Brora (Bathonian), Sutherland

[NC 896 029]–[NC 904 033]

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Introduction

The GCR site on the Sutherland coast south of Brora comprises foreshore exposures first described by Judd (1873) and later Lee (1925). The strata, of inferred Bathonian age, were named the 'Brora Coal Formation' by Neves and Selley (1975), and include a coal seam that was worked intermittently hereabouts from early times (1598) and commercially from the early nineteenth century until 1974 (Murchison, 1829a; Miller, 1859; Neves and Selley, 1975). The succession is overlain by the Brora Argillaceous Formation, the basal bed of which (the Brora Roof Bed) has yielded Early Callovian ammonites (see Brora (Callovian) GCR site report, this volume). The base of the exposed section is marked by the Brora Fault, which downthrows Oxfordian sandstones (Brora Arenaceous Formation) against the Brora Coal Formation. Interest in these beds was renewed in the late 1970s because they represent stratigraphical equivalents of productive reservoir sandstones in the North Sea. Detailed stratigraphical work was undertaken by Hurst (1981) who formally divided the Brora Coal Formation into the Doll Member (below) and the Inverbrora Member (above), with type sections in the GCR site. Most recently the sections have been described by Hurst (in Trewin and Hurst, 1993).

Description

The following description is based on Hurst (1981) and Hurst (in Trewin and Hurst, 1993). The outcrops have subdued relief and are submerged at high tide. Although they are covered by numerous erratics (largely of Devonian age) and beach sand, there are few breaks in the section, but not all of the beds described below are necessarily visible at any one time.

The Brora Roof Bed forms a prominent reef marking the seaward limit of exposure along almost a kilometre of foreshore that comprises the GCR site (Figure 6.4). Westwards from the Brora Roof Bed, the Inverbrora Member (*c.* 15 m thick) comprises black carbonaceous shales including some bituminous shales approaching oil-shale (total organic carbon: 26%). The shales are usually finely laminated with abundant drifted plant material, thin lenses of coal, and small pyrite concretions that sometimes replace plant debris. Two coal seams were recorded in this section by Hurst (1981); one directly beneath the Brora Roof Bed; and another, much thinner one, *c.* 8 m lower. According to both Neves and Selley (1975) and Hurst (in Trewin and Hurst, 1993), the higher one, known as the 'Brora Coal', is not exposed on the foreshore. Both coal seams are friable and veined by a yellow stain indicative of their high sulphur content (Judd, 1873). Two thin green shell-beds with the bivalves *Neomiodon* and *Isognomon* preserved in aragonite occur about 3.5 m below the Brora Roof Bed. Below these shell beds, the shales become pale-grey and give way to mudstones.

The top of the underlying Doll Member is marked by a laterally extensive, siderite-cemented, grey, brecciated mudstone with a distinctive brown-weathering colour (Bed 1 of Hurst, 1981). Thin, rippled sandstones with plant debris are associated with this marker bed, which often forms a ridge on the foreshore some 0.1–0.2 m higher than the surrounding grey mudstones. Silicified logs are common in the mudstones between this bed, from which the bivalve *Unio* was recorded by Neves and Selley (1975), and a siderite-cemented mudstone that forms a marker bed c. 3 m lower in the succession (Bed 2 of Hurst, 1981). Siderite-cemented mudstones ('cementstones' of Lee, 1925) occur at four levels (beds 1, 3–5 of Hurst, 1981) and provide markers that allow the vertical succession in the Doll Member to be established ((Figure 6.5); Hurst, 1981). Granular siderite is present within the mudstones underlying beds 2 and 5, and gives the mudstones a sandy texture. Trough cross-bedded sandstones, often calcite-cemented, become more abundant as the succession is descended. The highest sandstones occur as small lenses, often less than 5 m wide and only 0.1–0.3 m thick. A major sandstone unit, called the 'Do11 Sandstone Unit' by Hurst (1981), overlies an erosion surface that cuts into the grey mudstones near the base of the exposed section. It is a white, fine-grained, friable sandstone that is quartz- and kaolinite-cemented. About 500 m to the south-west of the GCR site, almost all of the Doll Member is again exposed in the crest of a small anticlinal structure seen in the intertidal extension of a small headland [NC 893 026].

Interpretation

The Doll Member is approximately equivalent to the beds previously described as the 'White Sandstone' and 'clays and brecciated sands and cementstones'; the Inverbrora Member is approximately equivalent to the 'bituminous shale with bivalves' and the 'Brora Coal' of previous authors (Hurst, 1981).

The mudstones of the Doll Member, which contain no noticeable silty or sandy horizons and very little plant-debris, are interpreted as overbank fines of a fluvial to deltaic environment (Hurst, 1981). The relative lack of plant debris is probably due to the fact that only periodic inputs of organic detritus were received during floods (Hurst, 1981). Such an environmental model is supported by the occurrence of silicified logs, the presence of which suggests a relatively rapid rate of sediment deposition — sufficient to bury the logs and quickly isolate them from the effects of oxidation and bacterial decomposition, and allow silicification. A rich non-marine palynoflora has been recovered from the mudstones of the Doll Member, and a rich freshwater ostracod fauna from between beds 3 and 4 (J. Fenton in Hurst, in Trewin and Hurst, 1993). The influx of the latter is approximately coincident with a marked change in the clay mineralogy from a predominantly kaolinite + illite/smectite assemblage to an illite + kaolinite assemblage (Hurst, 1985). An abundance of kaolinite, which is also dominant in the siderite-cemented beds, is associated with leaching processes caused by subaerial exposure. Siderite cement, itself, is common in freshwater mudstones, and the freshwater bivalve *Unio* has been recorded from Bed 1 (Neves and Selley, 1975). The brecciated internal texture of the siderite-cemented mudstone of this bed is similar to structures formed by soil-forming processes. Both this and the desiccated surface with polygonal cracking infilled with grey mudstone of Bed 4 suggest early lithification and subsequent alteration at, or near, the surface. Further confirmation of subaerial processes is the presence of sandstone with rootlets close to Bed 5. All of the sandstones of the Doll Member are interpreted as of fluvial origin, with occasional parallel laminae and current-ripple lamination (Hurst, 1981). The foreset laminae indicate a transport direction from the west or north-west, which, according to Hurst (in Trewin and Hurst, 1993), suggests that Hudson's (1962, 1964) idea that the sand detritus was derived from the Grampians to the south or south-east, because of the presence of staurolite, is unlikely. Possible westerly sources of staurolite are known; for example the Lewisian rocks of the Outer Hebrides (Coward *et al.,* 1969; Hurst, 1982, 1985). Equally, it could have been derived via the Old Red Sandstone. J.D. Hudson (pers. comm., 1996) still believes an Outer Isles source to be improbable because both the Minch Basin and the Highlands get in the way.

Marine microplankton were first recorded from the Inverbrora Member by Lam and Porter (1977), and MacLennan and Trewin (1989) subsequently reported dinoflagellate cyst assemblages representing variable marine influences in a lagoonal environment. Marine conditions are also indicated by the presence of marine benthic foraminifera (Hurst in Trewin and Hurst, 1993). Such conditions are also borne out by the mineralogy of the Inverbrora Member, which, in contrast to the Doll Member, contains diagenetic pyrite and no known siderite; pyrite forms to the exclusion of, or in addition to, siderite when the pore water in the sediment is rich in sulphates (i.e. marine). Hudson (1962) interpreted the presence of *Isognomon* in the shell beds of the Inverbrora Member as representing an incursion of more marine conditions. Below the shell beds, the crustacean *Euestheria,* indicating freshwater or brackish-water conditions, is found concentrated on some bedding planes (Hurst, 1981). Amongst the drifted plant material, Stopes (1907) recorded species of *Equisetum* (mares tails) as well as *Ginkgo, Goniopteris, Todites* and *Cladophlebis.* The 'Brora Coal', at the top of the succession, was deposited when the lagoon became isolated from the sea, and swamp conditions spread over the lagoon area with the accumulation of abundant plant material including *Equisetum* and conifer wood (Harris and Rest, 1966). According to Hurst (in Trewin and Hurst, 1993), the absence of a seatearth below the coal is evidence that the water depth in the lagoon was initially too great to allow rooting of plants. The initial deposits of the coal comprised drifted materials; rootlets have been recorded from a dirt bed within the coal.

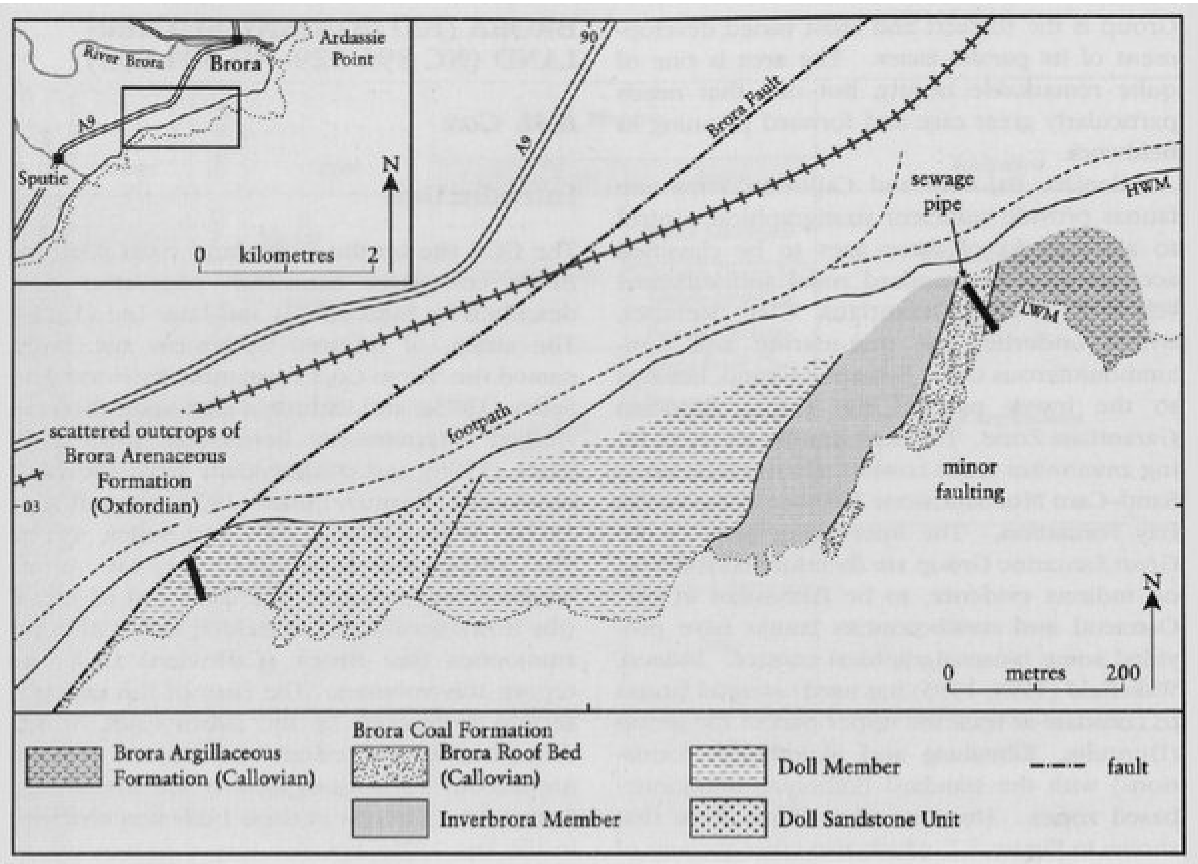
Since Lam and Porter's (1977) recovery of the dinoflagellate cyst *Gonyaulacysta* (now *Tubotuberella*) cf. *dangeardii* Sarjeant, 1968 from the topmost shell bed of the Inverbrora Member, the whole of the Brora Coal Formation has been inferred to be of Bathonian age with the Bathonian–Callovian boundary being placed above the coal/beneath the Brora Roof Bed. However, more recently acquired and extensive palynological data (high-abundance–low-diversity dinoflagellate cyst assemblages) suggest that the boundary in fact lies within the Inverbrora Member (MacLennan and

Trewin, 1989). According to Hudson (pers. comm., 1996), the shell beds of the Inverbrora Member are very like those in the Upper Ostrea Member at Staffin (see GCR site report, this volume) and these two units may correlate. Palynological placement of the Bathonian–Callovian stage boundary is also comparable at the two sites.

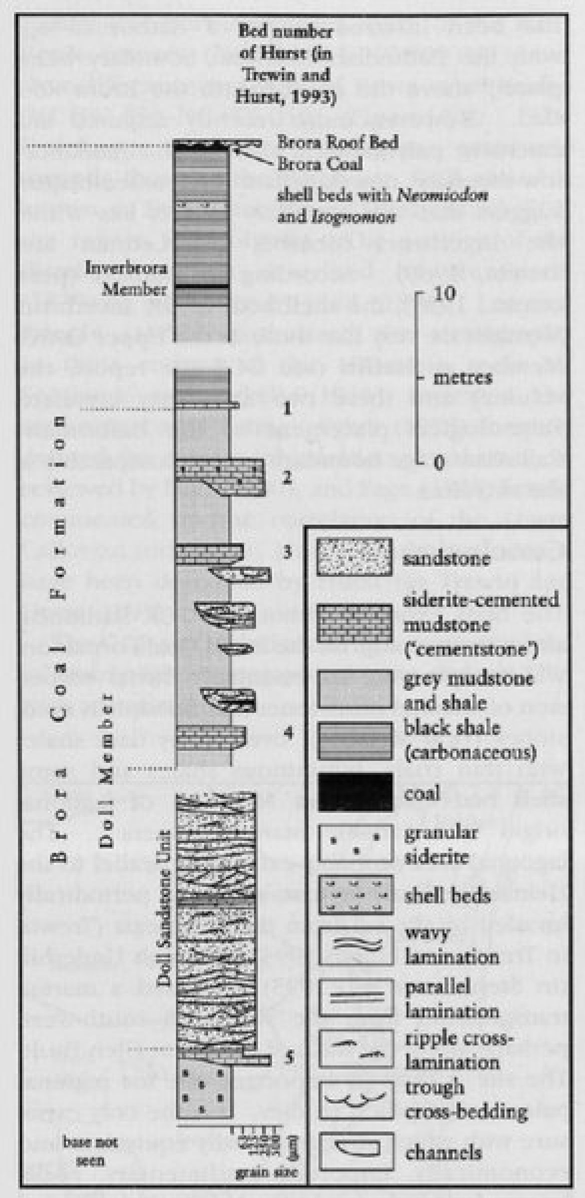
Conclusions

The beds exposed within the GCR Bathonian site at Brora comprise the Brora Coal Formation, which represents an essentially fluvial succession of channel sandstones and floodplain mudstones (Doll Member), overlain by dark shales with thin coals, bituminous shales and some shell beds (Inverbrora Member) of lagoonal origin with variable marine influence. The lagoonal area probably extended parallel to the Helmsdale Fault system, and was periodically invaded by the sea from the north-east (Trewin in Trewin and Hurst, 1993), although Underhill (in Stephen *et al.,* 1993) proposed a marine transgression from the west and south-west, perhaps along the trace of the Great Glen Fault. The site is thus an important one for regional palaeogeographical studies. It is the only exposure with which stratigraphically equivalent and economically important sedimentary rocks known from subcrop in the Moray Firth and farther afield in the North Sea can be compared, particularly with regard to sedimentology and palynofacies.

References



(Figure 6.4) Locality and geological sketch map for the Brora (Bathonian) GCR site. (After Hurst (in Trewin and Hurst, 1993, figs 1, 3).))



(Figure 6.5) Graphic section of the Brora Coal Formation at the Brora (Bathonian) GCR site. (After Hurst (in Trewin and Hurst, 1993, fig. 4).))