Enard Bay

[NC 021 140]–[NC 039 140]

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Introduction

The Enard Bay GCR site covers little more than a square kilometre in total but displays an excellent and accessible coastal section on the south side of Enard Bay, south-west of Lochinver (Figure 4.24). Its importance comes from the easily demonstrable superposition of typical Torridon Group sedimentary rocks on the Stoer Group, the latter represented by the Stac Fada Member. In this respect it is unique and constitutes a cardinal point in Scottish Precambrian stratigraphy. Both Torridonian groups lie unconformably on an irregular erosion surface cut in the basement Lewisian Gneiss Complex, which shows significant topographical relief. The Geological Survey mapped the area in 1888, prior to the establishment of any formal Torridonian stratigraphy, and consequently the importance of this site was overlooked. Gracie and Stewart (1967) first described the detailed geology and recognized its wider significance. It is extraordinarily complex due to the fact that both the Stoer and Torridon groups rest on landscape unconformities, with the younger Torridon Group unconformity cutting across the older Stoer Group unconformity. Breccias, sandstones and siltstones overlie each unconformity, and care is needed to distinguish the basal rocks of one group from those of the other. The most important criterion is the composition of the clasts, which are of Lewisian gneiss in the Stoer Group, but include reworked sedimentary rocks in the Torridon Group.

Palaeomagnetic investigations by Stewart and Irving (1974) showed quite different palaeomagnetic directions in the sedimentary rocks immediately above and below the unconformity separating the Stoer and Torridon groups at Enard Bay, similar to the directions found at Rubha Dunan and elsewhere. Subsequent work on the Stac Fada Member and Rudha Beag Sandstone at Enard Bay by Smith *et al.* (1983) confirmed this conclusion and suggested ages of *c.* 1100 Ma for the Stoer Group and *c.* 1040 Ma for the Torridon Group, based on comparison of the palaeomagnetic data with the apparent polar wander path for the Proterozoic. Recent radiometric dating of a limestone from the Stoer Group at Enard Bay has given a Pb-Pb isochron age of 1199 ± 70 Ma and a Rb-Sr whole-rock age of 1009 ± 130 Ma on the Poll a' Mhuilt Member at Stoer (Turnbull *et al.,* 1996). The same study produced an Rb-Sr whole-rock date of 994 ± 48 Ma for Diabaig Formation phosphate nodules from Diabaig. These dates are compatible with the palaeomagnetic estimates, and confirm that a considerable period of time (over 100 million years) elapsed between the deposition of the Stoer and Torridon groups.

Controversy has developed recently regarding the deposition of the basal Stoer Group sediments at Enard Bay, which have been variably interpreted as alluvial (Gracie and Stewart, 1967; Stewart, 1997; Young, 1999b), and as glacial (Davison and Hambrey, 1996). Samples from Enard Bay have also been used in recent provenance studies based on U-Pb isotopic ages of detrital zircons (Rainbird *et al.,* 2001).

Description

The GCR site comprises a continuous rocky shoreline section some 3.7 km long from Achnahaird Bay in the west around the promontories of Rubha Beag and Rubh' a' Choin to Garvie Bay in the east. It also includes the immediate rocky hinterland areas on the northern slopes of Cnoc Mòr an Rubha Bhig. Much of the inland area to the south is now planted with conifers. A geological map and section are shown in (Figure 4.24). The Stoer Group in the area of the map rests unconformably on hills of Lewisian gneiss. It totals 350 m thick, of which the lowest 200 m belong to the Clachtoll Formation. Small Lewisian inliers (hilltops) appear just south of the map area [NC 022 134], near the stratigraphical top of the section, showing that basement relief at the time of Stoer Group deposition was similar to the stratigraphical thickness preserved today, i.e. several hundred metres.

The lowest sedimentary rocks in the area are massive breccias, which are well exposed on the headland [NC 035 147] about 450 m south-east of Rubh' a' Choin. Blocks of weathered felsic gneiss in the breccia here are commonly coloured pale-green by pumpellyite, and Hay *et al.* (1988) recorded pumpellyite alteration and veining of the underlying gneiss. The massive breccia is sharply overlain by bedded breccia with thin red sandstone interbeds. The contact between the two types of breccia is well exposed on the headland (Figure 4.25), only a few metres below a prominent outlier of the Applecross Formation sandstones at [NC 0359 1470]. At one point the contact is clearly erosional.

Rocks of the bedded breccia facies are also exposed at [NC 0278 1463], about 100 m northwest of the ruined bothy on the southern shore of Camas a' Bhothain, where gently dipping brownish-grey interlaminated sandstones and mudstones contain blocks of gneiss, varying in size up to 2 m across (Figure 4.26). The laminae below the clasts have been depressed, whilst those above drape over the tops of the blocks. This led Davison and Hambrey (1996) to interpret the clasts as dropstones, deposited in moderately deep water from melting glacial ice. However, laterally equivalent sandstone bedding surfaces are covered by symmetrical ripple marks and well-developed desiccation polygons, which suggest a shallow-water environment (Stewart, 1997; Young, 1999a). The blocks are lithologically and geochemically similar to the Lewisian gneisses that underlie the succession and form the ridge against which the sandstones onlap to the west. Hence, the blocks are unlikely to have been transported far from their source. These bedded breccias, and the underlying massive gneiss breccia, can be traced westwards round the headland into the next bay, where they can be seen to underlie red siltstones which belong to the Poll a' Mhuilt Member of the Bay of Stoer Formation.

To the south of Rubh' a' Choin, the bedded breccia facies grades upwards into a volcani-clastic sandstone, which can be identified from its distinctive lithology, and from its stratigraphical relationships, as the Stac Fada Member (Figure 4.24). This member is 32 m thick here, three times the thickness found elsewhere. The lowest 20 m is massive and is relatively rich in gneiss clasts, suggesting that underlying breccias and sandstones were reworked during the deposition of these rocks. By contrast, the uppermost 12 m of the member contain conspicuous accretionary lapilli. Extensive erosion surfaces are also present, and it is clear that the topmost 4–5m of the member has been strongly reworked.

The Stac Fada Member passes up into massive red siltstones of the Poll a' Mhuilt Member, which includes thin limestone beds that appear discontinuous owing to decalcification along joint planes. To the west, about 120 m north of the bothy at [NC 0235 1468], limestone encrusts gneiss breccia. Farther west still, in the floor of a small bay at [NC 0272 1467], 175 m north-west of the bothy, about 25 m of siltstone are exposed. The siltstone rests on massive gneiss breccia partly cemented by limestone, and is overlain by the Rudha Beag Sandstone that here forms a scarp feature. The Rudha Beag Sandstone probably correlates with the Meall Dearg Formation at Stoer but the old name is retained here with informal status.

The Rudha Beag Sandstone consists of about 150 m of fine- to medium-grained reddish-grey sandstone with interbeds of horizontally laminated sandstone up to 2 m thick. Grain size is invariably less than 1 mm, and contortions, ripples, silty interbeds or drapes are absent from this unit. However, tabular planar cross-bedding is common, with set thickness ranging from a few decimetres up to 5 m. Individual foresets are only a few millimetres thick and are asymptotic to the basal erosion surface, which is generally planar but locally has a relief of up to 10 cm. Foresets generally dip at an angle of 16°–20° to truncation surfaces, and had a mean dip direction towards 244° before tectonic tilting.

Torridon Group rocks, which unconformably overlie the Stoer Group rocks in this area, are exposed on the peninsula of Rubh' a' Choin and also immediately to the north-east of the bothy. They closely resemble the rocks of the Diabaig Formation in its type area (see Diabaig GCR site report, this chapter), and like them are overlain by pebbly sandstones typical of the Applecross Formation. The basal breccio-conglomerate, which can be seen on the coast about 200 m north-east of the bothy, contains blocks exclusively derived from the Rudha Beag Sandstone, some as much as 11 m in size. Elsewhere, by contrast, it contains both gneiss and sandstone clasts derived from the immediately underlying basement. On the coast, 400–500 m south-east of Rubh' a' Choin at [NC 035 146] and [NC 036 146], both the matrix and the clasts contain green pumpellyite (Hay *et al.,* 1988).

A few metres of mainly grey fissile siltstones and tabular sandstones belonging to the Diabaig Formation are developed south and south-east of Rubh' a' Choin [NC 034 146]. The topmost metre is red and contains a thin bed packed with centimetre-sized clasts of gneiss, fine-grained red sandstone (probably derived from the Stoer Group) and orthoquartzite.

Fissile siltstone and beds beneath the Applecross Formation on the coast at [NC 037 145] are all red. 'Channels', several metres across and reaching a depth of 80 cm, have been reported in these siltstones (Gracie and Stewart, 1967). They are infilled by fine-grained, laminated sandstones and siltstones essentially concordant with the 'channel' sides and floor, and are now believed to have formed by penecontemporaneous extension and attenuation of the beds, rather than by erosion. On both Rubh' a' Choin and on the coast to the south-east, red, pebbly coarse sandstones of the Applecross Formation overlie the siltstones. These are the highest rocks in the Torridon Group sequence at Enard Bay.

Interpretation

As mentioned above, Davison and Hambrey (1996, 1997) have interpreted the large gneiss clasts in the laminated sandstones in the basal part of the Stoer Group at Enard Bay as dropstones, deposited from melting ice. They also invoked other pieces of evidence, including the interpretation of asymmetrical gneiss palaeohills as roches moutonnees, to suggest that the basal Stoer Group sediments were deposited under glacial conditions. Stewart (1997, 2002) and Young (1999a) strongly disputed this interpretation and contended that the observed features are compatible with deposition in alluvial fans. Preliminary oxygen isotope data (Davison and Hambrey, 1996; Turnbull *et al.,* 1996) for Stoer Group limestones from Enard Bay do indicate the possibility of a cold-water non-marine environment, but the restricted δO^{18} values could equally be interpreted as a cliagenetic signature. At present, it seems more probable that the Stoer Group breccias and siltstones were deposited in alluvial fans and lakes, whereas the Rudha Beag Sandstone was probably laid down as straight-crested transverse dunes in river channels.

The sandstone-boulder conglomerate unit at the base of the Torridon Group, exposed just to the north-east of the bothy, is unusual in showing features typical of a rotational landslide or slumped mass. The original eastern margin of the deposit can be fixed accurately, about 300 m from the present Rudha Beag Sandstone scarp, whereas farther to the east the basal breccia of the Torridon Group was derived from underlying rock-types. The sandstone conglomerate must have originally extended westwards to the foot of the scarp, but has been eroded from the intervening zone in recent times. The original slip, using the equations of Anderson and Dunham (1966), was probably about 100 m high, the upper 75 m consisting of Rudha Beag Sandstone. The sandstone moved on the underlying, water-saturated siltstone, which is about 25 m thick near the existing Rudha Beag Sandstone scarp. By comparison with recent landslips it may be deduced that, when movement occurred, the Rudha Beag Sandstone and the partly compacted siltstone beneath it were porous, rain-soaked and consequently weak. The collapse of the sandstone scarp may also account for the shearing and disruption in the uppermost metre of the underlying siltstone, exposed 120 m north of the bothy at [NC 0286 1463].

The rest of the Torridon Group sequence at Enard Bay mirrors that of the underlying Stoer Group in comprising alluvial-fan breccias and sandstones grading up into silty lake deposits. In both cases sandstones deposited in braided rivers overlie these sequences. The red mud- stones that form the Poll a' Mhuilt Member of the Bay of Stoer Formation, and the fissile grey siltstones in the Diabaig Formation of the Torridon Group, are believed to be lake deposits on account of the low boron content in the illite (Stewart and Parker, 1979).

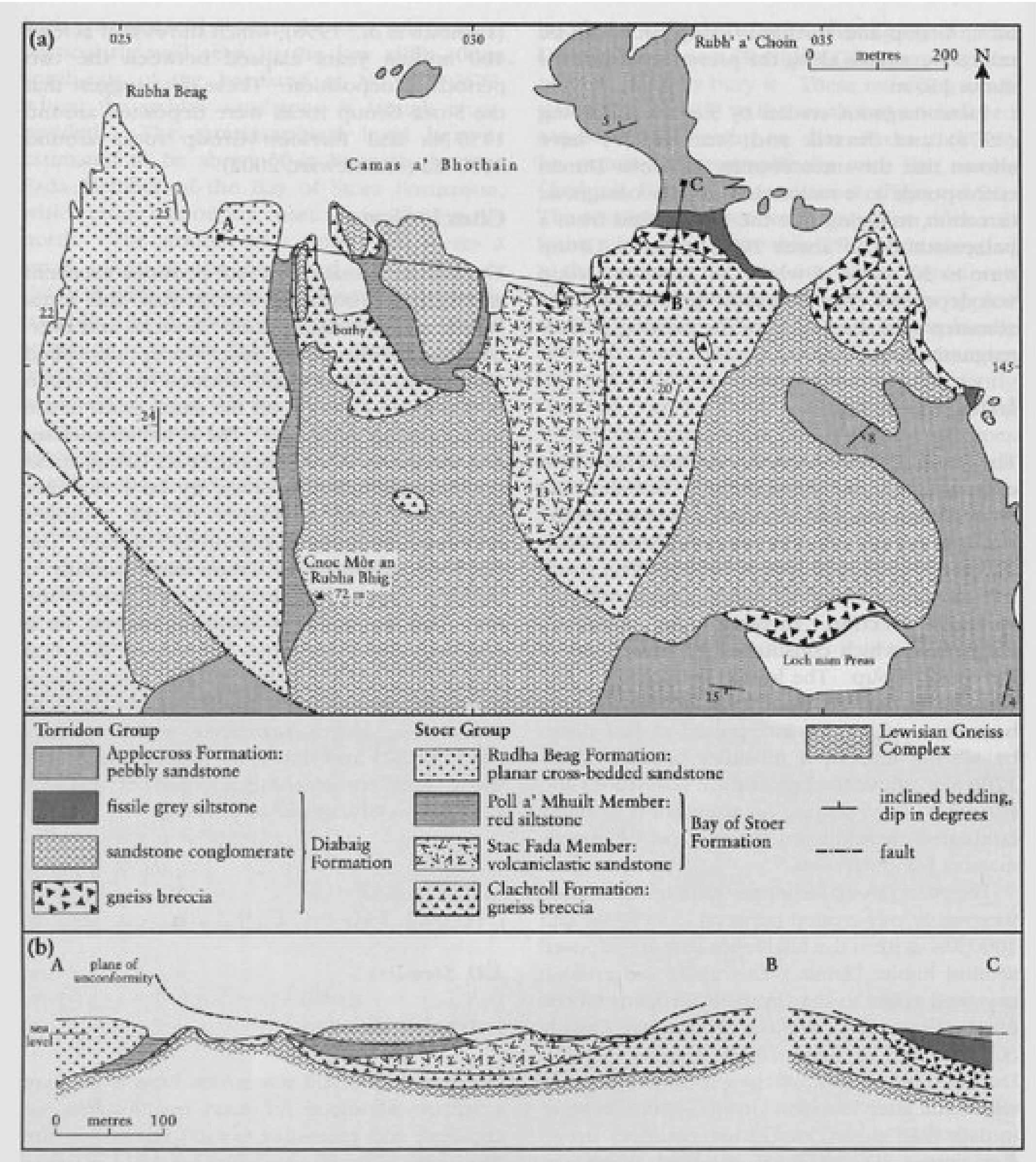
Recent provenance work on samples from Enard Bay (Young, 1999a; Rainbird *et* al., 2001) has confirmed that, whilst the Stoer Group sediments were originally derived from local basement rocks, the Applecross Formation sandstones (Torridon Group) were derived from a more-distal source. Although Rainbird *et al.* (2001) showed that only 16% of the detrital zircons in these sandstones are Grenvillian in age (*c.* 1100–1200 Ma), the Grenvillian Orogeny was a complex continent-continent collisional event during which older rocks were undoubtedly reworked and uplifted (Gower and Krogh, 2002). Hence, a Grenvillian mountain range may well have supplied sediment to the large-scale rivers that fed the Torridonian basin.

Conclusions

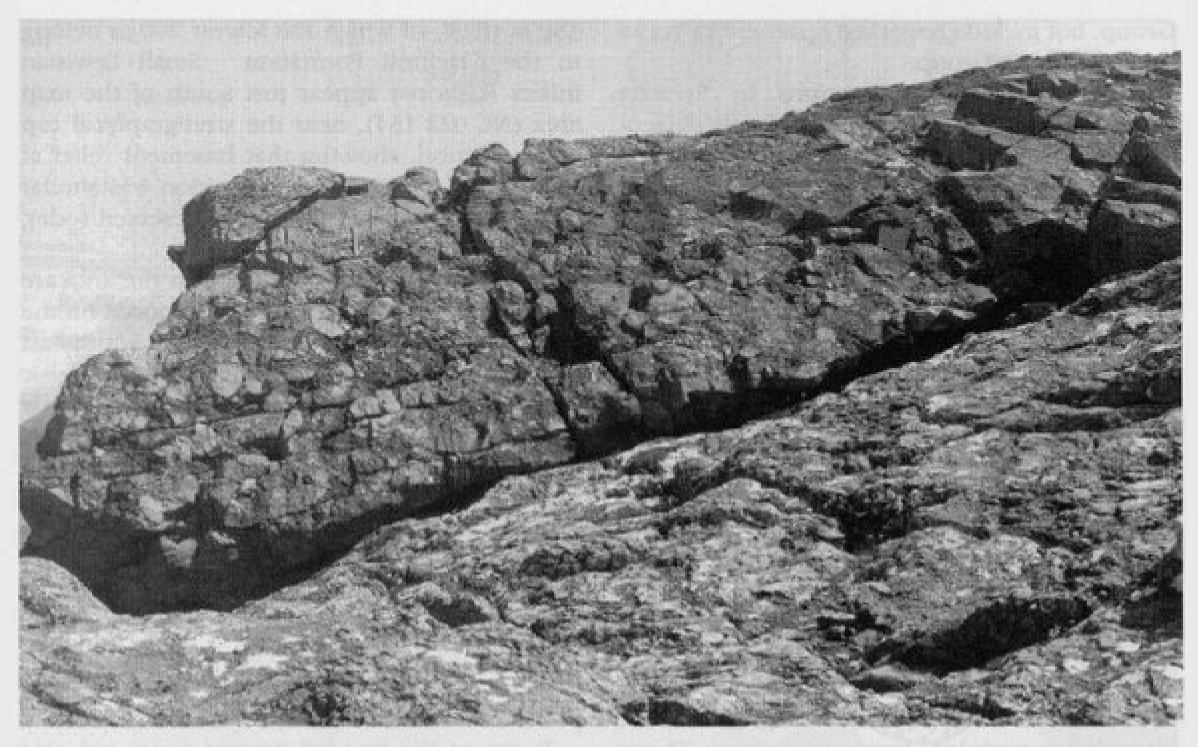
The Enard Bay GCR site displays evidence of two phases of Precambrian landscape formation and burial by Torridonian sediments. Alluvial breccias, lake sediments and volcaniclastic sands belonging to the Stoer Group covered the earlier landscape, with several hundred metres of relief cut in the underlying Archaean and Palaeoproterozoic Lewisian gneisses. The sediments and volcaniclastic unit were deposited about 1200 million years ago. The second landscape was formed in both the Lewisian gneisses and the older, now lithified Stoer Group. Alluvial breccias and lake sediments of the Torridon Group, deposited about 1000 million years ago covered this later landscape. Unusually, at the base of the Torridon Group sequence is a large landslip or slumped mass, originally some 100 m high, that contains blocks of Stoer Group sandstone up to 11 m across.

The site is of prime stratigraphical importance because it is the only place where the unconformable relationship between the Stoer Group and the overlying Torridon Group can be proved unequivocally. The Stoer Group is uniquely identified by the presence of the volcaniclastic Stac Fada Member, and the Torridon Group by the Applecross Formation with its diagnostic suite of durable pebbles. At other sites where the unconformity has been identified (e.g. the Rubha Dunan GCR site), the Stac Fada Member is lacking and palaeomagnetic studies have been needed to prove that the Stoer and Torridon groups formed at different palaeolatitudes. At Enard Bay several of the elements have been isotopically dated, and their provenance and palaeomagnetic declination and inclination are known. Student parties regularly visit the site because it condenses much of the sedimentary history of the Torridonian into a small and accessible area. The Enard Bay GCR site is thus of international importance for teaching purposes and for continued research into Proterozoic depositional environments.

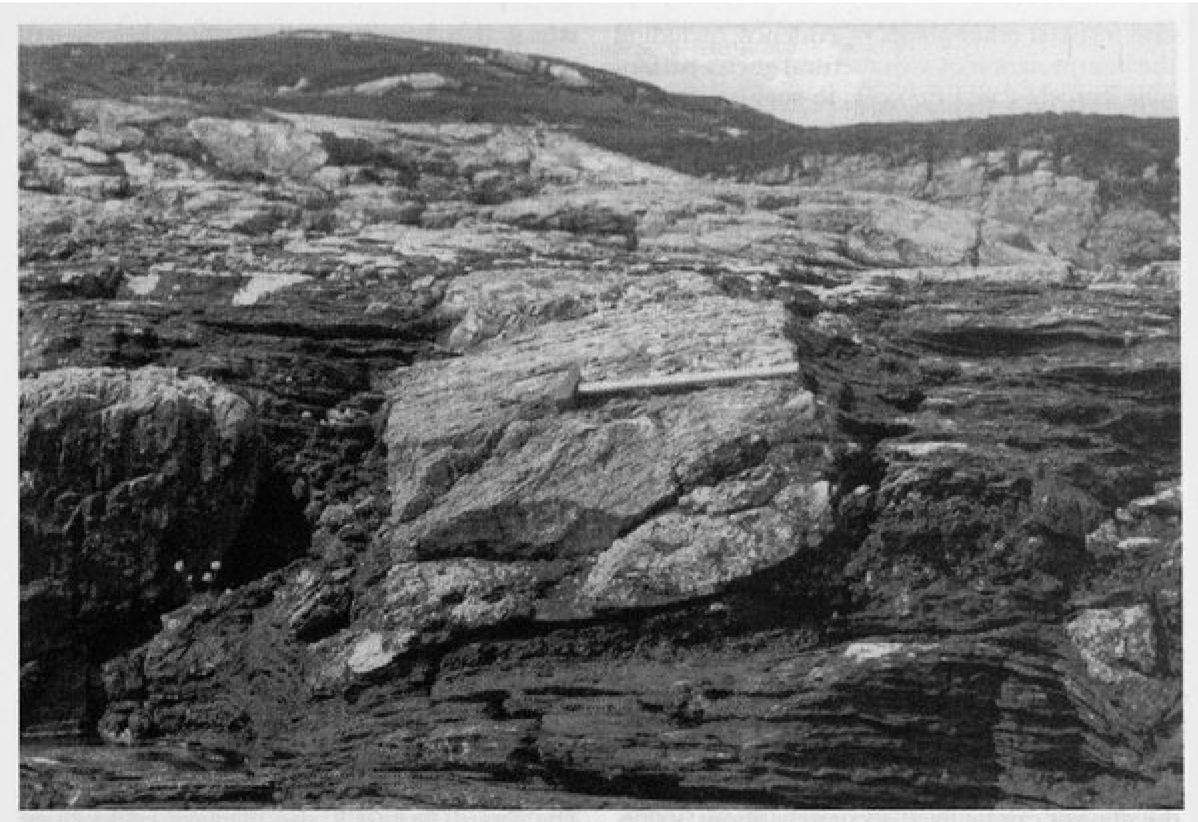
References



(Figure 4.24) Geological map and true-scale cross-section of the Enard Bay area.



(Figure 4.25) Massive breccio-conglomerate at the base of the Stoer Group at Enard Bay. The breccia passes upwards, to the right, into brown tabular-bedded coarse sandstone. The hammer, which is 53 cm long, marks the base of a small outlier of Applecross Formation unconformably overlying the breccia. The locality is to the south-east of Rubh' a' Choin at [NC 0359 1470]. (Photo: A.D. Stewart.)



(Figure 4.26) Gneiss blocks in the bedded breccia facies of the Stoer Group at Enard Bay, interpreted by Davison and Hambrey (1996) as glacial dropstones. The dark-brown sandstones between the boulders range in grain size from fine to very coarse. Lewisian basement is seen in the background above the block with the hammer. The locality is at high-water mark about 250 m north-west of the ruined bothy [NC 0278 1463]. The hammer shaft is 50 cm long. (Photo: A.D. Stewart.)