Durness and Balnakeil

[NC 358 687], [NC 361 630], [NC 389 657] and [NC 372 676]–[NC 425 668]

Introduction

The Durness area is much the most important site for the Cambrian–Ordovician stratigraphy of the Hebridean Terrane in north-west Scotland. It shows the most complete representation of the Laurentian foreland sequence and is the type area for the Durness Group.

The site is extensive, covering parts of the shore of the Kyle of Durness, Balnakeil Bay (the older spelling was 'Balnakiel) and the areas to the south and east of Durness (Figure 12.3). The rocks range from the unconformity at the base of the arenaceous Eriboll Sandstone Formation, through the An t-Sròn Formation to the carbonates that make up the entire known thickness of the Durness Group, all seven formations of which are exposed in the area. A Cambrian age is accepted for the lower units, from the basal unconformity to very near the top of the Eilean Dubh Formation. The overlying Sailmhor and Sangomore formations are of Tremadoc age, and the Balnakiel, Croisaphuill and Durine formations are of Arenig and possibly early Llanvirn age.

For 140 years geologists have recognized the close resemblance of the Durness carbonate rocks and their fossils to those of eastern Canada (e.g. north-west Newfoundland), whereas equivalent rocks in Wales bear no resemblance and the faunas have no species in common. These contrasts provided key evidence for the concept of a proto-Atlantic (or Iapetus) Ocean and led ultimately to the modern understanding of Cambrian–Ordovician palaeogeography in the North Atlantic region, in which it is postulated that the sequences in Scotland and Wales were deposited on opposite sides of a wide oceanic barrier. Thus Durness is a key site, both for the excellent exposures of the stratigraphy and for the international implications for correlation and palaeogeography.

Macculloch (1836), Cunningham (1841) and Nicol (1857) had worked on the Durness area, but it was Murchison who first made a detailed study of the Durness Group (Murchison, 1859), whilst the fossils that Charles Peach had collected from the area were described by Salter (1859) as 'lower Silurian' (rather than Devonian or Carboniferous, as had earlier been supposed). The region was visited by many of the combatants, notably Lapworth, during the years of the Highlands controversy (Oldroyd, 1990), but only after the controversy had been resolved was the stratigraphical succession described in detail by Peach *et al.* (1907); their work remains the most comprehensive summary of the stratigraphy and structure of the area.

Since that time, the sedimentology of both the arenaceous and the carbonate units have been subjected to detailed analysis by Swett (1969), Swett *et al.* (1971) and McKie (1990a, b). The stratigraphy has also been the subject of debate: fissuring and erosion at the top of the Sailmhor Formation was attributed by Palmer *et al.* (1980) to the development of an Ordovician karst surface and was said to represent a break in deposition corresponding to the whole of the Middle and Upper Cambrian. They accordingly used the break to propose division of the Durness Group into a lower and an upper part. Palmer *et al.*'s interpretation was challenged by Nicholas (1994), who regarded the fissures as a much more recent phenomenon. Wright and Knight (1995) and Huselbee and Thomas (1998) have revised the international correlation of the lower parts of the Durness Group, whilst Fortey's (1992) work and unpublished studies by Drs M.P. Smith and D.H. Evans afford significant improvements to the correlation of the upper parts of the group. In consequence, the succession is considered fairly continuous and the Durness Group does not fall naturally into lower and upper parts.

Description

The Cambrian strata of Durness form a triangular area about 14 km long and up to 5 km wide, known as the Durness Basin (Figure 12.3). The strata were once continuous with those at Eriboll (see the An t-Sròn site report) but have been isolated from that outcrop by the action of two sets of normal faults, one extending NNE–SSW and the other trending almost perpendicularly. These faults have brought the Cambrian–Ordovician strata down to sea level. The structure of the Durness Basin contrasts sharply with that elsewhere in the Highlands, with normal faulting rather than thrust-faulting controlling the outcrop pattern.

The oldest strata lie on the western shore of the Kyle of Durness, north of Daill [NC 358 687], where there is evidence for a double unconformity — the basal Cambrian quartzites rest on the Precambrian Torridonian Sandstone, which in turn rests on Lewisian Gneiss. Red Torridonian sandstones and conglomerates dip gently south and form a scarp, whereas 100 m to the east there are quartzites of the Eriboll Sandstone Formation dipping ESE at about 15°, giving clear evidence of angular unconformity between the Torridonian Sandstone and the Cambrian (Figure 12.3). Farther north, the Cambrian sediments overstep the Torridonian Sandstone to lie directly on the Lewisian gneissose rocks. There is marked discordance between the planes of foliation in the gneiss and the plane of unconformity.

The False Bedded Quartzite and Pipe Rock members are not very well exposed around Durness, and they are described in more detail in the An t-Sròn site report, though the Pipe Rock can be examined between Smoo House and Sangobeg [NC 4245 6672], where it forms a faulted outlier.

The Fucoid Beds and Salterella Grit members of the An t-Sròn Formation are poorly exposed in the Durness area (partly because the sections are interrupted by the waters of the Kyle of Durness), so both divisions are considered in detail in the reports for other sites (An t-Sròn, Loch Awe and Fuaran Mor), at which they are better exposed. In contrast, the formations of the Durness Group are very well exposed in the Durness area.

The lowest division, the Ghrudaidh Formation, generally consists of about 60 m of lead-grey dolomites that are occasionally mottled. The formation takes its name from the house 'Grudie' [NC 361 632], at the head of the Kyle of Durness (on the Geological Survey map, Scottish sheet 114 west, of 1889, the formation name was spelt 'Grudaidh', but the 1893 re-issue spelt it 'Grudie', and later Peach *et al.* (1907) used 'Grudhaidh' or 'Ghrudaidh', the last of which seems the most generally used). The formation is exposed by the shore of the Kyle and on the hill slopes around Grudie, where it shows scarp and slack topography. The beds dip ESE at about 15° and strike up the side of Sithèan Mor to the south. Some beds are massive, thickly bedded and coarsely crystalline; others are more thinly bedded and fine-grained. Oolitic limestones are found in the middle of the sequence, a typical example being 30 cm thick and occurring within well-bedded dolomites. The oolites are dark-grey in a paler matrix. The base of the Ghrudaidh Formation is not exposed at Durness but is described at An t-Sròn (see site report).

The Eilean Dubh Formation is composed of thinly bedded flaggy dolomites with an abundance of sedimentary structures. East of Grudie the contact with the Ghrudaidh Formation is not seen, but the paler-coloured, sometimes red-stained rocks of the Eilean Dubh Formation can be seen overlying it on Sithean Mor and form the rest of the exposures on the shores of the Kyle. Farther east, the Sailmhor Formation, dark-grey limestones with abundant prominent chert nodules, extends southwards from the mouth of the River Dionard [NC 3643 6250] to the bridge. These beds are described in more detail below.

The lower divisions of the Durness Group are exposed on the hillside between the road and Cnoc na Maine 2 km south-west of Durness [NC 389 657]. The Ghrudaidh Formation occurs as both massive, coarsely crystalline units and finely crystalline, thinly bedded units, dipping ESE at 12°. *Planolites* burrows occur in places, giving the rock a mottled appearance. *Salterella* is recorded hereabouts (loc. 9a of Peach *et al.,* 1907, p. 626). Higher up the hillside, thinly bedded flaggy dolomites of the Eilean Dubh Formation occur as pale grey and occasionally pink beds, whose bases may be irregular and show load structures. Flaggy units between more massive beds show ripple cross-lamination and parallel lamination. These beds crop out with a scarp and slack topography. Near the hilltop are laminated, domal stromatolitic structures.

The best exposures of the beds above the Ghrudaidh Formation are on the shore of Balnakeil Bay [NC 372 676]–[NC 389 688], where there is a continuous succession from the Eilean Dubh Formation into the Balnakiel Formation (Figure 12.3). The Eilean Dubh Formation is called after the island of Eilean Dubh, and at the headland opposite this island are thinly bedded pale-grey dolomites, dipping south-east at 25° and estimated at 120–200 m in thickness. Large dome-like structures (Figure 12.4) with algal layers of *Cryptozoon* type characterize a stromalitic horizon that can be traced down the cliffs to the sea. Between the more massive algal horizons, fine-grained beds a few centimetres thick show parallel and cross-lamination, with scoured and loaded bases. Beds of lenticular mud-flake conglomerate occur. Apart from algae, macrofossils are not recorded from the Durness area, but the Cambrian age of most of the formation is constrained by conodonts, which indicate that the Cambrian–Ordovician boundary lies a few tens of centimetres below the top of the Eilean Dubh Formation (Huselbee, 1997; Huselbee and Thomas, 1998).

Strata of the Eilean Dubh Formation, which are easily eroded, extend along the foreshore and in the low cliff face for about 200 m, beyond which a 10–15 m high cliff [NC 378 688] shows the best known contact with the more resistant dark-grey dolomites of the Sailmhor Formation (Figure 12.5). This formation, about 150 m thick, consists of massive granular dolomites, with the spectacular dark-grey and white mottling that led to local use of the term 'leopard stone' (or 'leopard rock') for the formation. This mottling is due to differential dolomitization of branching burrow systems (cf. Palmer *et al.,* 1980). Chen is extensively developed, both as nodules up to 30 cm across and as finely laminated layers, commonly associated with paler-coloured beds that are interbedded with the leopard stone and which show parallel- and occasional cross-lamination and wavy bedding. The light colour of the chert horizons makes them conspicuous. Most of the scarce macrofossils recorded are Mollusca (Peach *et al.,* 1907). The gastropods *Euconia etna* (Billings) and *E. ramsayi* (Billings) are also both recorded from the Croisaphuill Formation, but the single trilobite recorded is not available for reassessment (Fortey, 1992). However, Dr D.H. Evans (pers. comm., 1997) has noted species of the cephalopods *Ellesmeroceras* and *Walcottoceras?,* indicative of the Gasconadian stage of the Canadian Series (cf. Flower (1978); roughly zones A to D of the Ibexian Series of the western North American Ordovician (see (Figure 12.2)) and conodonts of Tremadoc age occur in low abundance throughout the Sailmhor Formation (Huselbee, 1997; M.P. Smith, pers. comm.).

The breccias described by Palmer *et al.* (1980) consist of angular fragments of dolomite, often showing the characteristic mottling of the Sailmhor Formation, with subordinate fragments of chert. They are poorly sorted, with clasts from 1 mm to 20 cm across set at all angles in a finer-grained matrix. Most of the material forming these breccias appears to be locally derived from the Sailmhor Formation. The breccias are perpendicular to bedding and appear to represent fillings of fissures, some of which have been traced down to the top of the Eilean Dubh Formation (Palmer *et al.,* 1980). The upper surface of the Sailmhor Formation, which occurs at the base of a low cliff [NC 3841 6887]–[NC 3837 6886], is extensively brecciated and was considered by Palmer *et al.* (1980) to represent a karst surface, marking a considerable break in deposition. However, this interpretation was challenged by Nicholas (1994), who regarded the brecciation as a phenomenon of Tertiary or Recent age. Furthermore, evidence from fossils now indicates a relatively continuous succession.

The low cliff above this brecciated surface exposes the basal beds of the Sangomore Formation (up to about 180 m thick), which consists generally of fine granular dolomites. The basal few metres show much chert, occurring as large nodules and laminated layers up to 2 m thick. There is no sign of brecciation in these beds. Access to the overlying exposures is difficult, as they form steep cliffs, consisting of well-bedded, massive, fine-grained, pale-cream-coloured dolomites, with some laminated beds and rare massive units showing burrow-mottling resembling the 'leopard stone' lithology of the Sailmhor Formation. Towards the top of the for mation there are bands of pink and cream limestone. An anticlinal fold repeats these beds, along with the basal beds of the Balnakiel Formation. Although no fossils have yet been described from the Sangomore Formation, a fossil locality mentioned by Palmer *et al.* (1980) has yielded a probable *Ellesmeroceras* (Dr D.H. Evans, pers. comm., 1997), which supports evidence from conodont faunas for a Tremadoc age (M.P. Smith, pers. comm., 1997).

At the eastern end of the shore section in Balnakeil Bay, the Sangomore Formation is succeeded by the Balnakiel Formation. This, estimated at over 300 m thick, consists of alternations of dark- and light-grey dolomitic limestones, interbedded in units 5–20 cm thick. Irregular diagenetic nodules of white or pink chert are common. Towards the base of the formation, large *Cryptozoon*-likedomal stromatolitic structures occur, resembling those in the Eilean Dubh Formation. Relatively rich Shelly faunas are reported from scattered localities, some of which are within the present site. Many genera of gastropods — *Oriostoma, Holopea, Maclurea, Ceratopea, Ectomaria, Euconia, Hormotoma, Lecanospira, Trochonema* — are recorded from both this formation and the Croisaphuill; of them a few, such as *Hormotoma dubium* Donald, are known only from the Balnakiel Formation. Flower (1978) commented briefly on some of the cephalopods. One, *Dyscritoceras,* occurs in the lowest beds of the Balnakiel Formation and indicates a mid-Ibexian age (zones E–G), which correlates around the Tremadoc–Arenig boundary. Dr D.H. Evans (pers. comm., 1997) reports that higher in the formation there are pilocerids and proterocameroceratids, the latter including *Platysiphon,* which appears to be confined to the Jeffersonian (or Ibexian Zone H) (Figure 12.2). One trilobite, *Jeffersonia timon* (Billings), is known from the Balnakiel Formation SSW of Durness (Fortey, 1992, fig. 1d) and also indicates Zone H.

The overlying Croisaphuill Formation is well exposed in scarp and slack topography south of the Balnakeil to Durness road around [NC 396 680]. It consists of mid- and dark-grey dolomitic limestones, estimated as 145 m thick, partly thinly bedded in units 1–5 cm thick and partly thickly bedded (up to 30 cm thick) and massive, and sometimes burrow-mottled. Abundant chert nodules are developed along bedding planes and exploit the mottling. The shelly fauna has gastropods in common with that of the Balnakiel Formation but also includes the gastropod oper- *culum Ceratopea billingsi* Yochelson and the trilobite *Petigurus nero* (Billings), neither of which is recorded from lower in the succession. Dr D.H. Evans (pers. comm.) has noted a varied cephalopod fauna: pilocerids include *Cassinoceras,* protocycloceratids include *Protocycloceras mendax* (Salter), tarphycerids are represented by *Aphetoceras* and *Clytoceras,* and the troedssonellid *Buttsoceras* occurs in the upper part of the formation. These cephalopods indicate the Cassinian or high Ibexian zones I to K (Figure 12.2). Higgins (in Higgins and Austin, 1985, p. 44) recorded conodont faunas from near the base of the Croisaphuill Formation.

Exposures of the Durine Formation south of the road lie east of the Balnakiel Formation [NC 400 680] and extend beneath Durness itself It consists of fairly uniform light grey fine-grained dolomitic limestones, not well-bedded and generally lacking silicification and mottling, and approaches 200 m in thickness. Some beds show a fracture-cleavage, and the highest beds around [NC 404 675] are overthrust by a mass of Moine Schist. Shelly fossils are rare, but the gastropod *Hormotoma gracile* (Hall) is present, ranging up from the underlying formations. Higgins (1967, in Higgins and Austin, 1985, p. 43) recorded several species of conodonts from various levels in this formation.

East of Durness, a high-angle fault has uplifted the Durness Group such that further exposures of the Sailmhor and Sangomore Formations are seen in the cliffs around the inlet that leads to Smoo Cave [NC 415 679]–[NC 425 668]. The rocks dip to the south-east at 10° or less, and individual beds can be traced right around the headlands. The lower beds, referred to the Sailmhor Formation, are massive fine- to medium-grained dolomites, in beds 10–50 cm thick. Many beds show 'leopard stone' lithology, and chert horizons are common. The contact of the Sailmhor Formation with the overlying Sangomore Formation occurs in the sheer cliffs of the inlet (Figure 12.6). Nicholas (1994) reported that there is little evidence for brecciation, or for an undulating and weathered karstic surface, in the lower part of these cliffs; the outcrops suggest rather that the succession is straightforward, and there is no evidence for a significant break in deposition. The Sangomore Formation in and around Smoo Cave itself consists of cream, white and pink, massive, finely crystalline dolomites and limestones, well bedded in units up to 50 cm thick. Some thinner flaggy beds with parallel lamination also occur.

At Sangobeg, at the eastern end of the site, another fault introduces an outcrop of the Eriboll Sandstone Formation. A small cliff on the eastern side of the bay exposes 7–8 m of massive, thinly bedded, pink-stained quartzites, generally 5–10 cm thick, with thinner sandstones intercalated that pinch and swell laterally and show cross-lamination. To the west, beds with densely packed vertical burrows (which characterize the Pipe Rock Member) include simple pipes (*Skolithos* burrows) and trumpet pipes (*Monocraterion*).

Interpretation

The significance of the Eriboll and An t-Sròn formations is considered under the An t-Sròn site. Swett (1969) studied the carbonates of the Durness Group and considered that they were mainly of biochemical origin, forming in a warm, continuously subsiding shallow sea where the accumulation rate matched the subsidence rate. He proposed the following diagenetic sequence: 1, recrystallization; 2, dolomitization; 3, silicification; 4, calcitization; 5, dolomitization; this suffices to account for the structures, textures and compositions to be seen in the sediments and algal structures. He suggested an original aragonitic or calcitic composition for all the Durness carbonate rocks and considered the chert to be of secondary origin. Swett *et al.* (1971) judged the deposition of all these rocks to be under intertidal to supratidal conditions. The upward changes in texture and mineralogical composition were taken to indicate increasing maturity, reflecting isolation from clastic sources rather than increasing depth of water. However, the presence of burrow-mottling, which tends to occur in conditions interpreted as subtidal, suggests that a substantial part of the succession is of deeper, subtidal origin.

The Laurentian affinities of the faunas of the Durness Group were recognized when they were first described (Salter, 1859) and have been accepted ever since, as discussed by Fortey (1992), who gave a quantified estimate of the affinities of the trilobites. This area provides one particularly striking example of the faunal distributions discussed by Wilson (1966) when he argued for the existence of a proto-Atlantic ocean, now generally accepted and referred to as the Iapetus Ocean. In a wider context, the Cambrian evidence was reviewed by Conway Morris and Rushton (1988) and that for the Ordovician by Fortey and Cocks (1988), all of whom accepted the equatorial position of Laurentia (Figure 1.2).

The age and correlation of the formations of the Durness Group have frequently been discussed, much of the evidence being reviewed by Wright and Knight (1995) and Huselbee and Thomas (1998). The latter authors confirmed the long-held view that the Ghrudaidh Formation is Lower Cambrian, at least in its lower part, by finding *Olenellus* in a thrust horse of the formation in the Assynt district (Figure 12.1). The age of the Eilean Dubh Formation is more contentious (Wright and Knight, 1995, p. 13), on account of the paucity of fossils. Brasier (1977) assigned a late Early Cambrian age to a chert biota collected from near the base of the division in a fault-block near Inchnadamph, Assynt, whilst Nicholas' (1994) study of strontium isotopes suggested that the higher Eilean Dubh is Middle Cambrian or younger. Huselbee and Thomas (1998) collected conodonts from the uppermost parts of the Eilean Dubh, notably the basal Tremadoc taxon *Cordylodus lindstromi* Druce and Jones from the upper 10 cm of the formation. This shows that the base of the Ordovician lies just below the Eilean Dubh–Sailmhor boundary; the appearance of conodonts in the Durness Group at this level may be related to the world-wide earliest Ordovician transgression. A correlation of the barren intervening strata was proposed by Wright and Knight (1995), who made a close lithological comparison between Cambrian–Ordovician successions of Scotland with the succession of western Newfoundland, which is better constrained biostratigraphically. They place the Ghrudaidh–Eilean Dubh boundary close to the Middle–Upper Cambrian boundary, which is in agreement with most other evidence, apart from that of Brasier (1977). Their contention that the Durness and Newfoundland succession is 'largely continuous' is, however, debatable, since the faunas that control the latter sequence are far from being a complete representation of the Cambrian faunal succession in Laurentia; a number of breaks, whilst smaller than those proposed hitherto, may well be present.

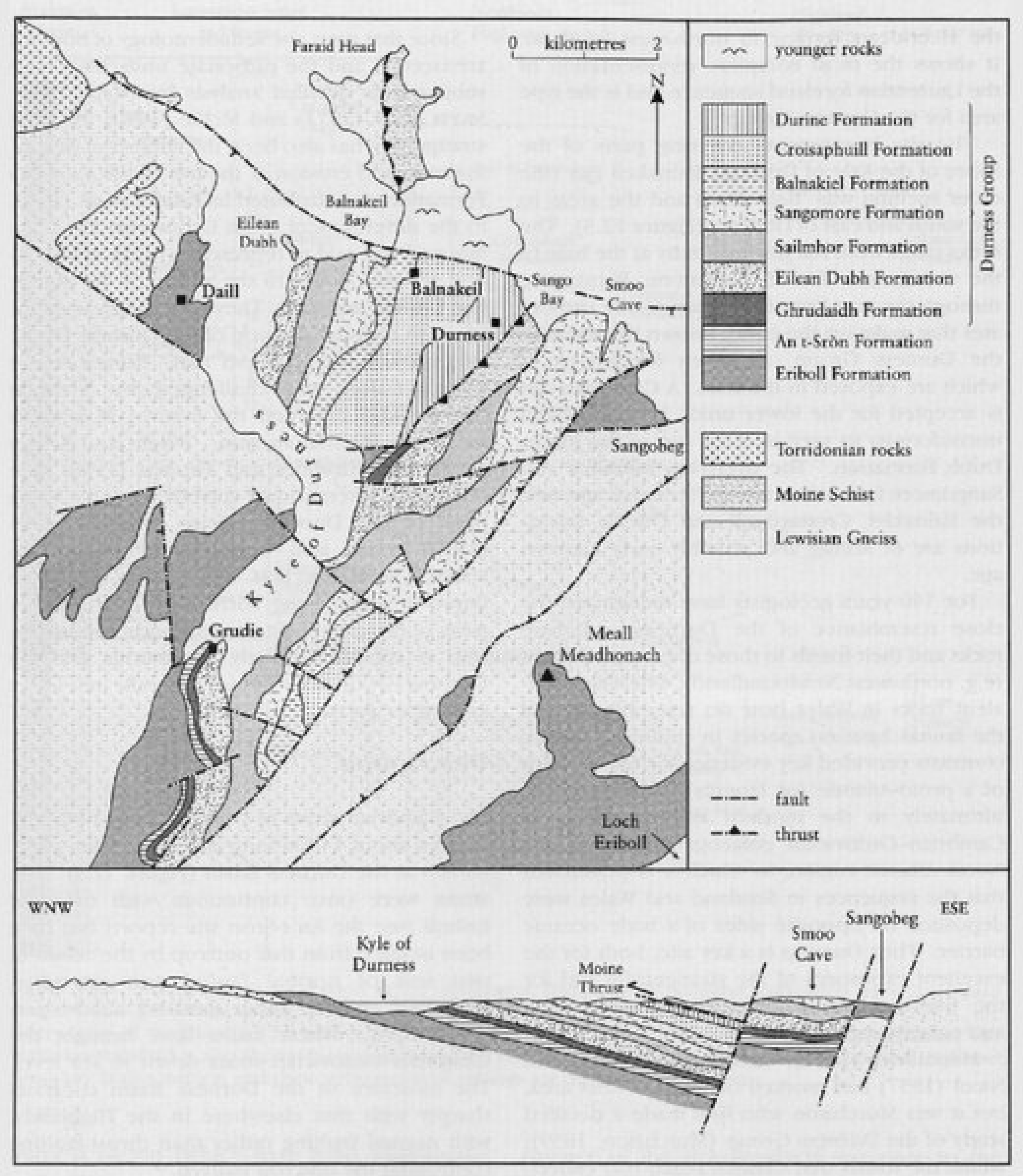
Evidence for an early Ordovician age for the Sailmhor and Sangomore formations has been cited, but no details are yet published: Wright and Knight (1995, p. 12) mention a basal Sailmhor fauna with cephalopods that Dr D.H. Evans (pers. comm., 1997) interprets as equivalent to the Gasconadian (approximately Tremadoc), and M.P. Smith (pers. comm., 1997) has recovered Tremadoc conodonts of North American mid-continent provincial affinity throughout both the Sailmhor and the Sangomore formations.

The correlation of the more fossiliferous Balnakiel and Croisaphuill formations with the higher Ibex (or Canadian) Series is better established, and Fortey (1992) has shown that the trilobites from both the Balnakiel and Croisaphuill formations are species known from Zone H of the western North American succession (equivalent to the earlier Arenig). Details of the cephalopods have yet to be published, but Dr D.H. Evans' work suggests that the Balnakiel corresponds to Zone H and the Croisaphuill to Zones I to K: that is, a slightly higher horizon than is suggested by the trilobite *Petigurus,* redescribed by Fortey. The conodonts from the Durine Formation (Higgins, in Higgins and Austin, 1985, p. 43) are typically North American mid-continent forms and are of early Whiterock (about late Arenig or early Llanvirn) age (Bergström in. Higgins and Austin, 1985, p. 50).

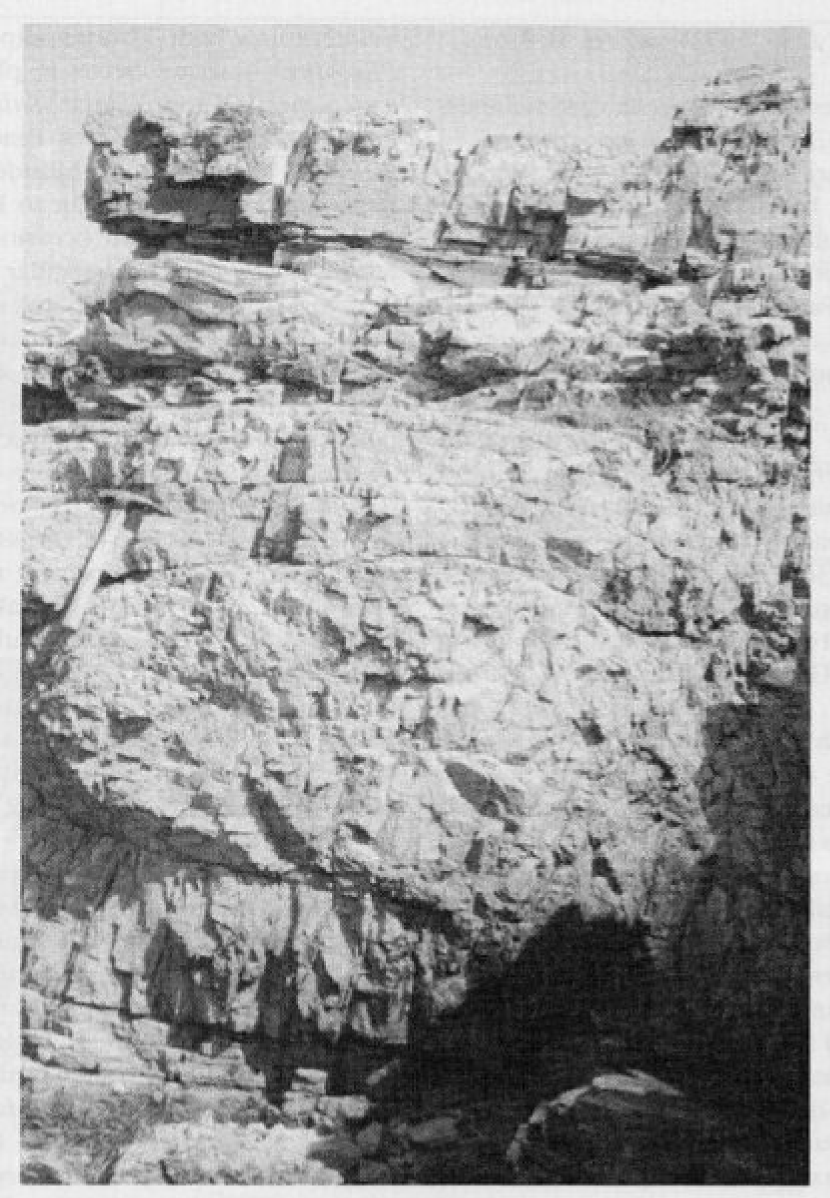
Conclusions

The Durness area is a site of international significance. It shows most completely the Cambrian and Ordovician strata of a fragment of the Laurentian Plate, formerly a part of North America and now attached to Scotland, and was historically one of the first examples of such a displaced fragment to be recognized on faunal grounds. The Durness area provides the fullest stratigraphical standard by which to interpret the complexities of the Moine Thrust belt in the north-west Highlands of Scotland.

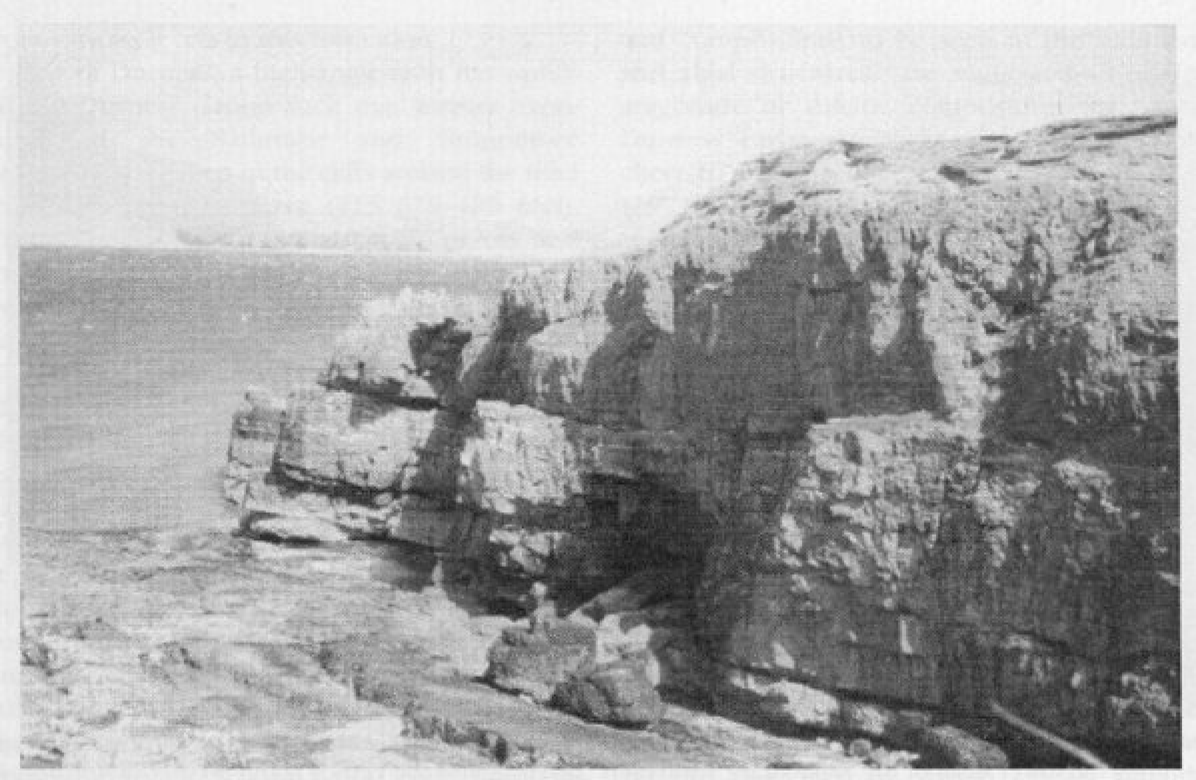
References



(Figure 12.3) Geological sketch-map of the Durness area, after Geological Survey of Scotland (1893), and schematic section from near Daill to Sangobeg (about 10 km), after Peach et al. (1907, fig. 20).



(Figure 12.4) Balnakeil Bay section, Durness. Algal growth in pale dolomitic limestone of the Eilean Dubh Formation. (Photo: J.K. Prigmore.)



(Figure 12.5) Balnakeil Bay section, looking north. Resistant carbonates of the Sangomore Formation forming a cliff above an eroded platform of the Sailmhor Formation. (Photo: J.K. Prigmore.)

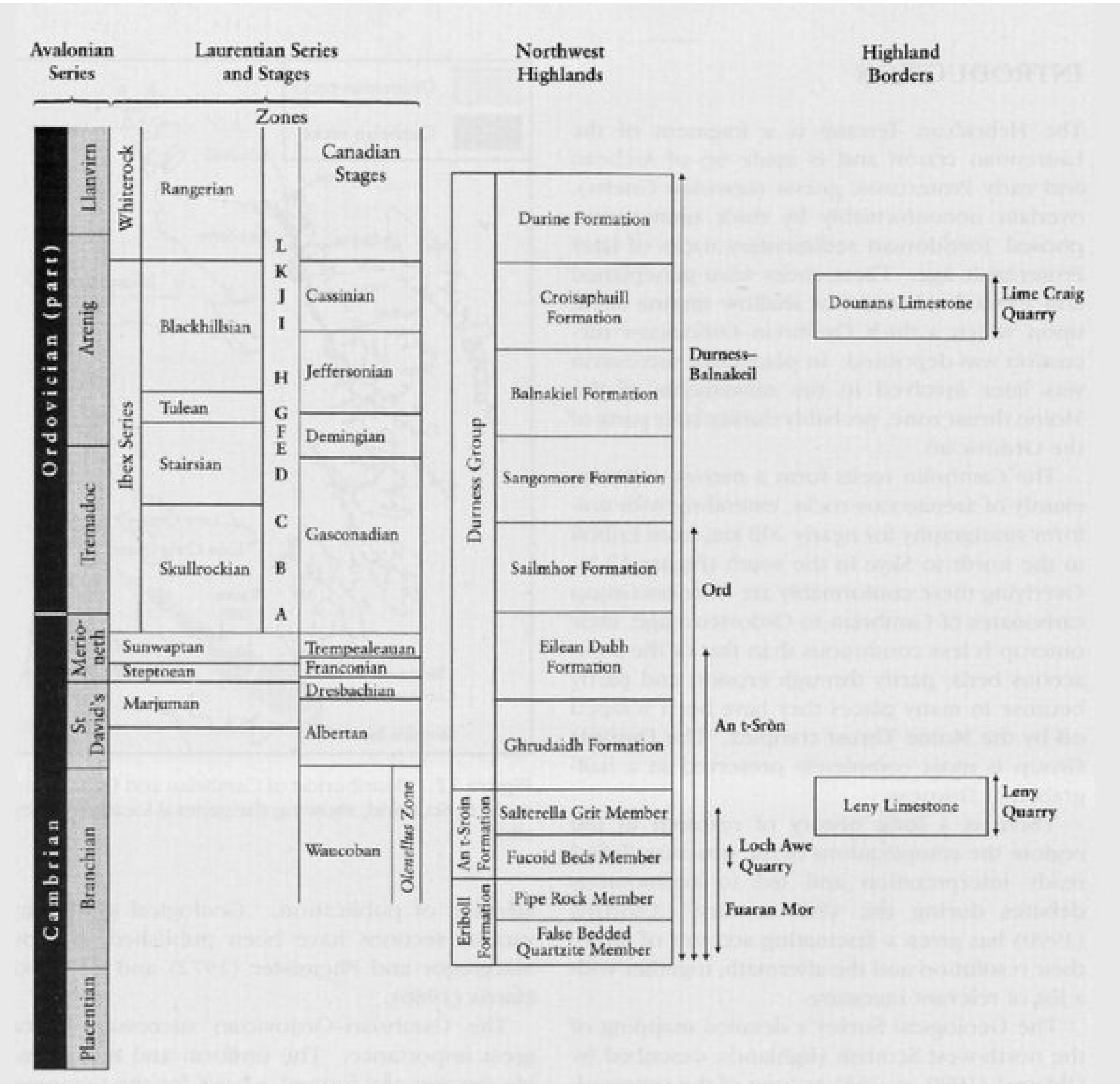
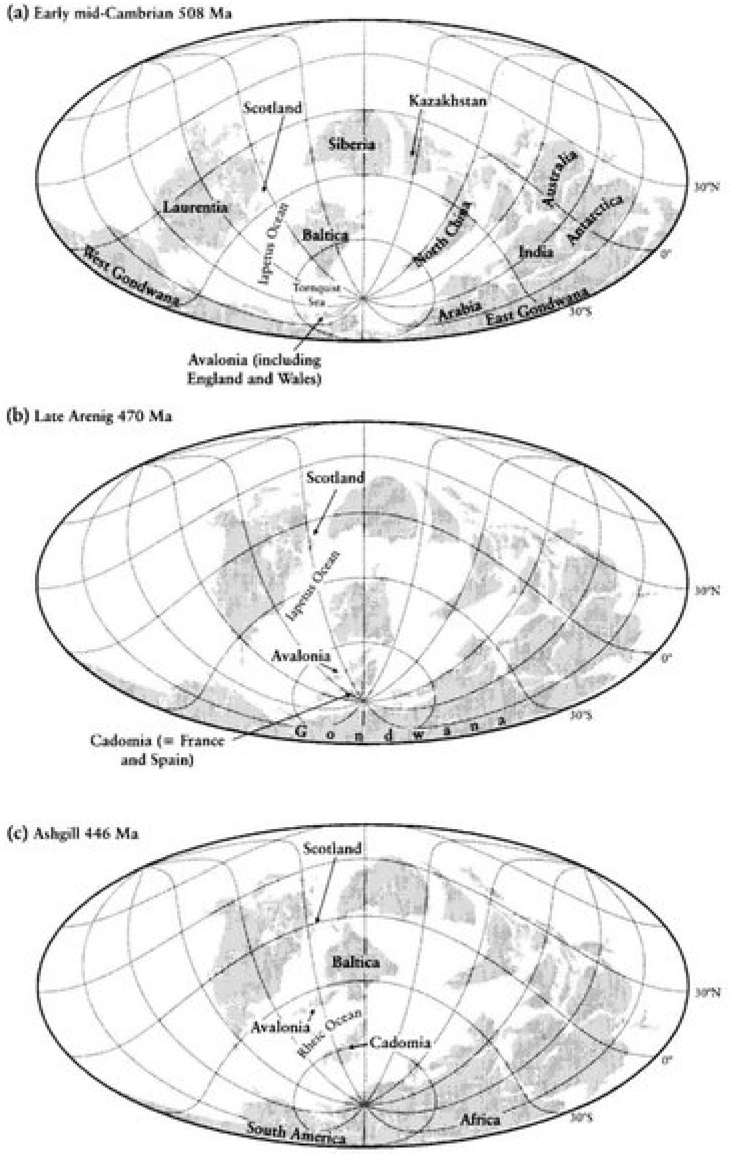


Figure 12.2 Stratigraphical succession in the north-west Highlands of Scotland, correlated with Laurentian (North American) chronostratigraphy; the scheme for the Ibex and Whiterock follows Ross et at(1997), the older stages of the Canadian Series being retained for reference to the succession of cephalopod faunas. The Avalonian standard is also shown for comparison. The Leny and Dounans limestones occur along the Highland Boundary fault complex, and their stratigraphical settings are discussed in the text.

(Figure 12.6) Smoo Cave, east of Durness. Cliffs of flat-lying Sailmhor Formation overlain in conformable succession by the lower beds of the Sangomore Formation. The height of the cliffs is about 30 m. (Photo: British Geological Survey photographic collection.)



(Figure 1.2) Palaeogeographical sketch-maps of the world, showing the changing relative positions of England, Wales and Scotland through the Cambrian and Ordovician. Adapted from maps generated by Dr David Lees using Atlaswinpro (Cambridge Paleomap Services).

(Figure 12.1) Distribution of Cambrian and Ordovician rocks in Scotland, showing the general location of key sites.