Stoer

[NC 041 283]–[NC 027 291], [NC 041 266]–[NC 039 281], [NC 045 328]

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Introduction

The Stoer GCR site, some 8 km north-west of Lochinver, represents the type area for the Stoer Group (Figure 4.6). The sequence is exposed in excellent coastal exposures, which clearly illustrate the sedimentology and structures of the group. The Stoer Group has an importance out of all proportion to its limited geographical extent (Figure 4.3), as it is the only non-metamorphosed Mesoproterozoic stratigraphical unit in Britain, having been formed about 1200 Ma, between the end of the Laxfordian orogeny at about 1750 Ma (Corfu *et al.,* 1994) and the deposition of the Torridon Group at about 1000 Ma. The rocks were originally assigned by the Geological Survey to the Diabaig Formation of the Torridon Group (Peach *et al.,* 1907), but were later recognized as an entirely distinct lithostratigraphical unit (Stewart, 1969) and given the name 'Stoer Group'. The Stoer Group has been described in detail by Stewart (1988a, 1990b, 1991b, 2002).

The Stoer Group rocks form a *c.* 2 km-wide belt on the Stoer peninsula lying between the basal unconformity and the NNE-trending Coigach Fault (Figure 4.6). They dip between 20° and 35° to the wisivv, with dips locally increasing close to the Coigach Fault, which throws down Torridon Group rocks to the WNW On the north coast of the peninsula, east of the Coigach Fault by Port Feadaig [NC 042 329], a basal conglomerate and up to 10 m of red siltstones of the Diabaig Formation unconformably overlie an irregular surface cut in the Stoer Group rocks. Coarse-grained pebbly sandstones of the Applecross Formation immediately overlie these basal Torridon Group siltstones and cut out the Diabaig Formation rocks to the north-west.

The sedimentary rocks of the Stoer Group include alluvial and aeolian sandstones, lacustrine mudrocks and carbonate rocks, and tuffaceous deposits. Palaeomagnetic measurements on the sandstones have established a well-defined magnetic pole (Smith *et al.,* 1983; Torsvik and Sturt, 1987), and thus have provided a key point on the Precambrian polar wandering path for Laurentia. The lacustrine deposits are important because of the presence of acritarch microfossils, probably marine phytoplankton, which deserve further study. The origin of the carbonate rocks is not yet fully understood (see below), but they are particularly important as they are the only undeformed, non-metamorphosed Precambrian carbonate rocks recognized in Britain.

The sandstones of the Bay of Stoer and Meall Dearg formations have three or four times more plagioclase than K-feldspar, whereas in the vast majority of sandstones in the geological column the ratio is reversed due to the relatively greater susceptibility of plagioclase to weathering. This implies that the source rocks of the Stoer Group at this GCR site must have been relatively unweathered.

Three sub-areas have been selected to do justice to the sedimentological complexity of the Stoer area (Figure 4.6). The first extends from Stoer village westwards along the northern shore of the Bay of Stoer to Meall Dearg and contains the stratotypes of the component formations and members of the Stoer Group. It also includes the best exposure of the lacustrine mudrocks and carbonate rocks. The second sub-area includes the coastal section and inland crags around Clachtoll, a few kilometres south of Stoer, where the lowest formation in the Stoer Group is more fully developed and more evidently related to the palaeogeomorphology than in the type section. The last sub-area lies on the north coast of the Stoer peninsula, near Port Cam and Port Feadaig, where aeolian sandstones are found.

Description

Bay of Stoer

The type section for the constituent formations and members of the Stoer Group (Stewart, 1969, 1990b) has its base about 33 m east of the old graveyard at Stoer [NC 041 284], and continues westwards along the foreshore and the low, easily accessible cliffs on the north side of Bay of Stoer as far as Meall Dearg [NC 027 290]. A graphic log of the section is shown in (Figure 4.7).

The base of the oldest unit, the Clachtoll Formation, is formed of massive breccia derived from the immediately underlying Lewisian gneisses. The breccia passes upwards into red tabular sandstone, well exposed in a small quarry near the north-east corner of the new graveyard [NC 0406 2832]. Massive dark-red muddy sandstone overlies the tabular sandstone facies, but the contact here is concealed by sand. A 2 m-thick section of the muddy sandstone is exposed in a small quarry near the roadside [NC 0398 2837]. The facies here is structureless but for a thin bed of very coarse sandstone, from which descend wispy, sand-filled veins. These appear to be relics of desiccation cracks in the muddy sediment, which have closed during a period of rewetting. Farther west, where the shore section starts [NC 0383 2832], there are good exposures of decimetre-scale bedded muddy sandstone with desiccation cracks and millimetre-sized holes, perhaps casts of former evaporite needles. Centimetre-thick beds of carbonate rock are common.

A 2 m-thick bed of very coarse sandstone interrupts the sequence, and forms a small promontory at [NC 0378 2831]. Small-scale trough-cross-bedding near the top of this sandstone shows that palaeocurrents flowed towards the south-west. The coarse sandstone can be traced south to Clachtoll and north to the coast at Port Cam, a distance of 6 km overall. A few metres above this sandstone marker bed a 5 m-thick sequence of fissile mudstone is exposed, grey in the lowest 0.5 m and red above. Ripple-bedded sandstones, which appear in the upper part of the mudstone unit indicate that palaeocurrents were directed towards the northeast. The uppermost sandstones, which are the highest beds in the Clachtoll Formation, contain pebbles of gneiss and quartz (but no quartzite) up to 1 cm across. The detritus in these rocks is solely derived from the local basement gneisses.

The top of the Clachtoll Formation is represented by an erosion surface, which is overlain by red sandstones containing rounded pebbles of gneiss and quartzite. These sandstones form a large promontory extending out into the Bay of Stoer at [NC 0371 2834]. The rocks above the erosion surface belong to the Bay of Stoer Formation, and are characterized by trough cross-bedding, soft-sediment contortions (Figure 4.8)a, pebbles of gneiss and fine-grained metasedimentary quartzite, and millimetre-thick concentrations of opaque and other heavy minerals.

The sandstones of the Bay of Stoer Formation are punctuated by sharply defined couplets of muddy sandstone and red mudstone. Five such couplets totalling 17 m in thickness are exposed on the shore [NC 035 285] about 70 m stratigraphically above the base of the formation. The same five couplets occur at Clachtoll to the south, and also on the northern coast of the Stoer peninsula between Port Feadaig and Port Cam [NC 0429 3291]–[NC 0432 3293]. Another group of couplets, totalling 8 m in thickness, occurs immediately below the Stac Fada Member at its type locality [NC 0332 2850].

Stac Fada [NC 033 284] is composed of muddy sandstone, which is unique in containing centimetre-sized lapilli of dark-green, vesicular volcanic glass. This unit is known as the 'Stac Fada Member' (Stewart, 1969). It is about 11 m thick at Stoer and can be mapped southwards for some 55 km, as far as Poolewe. The base locally cuts into the underlying sandstones and mudstones. Overfolded sandstone beds indicate mass movement to the south-west or west at the time of deposition, in contrast to the E-directed palaeocurrents implied by cross-bedding foreset orientations in the underlying sandstones.

The overlying, mainly fissile red siltstones and fine-grained sandstones are about 100 m thick and can also be mapped regionally. They form the Poll a' Mhuilt Member (Stewart, 1990b), named after the pronounced hollow in which they occur 1 km north of the coast section. This member includes some thin limestone beds, the origin of which is uncertain. Upfold (1984) suggested that they are stromatolitic, but the absence of clear diagnostic structures indicates that they may be inorganic (Stewart, 2002). Microplankton have been figured from the siltstone by Cloud and Germs (1971), and have also been reported from limestone at the same locality by Downie (1962). Palaeocurrents, whose orientation can be deduced from ripple-lamination and current lineations, flowed towards 100°, similar to those in the sandstones below the Stac Fada Member.

The massive siltstones at the top of the Poll a' Mhuilt Member are erosively overlain by red sandstones on the cliff 1 km west of Stoer church at [NC 030 286]. These sandstones belong to the Meall Dearg Formation, named after the hill that they form, and which stands a few hundred metres inland from the type section. The Meall Dearg Formation is generally characterized by planar cross-bedding in sets up to 1 m thick, laterally extensive intercalations of thinly bedded sandstone with wave ripples and desiccated mudstone drapes, but an absence of contorted bedding, pebbles or heavy-mineral bands. However, the lowest 7 m of the Meall Dearg Formation in the type section are and anomalous in being trough cross-bedded and pebbly. The pebbles resemble those in the Bay of Stoer Formation, but material from the Stac Fada Member is not present. This pebbly interval is sharply overlain by the typical planar cross-bedded lithology (Figure 4.8)b. Palaeocurrent directions in the pebbly interval and above are towards the west, counterposed to those in the Poll a' Mhuilt Member.

Clachtoll

At Clachtoll, south of the type section, the Clachtoll Formation infills a palaeovalley. The breccia facies is about 12 m thick near the centre of the palaeovalley [NC 043 273], while the overlying muddy sandstones are 200 m thick.

The lowest 120 m of the muddy sandstone are massive, and what appear to be bedding planes, for example in the roadside quarry at [NC 0423 2727], are in fact joints. Joints with similar orientation are seen in bedded muddy sandstones stratigraphically higher in the Clachtoll Formation, where they make a small angle with bedding.

The muddy sandstone has a fine-grained ferruginous matrix, separating larger grains (mainly feldspar) that make up about 30–40% of the rock. The geochemistry suggests that most of the matrix was originally ash-fall tuff, whose composition would have formed smectite on decomposition (Stewart, 1990b). There is clear evidence of repeated desiccation of the sediment (Stewart, 1988a). The repeated shrinking and swelling of the smectite-rich sediment probably accounts for the destruction of bedding features in most of the muddy sandstone.

Towards the Bay of Clachtoll the basement rises rapidly so that the massive muddy sandstone is either directly in contact with Lewisian gneisses, or separated from them by a few metres of breccia, or by tabular sandstones with gneiss clasts. Outcrops of breccia mantle the gneiss slopes in many parts of this area, indicating that the hills represent an exhumed Proterozoic landscape (Figure 4.9). Good examples can be seen on the south-east side of the bay at [NC 040 267], and on a hill of gneiss 350 m east of A Clach Thuill at [NC 041 267]. At this latter locality dilatational veins transect the gneiss for at least 5 m below the unconformity. The vein fill is red siltstone, unlike the matrix of the overlying breccias, and the siltstone is typically laminated, parallel to the regional bedding. The origin of the breccias, and of the fractures in the rocks, is rather controversial, and is discussed below.

Port Cam

The northern coast of the Stoer peninsula, around Port Cam, provides excellent exposures of the laminated sandstone facies of the Clachtoll Formation, believed to be of aeolian origin. The sandstones have an average grain-size of 0.2 mm, ranging up to a maximum of 2 mm. They contain cross-beds which are generally only a few grains thick, forming sets mostly a few decimetres thick but in places up to as much as 10 m. The foresets dipped up to 25° to the east before tectonic tilting. The laminated sandstone facies contains numerous interbeds of relatively coarse-grained, pebbly sandstone with strongly erosive bases, and desiccated red siltstone laminae. The facies is bisected by a gneiss-cobble conglomerate unit, informally termed the 'Rienachait conglomerate', which reaches the sea about 200 m east of Port Cam at [NC 0474 3293]. The conglomerate is about 8 m thick and has a strongly erosional base.

Pebbly sandstones of the Bay of Stoer Formation erosively overlie laminated sandstone about 100 m west of Port Cam [NC 0435 3294]. Farther west along the shore at Port Feadaig [NC 042 329] the Torridon Group unconformably overlies the Bay of Stoer Formation. Both groups have a westerly dip, the Stoer Group at 30° and the Torridon Group at about 20°. The lowest Torridon Group beds are red fissile mudstones and a basal conglomerate, both assigned to the Diabaig Formation, which are exposed only at low tide. Sandstones of the Applecross Formation in turn erosively overlie the thin Diabaig Formation units.

Interpretation

The earliest sediments, the Clachtoll Formation, were deposited on an irregular landscape, with a relief of up to *c.* 300 m; the eroded surface of the underlying Lewisian gneiss basement. The massive breccio-conglomerates, bedded breccias and tabular red sandstones seen in the Stoer area were probably deposited in alluvial fans. However, Davison and Hambrey (1996) suggested that some of the breccias around Clachtoll could represent glacial deposits, with infilled fractures in the gneiss having formed through hydro-fracturing beneath a glacier. Beacom *et al.* (1999) also interpreted the veins as dilational, but formed by tectonic hydro-fracturing. Stewart (1997) and Young (1999a) disagreed with the glacial hypothesis and considered that the weight of evidence still points to alluvial fans as a more likely depositional environment for the breccias. The fan deposits are thickest in the valley bottoms and absent from the ridges. In the palaeovalley around Clachtoll the alluvial-fan deposits pass laterally into muddy sandstones, which formed on ponded water mudflats (Stewart, 1988a). These muddy sandstones were rich in smectite group clay minerals, partly due to enrichment in Mg and Ca from basic rocks in the hinterland, but mainly supplied by ash-fall tuff (Stewart, 1990b). Seasonal wetting and drying subsequently destroyed any original bedding features.

Alluvial, trough-cross-bedded, red sandstones and gneiss-cobble conglomerates infill the northern palaeovalley around Port Cam, and near the northern coast they interdigitate with laminated red sandstones. The latter are believed to have been laid down on barchan sand dunes because of their grain size and cross-bedding and the presence of several tongues of evidently water-laid, massive, pebbly sands with erosive bases. A possible explanation for the contrast in the valley fill between Clachtoll and Port Cam is syn-depositional tectonic tilting of the area, which eliminated the longitudinal gradients of some palaeovalleys so that they became the sites of lakes or swamps, whereas other palaeovalleys retained vigorous streams.

The last event in the burial history of the basement relief was the formation of a lake over the whole area, represented by red mudstones near the top of the Clachtoll Formation. At this point the palaeoslope apparently changed abruptly through 180° from westerly to easterly, marking the start of a second phase of sedimentary history.

The lake sediments were covered by the pebbly alluvial sands of the Bay of Stoer Formation, which were deposited by braided rivers coming from the rift flanks (Stewart, 1988a). This fluvial sedimentation was frequently interrupted by down-warping of the alluvial plain, perhaps due to volcanic eruptions, allowing the formation of temporary lakes. The lake deposits are the muddy sandstone–red mudstone couplets described above, of which the most remarkable are those constituting the Stac Fada and Poll a' Mhuilt members. The volcanic association is demonstrated by the abundance of glassy lapilli in the Stac Fada Member, which differentiates this unit from the other muddy sandstones.

Lawson (1972) interpreted the Stac Fada Member as a hot pyroclastic flow, while Sanders and Johnston (1989) suggested that it represents an extrusion of fluidized peperite resulting from the injection of hot magma into wet sediment at depth. Most recently, Stewart (1990a,b) has studied the geochemistry of these rocks and interpreted them as having formed when ash-fall tuff was washed into temporary lakes together with more-typical sediments of the Bay of Stoer Formation.

The top of the Poll a' Mhuilt Member is marked by another abrupt change in palaeocurrent direction, this time from easterly back to westerly. This last phase of sedimentation, represented by the Meall Dearg Formation, was again alluvial, but the channels were wider and the slopes more gentle than in Bay of Stoer Formation time. The cross-bedding was formed by transverse bars, rather than as dunes.

The reversals of palaeocurrent direction through 180° indicate that the sediments of the Stoer Group accumulated in an active rift-valley trending north–south (Stewart, 1982). Geochemical and detrital zircon studies on rocks from Stoer confirm that the main source for these sediments was the local Lewisian gneisses (Van de Kamp and Leake, 1997; Young, 1999a; Rainbird *et* al., 2001). The volcanic glass in the Stac Fada Member has been shown to be silica-undersaturated and potassic, further supporting a rift setting (Stewart, 1990b).

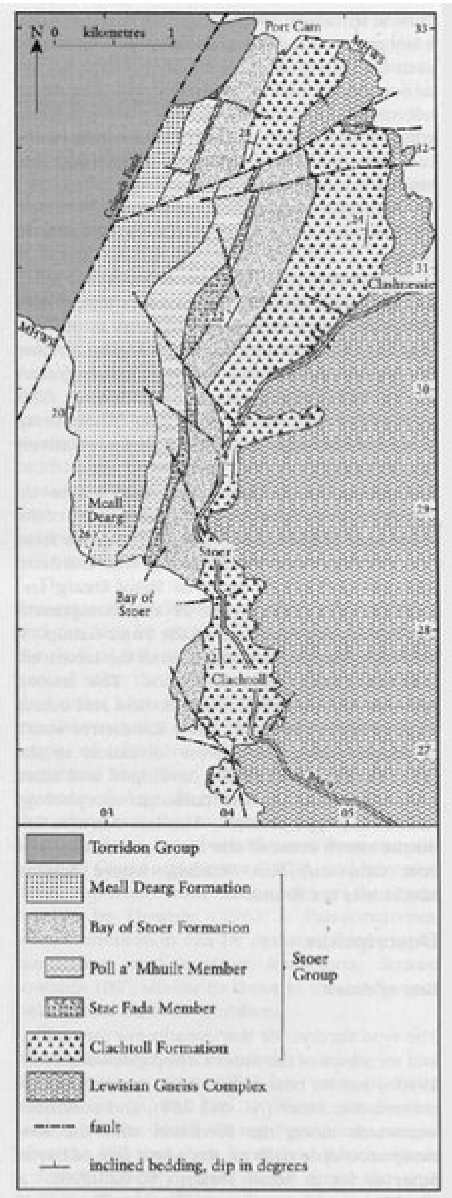
The palaeoclimate during deposition of the Stoer Group was probably semi-arid. The palaeo-latitude, deduced from earlier palaeomagnetic studies (Torsvik and Sturt, 1987), was 10°–20° N, but the revised data of Buchan *et al.* (2000,

2001) and Darabi and Piper (2004) suggests that the area lay between 20° and 25° N. This corresponds today to climates ranging from tropical savannah to desert. The absence of significant chemical weathering of mineral grains in both the alluvial sandstones and the locally derived sedimentary rocks near the basal unconformity is consistent with a semi-arid climate over the whole area of the rift (Young, 1999a; Stewart, 2002).

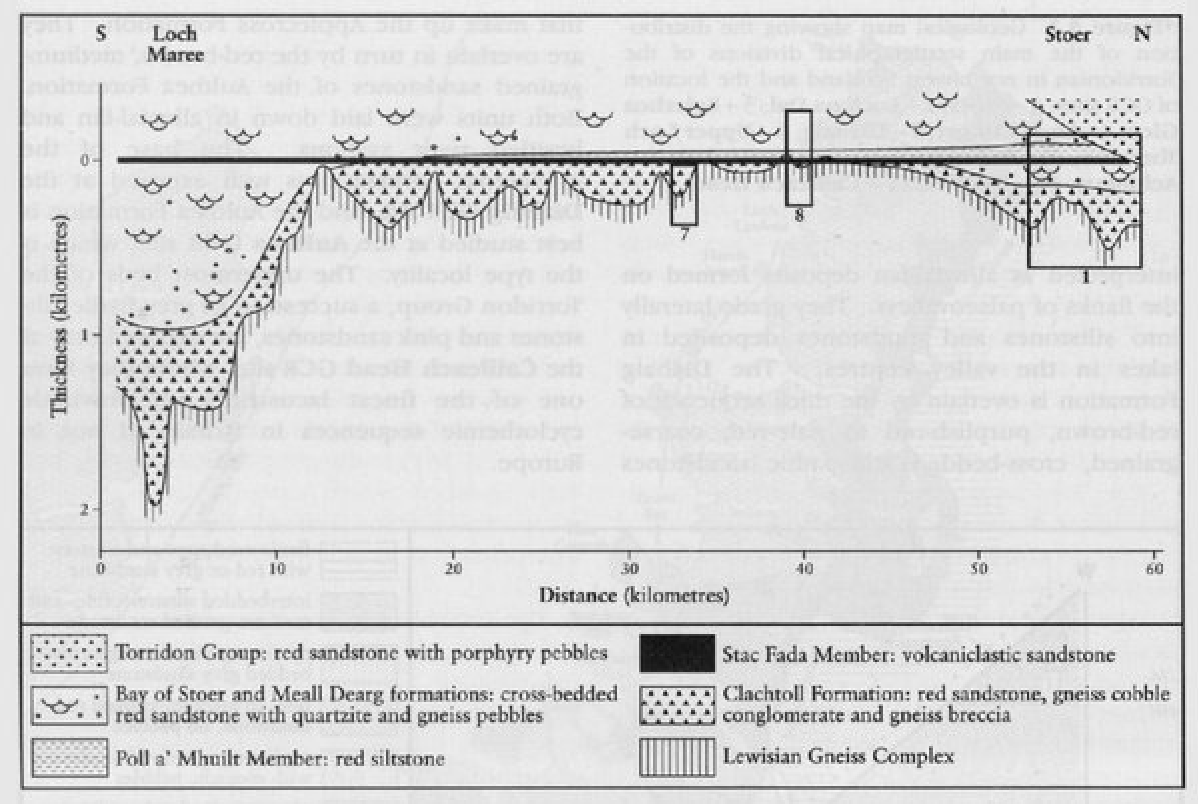
Conclusions

The Stoer GCR site contains the type section of the Stoer Group, which consists of sedimentary breccias, sandstones and mudstones with minor carbonate rocks and volcanic rocks, interpreted as deposited in an evolving Mesoproterozoic rift. It provides the best exposures in Britain in which the complex interplay of fluvial, aeolian, lacustrine and volcanic processes within a rift sequence of this type can be studied. Because of their superb exposure and lack of metamorphism, the sedimentary rocks at Stoer have a significant potential for further geochemical, palaeontological and isotopic studies, which can be used to study palaeo-environments during the Proterozoic. There are no comparable sedimentary rocks of similar age on the Laurentian shield, or in Europe, and the site is therefore of international importance.

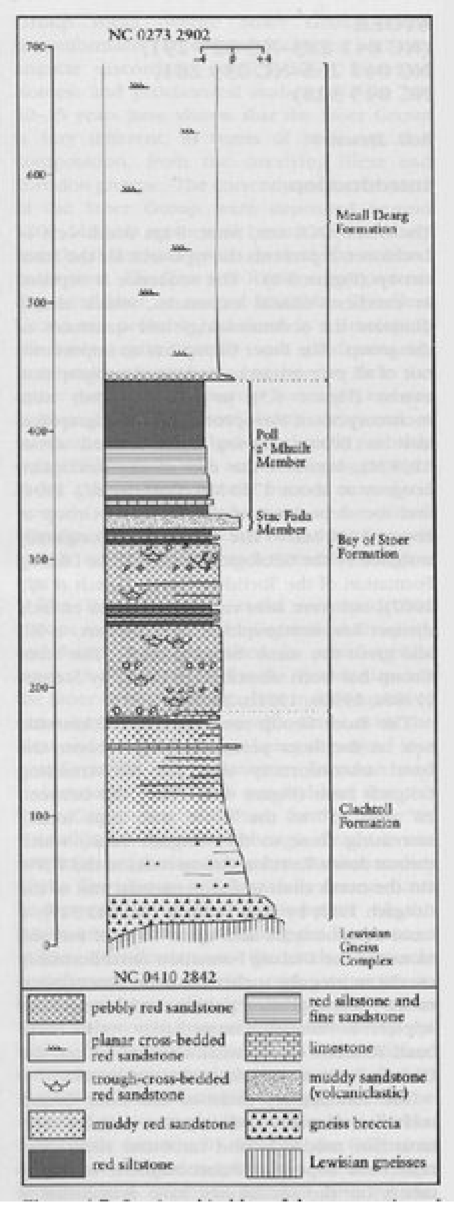
[References](#)



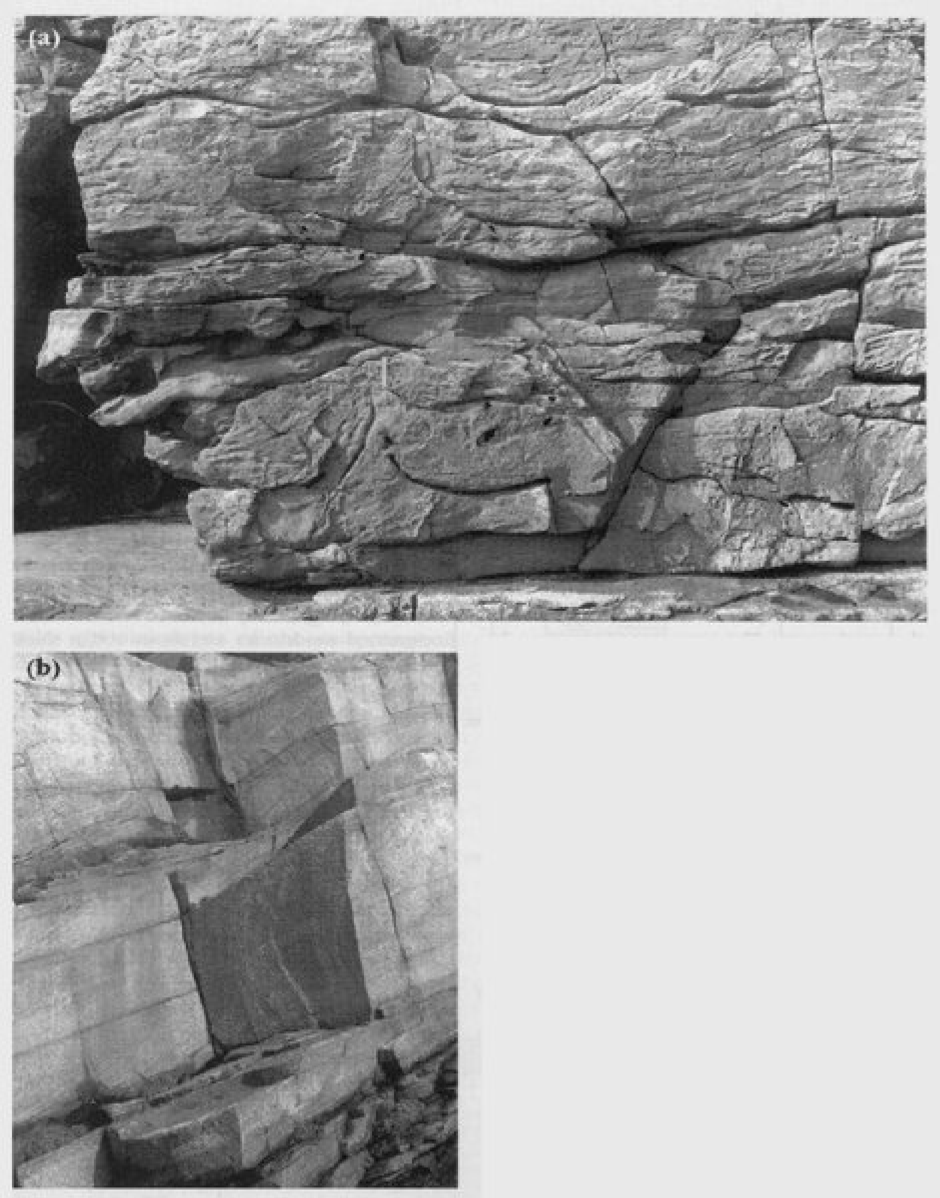
(Figure 4.6) Geological map of the area around Stoer.



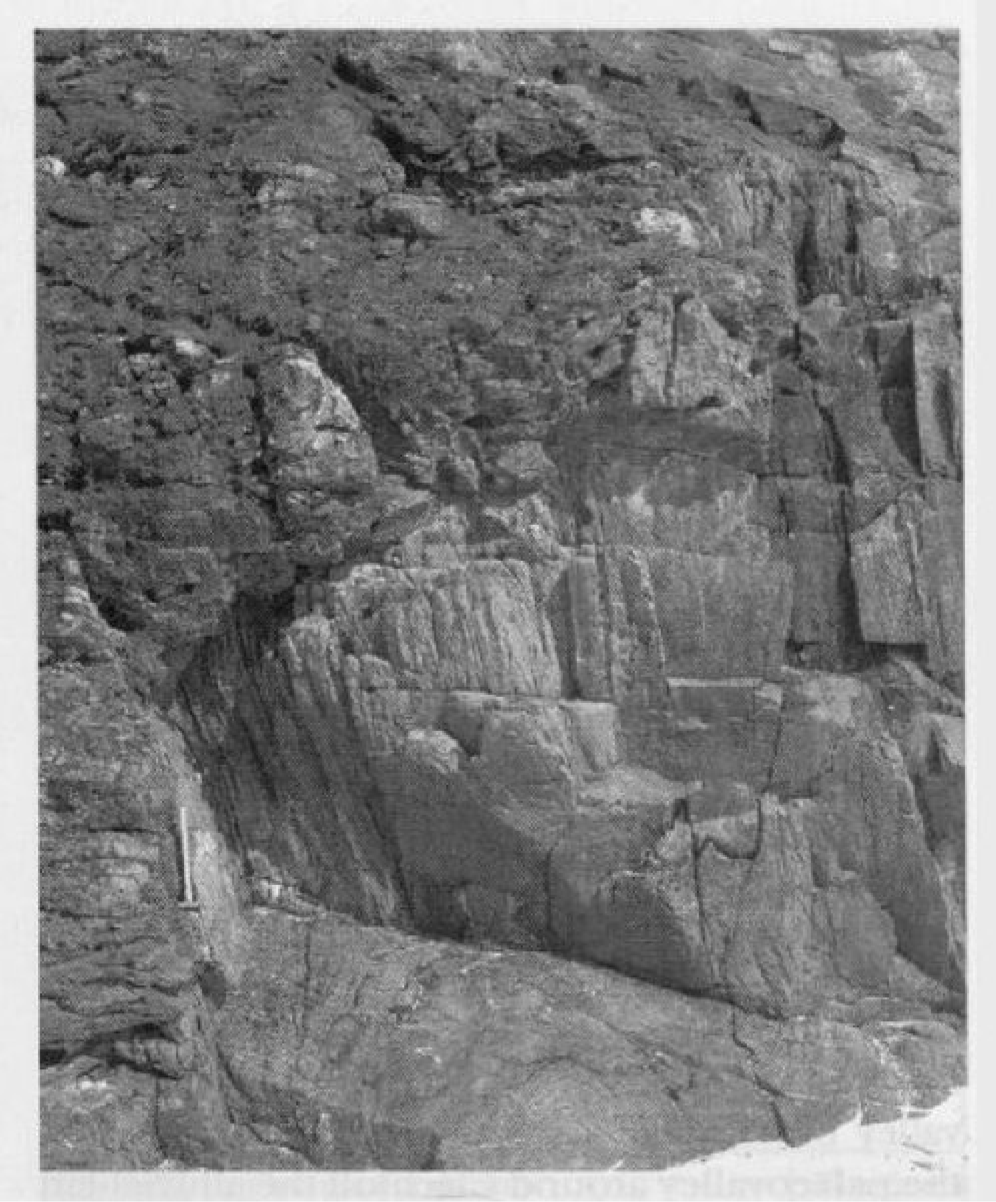
(Figure 4.3) Stratigraphical section through the Stoer Group perpendicular to the dominant western and eastern palaeocurrent directions. The stratigraphical positions of GCR sites are shown as boxes, numbered as in Figure 4.1.



(Figure 4.7) Stratigraphical log of the type section of the Stoer Group, along the north side of the Bay of Stoer, west of the old graveyard. Grain-size scale from +4 0 to -4 0 (0.06–16 mm).



(Figure 4.8) (a) Trough-cross-bedded red sandstones of the Bay of Stoer Formation at Clachtoll [NC 0359 2728] in the Stoer GCR site. Contorted bedding is common in the formation; the crest of a water-escape cusp is marked by the ruler (20 cm long). (b) Planar cross-bedded red sandstone of the Meall Dearg Formation at Meall Dearg [NC 0299 2855] in the Stoer GCR site. The two sets in the centre of the photograph are each about 25 cm thick. Contorted bedding is absent from this formation. (Photos: A.D. Stewart.)



(Figure 4.9) Breccia of the Clachtoll Formation resting on Lewisian gneisses at Clachtoll Bay in the Stoer GCR site. The hammer is 50 cm long. (Photo: British Geological Survey, No. P005850, reproduced with the permission of the Director, British Geological Survey, © NERC.)