the Allt na Bradhan and Allt Leum Neill streams. The superficial deposit in this area, although not thick, obscures the contact between the Torridonian Sandstone and the Cambrian Quartzite. Boulders of sandstone and quartzite abound – some up to 5 m in diameter. This zone of subdued hummocky moraine was taken by Lawson (1986) to represent the eastern extent of a small glacier during the Loch Lomond Stadial. Striated quartzite surfaces on Druim na h-Uaine Moire [2225 9280] indicate two ice-flow directions: W-E and S-N (Lawson, 1986), although the former could be interpreted to represent ice flow in the opposite direction. A similar, smaller, area of bouldery morianic deposits occurs 500 m to the N, near the source of the Unapool Burn [2225 9287].

### 2.2.2 Loch na Gainmhich

A large wedge of drift covers the ground between the A894 and Loch na Gainmhich. This sediment accumulation, projecting from the NW flank of Glas Bheinn forms a broad, low ridge c. 500 m long. The surface of this feature is smooth except for occasional mounds and boulders. The deposit overlies the plane of the Glencoul Thrust and hence obscures the thrust contact between the Durness limestone and Lewisian gneiss. The thickness and composition of the drift wedge is uncertain as there are no natural exposures. The surface material consists of a grey, poorly consolidated, unsorted, sandy-silty diamicton, containing subangular boulders and cobbles of gneiss and Cambrian quartzite. The feature is interpreted as a wedge of morainic material formed either as a lateral moraine or as a medial moraine complex between glaciers occupying the Allt Sgiathaig and Loch na Gainmhich depressions.

Four or five, small, discrete ridges of morainic material occur on the hillside to the S of Loch na Gainmhich [2245 9283]. These constructional landforms comprised of a similar grey, poorly consolidated, unsorted, diamicton probably represent ice-marginal positions of a glacier that retreated into Coire Dearg on Glas Bheinn.

### 2.2.3 N of Glas Bheinn and Beinn Uidhe

Coire Dearg [2251 9272] lies to the N of the the summit of Glas Bheinn (776 m). The backwall is steep and cut into folded Cambrian quartzite, whilst the floor is cut into Lewisian gneiss. A thin carpet of subrounded and subangular quartzite gravel, cobbles and boulders covers ice-moulded gneiss outcrops. This deposit teminates abruptly at the lip of the corrie and has been mapped by Sissons (1977) and Lawson (1986) as a 'drift limit'. The clarity of this boundary is striking. The deposit has no topographic expression but is probably supraglacial melt-out (ablation) moraine produced by the downwasting of a small corrie glacier.

Another, albeit less striking, boulder deposit occurs in the adjacent corrie – Coire Gorm [2260 9265] – and continues sporadically as far as Lochan Bealach a' Bhuirich [2260 9278]. Loose, angular to subrounded, quartzite debris (boulder, cobbles, gravel) is abundant amongst the ice-worn gneiss outcrops. Again no end moraines are evident in the corrie. However, in places the debris is thick enough to form low, irregular-shaped, mounds. The nature of the deposit suggests that the boulder veneer was laid down as a small, relatively clean, ice mass melted in situ.

Other areas of bouldery morainic deposits occur on the Lewisian gneiss near Poll Amhluaidh [2272 9274], 600m to the N [2271 9282], and near the N slopes of Beinn Uidhe [2270 9265, 2276 9265, 2282 9264]. These deposits vary in thickness but rarely exceed 1-2 m. In places, quartzite boulders form distinct belts, up to 300 m long, aligned N-S, probably indicating the direction of former ice flow. Poorly developed flutings within these coarse bouldery deposits, particularly around [2276 9265], may also be local palao ice-flow indicators.

### 2.2.4 Around Loch Beag and Glencoul

The best suite of moraines on NC22 are found around the head of Loch Beag and in the deep U-shaped trough now occupied by the Amhainn an Loch Bhig (Glen Beag). A distinct, sharp-crested, asymmetric ridge of sediment laps against the spur Blar na Uamhaig at 140 m OD [2280 9298]. This termino-lateral push moraine, over 250 m long and up to 4 m high, probably marks the maximum extent of an ice lobe that extended into Loch Glencoul as far the small tidal islands [2267 9303]. The ridge continues for 400 m as a well-defined drift limit along the NW side of Meall Ruigh na Coinich [2280 9294]. Several smaller ridges occur just inside the main ridge, suggesting small-scale oscillations of the ice margin at this position. The ground to the west, adjacent to Loch Beag, is covered by morainic mounds and abundant quartzite and gneiss boulders. No good exposures of the glacigenic sediment were observed.

In Glen Beag, moraines were mapped on the E valley side. Notable features include a prominent lateral moraine and accompanying meltwater channel at 160-220 m OD [2280 9290]. A 3-4 m high moraine, composed of poorly consolidated sandy diamicton, also dams a small lochan [2285 9297] at 240 m OD. Recessional moraines are found lower down the valley side and further S. Most of the ground below 80 m OD is covered by a 1-3 m thick spread of poorly sorted morainic debris. A conspicuous group of morainic ridges and mounds occurs on the valley floor [2283 9281], near the foot of Eas a' Chual Aluinn waterfall.

On the W side of the glen, morainic deposits are thinner and have been partly obscured by rockfall and talus debris. Small benches of gravelly drift at 20-30 m OD, probably composed of till or morainic material, are located near the mouth of Abhainn an Loch Bhig [2272 9290, 2273 9288]. These may represent fragments of an ice-marginal glaciofluvial terrace or a Late Devensian raised beach.

Two significant areas of moundy morainic deposits occur in large bedrock hollows where the glen narrows [2283 9273, 2289 9294]. Covered by a spread of abundant quartzite and gneiss boulders, the morphology of these closely spaced ridges suggest subglacial rather than ice-marginal formation. Lawson (1986) mapped these as areas of fluted 'hummocky moraine'. Striae and streamlined bedrock features support the idea of channelled ice-flow along the valley axis.

Three small mounds of morainic debris occur on the N shore of the lochan at the head of the fault-controlled A'Chailleach gorge [2298 9259].

### 2.2.5 Traligill and Poll an Droighinn valleys

Two moraines were mapped in the Traligill valley. The first [TOM 003] [2261 9220], an arcuate end moraine, is cut by the track leading to Glenbain cottage (Fig. 2.2.5). Over 200 m long and 4 m high this feature is composed of an orange-brown poorly consolidated sandy matrix-supported diamicton. The diamicton is crudely bedded, dipping 20-30$^{o}$W. Sand lenses show occasional stratification and gravel pockets show imbrication. Clasts are rounded, subrounded or subangular. Four major rock types are represented, in order of abundance: limestone, quartzite, gneiss and igneous mafics. The moraine may be partly comprised of reworked glaciofluvial sediment or have a debris flow component.

Figure 2.2.5. Section through a moraine ridge near Inchnadamph [2261 9220], deposited during the retreat of the Traligill valley glacier. Note the crude bedding. Dr T Bradwell for scale. BGS Registered photograph P500360.

The second moraine [TOM 039] occurs higher up the valley, at the mouth of Gleann Dubh [2273 9210]. An arcuate ridge, of similar dimensions to the first, is composed of an orange-brown sandy-silty matrix-supported diamicton. The clasts are subrounded to subangular and predominantly of quartzite and gneiss. The sediment appears structureless with no evidence of sorting or reworking. This moraine, like the first, probably represents a stillstand during overall recession of a glacier in the Traligill valley.

Numerous hummocks and poorly defined ridges occur within an area of moundy glacial deposits S of the Allt Poll an Droighinn. The largest of these ridges is located on the hillside at 250 m OD [2267 9222]. This moraine probably relates to the same ice-margin responsible for the lower Traligill moraine. It is uncertain how an area of moundy deposits further upstream [2272 9223] relates to former glacier margins. Much of this area is peat covered and no exposures in the glacial deposits were observed in the Poll an Droighinn area.

### 2.2.6 Inchnadamph to Achmore

An area of moundy glacial deposits occurs in a large hollow near Poll Dubharach [2255 9235]. Immediately W of the Cambrian quartzite escarpment lies an area of closely spaced ridges and low mounds which extend over an area approximately 600 x 500 m. Some of the ridges appear to start at the foot of the of the quartzite cliff. An area to the W, within the meander of the Allt a' Chalda Mor, consists of only low mounds (<2 m high) with no apparent order. The general trend of the more linear features is from E-W. Small exposures reveal a grey sand-rich matrix-supported diamicton containing predominantly subrounded and subangular quartzite clasts. Other lithologies are only present in small percentages implying a local debris source. The morphology of the features, combined with their geographical location, suggests a subglacial rather than ice-marginal origin. They have much in common with the areas of fluted hummocky moraine in Glen Beag (see 2.2.4). However, an ice-marginal formation cannot be ruled out.

Further N, between the Allt nam Breac stream and the S slopes of Glas Bheinn is a belt of hummocky boulder-strewn ground. Probably morainic in origin, this deposit has been partly obscured by bouldery slope deposits and talus. No sections were found. The deposit flanks Glas Bheinn for almost 2 km, as far as Larig Unapool [2227 9275] where it meets the large medial? moraine complex at Loch na Gainmhich.

### 2.2.7 Loanan Valley

Lawson (1981, 1986) described moraines in the Loanan valley, around Stronchrubie [224 919]. He suggested that they related to the former existence of a glacier on the eastern flanks of Canisp during the Loch Lomond Stadial. His striae measurements appeared to confirm the flow direction from west to east, down the quartzite dip slope. Lawson (1986) reconstructed the extent of the 'Stronchrubie glacier', based on moraine mapping and from this calculated various volumeteric parameters. The equilibrium-line (firn-line) altitude, based on the area:altitude ratio, was placed at 239 m OD, curiously 180 m lower than other reconstructed Loch Lomond Stadial glaciers in the Assynt-Coigach region (Lawson, 1994).

Field mapping in 2002 confirmed the existence of the moraines in the Loanan Valley but throws doubt on the validity of Lawson's 'Stronchrubie glacier'. Moraines of similar size and morphology, yet to be mapped in detail, were also identified around Loch Awe and near Ledbeg farm [NC 21].

The Loanan valley runs N-S between the Canisp massif and the limestone escarpment of Stron Chrubaidh. The valley floor is flat and in places peat covered. River alluvium covers the lowest ground, although the lower part of the valley may have been occupied by water from Loch Assynt. Moraines occur W of the river Loanan up to 200 m OD. To the E, they occur up to the foot of the limestone escarpment (~150 m OD). Most of the morainic landforms are moundy, non linear, apparently disorganised, deposits composed of poorly sorted, poorly consolidated sandy diamicton. However, several linear ridges occur which probably relate to the former extent of the glacier in the area. The most notable of these are:- two or three closely spaced NE-SW trending ridges 5-10 m high [2242 9202], a NW-SE trending ridge 5 m high [2245 9199], a sharp-crested NE-SW trending ridge 2-3 m high [2250 9203], and two NW-SE trending ridges 5-10 m high [2240 9204]. These moraines and the surrounding landforms have been mapped in detail (Fig. 2.2.7). BGS mapping has revealed a considerable suite of morainic landforms on the Loanan valley. By comparison, Lawson (1986, 2002) identified only a relatively small number of moraines in this location. Although a pattern is difficult to distinguish, it is clear from the landform evidence that these moraines were not deposited by a valley-side "Stronchrubie" glacier in the vicinity of Meallan Liath Beag (as proposed by Lawson, 1986). It is more likely that the moraines relate to one or more outlet glaciers flowing into the Loanan valley from a source in the Assynt mountains to the E. The timing of this glacial event is presently unknown, although a Late Devensian age is highly probable.

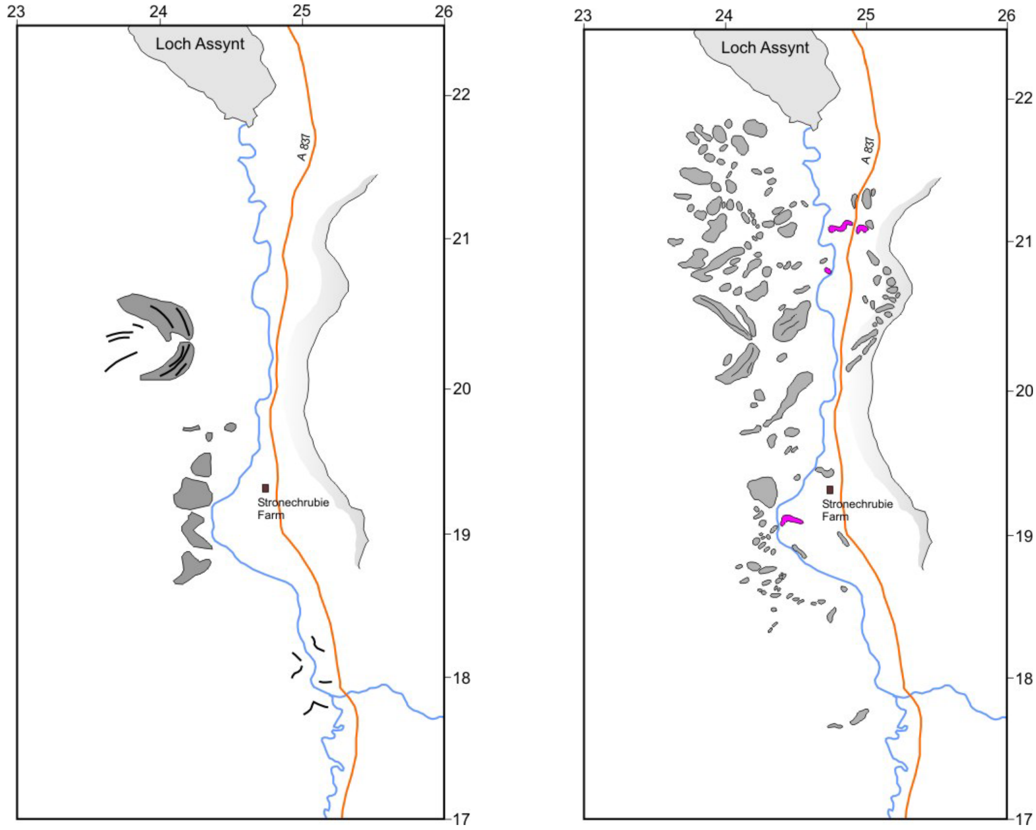


Fig. 2.2.7. Glacial landfoms in the Loanan valley [NC21/NC22] as mapped by Lawson (1986) (left) and the author (right). Moraines shown in grey; glaciofluvial deposits (eskers) shown in pink.

### 2.2.8 N shore of Loch Assynt

Two small isolated areas of morainic deposits were mapped near the N shores of Loch Assynt. Firstly, in the quartzite hollow around Lochan Feoir [2228 9253] where a chaotic collection of boulder-strewn low mounds suggest debris was deposited by a glacier as it flowed around the SE corner of the Quinag massif. Secondly, near the Lochinver road (A837) where the Allt na Droinn Cuilinn flows onto Lewisian Gneiss [2207 9259]. Here large mounds and E-W trending ridges probably indicate an ice-marginal position of a glacier that once-filled the Loch Assynt trough. No sections were examined in detail.

### 2.2.9 W of Beinn Garbh

This area, not yet visited (Nov 2002), appears to display a sequence of morainic deposits on Torridonian sandstone bedrock [air photos 621 89/90/91]. The glacial landforms may relate to a former glacier in the valley between Bheinn Garbh and Bheinn Reidh. The former existence of glaciers in this area has not been previously identified. An area of hummocky, or crudely fluted, ground lies adjacent to a number of discrete linear ridges. All features appear boulder strewn and are probably composed of morainic matrix-supported diamicton.

### 2.2.10 Beinn an Fhurain

An area of moundy morainic? drift ~1000 m long has been mapped from air photographs on the gentle quartzite slope running up to the Beinn an Fhurainn plateau [2294 9223]. This area has not yet been visited (Nov 2002).

## 2.3 GLACIOFLUVIAL SAND AND GRAVEL

Glaciofluvial sand and gravel deposits only occur within the Loanan valley on sheet NC22. Around 500 m S of Inchnamdamph, adjacent to the A837 road, is a conspicuous sharp-crested sinuous ridge around 150 m long and 5-6 m high [2248 9211] (A; Fig 2.3.1). The ridge terminates in a flat-topped mound. Although no sections were observed in the deposit the surface sediment is sorted, well-rounded, poorly consolidated sand and gravel. Boulders were conspicuously absent. The feature is probably a fragment of an esker, which was deposited in a subglacial meltwater conduit at the margin of an active warm-based ice mass.


Figure 2.3.1. Looking W from Sron Chrubaidh crags towards Beinn Garbh. A837 in the foreground. The dashed lines highlight the three main glaciofluvial deposits in the Loanan valley near Inchnadamph. A–Esker fragment; B–Moundy ice-contact deposit; C–Bedded outwash gravels. Canisp on far left, Quinag and Loch Assynt on right. BGS registered photographs P513471 & P13470.

On the opposite side of the A837 is a further sand and gravel deposit [2250 9212]. Somewhat larger, this deposit has an indistinct morphology and forms several large mounds covering an area around 200 x 250 m (B; Fig 2.3.1). It is associated with the esker and was probably deposited contemporaneously at the margin of an actively retreating glacier or ice cap. Again, no sections or internal structures were observed within this deposit.

A solitary, circular, flat-topped, 6 m-high, mound, lies 300 m further S [2247 9207]. This steep-sided feature is also composed of well-sorted, rounded, glaciofluvial sand and gravel with little fines content. This *kame* was deposited either in a subglacial conduit or by meltwater at the margin of a crevassed ice mass.

A small deposit of sorted, stratified, well-rounded sand and gravel occurs near the inflow of the River Loanan into Loch Assynt [2246 9218](C; Fig 2.3.1). This flat-topped deposit is 5 m thick and covers an area of 100 x 50 m. Small-scale cross bedding, typical of deposition in a sandur, was observed in a river-cut section. This may be a fragment of a former glaciofluvial outwash terrace deposited during deglaciation of the Loanan valley. Detailed examination was not carried out in 2002.

## 2.4 BLOCKFIELD

Prolonged weathering of well-jointed bedrock under periglacial conditions results in the breakdown and mechanical disintegration of rock surfaces. This process is exemplified on the Cambrian quartzite mountains of Assynt (Godard, 1965; Ballantyne, 1994). Blockfields were identified on the summit of Beinn Uidhe and Beinn an Fhurain by Lawson (1983); the latter was subsequently examined in more detail by Ballantyne (1994). BGS field mapping within NC22 has identified blockfields on Glas Bheinn and Quinag as well as delimiting the extensive blockfield areas on Beinn Uidhe and Beinn an Fhurain. With the exception of a small area on Quinag (see below), all the blockfields comprise extensive areas of openwork, angular, quartzite boulders with little or no interstitial fines on level or gently sloping mountain tops. The debris is autochthonous in character (ie. derived from *in situ* weathering of bedrock). The blockfield on Beinn an Fhurain is punctuated with areas of frost-sorted debris. Both active and relict polygons were noted [2293 9215], [2302 9216]. Although the thickness of the mountain-top detritus is not known, quartzite bedrock was observed in places.

Figure 2.4.1. Quartzite blockfield on the summit of Sail Gharb (808 m), Quinag. Dr. K Goodenough for scale. BGS Registered photograph P513703

Lower limits of *in situ* debris are difficult to distinguish with precision. On sloping surfaces (>5$^{o}$) accumulations of blocky debris may continue for some distance as blockslopes or, where confined, blockstreams. On Quinag, for example, blockfield debris on the quartzite dip slope continues down slope for over 500 m as a sheet-like mass movement deposit. However, the lower limits of blockfields have been mapped at ~700 m OD on Glas Bheinn, ~650-700 m on Beinn Uidhe, ~750 m OD on Beinn an Fhurain and range between ~520-800 m OD on Quinag. Within NC22, four small areas of blockfield occur on the Quinag massif. Cambrian quartzite blockfield occurs around the summits of Sail Gharbh [2210 9293] (Fig 2.4.1) and Spidean Coinich [2206 9277] and also around the subsidiary summit of the quartzite dip slope [2211 9273]. Highly weathered, well-rounded, Torridonian sandstone blocks lie on bedrock at an altitude of 700 m OD on Quinag [2203 9289] (Fig. 2.4.2). The bedding structures within the loose surface rocks correspond with those in the bedrock suggesting in situ disintegration. This ground represents an allochthonous sandstone blockfield resulting from prolonged exposure to the atmosphere.

Figure 2.4.2. Bedding structures in Torridonian sandstone bedrock near the summit of Quinag (~700 m OD). Note the highly fractured nature of the surface and the tendency to form loose rounded blocks. BGS Registered photograph P513707

## 2.5 HEAD

*Head* deposits were originally defined by De La Beche (1839) as accumulations of unsorted, unconsolidated rubble 'drift' in lowland Britain. Harris (1987) proposed a more recent definition: "slope deposits accumulated through various periglacial mass movement processes". Head has been mapped in five main areas on NC22: around Quinag, on Glas Bheinn, on the slopes of Beinn Uidhe and Beinn and Fhurainn, and near Inchnadamph.

The head deposits on NC22 can be subdivided into 2 types, each forming under different conditions. *Slope-foot deposits* form apron-like accumulations of unconsolidated angular debris at the base of slopes, normally greater than 15$^{o}$, where no free face exists above. Occasionally these deposits have a topographic expression forming broad lobes or hummocky spreads [2215 9290, 2239 9270]. They occur on Lewisian gneiss, Torridonian sandstone and Cambrian quartzite and can be up to 2-3 m thick. *Slope deposits* occur on hillslopes, between 3-45$^{o}$, and form sheets or lobes typically 0.5-2 m thick. These deposits are often bouldery, being simply the downslope portion of mobile blockfield detritus, for example on Spidean Coinich [2220 9272]. The term *blockslope* is sometimes used in the literature (eg. Ballantyne, 2002). This category of head deposits has a lithological preference on NC22, being largely sourced from Cambrian quartzite areas. The hillslope deposits result from mass movement and may be of different heritage or activity status. This is most clearly demonstrated on Glas Bheinn [2244 9265] (Fig. 2.5.1) where pale-coloured active lobes of quartzite debris overprint older, lichen- covered, relict slope deposits. Further studies would be needed in this high altitude, maritime, environment to confirm the 'activity status' of these periglacial features.

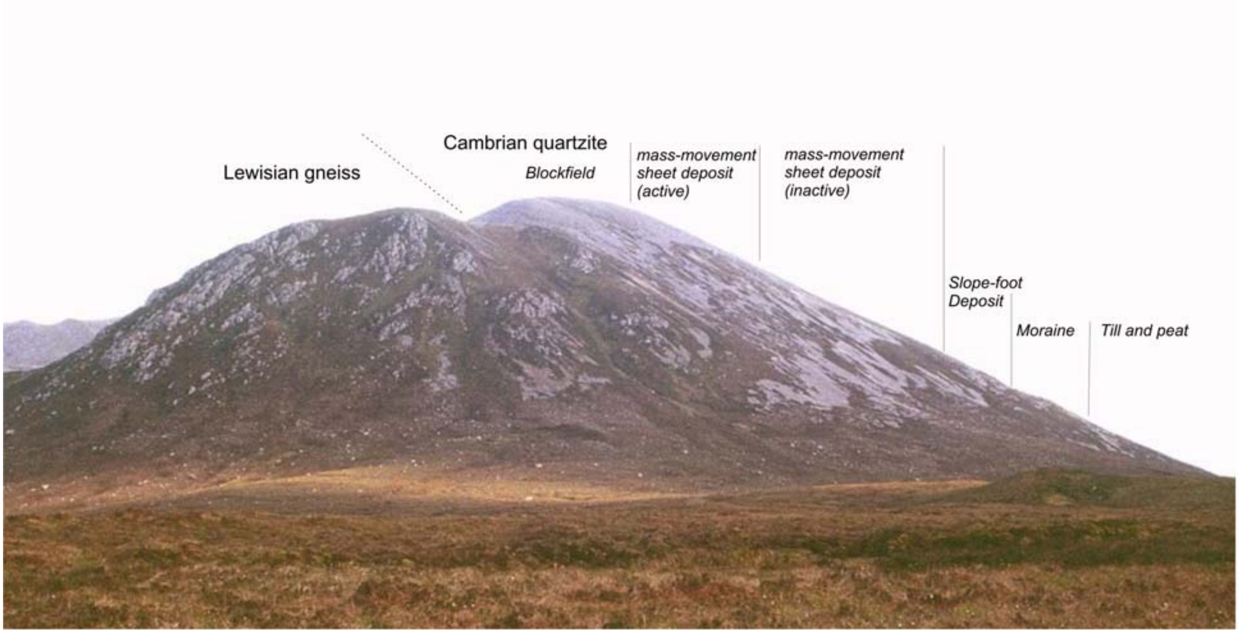


Figure 2.5.1. Superficial deposits on Glas Bheinn, viewed from the west. Note the subtle transition downslope from summit blockfield to mass-movement sheet (blockslope) to slope-foot deposit. Moundy morainic debris flanks the foot of the mountain. Note also that the gneissose portion of the mountain is largely free of head deposits. BGS Registered photograph P513472.

With the exception of those high-level deposits on the Cambrian quartzite slopes of Quinag, Glas Bheinn and the Beinn an Fhurainn plateau [2297 9216], the majority of the head deposits on NC22 are slope-foot accumulations of poorly sorted, angular clast-supported, diamicton.

## 2.6 TALUS

*Talus* is used to describe any accumulation of angular rock debris derived from a cliff or rock slope. Somewhat confusingly, *talus* and *scree* have become synonymous in the BGS classification scheme. It may be wise to consider re-adopting the term *scree* for debris-covered slopes where no mode of origin is implied. (cf. Ballantyne, 1994; 2002).

Several areas of talus were mapped on sheet NC22, predominantly at the foot of major rock slopes on the mountains of Quinag, Glas Bheinn, Beinn Uidhe, Beinn an Fhurainn, Conival and Beinn Reidh and often in association with head deposits. Talus thickness varies from 0.3 m to 3 m, and may be considerably thicker in places. Talus sheets and coalescent talus cones are particularly well developed in the steep-sided valleys of Glen Coul [2292 9290] and Glen Beag [2280 9279] at the foot of the Quartzite escarpments marking the Glencoul and Moine thrust planes. A talus apron comprised almost exclusively of angular, glassy, mylonite fragments surrounds the foot of the Stack of Glencoul [2289 9287]. Active-looking coalescent talus cones occur at the foot of the quartzite backwalls in Coire Dearg, Coire Gorm and Coire Bealach na h-Uidhe. The flanks of Quinag are cloaked in sandstone and quartzite talus, particularly Sail Gharbh. However, on the upper slopes the cover is patchy and much less than 1 m thick. This loose debris may not be talus *sensu stricto* (ie. rockfall-derived), but rather a weathering product derived from the underlying bedrock and partly modified by gravitational and/or slopewash processes [2210 9288]. It was not practical to make this distinction on the 1:25,000 mapface.

Figure 2.6.1. BGS Registered photograph P513520. Section through quartzite talus on the N shore of Loch Glendhu, NC23. The track is ~2 m wide and the talus is at least 3 m thick near the base of the deposit.

### 2.6.1 Talus cones

Where debris accumulates at the foot of a gulley or chute it has been mapped as a *talus cone* deposit. Ballantyne (2002) distinguishes between talus cones and debris cones based on morphological and sedimentological grounds. However, this scheme has not yet been adopted by BGS. Numerous talus cones were mapped in mountainous areas on sheet NC22, particularly in the vicinity of Lochan Bealach Cornaidh [2206 9281] (Fig. 2.6.2), S of Beinn Uidhe [2272 9254] and on the western flanks of Conival [2291 2201].

Figure 2.6.2. BGS Registered photograph P513495. Talus cone at the foot of a steep gulley in Torridonian sandsone, Spidean Coinich, Quinag.

Two notable, large, talus cones were mapped on NC22. Both are related to rockfall events. The larger of the two, to the E of Beinn Gharbh [2236 9223], was possibly due to a catastrophic event whilst the smaller, at the foot of Eas a' Chual Aluinn waterfall [2281 9278], appears to be due to incremental debris accumulation. The debris in the larger deposit comprises Lewisian boulders from the rockwall above, ranging from <1 to >5 m in diameter. The timing of this rockfall is not known although it is clearly postglacial. Large *Lecanora* lichens (>200 mm) on the boulders imply a considerable period of stability, probably since at least the mid Holocene.

Two, extremely large, talus cones both falling in NC23, are worthy of special mention. The first, at the foot of Bealach na h-Earbaige [2284 9333] near the head of Loch Glendhu, is approximately 400 m wide at its base and ~350 m from apex to toe (Fig. 2.6.3). The cone terminates at sea level and has a surface slope of 17-20$^o$. The cone contains c. 1x10$^6$ tonnes of debris. This is an order of magnitude more than could have been expected to be deposited by the small stream that presently occupies the steep valley. Instead it is suggested that the cone formed during the Late Devensian or Loch Lomond Stadial, when a small ice cap occupied the plateau of Beinn Aird da Loch. Sediment from the ice-margin, supplemented by debris carried by meltwater, would have accumulated in a cone at the foot of the steep valley. Hence, this debris cone is probably of glacial or glaciofluvial origin and could be important for reconstructing former ice limits.

The second talus cone is located at the foot of the mighty Sail Gharbh buttress and is of similar dimensions to the Glendhu cone – 300 m wide, 400 m long and with a surface slope of 20-25$^o$. (Fig. 2.6.4). Although the volume of debris is great, all the material is sourced from two huge gulleys that cut deep into the sandstone buttress. The talus cone clearly post-dates ice sheet glaciation. However, much of the sediment probably accumulated during the Lateglacial or Loch Lomond Stadial when the climate was more conducive to talus production. The feature is strictly periglacial, unlike the Glendhu talus cone which is probably ice-marginal or paraglacial. A large ravine-like channel, over 5 m deep, cuts through the cone suggesting a major adjustment to base level change. The timing of this event and the activity status of the cone are uncertain.

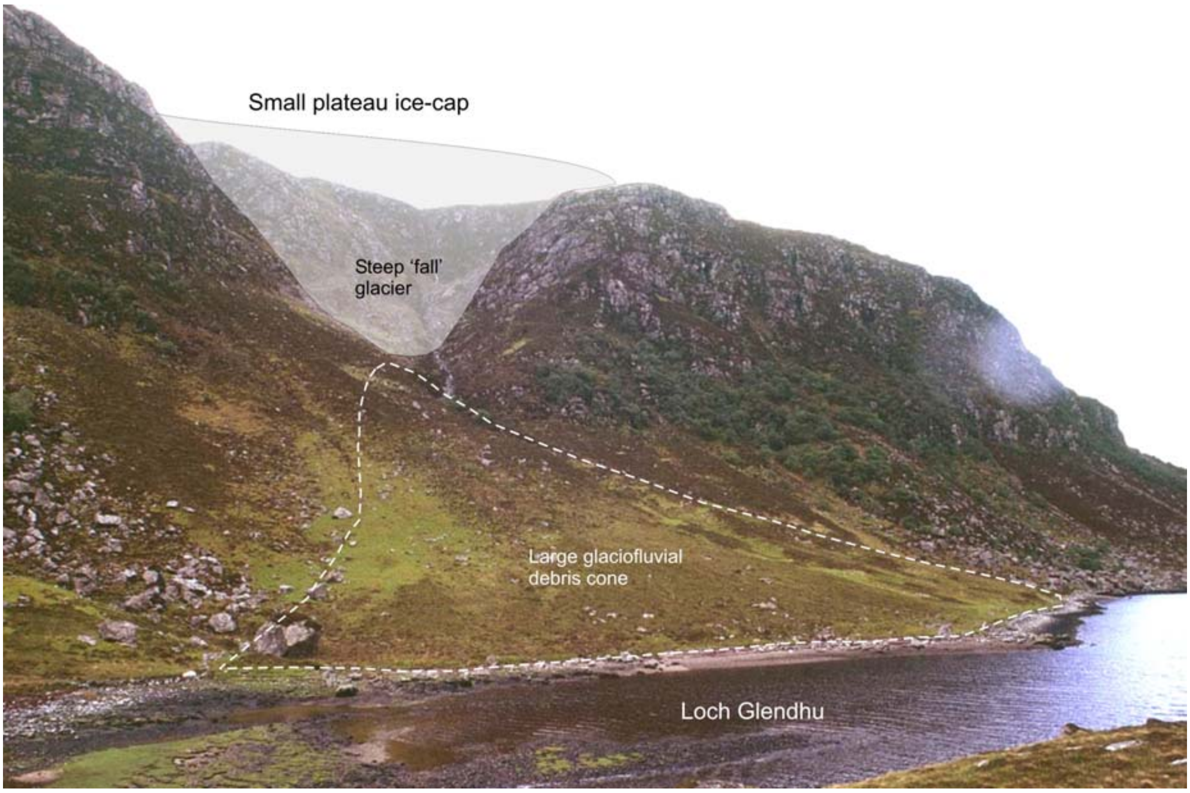


Fig. 2.6.2. The large debris cone at the head of Loch Glendhu that probably formed during the retreat of a local ice cap. BGS registered photograph P513437.

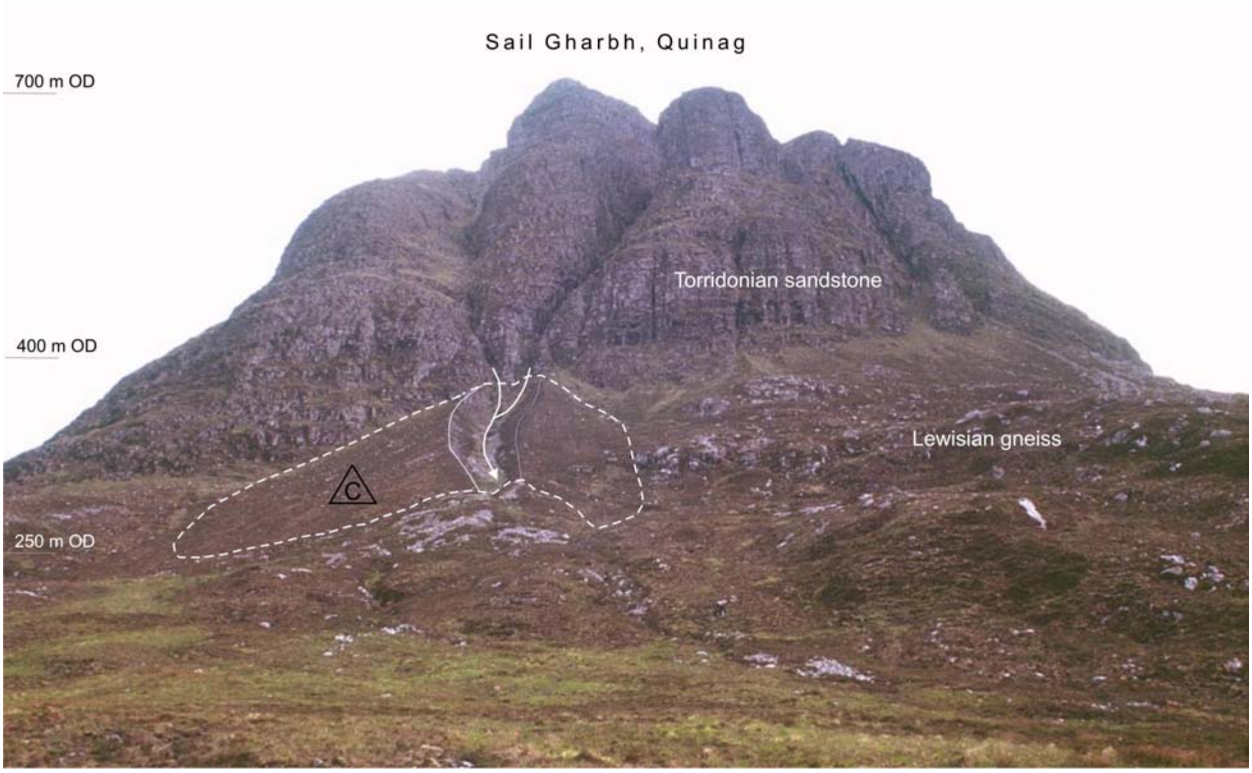


Figure 2.6.4. The large talus cone beneath Sail Gharbh buttress has probably been accumulating since Late Devensian times. BGS registered photograph P513486.

## 2.7 ALLUVIUM

Alluvium is relatively sparse on NC22. The main areas occur in the Loanan valley, near Inchnadamph, and in the Glen Beag trough. The banks and floodplain of the River Loanan are composed of fine-grained alluvium, typically silt and mud that has settled out of suspension. These valley-floor deposits are often overlain by peat that obscures the true extent of the alluvium. Large birch and pine tree fragments were found in the Loanan Valley alluvium, these could be *in situ* roots of a mid-Holocene forest (Fig. 2.7.1).

Figure 2.7.1. Organic and minerogenic alluvium in river bank, Loanan valley [2247 9206]. Note the large wood fragments and roots. Compass for scale. BGS Registered photograph P513537.

Sand and gravel-grade alluvium covers the floor of the large U-shaped trough at the head of Loch Beag [2282 9280]. Mapped as alluvium, this deposit may comprise reworked glaciofluvial sand and gravel, at least in part. This deposit grades into a tidal flat at high-water mark.

Smaller areas of alluvium were mapped along several water courses: Allt na Bradhan, Allt Sgiathaig, Allt nam Breac, Allt na Beinne Gairbhe and the stream in Glen Coul. Bouldery river deposits occur along the course of the Tralligil river [2264 9214], even in places where no river flows today. These deposits are testament to the occasional power of this ephemeral river.

### 2.7.1 Alluvial fans

The Inchnadamph Hotel, Lodge and surrounding houses are built on a low-angle cone of sediment at the mouth of the Traligill River [2252 9217]. This large alluvial fan, covering an area of 1000 x 600 m with a surface slope of 1-2$^o$, is composed of well-sorted cobbles, gravel and sand. The fan is relatively large for a Holocene feature and may have formed during deglaciation. Although mapped as an *alluvial* fan the landform is likely to be a complex feature with a glaciofluvial sediment component. The river presently flows in a wide channel 3-4 m below the surface of the fan (at Inchnadamph Bridge [2250 9218]).

An alluvial fan is mapped to the SW of Loch na Gainmhich [2245 9283]. This relatively steep feature (6-8$^o$ slope) may be also partly of glaciofluvial origin as a corrie glacier is known to have existed in Coire Dearg during the Loch Lomond Stadial (Lawson, 1986)

Smaller, Holocene, alluvial fans are mapped on NC22 at the mouths of subsidiary rivers and streams. Several such deposits occur on the southern shore of Loch Assynt [eg. 2224 9235]. A small alluvial fan also drains into the lochan on Quinag [2206 9283] from the Bealach a' Cornaidh.

## 2.8 PEAT

Peat is the most ubiquitous Quaternary deposit on NC22. However peat growth is dependent on certain geohydrological conditions and therefore does not occur on all rock types equally. Generally, peat fills only topographic depressions on the crystalline rocks (Lewisian gneiss, Quartzite) whilst peat is more widespread on Torridonian sandstone. On permeable Durness limestone, peat is commonly present where a clay-rich horizon prevents free drainage. Many areas mapped as peat almost certainly overlie a till subsoil.

Where proved, peat deposits on limestone bedrock were found to be moderately thick, up to 3.5 m in places [2281 9200]. Thinner peat deposits (~0.5-1.5 m) were found at high elevation and on impervious bedrock. No buried peat pre-dating the Holocene was identified.

## 2.9 OTHER DEPOSITS

### 2.9.1 Lacustrine deposits

Lacustrine beach deposits have been mapped around the fringes of the major water bodies on NC22. Beaches of sandstone pebble gravel are common on the shores of Loch Assynt. Good examples are found near Rubha na Moine [2231 9234] (Fig. 2.9.1). A gravel beach 150 m long connects Ardvreck castle – a tombolo – to the shore [2240 9237]. The slightly raised nature (+1-2m) of these beach deposits around Loch Assynt may be the result of continued isostatic uplift following the main Holocene sea-level transgression (c. 6500 BP).

Figure 2.9.1.

Well-sorted lacustrine beach gravels on the S shore of Loch Assynt. Note the height of the shingle ridges, formed by wave action. The highest represents a former water level up to 2.0 m above the present day (July 2002).

BGS Registered photograph P513443.

### 2.9.2 Artificial deposits

No areas of made, worked or disturbed ground are mapped on sheet NC 22.

# 3 Quaternary history

## 3.1 PREVIOUS RESEARCH

Early references to the glacial history of Assynt are sparse. Chambers (1853) identified that glaciers were responsible for sculpting much of the landscape in northwest Scotland. His observations in the Assynt region led him to pronounce that:

> "There are phenomena of smoothing, striation, and detrital accumulations, which can only be accounted for on the supposition of there having been, besides a *district glaciation* in the valleys, …an earlier *general glaciation* which has passed over the backs, if not the very summits of the hills." (p249)

Peach and Horne (1892), Officers of the Geological Survey, mapped the extent of Moine schist and Lewisian granite erratics on the hills of the Northwest Highlands. In Assynt the maximum glaciation ice-divide was placed along the line of hills adjacent to the Moine Thrust Zone – *Glas Bheinn, Beinn Uidhe, Conival* and *Breabeg*. Peach and Horne (in Murray and Pullar, 1910) also noted evidence of a later glacial period, when ice flowed from localised, independent, ice-centres. This later, topographically-confined, *district* glaciation also appears in the Geological Survey's general glacial history of the adjoining sheet (Read *et al*., 1926: 173). As in much of Highland Scotland, officers of the Geological Survey had consistently recognised a three- or four-fold sequence of glacier waxing and waning:

1. Period of maximum glaciation
2. Period of waning glaciation with local centres of dispersion
3. Period of independent valley glaciers
4. Retreat of the ice and period of corrie glaciers

The final episode of *corrie glaciation* in Scotland is particularly marked in Assynt according to Peach and Horne (1910). They cite Loch a' Choire Dearg [NC 927 225] and Loch a' Choire Ghuirm [NC 926 226] as excellent examples of corrie rock basins concealed by moraines (1910: 483). The occurrence of glacial deposits on the '50-ft' raised beach imply that in parts of northwest Scotland, at least, small independent glaciers must have survived until after the main Lateglacial sea-level fall (Hinxman, 1893; Peach and Horne, 1910: 475).

Boyd (1956) alludes to the glaciation of Assynt when describing the former drainage of the lochs around Suilven. His general map of the Kirkaig catchment basin collates evidence collected by the Geological Survey (Peach and Horne, 1910). The map shows the directions of ice movement during two distinct periods of glaciation. This secondary glaciation appears to have been topographically confined, unlike the more extensive earlier event. It is also worth noting that Boyd (1956: 244) describes the existence of glaciers in the main valleys, although does not cite any direct evidence for this:

> "During the latter stages of the Ice Age a glacier advanced down a pre-existing valley from the slopes of Breabeg to Lyne; thence it turned north by Loch Awe and the River Loanan to Loch Assynt."

Evidence for raised loch levels – most notably raised "beaches" and numerous dry spillways – led Boyd (1956) to conclude that glaciers in the vicinity of Canisp and Cul Mor once dammed a substantial body of meltwater to the west. This long, narrow, water body, called "Loch Suilven", would have included the Cam, Veyatie, Fionn and Uidh na Ceardaich lochs. Originally the main lake outlet would have been through a deep NW-trending gorge in the Lewisian gneiss known as Allt a' Mhuilinn. As the ice retreated, and successively lower topographic cols were revealed, the water escaped via different routes, until eventually each lake basin became isolated. Cam Loch would have been the first lake to be isolated. At that time its surface was coincident with the present-day 140 m OD contour and would have extended to the confluence of the Ledmore and Ledbeg rivers. According to Boyd (1956), a series of depositional terraces and lacustrine flats correspond with lake spillways at different elevations, the lowest of these being the present-day drainage channel – the River Kirkaig. Although the evolution of the drainage pattern around Loch Fionn and Cam Loch is chronologically undetermined it does shed important light on the relative rate and pattern of deglaciation in the Assynt area.

Charlesworth's (1956) paper on the Lateglacial history of the Scottish Highlands and Islands remains the most comprehensive single contribution to British glacial geology this century. Covering over 20,000 square miles, Charlesworth reconstructed the decay of the northern half of the last British Ice Sheet. On the Lewisian country of western Sutherland, Charlesworth was confronted by a distinct lack of moraines with repeated traverses failing to find any trace. Further to the east, moraines relating to numerous ice-marginal positions were in abundance. In Assynt, Charlesworth (1956) envisaged a period of extensive ice-sheet glaciation giving way to a period of more localised ice-cap glaciation. Although lacking any chronological control, he placed a large glacier in the depression now partly occupied by Loch Assynt, at the same time as another filled the north-south Loanan-Ledbeg valley. Both of these were fed primarily from the Ben More-Breabeg massif. According to Charlesworth, other large glaciers existed in Glen Oykel, Upper Glen Cassley, Loch Glendhu and Loch Glencoul. Another, known as the *Bradhan Glacier*, retreated into the large corrie on the southern side of Quinag. In the Coigach area, ice almost reached the present-day coastline at Loch Oscaig and Loch Sionascaig, whilst another lobe of ice flowed south down Strath Canaird. By his own admission, Charlesworth accepts that his reconstructions are "not free from difficulties", yet there is a striking similarity between his *Stage M* and the Loch Lomond Stadial reconstruction presented 20 years later by Sissons (1977).

Since the 1960s, Quaternary science has progressed in both qualitative and quantitative terms. Pennington *et al*. (1972) instigated lithostratigraphic analysis of sediment from freshwater lochs around northern Scotland. Pollen and diatoms within lake-bottom sediments, constrained by radiocarbon dating, allowed a clear record of Late- and Postglacial environmental change to be reconstructed. Several lochs within the Assynt district were cored including Loch Sionascaig, Cam Loch and Loch Ailsh. Cam Loch proved to be the most revealing site, yielding a complete Lateglacial sequence. Soft, grey, minerogenic clay, at the bottom of the sequence, containing a pioneer pollen and diatom community, dates to before ~13 ka BP. This is overlain by an organic silt layer. A second grey clay, containing a low diatom species diversity, was found higher up the sequence dating to shortly after ~11 ka BP. The uppermost 2 m of organic mud exhibits a wide range of diatom taxa and pollen grains. This broadly four-part sequence is typical of the Lateglacial environment in Northern Europe and represents the *Bølling-Allerød-Younger Dryas* climatic oscillations. The increase in minerogenic material in Cam Loch c. 12 ka BP is supposed to indicate an intense period of soil disturbance resulting from a return to periglacial conditions. Therefore, glaciers did not directly affect the loch during the Younger Dryas period (Pennington, 1977). Organic sedimentation in Cam Loch since 10,226+/-190 BP is associated with relatively warm, stable, Holocene conditions.

Sissons (1977) studied the former extent of glaciers that reappeared during the Younger Dryas chronozone, known in Britain as the *Loch Lomond Stadial*. Whether glaciers completely disappeared from Scotland during the brief *Windermere Interstadial* period is still the focus of debate. Sissons acknowledges the work of his predecessors notably Peach *et al*. (1913) but stresses that their adherence to a strict paradigm regarding the orderly sequence of events at the end of the last glaciation “prevented their recognising the contemporaneity of large valley glaciers and small corrie glaciers” (Sissons, 1977: 45). Within the area of the Assynt Special Sheet, Sissons (1977) identifies 7 discrete glaciers, including one on Cul Mor. The largest of the palaeo-glaciers, in Glen Oykel, was over 23 $km^2$ and almost 9 km in length. At the same time, smaller glaciers, 0.3 and 0.5 $km^2$ respectively, formed in the sheltered north- and east-facing corries of Glas Bheinn. Three small corrie glaciers were also identified on Ben Mor Coigach (Sissons, 1977). Sissons made a regional palaeoclimatic assessment based on reconstructed firn-line altitudes of glaciers in northern Scotland. The linear rise in firn-line altitude from northwest to southeast equates to a steady decrease in precipitation with distance from the Atlantic Ocean.

Lawson (1981, 1983, 1986, 1990, 1995) studied several aspects of the Quaternary geomorphology of Assynt. Using glacial striae, erratics and some geomorphological evidence, Lawson (1983) constructed a model of ice-cap development, deglaciation and subsequent recrudescence in the Assynt area. Lawson believed that during the Last Glacial Maximum glaciers overtopped even the highest mountains. Radiocarbon dating of reindeer antlers placed the onset of glaciation around 26 ka BP, although theses dates may be derived from material of widely differing age and are therefore still equivocal (Lawson, 1995). Reindeer did not return to the Highlands of northwest Scotland until the early Holocene (8.3 ka BP) when the mountains were ice-free.

Lawson (1983, 1986) also refined the work of Sissons on the Loch Lomond glaciation of the region, making minor changes to the glacial limits. Further glacial deposits, not identified by Sissons, in the valley of the Loanan River near Stronchrubie, were attributed to a small Loch Lomond glacier on the lower flanks of Canisp (Figure 5). Lawson (1986) made palaeoclimatic inferences based on the size and distribution of these seven reconstructed glaciers. He related the rise in firn-line altitude from SSW to NNE to the palaeo-direction of prevailing snow-bearing winds. The apparently anomalous nature of the *Stronchrubie* glacier (ELA = 239 m) is attributed to the large snow-blowing catchment to the SW (Lawson, 1986), although the glaciological grounds for such a glacier hypsometry are questionable. Neither Sissons nor Lawson found evidence for readvances of the main Late Devensian ice cap. Moreover, both authors suggest that deglaciation was uninterrupted and had been completed by ~14 ka. The subsequent *Loch Lomond Stadial* readvance, 12.5–11.5 ka BP, culminated during a brief return to glacial conditions.

Lawson also studied speleothems – calcitic precipitates growing on the roof and floor of caves – in the Inchnadamph area of Assynt. Normally precipitated from groundwater during relatively warm, wet periods, the isotopic composition of these calcite growths reveals important information about the palaeoclimate. $Th^{230}/U^{234}$ disequilibrium techniques have yielded speleothem dates from interglacial periods over the last 200 ka (isotope stages 4, 5a, 5e, and 7) (Lawson, 1981; Lawson and Atkinson, 1995). Clustered dates also indicate a period of groundwater recharge during the Middle Devensian, possibly supporting the evidence for a brief interstadial in Britain (Sutherland, 1984; Bowen *et al*., 1986). Speleothem growth has continued uninterrupted since ~9 ka BP in Northwest Scotland. Baker *et al*. (1993) also studied the stalagtites in the *Cnoc nan Uamh* caves near Inchnadamph. Their high-resolution isotopic studies provided new information on the rate of speleothem growth from year to year. These data indicate that, in certain conditions, calcite precipitation rates over the last 10,000 years may reflect general climatic trends on decadal and centennial timescales (Baker *et al*., 1993).

Within the last 20 years it has come to light that the summits of the highest mountains in western Scotland protruded through the ice even during the height of the Late Devensian Glaciation (Thorpe, 1981, 1986; Ballantyne, 1984, 1997). McCarroll *et al*. (1995) and Ballantyne *et al*. (1998) have used glacial trimlines – the boundary between ice-scoured terrain and severely frost-weathered mountain-top detritus – to examine the maximum altitude attained by glaciers in northwest Scotland during the Late Devensian. Several workers have challenged this view, however. Sugden, (1968, 1974), Boulton, (1979), Rasmussen (1984), and McDougall (2001) all suggest that high-altitude blockfields may have been covered by thin, cold-based, plateau ice-caps during previous glacial episodes. Whalley *et al.* (1981) have shown how apparently mature blockfields in northern Norway have emerged from beneath thin cold-based ice-fields during recent decades. The debate is still ongoing. However, Ballantyne *et al*. (1998) have convincing cosmogenic-isotope surface-exposure ages, clay mineralogical evidence and bedrock-joint depth data that imply a glacial origin for these weathering limits.

In Assynt, McCarroll *et al.* (1995) identified periglacial trimlines on seven of the highest hills in the region. The altitude of these weathering limits ranges from ~650 m OD on Quinag and Ben More Coigach to 800-850 m OD on Conival and Ben More Assynt. The features on Glas Bheinn at 730 m OD and Spidean Coinich at 700 m OD are the most pronounced. McCarroll *et al.* (1995) have suggested that the regular decline in weathering-limit altitude from east to west across the Assynt area represents the surface slope of the Late Devensian ice-sheet. This geomorphological evidence implies a ice-surface gradient of 8-12 m $km^{-1}$ and places the ice-divide during the Last Glacial Maximum to the east of the Assynt mountains.

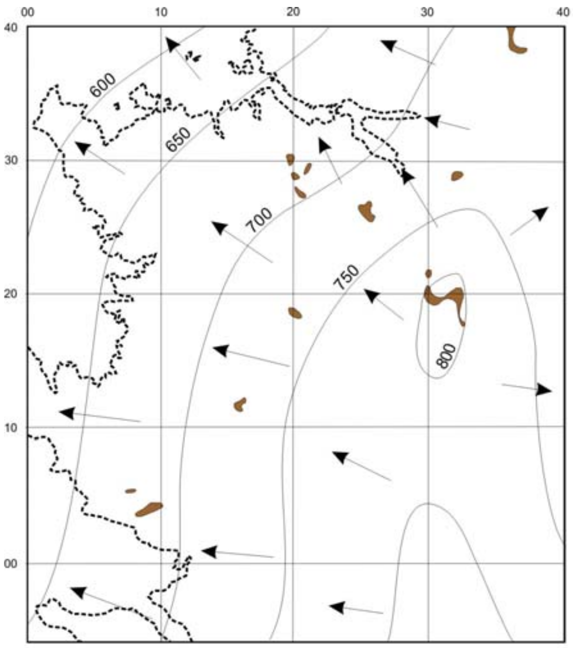


Figure 3.1.1 Maximum extent of the Late Devensian Ice sheet (~22ka BP) in the Assynt area of Northwest Scotland, according to Ballantyne *et al*., (1998) and Lawson (1995). Ice-surface contours are shown in metres above present-day sea level. The reconstruction is based on the altitude of weathering limits and the maximum altitude of glacially abraded rock and erratic boulders. Dark brown areas are former nunataks. General ice flow arrows are also shown.

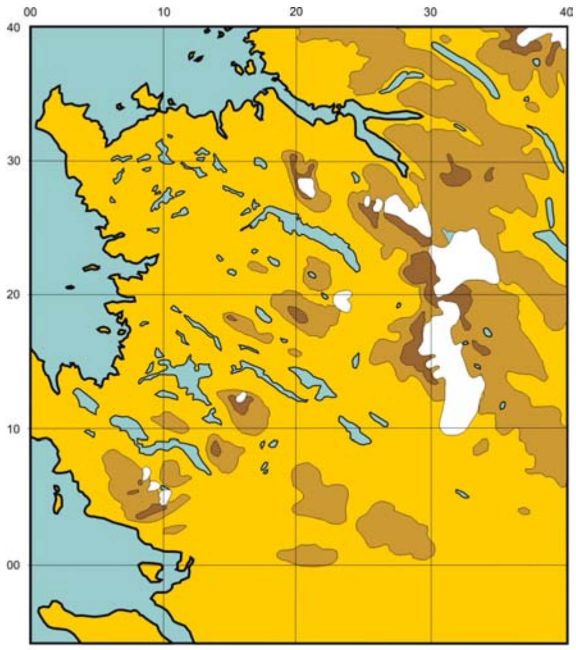


Figure 3.1.2. The extent of Loch Lomond Stadial glaciers (12ka BP) in the Assynt area, according to Sissons (1977) and Lawson (1986, 1995). The reconstruction is based on geomorphological field mapping and aerial photograph interpretations. The coastline is taken to be the same as the present day.

The models of ice-sheet thickness for Assynt proposed by McCarroll *et al.* (1995) and Ballantyne *et al* (1998) are still the subject of some debate and have yet to be rigorously tested or chronologically constrained. Evidence from other workers appears to question the validity of certain ice-free nunataks in the Assynt-Coigach area (Lawson, 1983; Bradwell & Krabbendam, 2003).

## 3.2 THE IMPLICATIONS OF NEW MAPPING : A DISCUSSION

Detailed Quaternary mapping by BGS during 2002 has shed further light on the glacial history of Assynt, provoking new ideas regarding the extent and configuration of Late Devensian glaciers in the region.

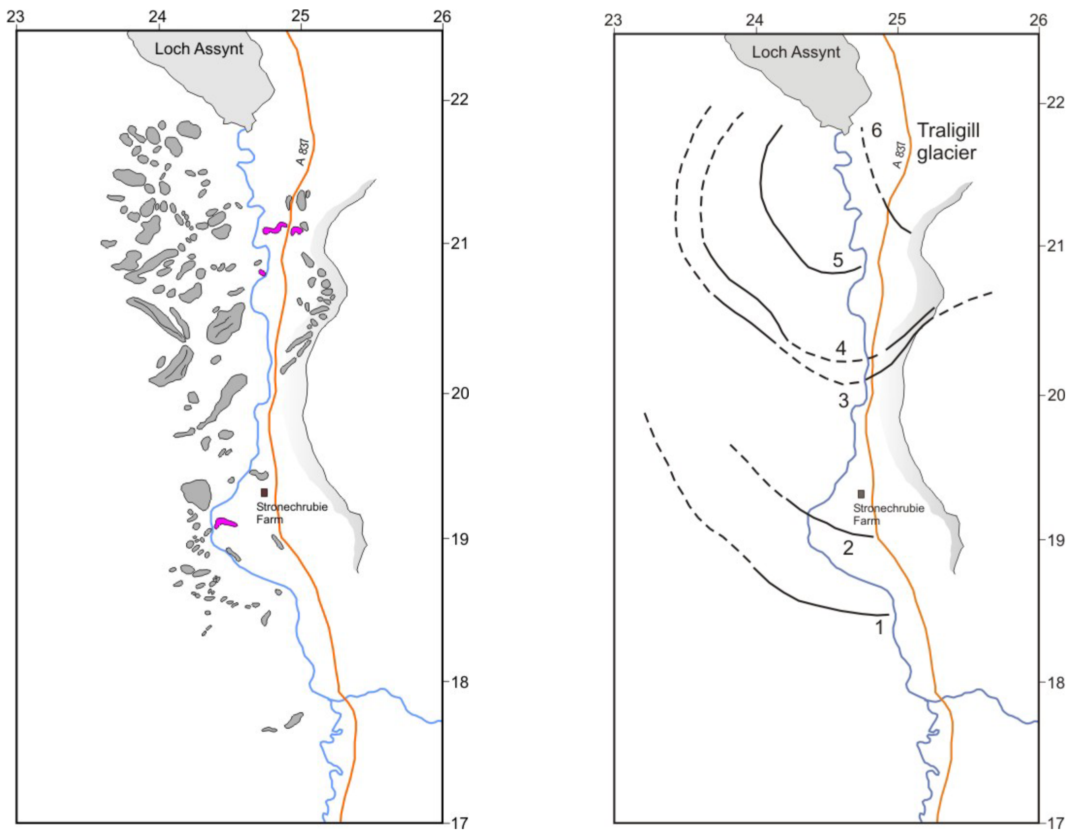


Figure 3.2. Moraines in the Loanan valley mapped in 2002 (left). Reconstructed pattern of glacier retreat based on new mapping (right). The complex geomorphology is probably the result of a glacier lobe overprinting pre-existing glacial deposits in the vicinity of Stronchrubie.

The distribution of the moraines in the Loanan valley indicates active retreat of an outlet valley glacier. The *Traligill glacier* sourced on the Conival-Beinn an Fhurain massif flowed down Gleann Dubh to Loch Assynt. Cross-cutting striations in the vicinity of Meallan Liath Mor [NC 919 223] demonstrate that at its most extensive this glacier flowed SW and filled the entire valley. As the glacier retreated the ice-margin oscillated. These flucuations or stillstands are represented by moraines at locations 1-6 (Fig. 3.2). Other morainic landforms aligned parallel to ice-flow are probably flutes and older glacial deposits that were overridden by the readvancing Traligill glacier. This valley glacier was almost certainly sourced in the high ground forming the present-day watershed. It is likely that the glacier-accumulation area was part of a mountain ice cap, possibly centred over the head of Glen Oykel [230 918]. If this were the case, the Traligill glacier would have been just one outlet draining a local ice field. Other glaciers would have flowed W down the Ledbeg and Allt nan Uamh valleys, N from Coire a Mhadaidh towards Gorm Loch Mor, E into Glen Cassley and S down Glen Oykel itself. Further evidence for such a glacier configuration is currently being investigated.

This model of glaciation differs radically from those proposed by previous workers (Sissons, 1977; Lawson, 1986). It implies that the Assynt mountains were an independent source of ice during the Late Devensian. Although it is not yet known when this phase of glaciation occurred, it must postdate the main ice-sheet glaciation (~22-18 ka BP) and pre-date the localised corrie glaciation, thought to be of Loch Lomond Stadial age (12.5-11.5 ka BP). Pennington *et al.* (1972) found no sedimentological evidence for renewal of glaciation in the catchment area of Cam Loch following the Lateglacial Interstadial. This makes it unlikely that the glacier configuration suggested here could have existed during the Loch Lomond Stadial. Therefore an age of ~15-18 ka cal BP is suggested for the Loanan valley moraines.

# 4 Synthesis

Quaternary mapping in northern Assynt (NC22) has revealed a more complex distribution of glacial deposits than previously reported. A new model of deglaciation has been proposed based on a resurvey of morainic and glaciofluvial landforms in the Loanan valley. This phase of valley glaciation must post-date the Late Devensian maximum (Dimlington Stadial) and pre-date the Loch Lomond Stadial. This evidence collected in 2002-2003 shows that ice-sheet deglaciation in NW Scotland was punctuated by small-scale readvance events resulting from either climatic fluctuations or changes in glacier configuration.

More fieldwork in central Assynt is planned for 2003-2004. BGS mapping will continue on the adjoining 25:000 maps – NC21, NC31 and NC32. Further geoscientific research will concentrate on the spatial distribution and stratigraphy of Quaternary deposits. The identification of more morainic landforms, in particular, will enable a more detailed picture of deglaciation to be derived. Verification of ice-free areas and chronological constraint will also be sought. Ultimately, it is hoped that the Late Devensian glacier oscillations identified in this study could be correlated with those recently identified elsewhere in northern Scotland (eg. Robinson and Ballantyne, 1979; Merritt *et al.*, 1995; Everest, 2003).

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