# Excursion 2 Bathonian to Oxfordian strata of the Brora area

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**Purpose**

To demonstrate the main features of the succession from the Brora Coal Formation to the Balintore Formation in the Brora area. The excursion is divided into four itineraries that can be timed to make best use of the tides.

Itinerary 2.1 The Brora Coal to Brora Arenaceous formations on south foreshore Brora and at Strathsteven.

Itinerary 2.2 The Brora Arenaceous Formation, south bank of the River Brora.

Itinerary 2.3 The Brora Argillaceous Formation, north bank of the River Brora.

Itinerary 2.4 The Brora Arenaceous and Balintore formations, north foreshore, Brora.

**Access and general information**

About two days of excursion are described in the four itineraries. The localities are easily accessible on foot, generally along recognised rights of way, and short distances from parking areas. Brora is an excellent starting point for visiting all localities, and has shops, hotels, parking space and public conveniences.

Localities are shown on the general map (Figure 2.1). The order in which itineraries are taken will depend on the state of the tide; coastal localities 1, 2, 6, 9 and 10 require low tide. Although the tidal range at Brora is considerable (>2 m) there is little danger of being cut off by the rising tide. Should one be surrounded suddenly by the sea, no more should be necessary than a knee-deep wade across the shallow slope of the wave-cut platform. A more hazardous feature of visiting the inter-tidal localities is the seaweed and slimy green algae that often make conditions treacherous underfoot. The shore exposures are cleanest in spring following winter storms. Access details are given in each itinerary.

**Introduction**

The general geology of the succession is described in the Geological History section of this volume and the stratigraphy summarised in (Figure 2.2). Many different workers have attempted to unravel the stratigraphy of the area and measure thicknesses of the units. Poor exposure, shallow dips and probable local thickness variations make this task difficult; hence, thickness estimates vary considerably between authors.

The Brora Coal Formation consists of an essentially fluviatile sequence of channel sandstones and floodplain mudstones of the Doll Member (Hurst, 1981), overlain by the dark shales with thin coals, bituminous shales and two shell beds of the Inverbrora Member, which was deposited in a lagoon with variable marine influence (MacLennan and Trewin, 1989). The Brora Coal was deposited during a period of isolation of the lagoonal area from the sea; waterlogged plant debris first accumulated, followed by coal formation over a wide area (as far as Balintore and the Beatrice Oilfield). The Brora Coal was mined intermittently from early times (1598) but the mining finally ceased in 1974 (Owen, 1995). The Brora Coal Formation is usually considered to be Bathonian in age but dinocysts indicate that the base of the Callovian may lie within the Inverbrora Member (MacLennan and Trewin, 1989).

Overlying the Brora Coal is the Brora Roof Bed, a marine sandstone that records a rapid marine transgression and subsequent deepening water, in which the Brora Shale Member of the Brora Argillaceous Formation was deposited. Parts of the Glauconitic Sandstone and Brora Brick Clay members are present on the shore, but are usually poorly exposed and are best seen inland (Itinerary 3). Since the completion of the work by Sykes (1975a, b) many exposures of the Brora Argillaceous Formation have been lost, notably those near the former brick works, which are now landscaped.

The Brora Arenaceous Formation is sandstone-rich, in which a general coarsening-upward character represents deposition in a coastal sandbar environment (Sykes, 1975a). Much of the building stone used in Brora is from the Brora Arenaceous Formation, largely from Clynelish Quarry [NC 893 045] and Braamberry Quarry [NC 893 049]. Ammonites from Clynelish Quarry decorate the clock tower in the centre of Brora.

Very limited exposure of the Balintore Formation is found at Brora, consisting of approximately 12m of interbedded muddy carbonaceous sandstones and 'limestones', which are siliceous spiculites subsequently recrystallised to carbonate (Sykes, 1975a). Outcrop is restricted to a small area on the foreshore north of Brora [NC 914 041].

The structural dip in the Brora area is generally 10° or less. Steeper dips are recorded near the Brora Fault and along the limbs of the anticlinal structures at Fascally [NC 899 040]. Gentle S-folding sub-parallel to the coastline can be traced, similar to the structural trend identified further NE in the Kimmeridgian Helmsdale Boulder Beds (Excursion 3). Poor exposure limits comparison between the different fault compartments but structural trends are not readily mappable across fault planes, evidence which may be indicative of some lateral movement on faults.

Most of the lithostratigraphic boundaries shown in (Figure 2.2) can be mapped reliably, but on a finer scale there are considerable problems when defining the thicknesses and distribution of individual members. From careful examination of Sykes (1975 a, b), all available borehole data and my own field measurements, it is assumed that the thicknesses given in (Figure 2.2) are reliable for members of the Brora Coal and Brora Argillaceous formations, but much less reliable for the Brora Arenaceous Formation. Previous estimates of the total thickness of the Brora Arenaceous Formation vary from 30m (Lee, 1925), to >60m (Sykes, 1975a), and up to 122 m (Judd, 1873). My preference is for Lee's estimate, structural and thickness measurements making it difficult to accommodate more than a 40 m total thickness for the whole of the Brora Arenaceous Formation.

## Itinerary 2.1 Brora Coal to Brora Arenaceous formations on south foreshore, Brora and at Strathsteven

### Purpose

To examine the Brora Coal Formation demonstrating the upward transition from alluvial plain (Doll Member) to marine-influenced lagoonal conditions (Inverbrora Member) and the major Callovian marine transgression that initiated deposition of the Brora Argillaceous Formation. Marine-bar sandstones of the Brora Arenaceous Formation are seen at Strathsteven and the Brora Fault can be demonstrated.

### Access

The itinerary can be commenced at Brora or from the small parking area near Sputie [NC 8880 0245]. The track to the parking area at Sputie leaves the main road at [NC 885 025] is narrow and passes under the railway, the tunnel being only just wide enough for a minibus. There is only room for three or four cars at the parking area. This parking can be used for localities 2 and 3 if the party does not wish to walk from Brora.

Starting at Brora either walk to the shore or take Harbour Road by turning east immediately south of the road bridge in Brora. Park at the car park near the old radio station (now a storage facility) and walk south to the point where the sewage pipe crosses the beach (Figure 2.3). Localities 1 and 2 require low tide, and sand and seaweed cover frequently obscures large areas of outcrop.

### Locality 1. Brora Coal and Brora Argillaceous formations, south foreshore [NC 905 032]

The excursion is best started from the most easily identified point in the succession, the Brora Roof Bed, which forms a prominent reef marking the seaward limit of exposure along almost 1 km of the foreshore [NC 905 032] to [NC 902 029]. The sewage pipe crosses the beach [NC 905 032] (Figure 2.3) about 500 m SW of the old radio station, and is fixed to the Brora Roof Bed.

**Brora Argillaceous Formation**

The Brora Roof Bed is the basal bed of the Callovian Brora Argillaceous Formation (Sykes, 1975a), and was deposited during the regional Lower Callovian marine transgression. Sykes (1975a) describes the Roof Bed as an overall fining-upward sequence of intensely bioturbated medium-grained sandstone with a few quartzite pebbles. The thickness of this bed in the Brora area varies up to 2.3m.

Fossils are common but difficult to extract from the calcite-cemented sandstone. In some areas on the top surface of the Roof Bed the gastropod *Pietteia* shows a preferred orientation of shell apices towards the SW (Sykes, 1975a), and the bivalves *Myophorella, Gervillella, Corbula* and *Pleuromya* may be seen, the latter in vertical burrowing position. Reworked fragments of the coal are present.

The sandstone was deposited in a shallow marine coastal setting and rests on the Brora Coal (not exposed). To the south (30 km) at Balintore (Cadh' an Righ) a thinner (0.5 m) laterally equivalent sandstone rests on an eroded and bored surface of the Brora Coal (Sykes, 1975a; MacLennan and Trewin, 1989).

The Roof Bed grades upward rapidly into the Brora Shale (only exposed at low spring tide) that was deposited in an open marine environment, as is evidenced by the presence of ammonites and belemnites. Although the shales are very dark and organic rich, there is a fauna of bivalves present including *Trautscholdia, Thracia, Protocardia and Meleagrinella.* Both shallow- and deep-burrowing forms are present; thus bottom-water conditions were not continuously anoxic. However, reducing conditions prevailed beneath the sediment/water interface as shown by the high organic content. Abundant angular shell debris is probably the result of predation by fish or arthropods on the molluscan population. Both land-derived material (plant fragments and spores) and marine microplankton (dinocysts) are abundant (MacLennan and Trewin, 1989) and are indicative of nearshore open-marine conditions.

About 100m east of the sewer pipe the first outcrops of the Glauconitic Sandstone Member are seen low on the beach. The typical lithology is a muddy, glauconitic, bioturbated, very fine-grained sandstone with glauconite concentrations in burrows. Sideritic and phosphatic concretions are present and belemnites are abundant in several beds.

Further west parts of the Brora Brick Clay and Fascally Siltstone members form a broad low intertidal platform. Few details are visible here apart from some large calcareous concretions. Toward the river mouth, there are extensive but low-lying exposures of parts of the Brora Arenaceous Formation. Fracturing and hardening of some sandstone outcrops is associated with faulting near the mouth of the Brora River. The Brora Argillaceous Formation is described in more detail in Itinerary 3.

**Brora Coal Formation**

Return to the starting point at the Roof Bed and locate exposures of dark micaceous and carbonaceous shales of the Inverbrora Member of the Brora Coal Formation due west of the Roof Bed. The Inverbrora Member includes some bituminous shales approaching oil-shale in composition (up to 26% Total Organic Carbon), and two thin green shell beds with *Neomiodon* and *Isognomon,* which are still aragonitic, and occur about a metre apart in the sequence ((Figure 2.4). Abundant drifted plant material is present in the shales, Stopes (1907) having described three species of *Equisetum* and nine other plants including leaves of *Ginkgo.* The shales are mostly finely laminated, contain thin lenses of coal and have small pyrite concretions that sometimes replace plant debris. The shell beds are reworked and winnowed at their tops, with rounded shell debris. Lam and Porter (1977) first recorded marine microplankton from the Inverbrora Member, which has been confirmed by MacLennan and Trewin (1989) who have shown that dinocyst assemblages are present that represent variable marine influence in a lagoonal environment. The presence of marine benthonic foraminifera confirms the influence of marine conditions.

The Brora Coal was deposited when the lagoon became isolated from the sea and abundant plant material including *Equisetum* and conifer wood (Harris and Rest, 1966) accumulated. The absence of a seat-earth 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 coal comprise drifted materials. Rootlets have been recorded from a dirt bed within the coal.

The composite section (Figure 2.5) of the Brora Coal Formation shows the general features of the outcrop that lies to the west of the Roof Bed. Exposures are low-lying and subject to sand, seaweed and boulder cover; thus, beds described here may not be visible. Below the shell beds the Inverbrora Member becomes lighter grey, less rich in carbonaceous material, and the shales give way to mudstones. This trend continues into the underlying Doll Member where grey mudstone predominates. The top of the Doll Member is marked by the occurrence of a laterally extensive siderite-cemented, grey, brecciated mudstone with a distinctive red-brown weathering colour (Bed 1). Thin rippled sandstones with plant debris are associated with Bed 1 that, when exposed, forms a ridge on the foreshore some 10–20 cm higher than the surrounding mudstones. Finding Bed 1 is usually quite simple and provides a useful line of reference from which the rest of the section can be examined.

Neves and Selley (1975) record the presence of the freshwater bivalve *Unio* from Bed 1 and a rich freshwater ostracod fauna was recovered between Beds 3 and 4 (R. Titterton, pers. comm.) (Figure 2.5). A rich non-marine palynoflora has been recovered from mudstones of the Doll Member (J. Fenton, pers. comm.) and silicified logs are common along a horizon between Beds 1 and 2 (Hurst, 1981).

Siderite-cemented mudstone horizons ('cementstones' of Lee (1925)) can be correlated laterally and allow the vertical sequence of the Doll Member to be established (Hurst, 1981). The brecciated internal texture of Bed 1 is similar to structures formed by pedogenic (soil-forming) processes, a possibility to some extent confirmed by mineralogical analyses that prove the clay mineral kaolinite is more abundant in the siderite-cemented horizons than elsewhere (Hurst, 1985). The abundance of kaolinite is associated with leaching processes caused by subaerial exposure, often associated with deep weathering. Further confirmation of subaerial processes in the formation of the siderite-cemented beds is the presence of desiccation cracks in Bed 4, and a sandstone bed with rootlets close to Bed 5.

Siderite (iron carbonate) cement is common in freshwater mudstones and provides useful palaeoenvironmental information. As the iron in siderite is present in reduced form it is implied that the cement formed in a reducing environment. Furthermore, the pore water from which the siderite precipitated can be assumed to have been very low in dissolved sulphate, i.e. unlikely to have been of marine origin. In sulphate-rich pore water pyrite (iron sulphide) would form to the exclusion of, or in addition to, siderite. It is interesting to compare the diagenetic mineralogy of the Doll and Inverbrora members. The Doll Member contains diagenetic siderite with no known occurrence of pyrite, whereas the Inverbrora Member contains diagenetic pyrite with no known occurrence of siderite. The mineralogical variation may be attributed to an increased marine influence during deposition of the Inverbrora Member, giving higher sulphate content in the sediment pore waters, an interpretation confirmed by palaeontological data.

The large influx of freshwater ostracods between Beds 3 and 4 (Figure 2.5) is approximately coincident with a marked change in the clay mineralogy of the mudrocks, from a predominantly kaolinite + illite/smectite assemblage to an illite + kaolinite assemblage (Hurst 1985). No sedimentological evidence is found that corresponds to the palaeontologic/clay mineralogic boundary.

As one continues a stratigraphic descent of the Doll Member it should be noted that the abundance of sandstone increases (Figure 2.5). At first sandstones occur as small lenses, often less than 5 m wide and only 10 to 30 cm thick. The sandstones are invariably calcite cemented and are easily missed due to the presence of erratics, largely of Devonian age, that litter the shoreline in this area. At the base of the exposed section is the white, fine-grained Doll Sandstone Unit [NC 898 029]. The Doll Sandstone Unit is not calcite cemented; it is lightly consolidated, containing only minor kaolinite and quartz cements, and is estimated to be at least 20m thick, although the level of exposure often limits observation. All the sandstones are interpreted to be of fluvial origin and contain trough cross bedding with occasional parallel laminae and current ripple lamination (Hurst 1981). The foreset laminae indicate a transport direction from the west or NW with current ripple lamination with more diverse orientation, sometimes normal to the foresets. A derivation of sand detritus from the Barrovian metamorphic rocks of the Grampians to the south or SE was postulated by Hudson (1962, 1964) because of the occurrence of staurolite in the sandstones. In the light of the palaeocurrent data this seems to be unlikely. Possible westerly sources for staurolite are within the Lewisian of the Outer Hebrides (Coward *et al.,* 1969) or from the erosion of post-Barrovian (Devonian) sedimentary rocks deposited west of Brora (Hurst, 1982, 1985).

Close to the line of the Brora Fault and at the south-western extremity of outcrop shown in (Figure 2.3), spectacular intensely fractured and micro-faulted outcrop of the Doll Sandstone occurs. The fracturing records the brittle deformation of the Doll Sandstone in the hanging wall of the active Brora Fault. This outcrop is frequently buried in beach sand. About 80 m east of this area mudstone interbedded with the Doll Sandstone dips at up to 30° to the SE, a local steepening associated with drag against the Brora Fault.

### Locality 2. Brora Coal Formation and the Brora Fault near Sputie Burn [NC 893 026]

Continue about 500 m SW to locality 2, which is an intertidal extension of a small headland 500 m NE of the mouth of Sputie Burn (Figure 2.6). Exposures of the Doll Member are easily accessible at this locality. The lithostratigraphy is as described for the Doll Member at locality 1.

The area of outcrop is the crest of a small anticlinal structure, the axis of which can be observed a few metres above low water mark at the eastern-most tip of the exposure. Unlike the previous section, this section is examined by working up-sequence. The main part of the exposed section dips at angles up to twenty degrees toward WNW–NW. Dips increase toward the NW as the Brora Fault is approached. Outcrop is restricted to the Doll Member, a section from slightly above Bed 1 to the top of the Doll Sandstone Unit usually being visible (Figure 2.7).

In detail, the sequence is very similar to the main outcrop further NE. A major advantage at this locality is that the exposure is better and less spread than at locality 1. Particularly well exposed are the siderite-cemented mudstones and siltstones that form prominent reefs among the softer mudstones. Examination of the different siderite-cemented beds allows them to be identified as the same 'Beds' shown in (Figure 2.4), so allowing lateral correlation to be made. Further confirmation of the stratigraphic position of the section is established by the occurrence of the horizon containing silicified logs between Beds 1 and 2.

Of additional interest at this locality is the exposure of the Brora Fault, which has downthrown the Brora Coal Formation such that it is in contact with sandstones of the Oxfordian Brora Arenaceous Formation. The throw of the Brora Fault can only be approximated, since the precise level of the exposure within the Brora Arenaceous Formation is unknown. However, the entire Brora Argillaceous Formation is faulted out (88.6m, Sykes, 1975a), the Inverbrora Member is missing (15 m, Hurst, 1981) and the Fascally Member of the Brora Arenaceous Formation (6.5 m Sykes, 1975a) is also missing. The Brora Arenaceous Formation sandstones exposed at Strathsteven (Locality 3) are believed to be part of the Clynelish Quarry Sandstone Member with the base of the Brora Sandstone Member possibly near the top of the cliffs. The sandstones commonly contain moulds of marine bivalves and some burrows and plant debris, characteristics typical of the Clynelish Quarry Sandstone Member. A throw in excess of 140 m is thus possible. If Lee's (1925) 30 m thickness for the Brora Arenaceous Formation is utilised, a throw of about 100 m is obtained.

Location of the Brora Fault is straightforward as the fault zone is cemented, making the Brora Arenaceous Formation into a more resistant lithology than the surrounding lithologies. Displacement occurred along several sub-parallel planes, and the width of the fault zone and degree of cementation vary. Good examples of oblique slickensides are present on a landward-facing surface by a metal post near high watermark (Figure 2.8). The fracture is part of the Brora Fault zone. The fault can be traced over most of the exposed foreshore and the fault-associated cementation of the Brora Arenaceous Formation is characteristic. There is no apparent alteration of mudstone lithologies adjacent to the fault zone. Upstanding cemented reefs of Brora Arenaceous Formation occur along the shoreline to the SW beyond Sputie Burn, and mark the continuation of the Brora Fault. The zone affected by cementation seems to vary in breadth from up to 20 m down to apparently nothing toward the NE.

If this itinerary is being completed on foot from Brora, continue SW to the prominent cliff at locality 3.

### Locality 3. Brora Arenaceous Formation, Strathsteven Cliff [NC 886 021]

From the car park at Sputie Burn, the locality is some 300m SW and a path through the disused quarries can be followed (Figure 2.1), (Figure 2.6). Tides do not affect this locality.

At Strathsteven, the thickest continuous vertical outcrop section of the Brora Arenaceous Formation is seen. As no contacts with underlying or overlying formations are visible, it is impossible to know at which stratigraphic level the outcrops occur.

Sykes (1975a) assigns the sandstones at Strathsteven to the Brora Sandstone Member, but there are significant differences between these sandstones and those assigned to the Brora Sandstone Member elsewhere in the Brora area (Localities 6 and 9). The Strathsteven sandstones are generally fine- to medium-grained, well sorted, and rarely contain quartz pebbles. Interbeds of fine-grained sandstone with clay drapes and current ripples are present. Well-developed cross-bedding is uncommon. Moulds of leached bivalves, often brown, are common. These characteristics are more typical of sandstones of the Clynelish Quarry Sandstone Member rather than the Brora Sandstone Member.

Structural measurements are complicated by the lack of distinct bedding planes, a general dip towards SE being inferred. Direction of sediment transport as recorded by cross-bedding has a general trend from NW to SE; however, much variation is present. The NE face of the northernmost cliff has large-scale features that dip to the SE. If these features are sedimentary they can be interpreted as part of a large seaward dipping marine sandbar. The seaward (SE) face of the cliff (Figure 2.9) exposes a strike section which dips seaward and has elongate lenticular bedding units in which cross-bedding is sometimes identifiable. Bivalve moulds, dominated by pectinids, are common. Good sorting and the removal of any carbonate by leaching have produced high porosity and permeability, averages of 29.8% and 5.1D respectively (based on 18 core plug measurements from the northernmost cliff).

It would be a mistake to concentrate solely on the sedimentological characteristics of the Strathsteven exposures. Indeed, probably their most striking feature is the abundant sub-vertical fracturing. Many fractures sole-out along bedding surfaces; others are vertically continuous at least over the scale of the outcrop. Very few of the fractures have discernible vertical displacements and have probably formed as a result of expansion due to pressure reduction (unloading) during uplift.

At the top of the exposure to the SW [NC 885 020], there is some evidence of fining-upward sequences that are more typical of the Brora Sandstone Member. It is possible that the transition from the Clynelish Quarry Sandstone Member to the Brora Sandstone Member is approximately coincident with the top of the exposures at Strathsteven. The lack of exposure of the Clynelish Quarry Sandstone Member–Brora Sandstone Member boundary elsewhere makes lithostratigraphic division of the Brora Arenaceous Formation problematic. A high degree of lateral and vertical facies variation is expected in marine sand bars; however, it is a mistake to dismiss the problems of correlation because of an inferred depositional complexity.

If the exposures at Strathsteven belong predominantly to the Clynelish Quarry Sandstone Member and the base of the Brora Sandstone Member is near the top of the exposed section [NC 885 020], it would be reasonable to expect that the Fascally Sandstone Member is relatively close in the sub-surface near to the base of the cliffs. In the eventuality of these assumptions being correct, the fine-grained Fascally Sandstone Member and underlying Brora Argillaceous Formation would be effective barriers to surface drainage — a possible reason for the occurrence of the marshy area below and to the south of the cliffs? These assumptions imply that the Clynelish Quarry Sandstone Member is approximately 10 m thick in the Strathsteven area.

As with the exposures of the Clynelish Quarry Sandstone Member and Brora Sandstone Member described at localities 4, 5 and 6, the Strathsteven sandstones are interpreted as marine sand bar facies deposited under the influence of tidal currents. The sandstones were deposited during periods of high depositional energy that were separated by lower-energy periods, possibly involving current reversal, during which clay/silt-rich drapes were deposited. Renewed deposition of sand often eroded both clay drapes and underlying sand units, as recorded by the presence of numerous discontinuous reactivation surfaces.

## Itinerary 2.2 The Brora Arenaceous Formation, south bank of the River Brora

**Purpose**

To examine exposures of the Brora Arenaceous Formation on the south bank of the River Brora.

**Access**

Localities 4, 5 and 6 are reached by using public footpaths (Figure 2.1). Follow the A9 road southward from the centre of Brora until an entrance is reached on the north side of the road beside the house called Catlaw about 50 m beyond Harry Gow's bakery, confectionery and ice cream shop. From this entrance follow a footpath westward through woods overlooking the river until, after climbing over a stile, the path descends to river level at locality 5. Continue upstream following the path high above the river bank; progress may be impeded by vegetation. The path eventually drops down to the swampy area around Cawcrask at the upstream end of the high bank where exposures are accessible. Locality 4 is about 20 minutes walk from the centre of Brora. Localities 5 and 6 can be reached by walking downstream from locality 4. The limit of tidal influence is at locality 5 but access is unaffected by tides. Locality 6 is affected by tides but is usually accessible at half tide. Locality 6 can also be reached from the centre of Brora by climbing over a partly derelict stile in the wall between the clock tower and Sutherland Arms Hotel. Localities 4, 5, and 6 make a convenient half day excursion.

**Introduction**

General features of the Brora Arenaceous Formation are described in the geological history section and the basic stratigraphy is illustrated in (Figure 2.2). The three members of the formation form an overall coarsening-up sequence onto which are superimposed several smaller-scale fining-up sequences. A marine depositional environment is present throughout.

Sykes (1975a) quotes locality 5 as the type section for the Fascally Sandstone Member. Normally however, none of the Fascally Sandstone Member is exposed on the south side of the river at Fascally. It is assumed that Sykes' true type section is on the north bank of the river opposite locality 5, where a full section of the Fascally Sandstone Member is exposed.

Clynelish Quarry [NC 893 045] (Figure 2.1), after which the member is named, is not included as part of this guide. The quarry is disused and the site of a scrapyard. Although the rich *lamberti* Zone fauna described by Sykes (1975a) may attract some visitors, do be prepared for a disappointment. The sandstones have tight microcrystalline quartz cement and secondary porosity due to dissolution of *Rhaxella* (sponge) spicules is seen in thin section (Vagle *et al.,* 1994; 1995). Some elements of the fauna can still be collected from small exposures and tip material. A fine ammonite from Clynelish Quarry is placed in the front of the clock tower in the centre of the village. Locality 5 is the type section of the Clynelish Quarry Sandstone Member, and despite not containing a rich fauna it does have excellent exposure of the typical sedimentary facies.

A further exposure of the Clynelish Quarry Sandstone Member, not described in this guide, is at Braamberry Quarry [NC 893 049] (Figure 2.1). Here, a thicker section is better exposed than at Clynelish Quarry without the tight silica cement. The presence of quartz pebbles and clearly defined cross-bedding are reminiscent of the Brora Sandstone Member, again raising doubts about the internal divisions of the Brora Arenaceous Formation.

### Locality 4. Fascally Sandstone Member and Clynelish Quarry Sandstone Member, Cawcrask [NC 899 039]

A gradual increase in dip northwards along the exposure marks the presence of an anticlinal structure between localities 4 and 5. At the southern end of the locality structural dips of less than 10° towards approximately ESE occur.

Sedimentological logs of localities 4 and 5 are given in (Figure 2.10). Clearly visible along the entire length of the section is the sharp boundary between the Fascally Sandstone Member and the Clynelish Quarry Sandstone Member. The Fascally Sandstone Member is a fine- to very fine-grained silty sandstone of marine origin. Belemnites and other Shelly marine fauna, especially the bivalve *Chlamys,* are common, although the original shell material has been removed by leaching, and fossils occur as iron-oxide stained moulds. Few primary structures are visible, as the Fascally Sandstone

Member is intensively bioturbated, networks of sub-horizontal burrows predominating. Sykes (1975b) notes the presence of *Thalassinoides.* Traces of wave-ripple lamination are distinguishable. On two core plugs porosities and permeabilities of 24.7% and 28.7% and 93 mD and 27 mD were obtained. Better exposure of the Fascally Sandstone Member occurs on the north bank at locality 5 and can be visited in association with Itinerary 3 of this excursion.

The increase in grain size between the Fascally Sandstone Member and Clynelish Quarry Sandstone Member is small, from fine to medium sand <125µm to <250µm ((Figure 2.10), Locality 4). Most obvious is the decrease in detrital clay content, exemplified by the colour change from the grey-green Fascally Sandstone to the pale yellow Clynelish Quarry Sandstone, which is well sorted, fine-grained and highly quartzose. At this locality traces of bioturbation are rare and fossils are restricted to leached fragments of bivalve shells. In equivalent strata on the foreshore immediately south of the river, bioturbation is well preserved, including large (approximately 20 cm diameter) vertical burrows. Preservation of fossils and bioturbation seems to be associated with the presence of an early diagenetic quartz cement.

A very slight overall coarsening-upwards sequence is observed in the Clynelish Quarry Sandstone Member, although individual bedding units often contain fining-upward sequences. At first sight the sandstones appear to be massive; however, some intervals are cross bedded and indicate a transport direction from WNW/NW. No channel form is recognised and each sandstone unit rarely exceeds 1 m thickness. The apparent lack of sedimentary structures is partly because the outcrop is orientated parallel to the depositional trend, which makes them difficult to see, and partly because the sandstones are very well sorted.

Detrital and authigenic clays are uncommon in the Clynelish Quarry Sandstone Member sandstones, which are classified as quartz arenites (Hurst, 1980). Clay-rich laminae are, however, common along the bedding surfaces between sandstone units. Frequently, the laminae are little more than 1–2 mm thick and contain finely-disseminated plant remains. The plant remains may previously have been pyritised, as they now have a rusty coloration caused by weathering. Approximately 1 m above the base of the Clynelish Quarry Sandstone Member is an interval with a concentration of muddy laminae. This interval is about 25–30 cm thick; however, thickness and internal characteristics vary laterally. In general, the interval comprises very fine-grained sandstones within which muddy lenses of fine- to medium-grained sandstone occur (Figure 2.10). The muddy layers are undulose and drape onto sandstone units. Some sandstone units are apparently enveloped by muddy laminae. Fine-grained sandstones within the muddy laminae sometimes contain current ripples. The muddy laminae are sometimes disrupted laterally by down-cutting erosive surfaces filled with sandstone.

Sykes (1975a) makes no specific sedimentological interpretation of the Clynelish Quarry Sandstone Member, the whole of the Brora Arenaceous Formation being interpreted as a coastal sandbar. The action of tidal processes can, however, be inferred with confidence based on the occurrence of mud drapes, the sharp erosive base of the member, the dominance of unidirectional current structures and the marine environment. Evidence of current reversal is not readily observable at this locality, as current ripples in the muddy intervals are too few and too indistinct to make a conclusive interpretation. No evidence is preserved of wave-influenced processes. A sub-tidal marine depositional environment is inferred with no direct evidence for a coastal affinity.

**Locality 5. Clynelish Quarry Sandstone Member, Fascally [NC 899 040]**

This locality lies on the northern limb of a gentle SE plunging anticline. Dips of around 15° toward SE are probable. An outcrop of the Faseally Sandstone Member on the opposing bank of the river illustrates the structural dip more clearly than in the Clynelish Quarry Sandstone Member.

The sequence is similar to that exposed at Cawcrask (Locality 4) as comparison of the sedimentary logs shows (Figure 2.10). A horizon of very fine-grained sandstone with muddy laminae is clearly visible about 2 m above the river level. This horizon may correlate laterally with similar laminated sandstones observed 1 m above the contact with the Fascally Sandstone Member at locality 4. Within the fine-grained sandstone interval current ripples are observed that appear to have formed in currents moving from ENE to WSW, i.e. slightly oblique to perpendicular in relation to the direction of the foresets in the cross-bedded sandstones. Structures within this laminated interval provide evidence of current reversal. Cross-bedded intervals are rarely clearly visible at this locality; however, the same uneven bedding thicknesses as seen at locality 4 are observed. Concentrations of leached shell debris are locally common.

Average porosity and permeability of 30.1% and 8.2% respectively are measured on core plugs from locality 5 (14 samples). Permeability increases upward in the section.

Above the laminar sandstone the vertical sequence is examined by moving southward toward the path. The remaining sequence shows an overall fining-upward trend in which bedding surfaces are often discontinuous. Muddy layers and mud drapes are most common near the top of the sequence, whereas shell debris is more common in the lower part of the sequence. Near the top of the exposed section, along the upper side of the path, approximately 0.5 m of very fine-grained bioturbated sandstone, similar in appearance to the Fascally Sandstone, is found. Interbedding of bioturbated facies within the otherwise clean Clynelish Quarry Sandstone Member was not recorded by Sykes (1975a, b).

The lower part of the Clynelish Quarry Sandstone Member and the top of the Fascally Sandstone Member are also exposed on the north side of the river opposite the harbour [NC 908 040] to [NC 910 039], where thin yellow sandstone beds and interbeds of muddy bioturbated sandstones are exposed. This locality is best visited at low tide.

### Locality 6. Brora Sandstone Member, Brora [NC 906 039]

Continue downstream to locality 6, which is immediately upstream of the road bridge. Approximately 5 m of the Brora Sandstone Member is exposed at locality 6. If the tide is low, riverside exposures can be examined between localities 5 and 6. The rock by the river is very slippery and extra care is needed. A large cliff exposure, which is only fully accessible at low tide, is located about 200 m upstream from locality 6 [NC 903 039]. At locality 6 a very low structural dip is apparent, the bedding surfaces along the river bank sloping at an angle similar to the surface of the river (<1°). It is of course very difficult to measure structural dip in sandstones that contain sedimentary structures that produce a bedding structure.

At the cliff face and along the river toward the bridge the Brora Sandstone Member comprises predominantly planar cross-bedded pebbly quartzose sandstones. From the terrace exposed below high-water mark up to the cliff face there is an overall coarsening upward. Bed thicknesses vary laterally and can be traced downstream along the riverside at low tide. Outcrops at the same stratigraphic level within the Brora Sandstone Member are found on the downstream side of the bridges and may be approached from the harbour. The cliffs on the north side of the river are not accessible but display similar features to outcrops at locality 6.

Unlike locality 5 no muddy horizons are seen and planar cross-bedding predominates. The approximate current direction derived from the orientation of the cross beds is from ENE, the opposite direction to that measured in the Clynelish Quarry Sandstone at Fascally (Locality 5). Leached shell fragments occur sporadically and sometimes form coarse lags at the base of foresets. Well-rounded quartz pebbles are characteristic both as lags and as isolated grains within otherwise poorly sorted medium- to coarse-grained sandstone. Sedimentary bedding characteristics are sometimes confused by the presence of low-angle fractures, which often sole out along bedding planes.

Average porosity and permeability at locality 6 are 31.3% and 4.6 D, respectively. Large ranges of porosity and permeability are present, 27% to 37% and 2.4 D to 12.9 D, respectively.

The Brora Sandstone Member is interpreted as being part of a tidal sandbar complex, probably a facies type that is part of both a lateral and, more often, a vertical facies association with the Clynelish Quarry Sandstone Member. The absence of mud drapes, and fine-grained material in general, is evidence of the continuous high-energy depositional environment which presumably removed any mud drapes deposited under still-stand conditions.

## Itinerary 2.3 The Brora Argillaceous Formation, north bank of the River Brora

#### Purpose

To examine the exposures of the Brora Argillaceous Formation exposed on the north bank of the River Brora.

### Access

From the north side of the A9 road bridge in the centre of Brora take the road westwards signed Gordonbush and Rogart (Figure 2.1). After slightly less than 1 km the recreation area and car park is reached. This is a sensible place to park although it is possible to drive a car up to Bruachrobie. From the car park, either the track to the east or the west of the pitch can be followed to Bruachrobie (views of locality 4, Brora Arenaceous Formation on the south bank of the river from the eastern path — remains of old brick clay pits from the western path). The locality is most readily accessible from the western end [NC 8875 0398], which is reached by following the overgrown track past Bruachrobie to the top of hill following the boundary fence approximately westward through several gates until a marked break of slope is reached. River level can be reached via a small gate near the edge of the cliff, giving access to outcrops of the Brora Brick Clay Member. Wellington boots or waders are recommended for examination of this locality, which is only accessible when the river is low.

Approximately 3 hours should be allowed to complete this itinerary.

### Introduction

The Brora Argillaceous Formation is nowhere well exposed. The shore section (Itinerary 1) is only visible at low tide, complicated by faulting and frequently obscured by seaweed and beach sand. Inland exposures have weathered surfaces that obscure many sedimentary features. Sykes (1975a, b) described the shore sections and sections from Coal Board boreholes. Landscaping in the Fascally area [NC 898 041] has destroyed sections once available in the Brora Brick Works pit described by Sykes (1975a, b). Biostratigraphic data are found in Sykes (1975a) and Lam and Porter (1977). Some details of the Brora Shale Member on the shore are given by MacLennan and Trewin (1989), and in Itinerary 1 of this excursion.

## Locality 7. Brora Argillaceous Formation, near Bruachrobie [NC 888 040]

### Brora Shale Member

About 80 m downstream from the western end of the cliff the top of the Brora Shale Member is exposed.

Approximately 2 m vertical thickness is exposed before thick vegetation obscures further examination. Exposure of the Brora Shale Member forms the core of an anticlinal structure the eastern limb of which takes exposures of the Glauconitic Sandstone and Brora Brick Clay members down to river level further downstream. Plant fragments, belemnites and phosphatic nodules are common in the sandy horizons. The sandy beds are interpreted to be the deposits of gravity-flows. They contain glauconite and a shallow-marine shelf bivalve fauna, presumably reworked by tidal or storm processes, and redeposited in a more stagnant deeper-water environment. Sykes (1975b) records the presence of the trace fossils *Thalassinoides, Diplocraterion* and *Chondrites* from the sandy beds, but they are absent from the shaly interbeds. Clearly, the background anoxic environment in which the shales were deposited was unsuitable for sustaining infaunal activity.

### Glauconitic Sandstone Member

The top of the Brora Shale Member is marked by a rapid coarsening-upwards into thick (0.5 m) glauconitic, very fine-grained sandstone (Figure 2.11), which marks the base of the Glauconitic Sandstone Member (Sykes 1975a). Three subdivisions are defined within the Glauconitic Sandstone Member: a basal unit comprising c.4.15 m of muddy glauconitic sandstones with thin shale interbeds; a middle unit comprising c.2 m of grey siltstone; an upper unit comprising c.3.9 m of slightly glauconitic silty sandstone. The siltstones have a sparse fauna but the sandstones contain abundant fossils and are bioturbated.

In the lowermost 4.15 m of the Glauconitic Sandstone Member eight small coarsening-upward sequences are identified. The sandstones are similar and characterised by rows of phosphatic nodules (cm-scale) and horizons of randomly-orientated tree fragments and guards of the belemnite *Cylindroteuthis puzosiana* (Figure 2.12). The phosphatic nodules contain sponge spicules of *Rhaxella poforata,* which are visible in thin section (Sykes 1975a). Despite the pervasive, intense bioturbation, the trace fossils *Thalassinoides, Diplocraterion* and *Chondrites* are identified at sandstone–shale boundaries (Sykes, 1975b).

The sandstones are silty with a high content of sand-sized glauconite grains. The glauconite is allochthonous, having formed at a sediment–water interface in gently agitated water that periodically disturbed poorly-oxygenated bottom waters. Faecal pellets and small shell fragments have probably been pseudomorphed by the glauconite. The glauconite has similar smectite content (30–40%) to clays in the surrounding siltstones and shales (Hurst, 1985). This similarity is indicative of the compositional uniformity of the source of clay detritus to the Moray Firth Basin during Callovian times. Deposition of the sandstones is interpreted as being the result of progradational events higher up on the shelf that caused the deposition of sand further offshore, perhaps during storm periods. Deposition of bituminous silty mud with a sparse infauna is indicative of poor circulation and poor oxygenation at the sediment–water interface. Sand deposition records periods of increased depositional energy and increased oxygenation when burrowing organisms colonised the area until anoxic bottom conditions were re-established. Mud deposition appears to have excluded the survival of an infauna in this lower unit.

Grey siltstones in the middle unit of the Glauconitic Sandstone Member become more silt-rich upward, the lowermost beds being dark and apparently bituminous. Fauna is scarce and restricted; Sykes (1975b) recorded the presence of the bivalve *Meleagrinella braamburiensis* and *Lingula craniae.* It is assumed that a break occurred in the progradation represented by deposition of the underlying unit, thus reestablishing fine-grained deposition. The decreased bituminous content upward is interpreted to represent the onset of more oxic conditions at the sediment–water interface.

Sandstones in the upper 3.9 m of the Glauconitic Sandstone Member are less glauconitic than in the lower unit, thus giving a cleaner appearance. Five coarsening-upwards beds are identified (Figure 2.11), the top bed being 0.8 m thick. Prominent carbonate concretions ('doggers') occur about 2 m from the top of the Glauconitic Sandstone Member. Sykes (1975a) suggests that the upper unit of cleaner sandstones in the Glauconitic Sandstone Member is the product of a period of reworking, evidence for which can be seen at Balintore in Ross-shire. Certainly the lower glauconite content of the sandstones is indicative of better oxygenated conditions in the shallower part of the basin from where it was derived. The shaly interbeds have more evidence of bioturbation than is seen lower in the sequence, again indicative of oxic conditions.

**Brora Brick Clay Member**

Approximately 5 m of an estimated total thickness of 15 m of the Brora Brick Clay Member crop out along the riverbank. The Brora Brick Clay Member is the finest-grained member of the Brora Argillaceous Formation and was until 1974 extracted in the Fascally area for making bricks.

The base of the Brora Brick Clay Member is marked by the abrupt change in grain size at the top of the last sandstone bed of the Glauconitic Sandstone Member. Laminated, slightly bioturbated muddy siltstones comprise the basal 1.7 m of the Brora Brick Clay Member. Fauna is sparse, Sykes (1975b) recording the occurrence of belemnites (*Cylindroteuthis puzosiana*)and the bivalve *Solemya woodwardiana.* Three thin, silty, very fine-grained sandstone beds may be visible near the top of the exposed sequence, which are the bases of three fining-upward units. Exposure of the upper part of this sequence is poor due to slippage and is often inaccessible if the level of the river is high.

The thin fining-upward sequences in the Brora Brick Clay Member are interpreted as being the result of deposition from small gravity flows. They are similar to sandstones in the Glauconitic Sandstone Member and contain an allochthonous fauna and glauconite derived from a nearer-shore environment.

Locality 8. Brora Brick Clay Member, west side of recreation area [NC 896 040] Access to this clay pit (Figure 2.1) is now closed. It is the only clay pit of the brickworks that survived the landscaping of the Fascally area. The exposures have uneven weathered surfaces.

### Locality 5. Fascally Sandstone Member [NC 899 040]

Depending on the river level access can be made on the north side of the river (Figure 2.1) either from the downstream side, to examine the Fascally Sandstone Member, or from the upstream side via the concrete embankment, to examine the top of the Fascally Siltstone Member. The locality is only accessible when the river is low.

A prominent series of calcareous nodules form a useful marker horizon that is approximately 1 m from the top of the Fascally Siltstone Member. The boundary between the members is marked by the first occurrence of intensely bioturbated, fine-grained, muddy sandstones (Sykes 1975a). The features of the sandstones have been described previously (Locality 4) and are not repeated here.

## Itinerary 2.4 The Brora Arenaceous and Balintore formations, north foreshore

### Purpose

To examine the Brora Sandstone Member at the top of the Brora Arenaceous Formation and the Ardassie Limestone Member of the Balintore Formation.

### Access

Take Golf Road eastward from the north side of the bridge in the centre of Brora to the golf club car park. A public footpath crosses the golf course to the beach. The rocks at locality 9 are covered at high tide, but some exposure remains at mid-tide. Sand cover severely restricts the level of exposure of the Brora Sandstone Member. The itinerary takes 1 hour or more depending on how much time is spent looking for fossils. Please do not hammer the outcrops; material can usually be found loose at the top of the beach at Ardassie Point.

### Introduction

On the northern foreshore at Brora exposures lie between the tide marks (Figure 2.13). Approaching Ardassie Point from the south as much as 10 m of the Brora Sandstone Member may be exposed together with approximately 12 m of the Ardassie Limestone Member (Sykes 1975a).

### Locality 9. Brora Sandstone Member and Ardassie Limestone Member, Ardassie Point [NC 913 041]

Despite the general overall upward-coarsening of the Brora Arenaceous Formation (Figure 2.2) this section has a slight overall fining-upwards trend that continues into the fine-grained sandstones and calcareous mudstones of the Ardassie Limestone Member. The lowest 2–3 m of the exposed section (often poorly exposed) comprises medium-grained sandstones with occasional pebbly or Shelly bottom-sets but lacking any well-defined lamination. Bedding planes are irregular and elongate dune forms are identified. Throughout the remaining part of the section trough cross bedding predominates with individual trough forms identifiable. Palaeocur-rent directions are toward the W and SW. Rounded quartz pebbles and phosphatic fragments are found in the lags of some foresets.

Smaller scale fining-upward sequences are identified within the overall fining-upward sequence. Near the top of the Brora Sandstone some vertical burrows are present, which probably record the initiation of deeper-water conditions.

The boundary between the Ardassie Limestone Member and the Brora Sandstone Member is distinct, changing from clean yellow sandstones to grey, very fine-grained, shaly sandstones. The contact is rarely exposed. Sykes (1975a) describes the rocks at Ardassie Point as muddy carbonaceous sandstones interbedded with slightly sandy spiculites, originally with opaline sponge spicules (*Rhaxella*)*,* which are now replaced by calcite. The sandstones are thoroughly bioturbated and fossil-iferous, large specimens of the bivalves *Pinna lanceolata* and *Gryphaea dilatata* occur preserved in life position, and the bivalve *Cucullaea* is common. Sykes (1975b) records the presence of a rich ammonite fauna typical of the *vertebrale* Subzone, which includes *Cardioceras* (*Subvertebriceras*) *densiplicatum, C.* (*Subv.*) *sowerbyi, C.* (*Scoticardioceras*) *excavatum and C.* (*Plasmatoceras*) *tenuistriatum.* Faunal diversity and content decreases upward.

Sykes (1975b) notes that the less diverse fauna at the top of the sequence is dominated by the bivalve *Chlamys* (*Radulopecten*) *fibrosa.*

Sedimentologically the sandstones of the Ardassie Limestone Member resemble the Fascally Sandstone Member with their characteristic mud-filled burrows and occasional traces of wave-generated structures. Because of the tight cementation in the 'limestones' it is impossible to measure any grain-size variations, but they are finer grained than the sandstones and may represent the tops of a series of fining-upwards units that occur throughout the Ardassie Limestone Member. The resumption of fine-grained sedimentation may be a response to a deepening of the basin and/or restriction of sand supply.

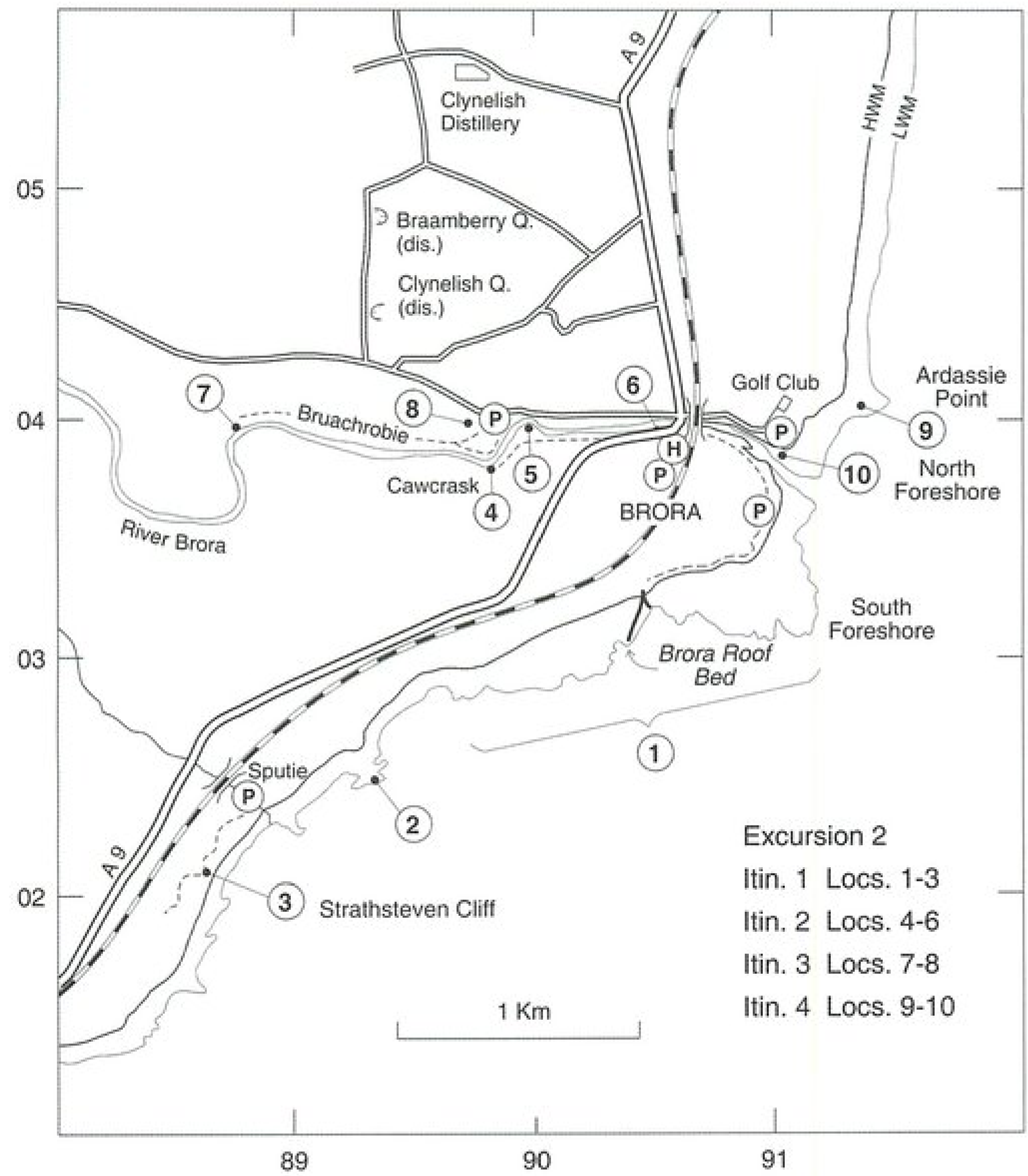
Deposition of the Ardassie Limestone Member is interpreted to have taken place on a marine shelf which was undergoing a period of regional transgression. Sandstones are thought to have been deposited either during storm periods or, during spring tides, winnowed by waves and finally colonised by organisms.

### Locality 10. Faulted sandstones [NC 911 038]

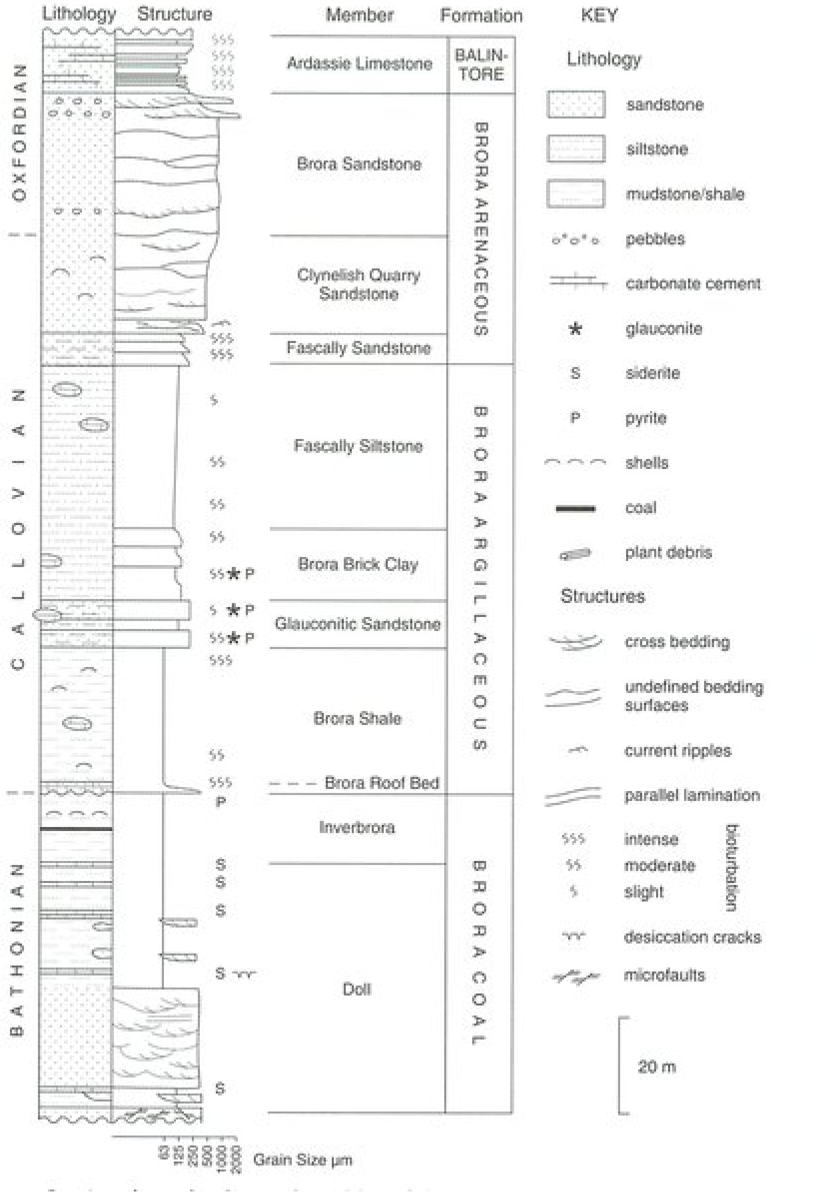
From locality 9 return southward toward the river estuary (Figure 2.13). At low tide exposures of sandstones of the Brora Arenaceous Formation can be examined on the foreshore. The outcrops are resistant due to quartz cementation and the presence of cemented, slickensided fractures. These features are evidence of a zone of faulting oriented between SE–NW and E–W.

The fault zone follows the line of the river and can be traced along the north riverbank and through the dilapidated picnic park in front of the Royal Marine Hotel. Quartz cementation associated with the fault zone is also present on the south side of the river mouth.

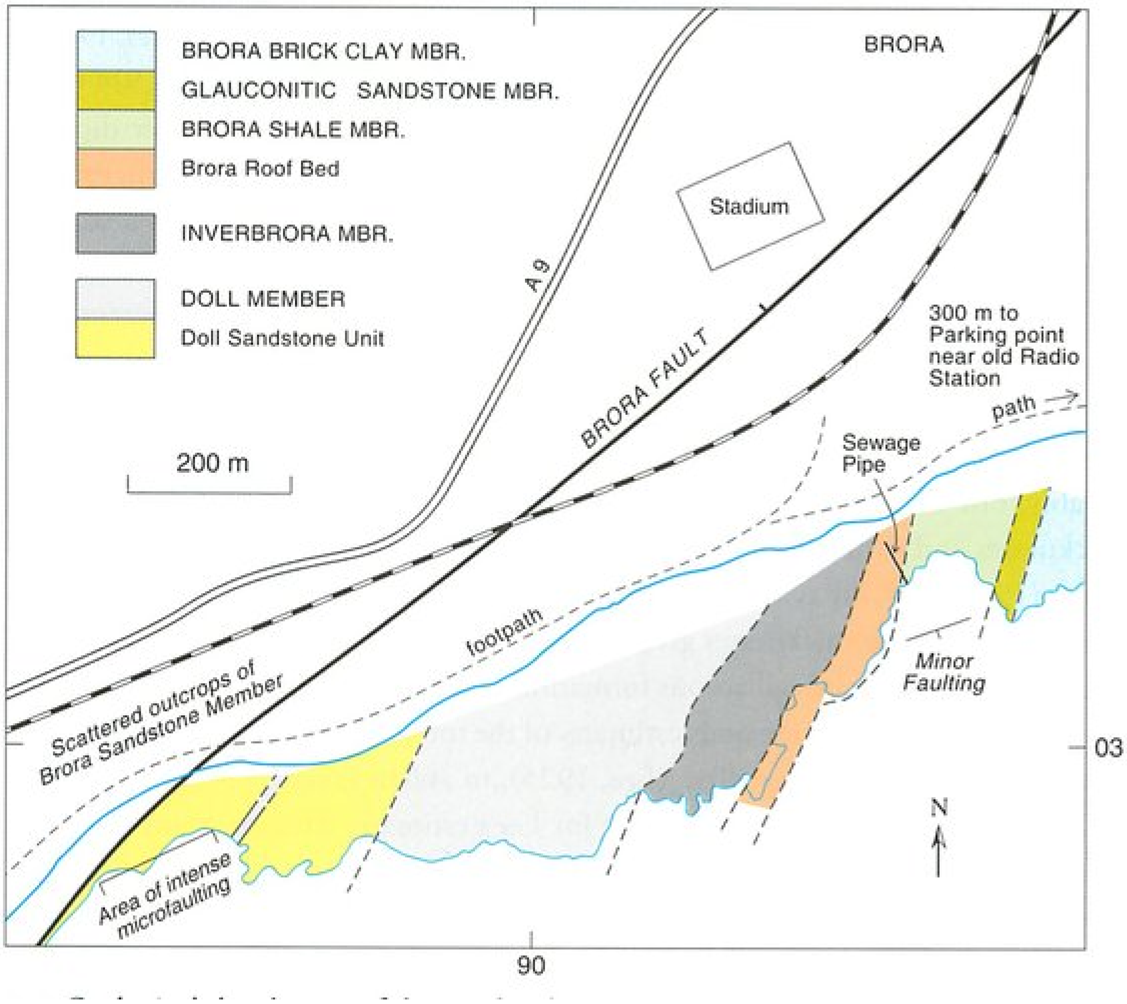
**References**




*(Figure 2.1) General locality map of the Brora area.*

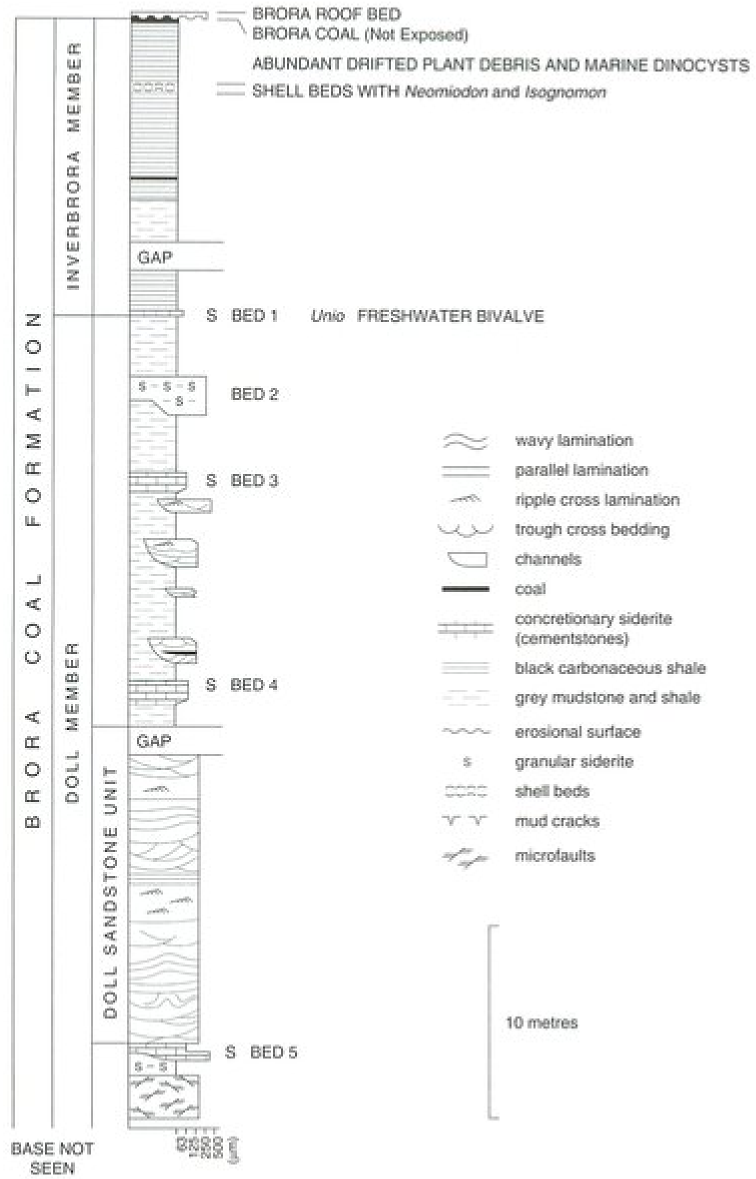



*(Figure 2.2) Stratigraphy and sedimentological log of the Bathonian to Oxfordian section at Brora.*

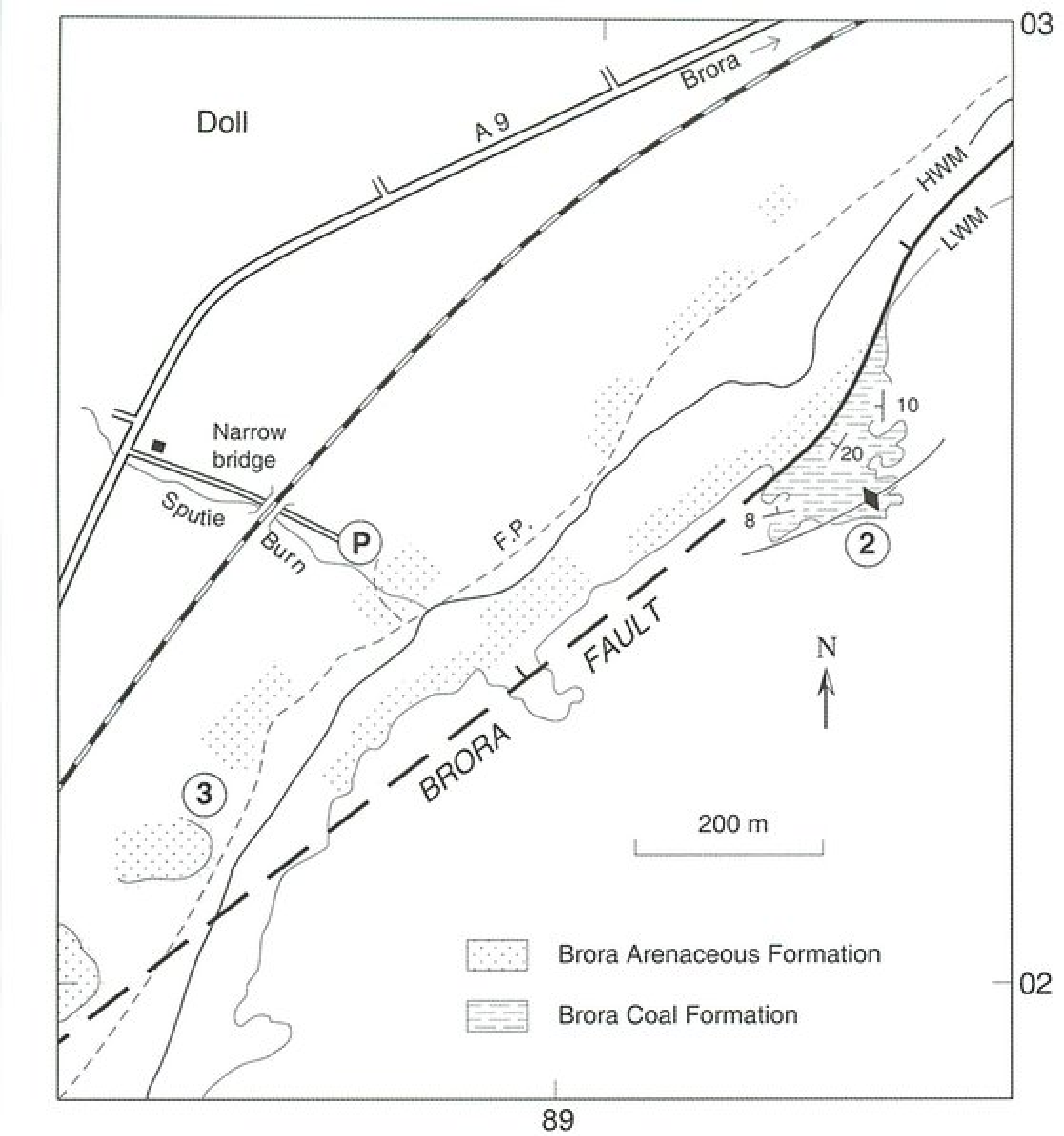



(Figure 2.3) Geological sketch map of the shore at locality 1

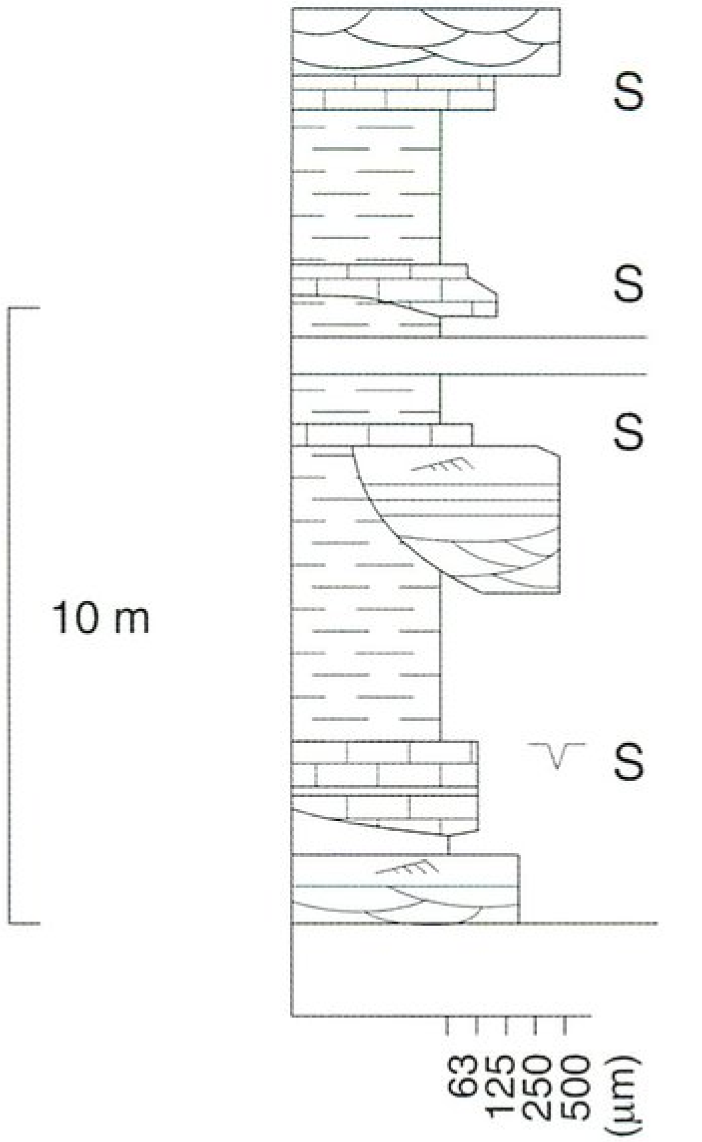

(Figure 2.4) Shell bed with Neomiodon and Isognomon near the top of the Inverbrora Member. Lens cap 52mm.



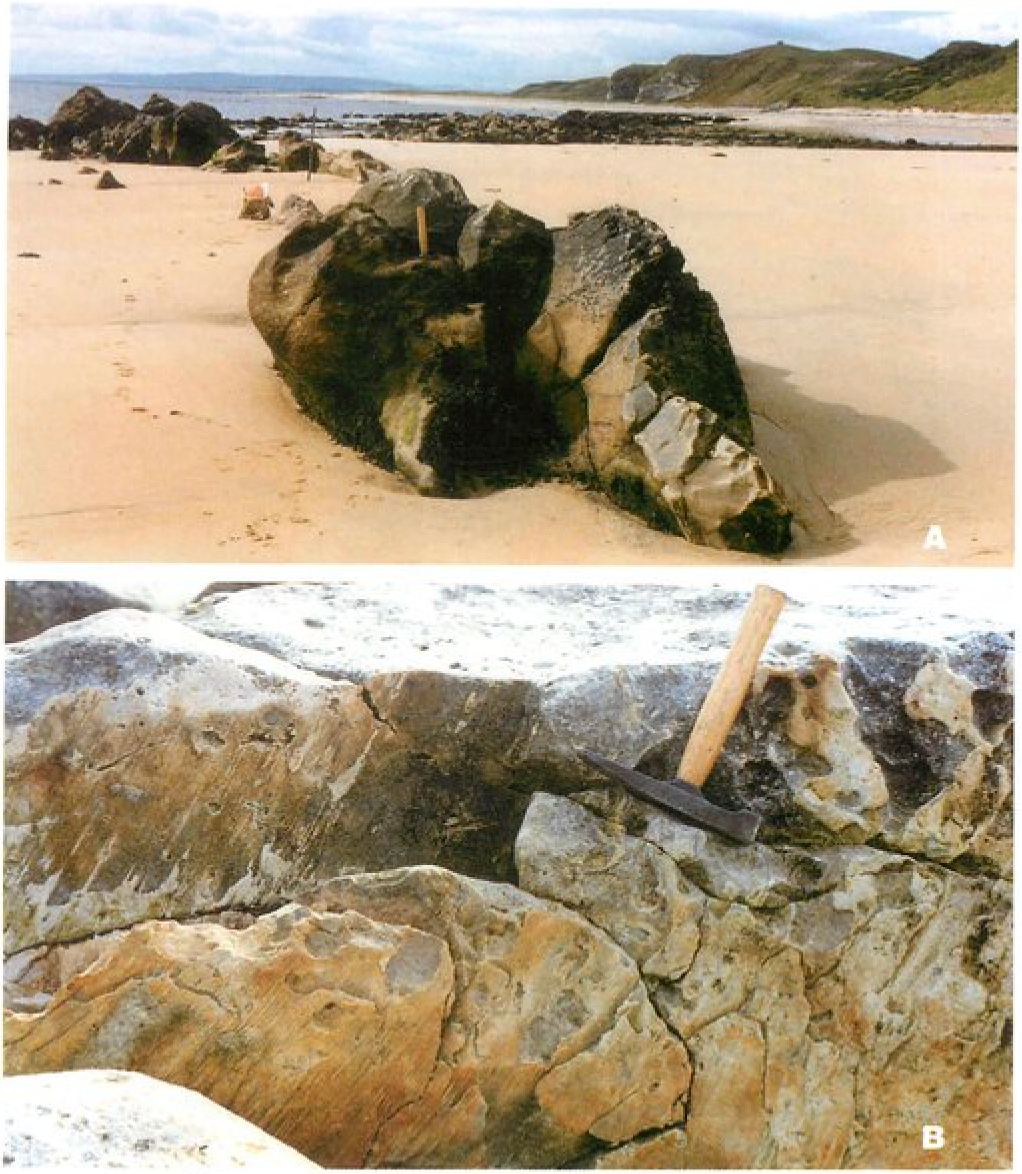

*(Figure 2.5) Sedimentary log of the Brora Coal Formation at locality 1.*




*(Figure 2.6) Sketch-map of the shoreline geology at localities 2 and 3.*

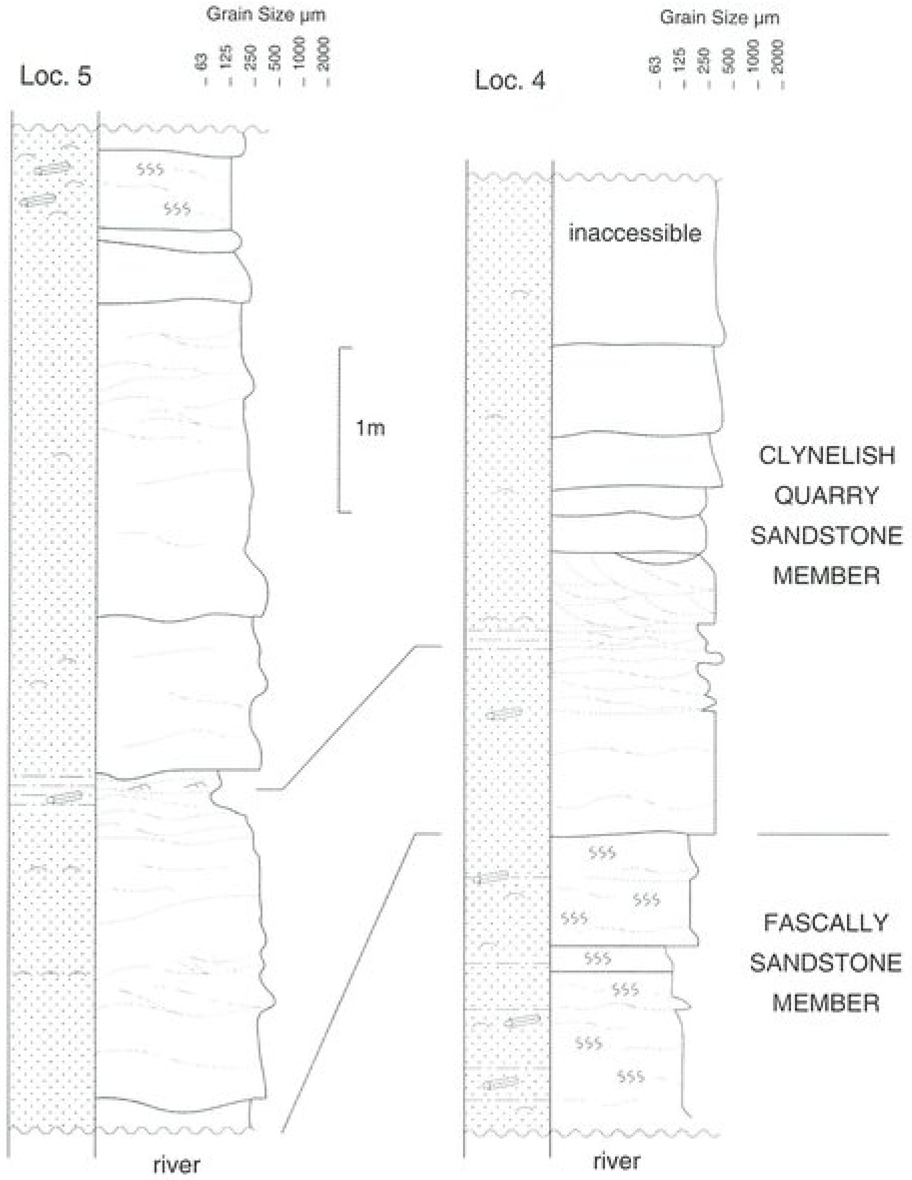



*(Figure 2.7) Log of the Doll Member of the Brora Coal Formation at locality 2 (key as for (Figure 2.5)).*

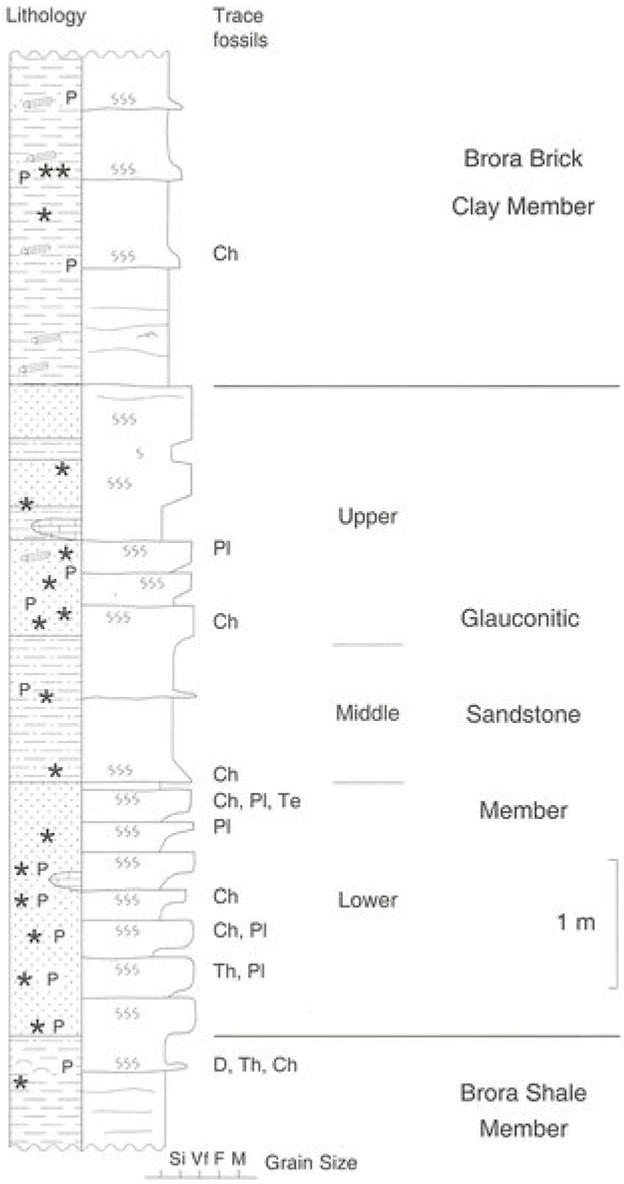


(Figure 2.8) Exposure of the Brora Fault along the foreshore on the NW edge of locality 2. A, the fault is defined by a zone of increased cementation, view of outcrops of quartz-cemented and veined fault rock, and B, slickensided surfaces on landward face of outcrop at top of the beach.

*(Figure 2.9) The Brora Arenaceous Formation at Strathsteven Cliff. Large-scale cross-bedding dipping seawards is seen in what is likely to be part of the Clynelish Quarry Sandstone Member.*

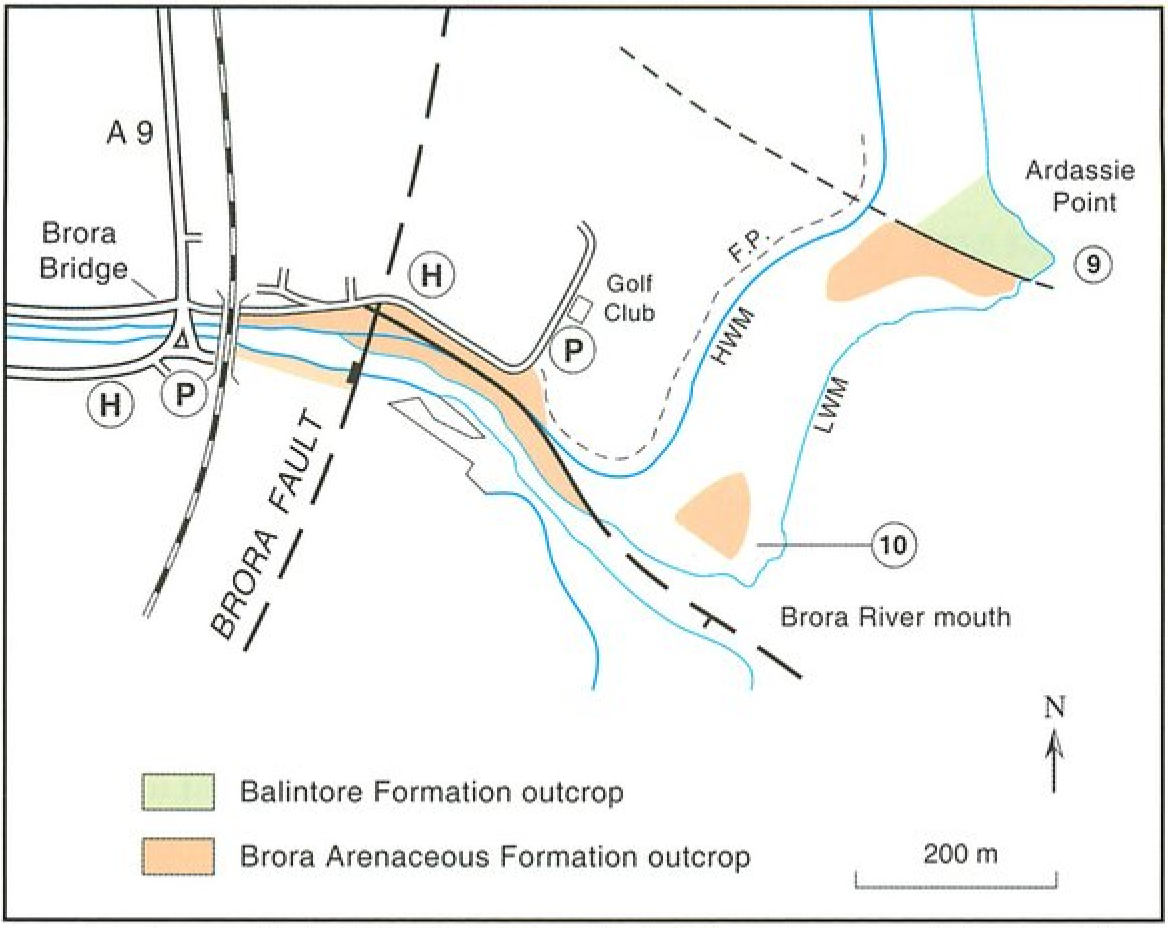



(Figure 2.10) Sedimentary logs of the Clynelish Quarry Sandstone Member and Fascally Sandstone Member at localities 4 and 5. (Key as for (Figure 2.2).)




*(Figure 2.11) Sedimentary log of the Brora Argillaceous Formation at locality 7. Key as for (Figure 2.2). P1, Planolites; Ch, Chondrites; Te, Teichichnus; Th, Thalassinoides; D, Diplocraterion.*


(Figure 2.12) Belemnites (Cylindroteuthis) that are common in the Glauconitic Sandstone Member and adjacent strata.




(Figure 2.13) Locality map for localities 9 and 10, Ardlassie Point and estuary of the Brora River