Jurassic, Northern Highlands of Scotland

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Contents

Lias

On the west coast at Applecross (P915496) about 58 m of Lower Liassic sediments are exposed in two stream sections and along the shore. They are equivalent in age to the lower Broadford Beds of Skye and range from Hettangian (*Alsatites liasicus* and *Schlotheimia angulata* zones) to Lower Sinemurian (*Arietites bucklandi* zone) (P915498). The lower part of the sequence contains several oolitic limestones and calcilutites, the upper is mainly sandstone and sandy shale with one prominent coral limestone. The abundant fauna includes the coral *Thecosmilia martini* as well as *Cardinia, Lima, Liostrea, Parallelodon* and *Schlotheimia* (Hallam, 1959). The sediments were laid down in a shallow sea which may from time to time have been brackish.

In the fault-bounded strip between Gruinard Bay and Loch Ewe, poorly exposed clayey limestone and blue clay overlie the Trias. Abundant loose lamellibranchs found on the shore of Loch Ewe suggest a Sinemurian age for these beds. In the south of the region, Lower Lias (up to 90 m thick) is exposed in several Fine sections in Morvern; strata ranging from Lower to Upper Lias occur in Ardnamurchan and are particularly well exposed on the shore east and west of Kilchoan. All these sediments are described in *British Regional Geology: The Tertiary Volcanic Districts* (Richey, 1961).

On the east coast of Sutherland, Lower Jurassic strata are intermittently Exposed on the shore at Dunrobin Castle, Golspie (P915499). They form a Condensed succession comprising a lower 72 m of argillaceous deltaic sediments with thin coal seams and rootlet beds, overlain by about 22 m of soft white quartzose sandstone with some shale partings, drifted plant remains and rootlet beds, succeeded in turn by over 18 m of dark micaceous, often marine, shales rich in ammonites and brachiopods. This sequence has been named the Dunrobin Bay Formation by Neves and Selley (1975) and its subdivisions are shown in P915500. Most zones of the Lower Lias may be present, although the only reliable zonal indicators are the ammonites in the Lady's Walk Shale which confirm the presence of the topmost Sinemurian *Echioceras raricostatum* zone and the basal Pliensbachian *Uptonia jamesoni* zone (Berridge and Ivimey-Cook, 1967).

Middle/Upper Jurassic

Sediments of this age crop around Brora (P915499) and on the foreshore south of Balintore

(P915496).

At Brora the lowest Middle Jurassic rocks are probably of Bathonian age (P915500). They are termed the Brora Coal Formation and are exposed on the foreshore between 0.9 and 1.6 km south-west of the mouth of the Brora River. The lower member (termed the Doll Member) comprises soft white quartzose sandstone up to 20 m thick, overlain by grey mudstones with thin beds of sideritic cementstone. Comminuted plant debris is common and, near the top of the mudstone, well preserved plants and silicified logs have been found. The upper Inverbrora Member consists of black laminated bituminous shales (containing a poor oil shale) and grey shales, overlain by the Brora Coal, which averages 1 m in thickness. There are several shell beds packed with the freshwater bivalve *Neomiodon*, some horizons with the brackish-water branchiopod *Euesthena*, and others with the bivalve *Isognomon*, which may be marine. The Brora Coal has been mined intermittently since 1598. The early workings were near the shore but after 1810 mining was confined to the area west and north of Brora. Neves and Selley (1975) have suggested that the Brora Coal Formation was deposited in a deltaic/estuarine environment which culminated in the formation of deltaswamp coals at the top. Hurst (1981), however, believed that it was formed in a largely fluvial environment which later stagnated into a delta swamp.

The Callovian and Oxfordian sediments of Brora are mainly marine in origin. They have been reclassified by Sykes (1975) into the formations and members shown in P915500. The Brora Argillaceous Formation is 88 m thick and commences with a hard ferruginous bioturbated sandstone (the Brora Roof Bed) which marks the Callovian marine transgression and contains a diverse fauna dominated by *Corbula obscura*. The presence of the ammonites *Kepplerites gowerianus* and *Proplanulites koenigi* indicates a *Sigaloceras calloviense* zone (P. *koenigi* subzone) age for the bed. The remainder of the Brora Shale Member is a 30 m thick sequence, fining upward from silty sandstone to bituminous shale. There is much shell debris and some shell beds composed of ?*Protocardia*, *Meleagrinella* and *Trautscholdia*. Ammonites are fairly scattered but provide evidence for the presence of most subzones of the *S. calloviense* and *Kosmoceras jason* zones. The ammonites indicate an open-water marine environment.

The Glauconitic Sandstone Member is a muddy greenish glauconitic sandstone with bands of phosphatic nodules which contain *Rhaxella* spicules. Ammonites indicative of the *K. jason* and *Kosmoceras obductum* subzones are fairly common and other fossils include *Lingula*, *Meleagrinella* and *Cylindroteuthis*. The environment of deposition was a reworked marine bar sand. The overlying Brora Brick Clay Member consists of intercalated grey-green clay and bituminous sandy siltstone, and has a prominent row of doggers in the middle. It has an abundant fauna of bivalves and well scattered ammonites, indicative of the *Erymnoceras coronatum* and *Peltoceras athleta* zones. The Fascally Siltstone Member is a sequence of coarse siltstones grading upward into fine sandstone. Its fauna is sparser than that of the underlying beds, but ammonites are present throughout, indicating that most of the member belongs to the *P. athleta* zone.

The top few metres of the Fascally Siltstone mark the onset of a gradual shallowing of the sea, and during the Upper Callovian and Lower Oxfordian times there were extensive shallow marine (and latterly coastal) sand bars in the Brora area. The sequence is known as the Brora Arenaceous Formation. The lowest sandstone unit, the Fascally Sandstone Member, is a muddy sandstone intercalated with siltstone, and is characterised by intense bioturbation. However, ammonites and lucinoid bivalves are still abundant. All ammonites indicate a *Quenstedtoceras lamberti* zone age. The Clynelish Quarry Sandstone member is well exposed along the Brora River and was formerly worked in the Clynelish Quarries west of Brora. It is a fine, friable, poorly cemented, highly siliceous sandstone with layers of carbonaceous debris and several horizons of convolute bedding, some of which suggest water expulsion. Its fauna is patchily developed. There are lucinoid bivalves, large specimens of *Chlamys*, and scattered ammonites of *Quenstedtoceras lamberti* zone type indicate that

the environment was still fully marine.

The Brora Sandstone Member forms prominent cliffs along the Brora River. Though mainly fine-grained and friable, it has some thin quartz conglomerates in the middle; trough cross-bedding indicates that the sediment was derived from the west. No ammonites have been recorded, but there are scattered marine bivalves, including *Gryphea dilatata*. The highest exposed part of the Oxfordian sequence at Brora, the Ardassie Limestone Member (P915499, P915500), comprises alternate beds of muddy carbonaceous sandstone and 'limestone', 0.3 to 1.1 m thick. The 'limestones' consist largely of calcified *Rhaxella* spicules. There is also a rich fauna of bivalves, with many *Cucullaea*, accompanied by *Gryphea* and *Pinna*. Ammonites, including several species of *Cardioceras*, indicate a *Cardioceras vertebrale* subzone age.

The foreshore section south of Balintore in Easter Ross (P216054) ranges in age from Bathonian to Middle Oxfordian, but the total thickness of the sequence is only 65 m, compared to 235 m of the roughly equivalent beds at Brora. The subdivisions, mainly established by Sykes (1975), are shown in P915501. The Brora Coal is only 20 cm thick here, and the overlying Brora Roof Bed only 50 cm. The latter has a similar lithology to the roof bed at Brora, but its upper surface is thickly covered with belemnites and wood fragments. The Cadh-an-Righ Shale is a condensed sequence which represents two ammonite zones; it is bituminous, with thin beds of glauconitic siltstone. Like the Glauconitic Sandstone of Brora it contains phosphatic nodules within a bed of limestone nodules. The overlying Shandwick Clay Member is a greygreen clay and siltstone with many burrows and rows of limestone nodules. Its main fossil is *Nuculoma*. Scattered ammonites indicate that it spans the *Peltoceras athleta* to the middle of *Cardioceras cordatum* zones. The Brora Arenaceous Formation is represented by only 12 m of sandy siltstone interbedded with calcareous siltstone. It contains fairly abundant, poorly preserved fossils; the most prominent are *Pinna* and *Pleuromya*. The Middle Oxfordian Balintore Formation has at its base the prominent Port-an-Righ Ironstone, which is a red weathering, nodular, glauconitic limestone with abundant ammonites. It is overlain by 22 m of coarse, poorly fossiliferous, bituminous siltstone, comprising several coarsening-upward rhythmic units.

Sykes (1985) has suggested that the Brora sequence was laid down in a shallow near-shore environment with a subtidal and sand-bar complex developed in Lower Oxfordian times. The condensed Balintore sequence, on the other hand, represents a deeper-water offshore facies. The Bow Buoy Skerry south of Ethie consists of carbonaceous sandstone with lenticular limestone beds. These have yielded ammonites suggesting an Oxfordian age.

Kimmeridgian

Strata of this age crop out along the coast of East Sutherland between Kintradwell and the Ord of Caithness, and in a narrow strip at Ethie in the Black Isle (where they are visible only at low tide). The presence of Kimmeridgian strata below low water at Port-an-Righ (south of Balintore) is indicated by the occurrence of loose nodules on the beach which contain the Kimmeridgian ammonite *Pictonia baylei*.

At Ethie the succession consists of about 45 m of grey-green mudstone and shale with beds of sandstone and grit, some bituminous shales (oil shale) as well as some thin beds and septarian nodules of brittle blue limestone (Waterston, 1951). The sediments are cut by a number of prominent sandstone sills and dykes which were probably formed during earthquakes by the intrusion of liquified sand from below (Waterson, 1950). The Ethie sediments are very fossiliferous with many well preserved bivalves, ammonites, and belemnites. The oldest beds probably belong to the *Rasenia cymodoce* zone; the higher ones contain *Amoebites* and raseniids characteristic of the upper part of

the R. *cymodoce* and basal *Aulacostephanoides mutabilis* zones.

East Sutherland

The Kimmeridgian sediments of this fault-bounded strip may be over 500 m thick. Their base is nowhere exposed and it is not certain if the lowest beds are the shales and boulder beds of Kintradwell or the Allt na Cuile Sandstone (P915500). The Allt na Cuile Sandstone is best exposed (P915499) between Lothbeg Point and the railway bridge across the Loth River, and in the gorges of the Allt na Cuile and Allt Choll further south-west. It is up to 50 m thick, white to orange, medium-grained and generally well sorted, with thin beds of sandy carbonaceous shale. It contains a shelly, shallow-marine fauna and has a number of lenses of fine debris-flow conglomerate with predominantly sandstone clasts.

Close to the Helmsdale Fault (e.g. in the Allt Choll gorge) the sandstone-breccias are very thick and contain some very large sandstone blocks. They were described as 'chasm breccias' by Bailey and Weir (1932), but Linsley (1972) considered them to have formed in submarine debris fans which accumulated along the relatively subdued submarine escarpment of the Helmsdale Fault. Farther from the Helmsdale Fault some of the graded sandstone units seen at Lothbeg Point have been described as grain-flow deposits (Neves and Selley, 1975).

The upper part of the Allt na Cuile Sandstone passes northward by interdigitation into a predominantly shaly sequence, termed the Lothbeg Shales. Though there has been considerable controversy about its age, the Allt na Cuile Sandstone is now thought to be Kimmeridgian and to range from the top part of the *Pictonia baylei* zone, via the *Rasenia cymodoce* and *Aulacostephanoides mutabilis* zones, possibly into the basal part of the *Aulacostephanus eudoxus* zone.

The greater part of the Kimmeridgian sequence of East Sutherland consists of thinly bedded bituminous shales, with ammonites and other fauna indicating deposition in a fairly deep sea. Interbedded with these shales are the boulder beds, which range in thickness from 1 m to nearly 10 m. These consist of mainly angular blocks and boulders varying in diameter from a few centimetres to the 'Fallen Stack' of Portgower which measures 34 m x 27 m x 9 m (P216087). The boulders are set in a sandy matrix which contains fossils of creatures that originally lived in a shallow-water or even a deltaic environment. The individual blocks have compressed and contorted the bedding of the underlying sediment, and some boulder beds display an upward Fining. There are also some solitary blocks embedded directly in deep marine shales, which are contorted around them.

There is a marked variation in the composition of the boulder beds up the sequence from south-west to north-east. At Kintradwell in the south-west (P915499) all the clasts are of sandstone, many of Old Red Sandstone type, with some Jurassic. Their matrix is a carbonaceous sandstone with the remains of tropical plants, probably derived from a deltaic environment. There are also some sandy and calcareous turbidites which are themselves slumped and contorted. At Loth and Kilmote all the clasts are red sandstone of Old Red Sandstone age, but between Kilmote and Portgower blocks of Old Red Sandstone flagstone facies appear and form all the blocks at Portgower and in the sections further north-east. From Kilmote northwards the matrix of the boulder beds changes to a gritty calcareous sandstone full of broken neritic and littoral fossils, including many brachiopods, echinoids and, particularly around Navidale, prominent blocks of reef coral (*Isastrea oblonga*). There are no boulders of Helmsdale Granite or Moine metasediment within any of the Boulder Beds.

The origin of the Boulder Beds has been the subject of much speculation. Early suggestions include crush-breccias (Murchison, 1829), ice-sheet deposits (Ramsay, 1865), violent flood deposits in an estuarine environment (Judd, 1873) and talus from cliffs, and the remains of fallen sea-stacks (M.

Macgregor, 1916). Bailey was the First to postulate that they accumulated at the foot of a submarine escarpment along the line of the Helmsdale Fault (Bailey and others, 1928; Bailey and Weir, 1932). He suggested that the debris was swept down the fault scarp by tidal waves or 'tsunamis' generated by earthquakes. The submarine-fan concept has since been refined and amplified by the work of Crowell (1961) Linsley (1972), Neves and Selly (1975) and Pickering (1984). Crowell showed that the blocks slid relatively slowly down the submarine scarp, mainly along gulleys. Neves and Selley pointed out that the boulder beds consist of two facies: a southwestern 'carbonaceous' facies of carbonaceous shales interbedded with turbiditic sandstones and boulder beds with Jurassic sandstone boulders set in a carbonaceous matrix; and a north-eastern 'calcareous' facies which contains no turbidites or Jurassic sandstone clasts, but has a calcite-cemented matrix full of comminuted shell material and corals. During the deposition of the southern facies the north-western (upthrown side) of the fault scarp was near sea level and covered by a vegetated delta; during the deposition of the northern facies, it was a shallow marine shelf with corals, neritic brachiopods and calcareous sands. Pickering has recognised a number of distinct facies within the Boulder Beds succession and has correlated these with the various physical environments along the fault scarp. The probable environment of deposition of the Helmsdale Boulder Beds is summarised graphically in P915502.

The age of the Boulder Bed succession has been obtained principally from the ammonites within the deep water shales, supplemented by the systematic study of palynomorphs (Lam and Porter, 1977). It is now believed that there is a virtually complete range of zones from the *Aulacostephanus eudoxus* zone in the southwest to the *Pavlovia pallasioides* zone at Navidale. Riley (1980) has suggested on palynological evidence (mainly dinocysts), that the youngest beds, exposed in Navidale Bay north of Helmsdale, may be of early Portlandian age.

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