British Middle Jurassic Stratigraphy

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Chapter 6

The Middle Jurassic stratigraphy of Scotland

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INTRODUCTION

B.M. Cox

Outcrops of Middle Jurassic rocks in Scotland are restricted to the north-east coast (former counties of Sutherland and Ross and Cromarty) and mainly coastal areas of the Inner Hebridean isles off the north-west mainland (notably Skye, Raasay, Eigg and Muck) (Figure 6.1). Both areas have a long history of investigation. Anderson and Dunham (1966) noted references to the Jurassic rocks of Skye dating back to the 1770s but the first major contributions date from the early part of the 19th century when Macculloch (1819) and Murchison (1829a,b), and later Forbes (1851), produced pioneer geological accounts. Hugh Miller (Cromarty stonemason,

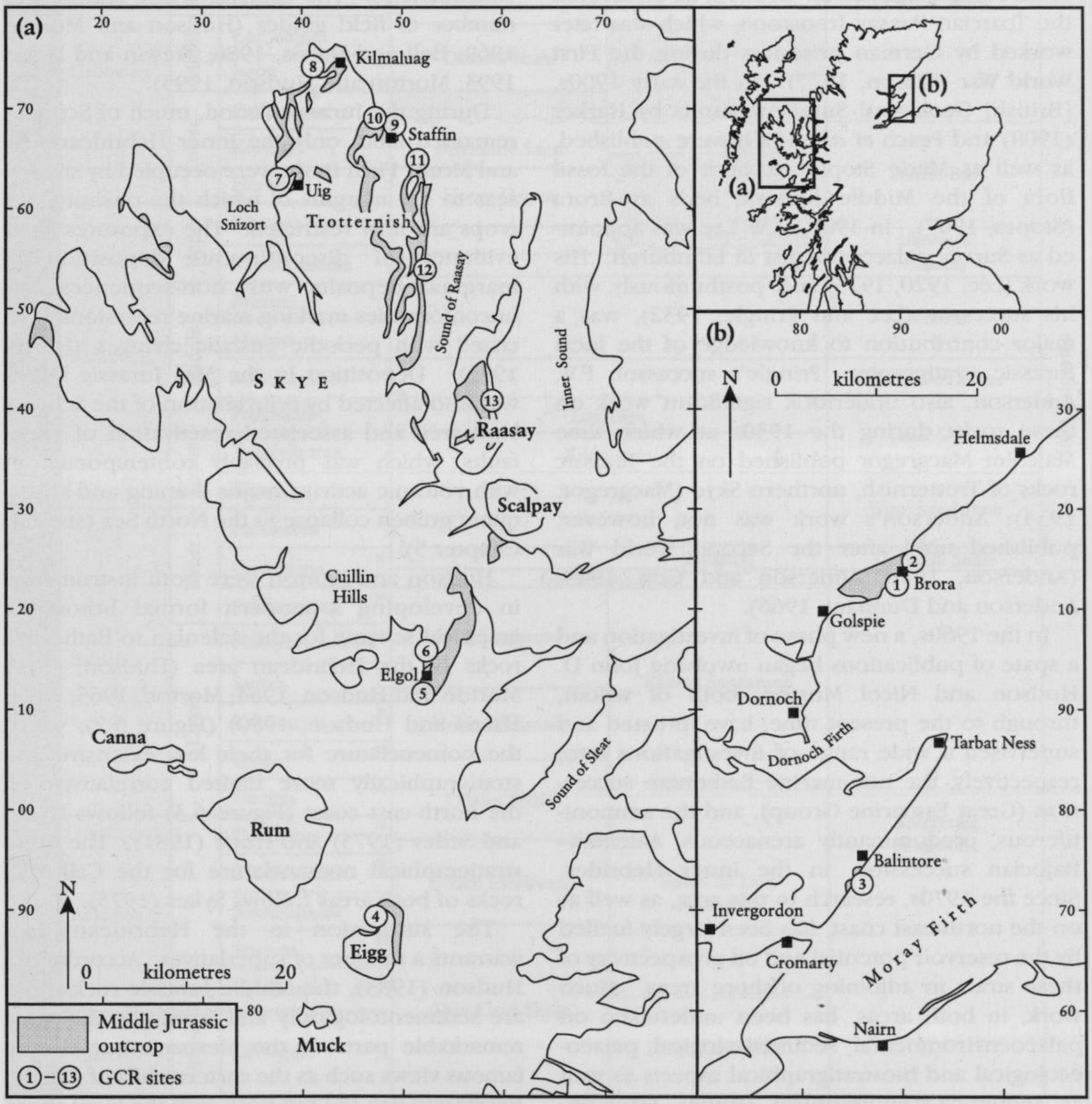

Figure 6.1 Geological sketch maps showing the location of the GCR sites described in Chapter 6. (1) Brora (Bathonian); (2) Brora (Callovian); (3) Cadh'-an-Righ; (4) Isle of Eigg; (5) Elgol–Glen Scaladal; (6) North Elgol Coast; (7) Dun Skudiburgh; (8) Duntulm (Cairidh Ghlumaig and Lon Ostatoin); (9) Staffin Bay; (10) Staffin; (11) Valtos; (12) Bearreraig Bay; (13) Beinn na Leac.

geologist and popular writer) visited the Hebridean outcrops in 1844 and 1845 (Miller, 1858) but the first major synthesis of the succession in both areas was produced by John Wesley Judd (1873, 1874, 1878) in a series of papers on the Mesozoic rocks of Scotland. Bryce (1873) also made a contribution at this time. Mapping and fossil collecting by the [British] Geological Survey commenced in the 1890s when H.B. Woodward began to map the Jurassic rocks of Skye and Raasay. In 1893, he discovered the Toarcian Raasay Ironstone, which was later worked by German prisoners during the First World War (Wilson, 1977). In the early 1900s, [British] Geological Survey memoirs by Harker (1908) and Peach *et al.* (1910) were published, as well as Marie Stopes' account of the fossil flora of the Middle Jurassic beds at Brora (Stopes, 1907). In 1907, G.W. Lee was appointed as Survey palaeontologist in Edinburgh. His work (Lee, 1920, 1925) and, posthumously, with his successor (Lee and Pringle, 1932), was a major contribution to knowledge of the local Jurassic stratigraphy. Pringle's successor, F.W. Anderson, also undertook significant work on these rocks during the 1930s at which time Malcolm Macgregor published on the Jurassic rocks of Trotternish, northern Skye (Macgregor, 1934); Anderson's work was not, however, published until after the Second World War (Anderson, 1948; Anderson and Cox, 1948; Anderson and Dunham, 1966).

In the 1960s, a new phase of investigation and a spate of publications began involving John D. Hudson and Nicol Morton, both of whom, through to the present time, have initiated and supervised a wide range of investigations into, respectively, the non-marine Bathonian succession (Great Estuarine Group), and the ammonitiferous, predominantly arenaceous, Aalenian–Bajocian succession, in the Inner Hebrides. Since the 1970s, research in this area, as well as on the north-east coast, has been largely fuelled by the reservoir potential and oil prospectivity of these strata in adjoining offshore areas. Much work, in both areas, has been undertaken on palaeoenvironmental, sedimentological, palaeoecological and biostratigraphical aspects as well as sequence-stratigraphical studies (Morton, 1971, 1972, 1973, 1975, 1976, 1983a,b, 1984, 1988, 1989, 1990, 1991, 1994; Savage, 1972; Waldman and Savage, 1972; Neves and Selley, 1975; Sykes, 1975; Hudson and Harris, 1979; Harris and Hudson, 1980; Hudson, 1980, 1983; Hurst, 1981, 1982, 1985; Bradshaw and Fenton, 1982; Andrews and Hudson, 1984; Andrews, 1985, 1986, 1987; Harris, 1989, 1992; MacLennan and Trewin, 1989; Morton and Dietl, 1989; Andrews and Walton, 1990; Wilkinson and Dampier, 1990; Gregory, 1990, 1991; Chen and Hudson, 1991; Riding *et al.*, 1991; Wilkinson, 1991, 1992; Riding, 1992; Hudson *et al.*, 1995). Much unpublished work has also been undertaken by and for commercial oil companies and consultancies. The exposures also feature in a number of field guides (Hudson and Morton, 1969; Bell and Harris, 1986; Trewin and Hurst, 1993; Morton and Hudson, 1995).

During the Jurassic Period, much of Scotland remained land; only the Inner Hebridean area and Moray Firth Basin were occupied by shallow seas to the margins of which the onshore outcrops are now restricted. The exposures show evidence of discontinuous deposition of marginal deposits with non-sequences and unconformities marking marine recessions associated with periodic eustatic changes (Harris, 1991). Deposition in the Mid Jurassic Epoch was also affected by rejuvenation of the Scottish land area and associated reactivation of major faults, which was probably contemporaneous with volcanic activity, major doming and subsequent graben collapse in the North Sea (see also Chapter 5).

Hudson and Morton were both instrumental in developing a modern formal lithostratigraphical scheme for the Aalenian to Bathonian rocks of the Hebridean area (Hudson, 1962; Morton and Hudson, 1964; Morton, 1965, 1976; Harris and Hudson, 1980) (Figure 6.2), whilst the nomenclature for their less extensive and stratigraphically more limited correlatives on the north-east coast (Figure 6.3) follows Neves and Selley (1975) and Hurst (1981). The lithostratigraphical nomenclature for the Callovian rocks of both areas follows Sykes (1975).

The succession in the Hebridean area warrants a number of superlatives. According to Hudson (1983), the Middle Jurassic rocks here are sedimentologically and scenically the most remarkable parts of the Mesozoic succession; famous views such as the eastern cliffs of Raasay; Bearreraig Bay, the Kilt Rock, and the Elgol shore with its backdrop of the Cuillins, on Skye; and the Bay of Laig on Eigg, all feature rocks of this age. The Bearreraig Sandstone Formation includes the thickest sandstone in the British Jurassic succession, and the Great Estuarine

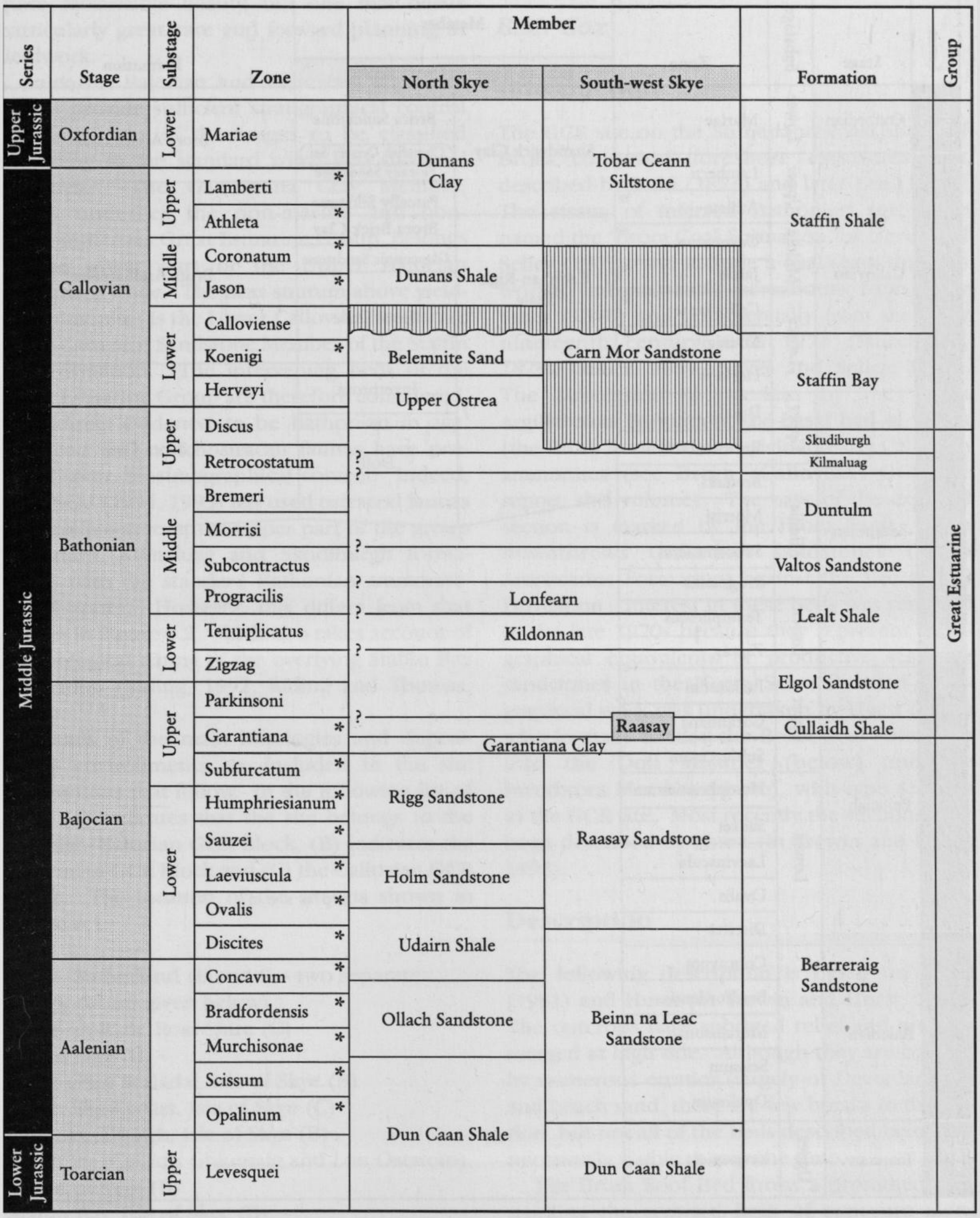

Figure 6.2 Lithostratigraphy of the Middle Jurassic rocks of the Isle of Skye and the Isle of Raasay (Inner Hebrides). Not to scale. (* = presence of zone indicated by ammonites.)

Series	Stage	Substage	Zone	*	Member: Cadh'-an-Righ	Member: Brora	Formation
Upper Jurassic	Oxfordian	Lower	Mariae		Shandwick Clay	Brora Sandstone	Brora Arenaceous
						Clynelish Quarry Sst.	
Middle Jurassic	Callovian	Upper	Lamberti	*		Fascally Sandstone	
			Athleta	*		Fascally Siltstone	Brora Argillaceous
		Middle	Coronatum	*	Cadh'-an-Righ Shale	Brora Brick Clay	
						Glauconitic Sandstone	
			Jason	*		Brora Shale	
		Lower	Calloviense	*			
			Koenigi	*			
			Herveyi			Inverbrora	Brora Coal
	Bathonian	Upper	Discus		?		
			Retrocostatum			Doll	
		Middle	Bremeri		?		
			Morrisi				
			Subcontractus				
			Progracilis				
		Lower	Tenuiplicatus				
			Zigzag				
	Bajocian	Upper	Parkinsoni				
			Garantiana				
			Subfurcatum				
		Lower	Humphriesianum			not	
			Sauzei				
			Laeviuscula				
			Ovalis			exposed	
			Discites				
	Aalenian		Concavum				
			Bradfordensis				
			Murchisonae				
			Scissum				
			Opalinum				
Lower Jurassic	Toarcian	Upper	Levesquei				

Figure 6.3 Lithostratigraphy of the Middle Jurassic rocks of north-east Scotland. Not to scale. (* = presence of zone indicated by ammonites.)

Group is the thickest and most varied development of its paralic facies. The area is one of quite remarkable beauty, but one that needs particularly great care and forward planning in fieldwork.

Aalenian, Bajocian and Callovian ammonite faunas provide sufficient stratigraphical control to allow rocks of these ages to be classified according to the standard zonal and subzonal schemes. The Garantiana Clay Member, which underlies the non-marine and non-ammonitiferous Great Estuarine Group, belongs to the lower part of the Upper Bajocian Garantiana Zone. The next stratum above yielding ammonites is the Lower Callovian Belemnite Sand–Carn Mor Sandstone Member of the Staffin Bay Formation. The intervening beds of the Great Estuarine Group are therefore considered, on indirect evidence, to be Bathonian in age. Ostracod and conchostracan faunas have provided some biostratigraphical control. Indeed, Wakefield (1994, 1995) has used ostracod faunas to correlate at least the upper part of the group (Duntulm, Kilmaluag and Skudiburgh formations) with the standard Bathonian ammonite-based zones. However, this differs from that shown in Figure 6.2, which also takes account of palynological dating of the overlying Staffin Bay Formation (Riding, 1992; Riding and Thomas, 1997).

Details of the main lithologies and depositional environments are included in the site descriptions that follow. In the following list of sites, (A) indicates that the site belongs to the Aalenian–Bajocian GCR Block, (B) indicates the Bathonian GCR Block and (C) the Callovian GCR Block. The location of the sites is shown in Figure 6.1.

Brora, Sutherland (B and C – two separate reports are given below)
Cadh'-an-Righ, Ross-Shire (C)
Isle of Eigg (B)
Elgol–Glen Scaladal, Isle of Skye (B)
North Elgol coast, Isle of Skye (C)
Dun Skudiburgh, Isle of Skye (B)
Duntulm (Cairidh Ghlumaig and Lon Ostatoin), Isle of Skye (B)
Staffin Bay, Isle of Skye (B)
Staffin, Isle of Skye (C)
Valtos, Isle of Skye (B)
Bearreraig Bay, Isle of Skye (A)
Beinn na Leac, Isle of Raasay (A)

BRORA (BATHONIAN), SUTHERLAND (NC 896 029–NC 904 033)

B.M. Cox

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

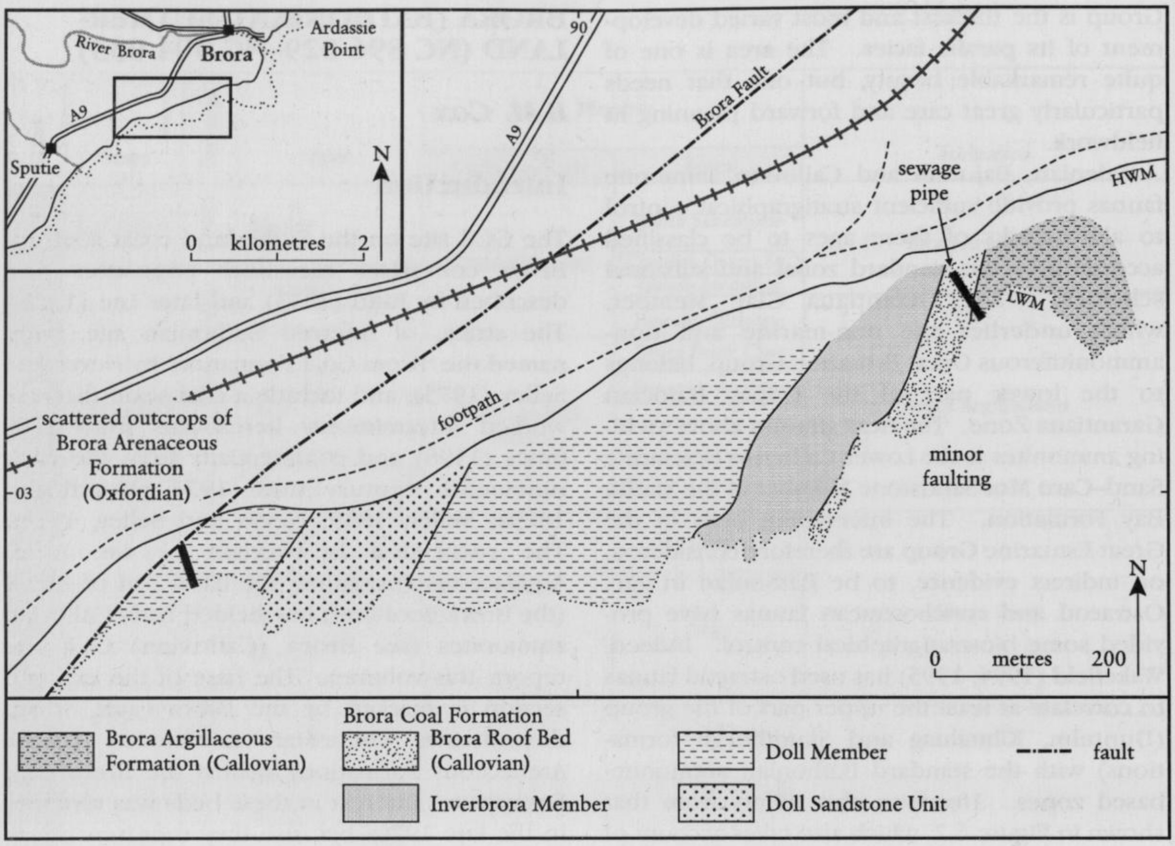

Figure 6.4 Locality and geological sketch map for the Brora (Bathonian) GCR site. (After Hurst (in Trewin and Hurst, 1993, figs 1,3).)

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

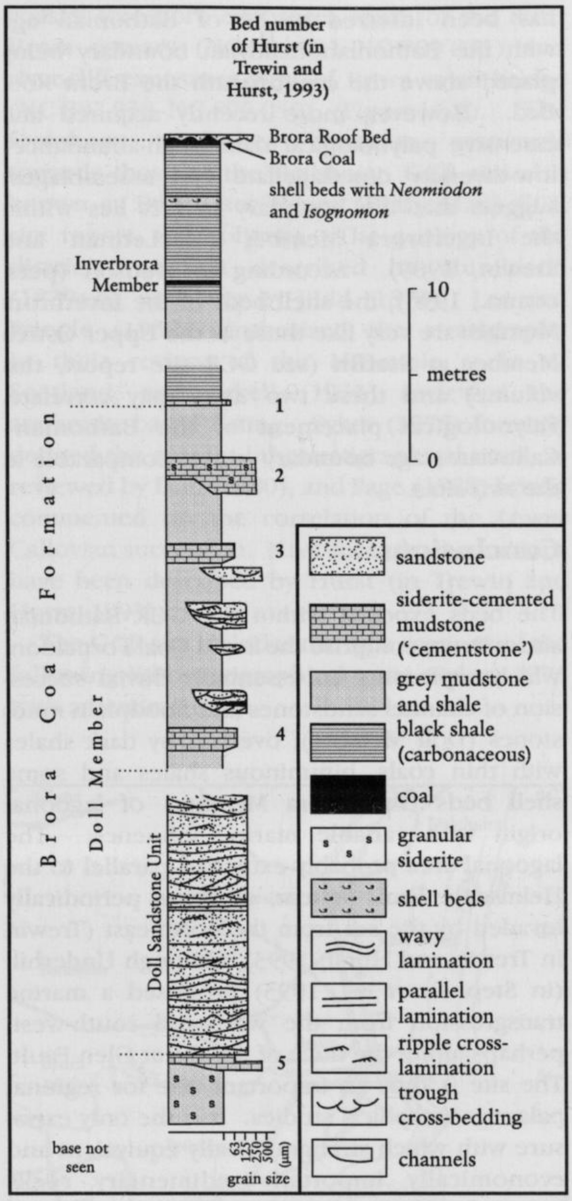

Figure 6.5 Graphic section of the Brora Coal Formation at the Brora (Bathonian) GCR site. (After Hurst (in Trewin and Hurst, 1993, fig. 4).)

and only 0.1–0.3 m thick. A major sandstone unit, called the 'Doll 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.

BRORA (CALLOVIAN), SUTHERLAND (NC 904 031–NC 909 031, NC 887 038–NC 899 040)

K.N. Page

Introduction

The exposures of Callovian rocks at Brora show an unusually thick succession dominated by shales and sandstones. The GCR site includes coastal foreshore exposures south of the River Brora estuary (NC 904 031–NC 909 031) and river-cliff exposures west of Brora town bridge (NC 887 038–NC 899 040) (Figure 6.6). The foreshore exposures continue eastwards towards those of the Bathonian GCR site also known as Brora (see **Brora (Bathonian)** GCR site report, this volume). The geology of the district was first described by Murchison (1829a,b), and later by Judd (1873). Lee and Pringle (1932) synthesized the stratigraphy in their review of the Mesozoic rocks of Scotland, and Arkell (1933) reviewed the ammonite-based dating. Sykes (1975) formally defined the current lithostratigraphical units, as reviewed by Duff (1980), and Page (1988) briefly commented on the correlation of the Lower Callovian succession. Most recently, the sections have been described by Hurst (in Trewin and Hurst, 1993).

The GCR site includes the type sections of the following lithostratigraphical units (Sykes, 1975 with amendments):

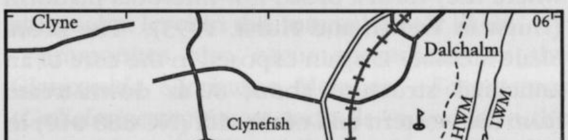

Figure 6.6 Locality map for the Brora (Callovian) GCR site.

- Clynelish Quarry Sandstone Member: south bank of River Brora; Locality 5 (NC 899 040) of Hurst (in Trewin and Hurst, 1993)
- Fascally Sandstone Member: north bank of River Brora; opposite Locality 5 (NC 899 040) of Hurst (in Trewin and Hurst, 1993)
- Fascally Siltstone Member: foreshore (NC 909 031) south of River Brora estuary; complete section not always visible, depending on level of sand
- Brora Brick Clay Member: for base, north bank of River Brora, see Locality 7 (NC 888 040) of Hurst (in Trewin and Hurst, 1993); for remainder, foreshore (NC 905 032) south of River Brora estuary
- Glauconitic Sandstone Member: cliffs in north bank of River Brora (NC 888 040) (see Locality 7 of Hurst (in Trewin and Hurst, 1993))
- Brora Shale Member: foreshore (NC 904 031) south of the River Brora estuary; only the lowest 15.6 m can be seen on the beach, and
- The type areas of the Brora Argillaceous and Brora Arenaceous formations.

The exposures also provide valuable reference sections for a number of Callovian chronostratigraphical units that make them of international interest, although they may be superseded by other European sites at which the subzonal boundaries may be formally defined in the future.

Description

The following composite section of the Callovian succession (comprising the Brora Argillaceous Formation and lower part of the Brora Arenaceous Formation) is based mainly on Sykes (1975) and Hurst (in Trewin and Hurst, 1993).

Thickness (m)

Brora Arenaceous Formation
Clynelish Quarry Sandstone Member
Friable, pale-yellowish, fine-grained, well-sorted, highly quartzöse sand with clay-rich laminae often with disseminated plant remains; variably bioturbated; elsewhere locally, several horizons of nodular, silicified sandstone; sedimentary structures apparently lacking except for some cross-bedding; fauna including abundant lucinoid bivalves, large *Chlamys*, and ammonites (*Euaspidoceras*, *Hecticoceras* and *Quenstedtoceras*) *c.* 20

	Thickness (m)
Fascally Sandstone Member	
Thickly bedded, grey-green, intensely bioturbated, muddy, fine- to very fine-grained, sandstone with sandy silts at top; fauna including bivalves (lucinoids with less abundant *Barbatia*, *Chlamys* and *Meleagrinella*); belemnites; common ammonites (*Kosmoceras* and *Quenstedtoceras*); *Thalassinoides* and traces of wave-ripple lamination	6.5
Brora Argillaceous Formation	
Fascally Siltstone Member	
Predominantly coarse siltstone passing up into fine sandstone; calcareous nodules at some levels; poorly fossiliferous with bivalve fauna showing gradual change from lucinoid- and/or *Cucullaea* (*Idonearca*)-dominated assemblages in lower finer-grained beds, to *Chlamys*-dominated assemblages in sandier beds near top; ammonites including *Kosmoceras*, *Longaeviceras* and *Peltomorphites*	33.5
Brora Brick Clay Member	
Bituminous, sandy silts and laminated muddy siltstones grading up into pale greenish-grey clay, in five rhythms; single row of limestone doggers near middle; fauna increasing in numbers and diversity upwards with bivalve assemblages dominated firstly by lucinoids and/or *Cucullaea* (*Idonearca*), then *Palaeonucula* and finally *Entolium*; *Bositra buchii* (Roemer) crowded in some clay horizons; *Solemya woodwardiana* Leckenby also present; belemnites and ammonites including *Kosmoceras* and *Binatisphinctes*; base marked by abrupt upward reduction in grain size	15
Glauconitic Sandstone Member	
Muddy, glauconitic, bioturbated silty sandstone (4.15 m) with thin, shale interbeds and horizons of phosphatic nodules associated with belemnite (*Cylindroteuthis*) accumulations, overlain by grey siltstone (2 m) and then slightly glauconitic, silty sandstone (3.9 m) showing five coarsening-upwards cycles and with a prominent bed of limestone doggers near base and horizons of phosphatic nodules (some containing *Rhaxella* sponge spicules); restricted fauna dominated by *Cylindroteuthis* and *Meleagrinella braamburiensis* (Phillips); *Lingula craniae* Davidson locally abundant; plant fragments and sporadic ammonites (*Kosmoceras*); trace fossils including *Thalassinoides*, *Diplocraterion* and *Chondrites* identifiable at sand-shale boundaries	10.1
Brora Shale Member	
Silty sands (2.3 m) grading rapidly upwards to very dark, organic-rich shales (*c.* 25 m) with some thin (0.05 m) seams of glauconitic sand and shell beds with bivalves (*Protocardia*? and *Trautscholdia* in lower part, *Meleagrinella* above); and sporadic ammonites including *Kepplerites* and *Sigaloceras*	*c.* 27.5
Brora Roof Bed: Intensely bioturbated, medium-grained sandstone with a few quartzite pebbles; top marked by thin, glauconitic sand with *Cylindroteuthis*, and top surface with preferentially orientated gastropods (*Pietteia*); relatively well-preserved ammonite fauna including *Kepplerites* and *Proplanulites*; otherwise fauna dominated by the bivalve *Corbula obscura* (J. Sowerby); *Myophorella*, *Gervillella*, *Pleuromya* (in vertical burrowing position) and reworked fragments of coal from underlying beds also present	up to 2.3
Brora Coal Formation	

The most easily identified point in the succession is the Brora Roof Bed, at the base of the Brora Shale Member, which forms a prominent reef marking the seaward limit of exposure along almost 1 km of the foreshore (NC 905 032–NC 902 029). About 100 m east of the sewage pipe that crosses the beach (NC 905 032), the first outcrops of the Glauconitic Sandstone Member are seen low on the beach. Parts of the Brora Brick Clay and Fascally Siltstone members are seen farther east where they form a broad low intertidal platform (Hurst in Trewin and Hurst, 1993). The Brora Shale Member is again exposed in the core of an anticlinal structure about 80 m downstream from the western end of the cliff (NC 888 040) in the north bank of the River Brora. The eastern limb of this structure then takes exposures of the overlying Glauconitic Sandstone and Brora Brick Clay members down to river level farther downstream; only the lowest third of the latter member crops out along the river bank. The Fascally Sandstone and Clynelish Quarry Sandstone members are well exposed in the river cliffs (NC 899 039–NC 899 040) nearer to Brora town centre. The sharp boundary between the two members is well exposed in the south bank at the southern end of the section but, normally, the best exposures of the Fascally Sandstone Member are seen in the north bank at the northern end of the section where the top of the Fascally Siltstone Member may also be seen.

Interpretation

The Brora Roof Bed yields a Lower Callovian ammonite fauna including the type specimen of the subzonal index taxon *Kepplerites* (*Gowericeras*) *gowerianus* (J. de C. Sowerby, 1827) (refigured by Tintant, 1963). The type specimen of the similar *K. childanum* S.S.

Buckman (1923a) although recorded from the 'Brora Roof Bed' is in a shaly matrix and may be from a higher horizon (Page, 1988). The Brora Roof Bed has also yielded the genera *Proplanulites* (Read and Phemister, 1925) and *Cadoceras* (Natural History Museum, London collections). As a whole, the fauna is consistent with the *gowerianus* Biohorizon of the Gowerianus Subzone (Koenigi Zone).

Ammonites occur sporadically in the overlying Brora Shale Member and include *Kepplerites* (*Gowericeras*) cf. *galilaeii* (Oppel) (Natural History Museum, London collections) indicative of the Galilaeii Subzone, Koenigi Zone, *Sigaloceras* ex gr. *calloviense* (J. Sowerby) (at *c*. 10.7 m above the base of the shale and indicative of the Calloviense Subzone, Calloviense Zone) and *Sigaloceras* ex gr. *enodatum* (Nikitin) (from borehole sections, and indicative of the Enodatum Subzone, Calloviense Zone) (Sykes, 1975; Page, 1988). Sykes' (1975) records of *Homeoplanulites* cf. *difficilis* S.S. Buckman and *Kosmoceras* sp. are problematic and do not, as originally suggested, necessarily prove, respectively, the Enodatum and Medea subzones, although a level in this interval is still likely.

Ammonites also occur sporadically in the Glauconitic Sandstone Member. *Kosmoceras* (*Gulielmiceras*) *jason* auctt. is recorded in the lowest part (Middle Callovian Jason Subzone and Zone), *K.* (*Zugokosmokeras*) *obductum* (S.S. Buckman) (macroconch and microconch) in the succeeding silts (Obductum Subzone, Coronatum Zone) and unspecified indications of the Grossouvrei Subzone (Coronatum Zone) are noted above (Sykes, 1975; Sykes in Duff, 1980).

The succession of age-diagnostic ammonites in the Brora Brick Clay Member includes, at the base, *Kosmoceras* (*Zugokosmokeras*) ex gr. *grossouvrei* R. Douvillé (including the microconch forms recorded under the names *gulielmi* (J. Sowerby), *castor* (Reinecke) and *pollux* (Reinecke)). These suggest the middle part of the Grossouvrei Subzone. Associated abundant macroconch and microconch *Binatisphinctes comptoni* (Pratt) at higher levels indicate the *comptoni* Biohorizon of the upper Grossouvrei Subzone. The lower part of the Upper Callovian Athleta Zone is indicated by *K.* (*Lobokosmokeras*) ex gr. *phaeinum* S.S. Buckman at *c*. 10.6 m above the base. Callomon and Sykes (in Duff, 1980) proposed the foreshore exposures south of Brora as an international reference section for the base of the Phaeinum Subzone, retaining the now lost Calvert Brickpit in Buckinghamshire (Callomon, 1968) as its 'type locality'.

Although ammonite faunas are poor in the Fascally Siltstone Member, the Phaeinum Subzone (Athleta Zone) is indicated near the base by *K.* (*L.*) ex gr. *phaeinum* and *Longaeviceras* cf. *placenta* (Leckenby). Higher levels include *K.* (*L.*) *proniae* (Teisseyre) at 10 m above the base (Proniae Subzone, Athleta Zone), *K.* (*K.*) ex gr. *kuklikum* (= *K. spinosum* auctt., part) at 29 m above the base (Spinosum Subzone, Athleta Zone) and *Quenstedtoceras henrici* R. Douvillé and *Peltomorphites* in the top 5 m (Henrici Subzone, Lamberti Zone) (Sykes, 1975). Callomon and Sykes (in Duff, 1980) proposed reference sections for the Proniae and Spinosum subzones on the foreshore south of Brora, and for the Henrici Subzone in river sections west of Brora. As with the Phaeinum Subzone, the 'type localities' of these three subzones (Calvert, Buckinghamshire for the Proniae Subzone and Woodham, Buckinghamshire for the Spinosum and Henrici subzones; Arkell, 1939b; Callomon, 1968) are now lost.

Ammonites are common in the Fascally Sandstone Member and include *Quenstedtoceras* ex gr. *lamberti* (J. Sowerby) and *Kosmoceras* ex gr. *compressum* (Quenstedt) and ex gr. *spinosum* (J. de C. Sowerby) indicating the Upper Callovian Lamberti Zone and Subzone. Callomon and Sykes (in Duff, 1980) proposed the river sections in the upper part of the member as reference sections for this subzone, the original type locality of which, at Woodham Brickpit, Buckinghamshire, is now lost, as already stated. Ammonites in the Clynelish Quarry Sandstone Member also indicate the Lamberti Zone and Subzone. They include common *Euaspidoceras hirsutum* (Bayle) (including the type specimen of *E. clynelishense* Arkell) with *Quenstedtoceras* ex gr. *lamberti* (including *Q. sutherlandiae* (J. de C. Sowerby)) and *Hecticoceras* sp. No ammonites were recorded by Sykes (1975) from the Brora Sandstone Member, which is assumed to be all, or mainly, of Late Jurassic (Early Oxfordian) age.

The Callovian succession at Brora has particular significance for sedimentological and palaeogeographical studies of the region. Callovian sedimentation began with a significant marine transgression represented by the sandstone of the Brora Roof Bed; this overlies non-marine coal and was deposited in a shallow-marine setting. The abundance of both land-derived material (plant fragments and spores) and marine microplankton (dinoflagellate cysts) in the overlying Brora Shale Member indicates a nearshore open marine depositional environment (MacLennan and Trewin, 1989). According to Hurst (in Trewin and Hurst, 1993), the Glauconitic Sandstone Member represents a period of slow deposition. The remainder of the Brora Argillaceous Formation and all of the Brora Arenaceous Formation forms a marine, coarsening-upwards sequence commencing with offshore marine clays of the Brora Brick Clay Member and culminating, in the Oxfordian Stage, in cross-bedded, porous, pebbly sandstones representing a coastal marine bar system. The rhythms in the Brora Brick Clay Member are interpreted as the result of deposition from small gravity flows (Hurst in Trewin and Hurst, 1993).

The Callovian succession is one of the thickest (*c.* 115 m) in Britain and, although lithostratigraphically distinct, includes a bituminous-shale episode in upper Middle Callovian, and lower Upper Callovian times (Brora Brick Clay Member), just as in the upper part of the Peterborough Member (Oxford Clay Formation) in southern and central England (see **Peterborough Brickpits** GCR site report, this volume). For discussion of the relationship of the Brora sections with those of the Balintore area, farther south, see **Cadh'-an-Righ** GCR site report (this volume).

Conclusions

The primary national significance of the Brora Callovian GCR site is that the exposures combine both lithostratigraphical type sections and chronostratigraphical reference sections. The coastal and river sections reveal the most complete and accessible sections in the Callovian rocks of the Moray Firth Basin. They represent the type areas of the Brora Argillaceous and the Brora Arenaceous formations and include the type sections of their component members. The fossils of these formations include many species of ammonite and bivalve, the type localities for some of which are here. It also includes reference sections for all of the Upper Callovian subzones (see Figure 1.3, Chapter 1). The diagnostic ammonite faunas, which have not been studied systematically, show a considerably lower diversity than those in southern England owing to a much-reduced Tethyan influence in these extremely northern Subboreal regions (cf. Page, 1996b). A corresponding relative increase in numbers of Arctic genera such as *Longaeviceras* may be expected but remains to be demonstrated. The site is an important one for palaeogeographical as well as stratigraphical studies (see **Cadh'-an-Righ** GCR site report, this volume).

CADH'-AN-RIGH, ROSS-SHIRE (NH 849 723–NH 853 733)

K.N. Page

Introduction

The sections at Cadh'-an-Righ represent a remarkably thinner and more muddy lateral equivalent of the classic Callovian succession at **Brora** (see **Brora (Callovian)** GCR site report, this volume, and Figure 6.7), *c.* 30 km to the north. Callovian rocks are exposed on the beach at Cadh'-an-Righ, 3.2 km south of Balintore, but they can be seen, dipping *c.* 70° seawards, only at low tides (Sykes, 1975). The GCR site extends for *c.* 1 km immediately south of Port an Righ. The sections were already known to Murchison (1829a) and were also mentioned by Judd (1873). Both Buckman (1924) and Lee (1925) described the succession in terms of the units recognized at Brora. Sykes (1975) formally defined the current lithostratigraphical units, as briefly reviewed by Duff (1980), and, more recently, the section was included in a palaeoenvironmental study by MacLennan and Trewin (1989). The site includes the type sections of the Cadh'-an-Righ Shale and Shandwick Clay members of the Brora Argillaceous Formation (NH 851 728 and NC 853 733 respectively).

Description

The following section of the Callovian succession is based mainly on Sykes (1975) with additional notes from MacLennan and Trewin (1989).

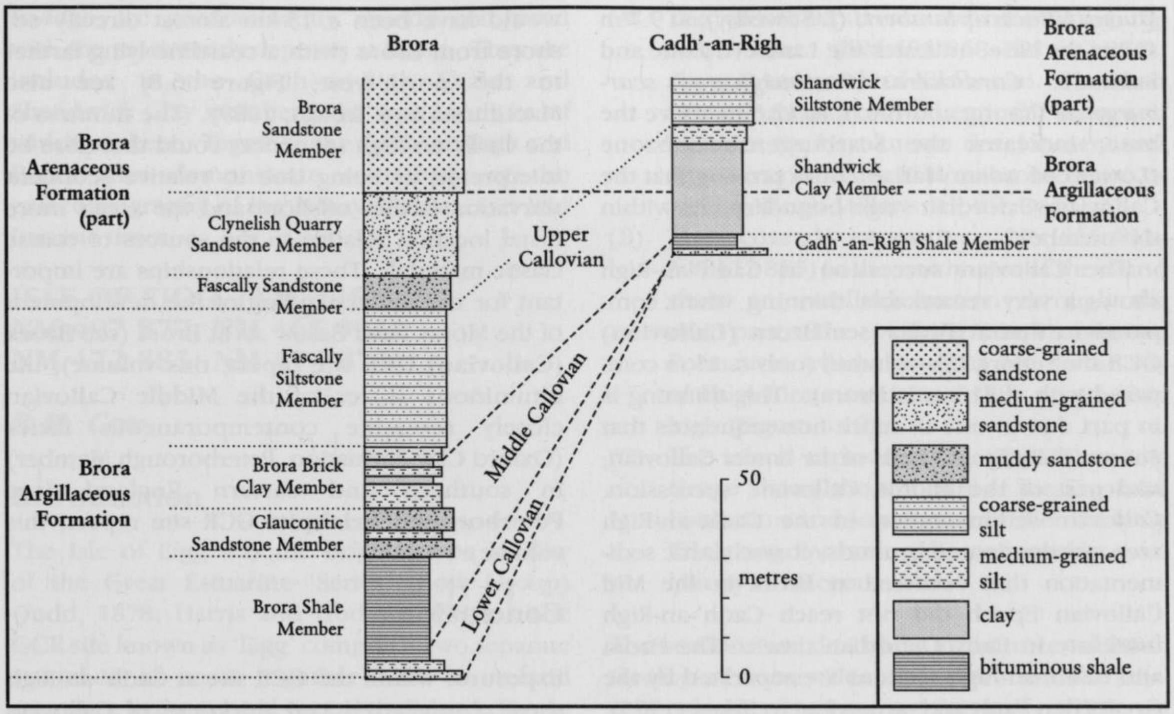

Figure 6.7 Correlation between the Callovian sections at the **Brora (Callovian)** and Cadh'-an-Righ GCR sites. (After Sykes, 1975, fig. 7.)

	Thickness (m)
Brora Argillaceous Formation	
Shandwick Clay Member (part)	
Grey-green clays with pyritic burrows; bands of carbonaceous debris in upper part with *c.* 4 m of sandy silt at top; bands of limestone nodules in lower part; low-diversity fauna with relatively common *Nuculoma* and ammonites; interburrowed junction with	*c.* 11.0
Cadh'-an-Righ Shale Member	
Bituminous shale with thin beds of glauconitic silt; band of calcitic concretions, 0.05–0.30 m thick with cone-in-cone margin in places, 1.3 m above base and enclosing smaller phosphatic nodules with sponge spicules; otherwise poorly fossiliferous with *Lingula*, *Cylindroteuthis* (concentrated in silts), fish debris and occasional ammonites (*Kosmoceras*); basal 0.05 m with laminae of reworked sand from the underlying Brora Roof Bed together with glauconite	3.7
Brora Roof Bed	
Intensely bioturbated, medium-grained sandstone; band of belemnites (*Cylindroteuthis*) at top with large coalified wood-clasts up to 0.20 m diameter; poorly preserved bivalves below, including *Pleuromya uniformis* (J. Sowerby), *Ctenostreon* sp. and pectinids	0.5

At the top of the underlying Brora Coal Formation, the 'Brora Coal' coal seam, which is not now exposed on the foreshore at **Brora**, can be seen.

Interpretation

The ammonite fauna allows the recognition of the standard Callovian zones and subzones. Just above the Brora Roof Bed, *Kosmoceras* (*Gulielmiceras*) *medea* Callomon, in the Cadh'-an-Righ Shale Member, indicates the (Middle Callovian) Medea Subzone, Jason Zone, and *K.* (*Zugokosmokeras*) *grossouvrei* R. Douvillé and *K.* (*Lobokosmokeras*) *phaeinum* S.S. Buckman, immediately above the calcitic concretions, indicate a level close to the Coronatum–Athleta zonal boundary (= Middle–Upper Callovian sub-stage boundary). These ammonite occurrences suggest that the concretionary horizon marks a non-sequence (Sykes, 1975).

In the Shandwick Clay Member, *Kosmoceras* (*K.*) cf. *tidmoorense* Arkell, at 3.5 m above the base, indicates the Spinosum Subzone (Athleta Zone)–Henrici Subzone (Lamberti Zone), and

Quenstedtoceras lamberti (J. Sowerby), at 9.7 m above the base, indicates the Lamberti Zone and Subzone. *Cardioceras (Scarburgiceras) scarburgense* (Young and Bird), at 12.3 m above the base, indicates the Scarburgense Subzone (Lower Oxfordian Mariae Zone) proving that the Callovian–Oxfordian stage boundary lies within the member.

The Callovian succession at Cadh'-an-Righ shows a very remarkable thinning when compared to that at Brora (see **Brora (Callovian)** GCR site report, this volume) (only *c.* 15 m compared with *c.* 115 m at Brora). This thinning is in part due to one or more non-sequences that cut out the younger beds of the Lower Callovian, and part of the Middle Callovian, succession. Callovian sedimentation in the Cadh'-an-Righ area was dominated by muds; coarse clastic sedimentation that occurred at Brora in the Mid Callovian Epoch did not reach Cadh'-an-Righ until late in Early Oxfordian times. The Brora and Cadh'-an-Righ sections are separated by the Great Glen Fault and, according to Sykes (1975), reconstruction of the relationship between the two sites, prior to *c.* 29 km of lateral movement on the fault, shows that the Cadh'-an-Righ area would have been *c.* 15 km almost directly offshore from Brora (with a coastline lying farther to the north-west; Figure 6.8; see also MacLennan and Trewin, 1989). The thinness of the Cadh'-an-Righ sequences could therefore be interpreted as being due to relative sediment starvation farther offshore and the area's more distal location relative to the sources of coarse clastic material. These relationships are important for the understanding of the development of the Moray Firth Basin. As at Brora (see **Brora (Callovian)** GCR site report, this volume), the bituminous shales of the Middle Callovian closely resemble contemporaneous facies (Oxford Clay Formation, Peterborough Member) in southern and eastern England (see **Peterborough Brickpits** GCR site report, this volume).

Conclusions

Exposures within the GCR site at Cadh'-an-Righ show a much reduced thickness of Callovian strata compared with those at Brora (see **Brora (Callovian)** GCR site report, this volume), *c.* 30 km farther north. The lithologies at Cadh'-

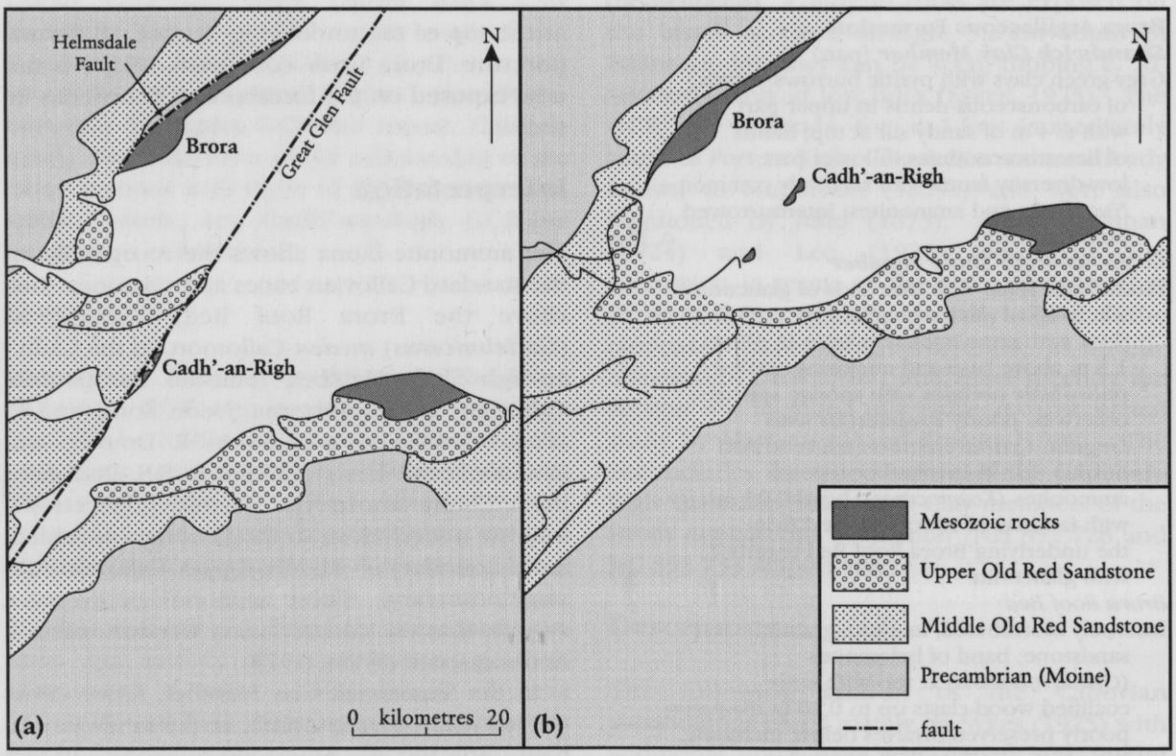

Figure 6.8 Sketch maps showing the relative positions of the **Brora** and Cadh'-an-Righ outcrops (a) after, and (b) before post-Jurassic movement along the Great Glen Fault. (After Sykes, 1975, fig. 2.)

an-Righ are predominantly muddy compared with the more sandy deposits at Brora. They are included in the Cadh'-an-Righ Shale and Shandwick Clay members, the type localities of which are here. Together, the Cadh'-an-Righ and Brora sites demonstrate something of the palaeogeography of the Moray Firth area in Mid Jurassic times.

ISLE OF EIGG, (NM 495 868–NM 497 877, NM 465 905–NM 472 885, NM 473 875)

B.M. Cox

Introduction

The Isle of Eigg was the original type locality of the Great Estuarine 'Series' (now Group) (Judd, 1878; Harris and Hudson, 1980). The GCR site known as 'Eigg' comprises two separate stretches of coast together with an inland exposure in the central part of the island (Figure 6.9).

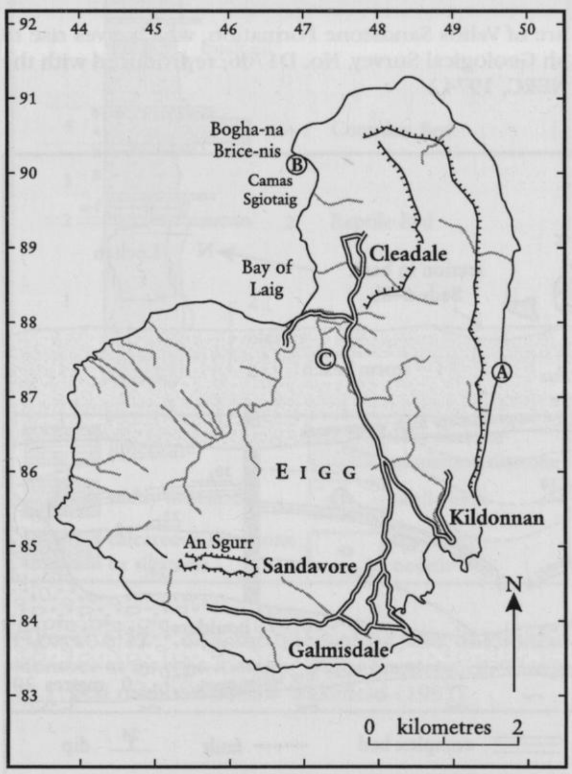

Figure 6.9 Locality map for the Isle of Eigg GCR site, which comprises three separate localities. (A) Coast north of Kildonnan; (B) Bogha na Brice-nis to Bay of Laig; (C) Laig Gorge.

(A) The oldest strata are exposed along the east coast (NM 495 868–NM 497 877), about 2 km north of Kildonnan. The Lealt Shale Formation is well exposed here, and includes the best-known development and type section of its Kildonnan Member, as well as 'Hugh Miller's Reptile Bed'.

(B) The coastal exposures (NM 465 905–NM 472 885) in the north-west of the island show an excellent section through the main part of the overlying Valtos Sandstone Formation, which, from Blàr Mór to the Bay of Laig, forms sandstone cliffs up to 40 m high (Figure 6.10).

(C) The inland exposure (NM 473 875) at Laig Gorge shows the top part of the Duntulm Formation and lower part of the overlying Kilmaluag Formation disconformably overlain by Cretaceous strata.

The sections are described in the recent British Geological Survey Memoir for Rum and the adjacent islands (Hudson in Emeleus, 1997) on which the following notes are largely based.

Description

(A) Coast north of Kildonnan

The lower part of the Lealt Shale Formation is well exposed between tidemarks and variably on the storm beach. There is an almost continuous section through *c.* 27 m of predominantly grey, silty shale or mudstone, including a thin bed of coarse calcareous sandstone and several beds of shelly limestone that form marker beds. This constitutes the type section of the Kildonnan Member (Figures 6.11 and 6.12). A detailed composite bed-by-bed description of the section is given by Hudson in Emeleus (1997, appendix 1) based, with amendments, on individual sections recorded by Hudson (1966). Wakefield (1994, 1995) and Hudson *et al.* (1995) also provided graphic sections.

The oldest beds, which are seen near the northern end of the exposure, contain shelly layers including small mytilid bivalves (probably *Praemytilus strathairdensis* Cox), unionoid bivalves, small gastropods (*Valvata* and neritids) and conchostracans (*Euestheria* and *Neopolygrapta*). The overlying 'Reptile Bed' (Bed 2 of Hudson) is mainly a sideritic gastropod biosparite; siderite mudstone lenses within it contain well-preserved small neritid gastropods,

Figure 6.10 Camas Sgiotaig, Isle of Eigg. The sea cliffs are of Valtos Sandstone Formation, which gives rise to the pure white 'singing sands' of the beach. (Photo: British Geological Survey, No. D1706; reproduced with the permission of the Director, British Geological Survey, © NERC, 1974.)

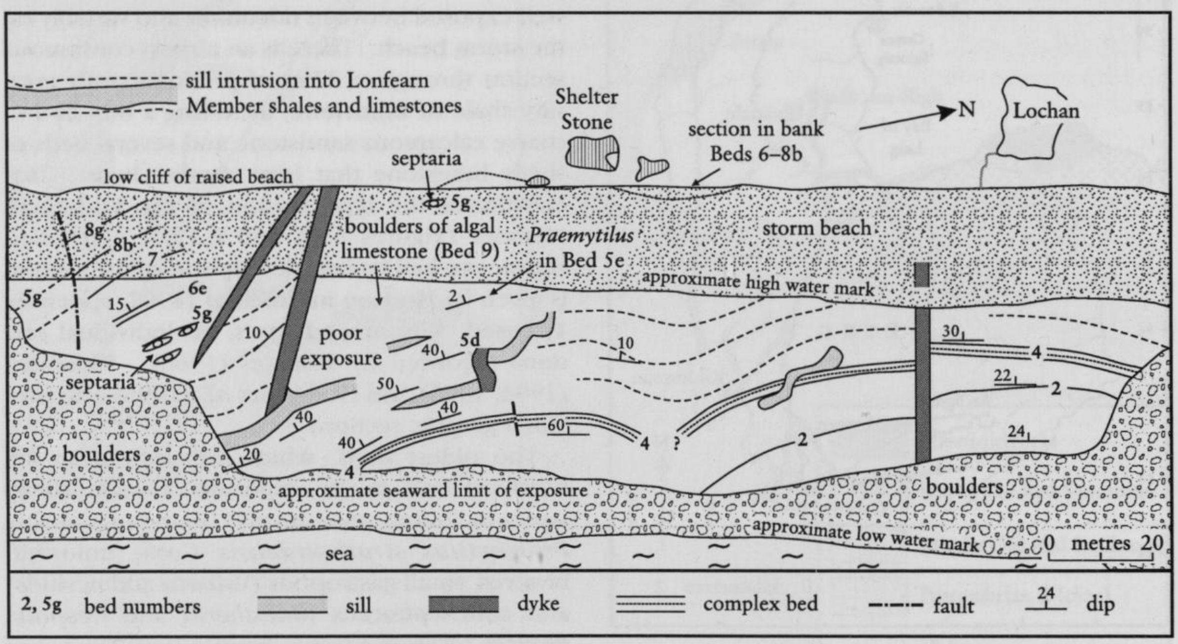

Figure 6.11 Geological sketch map of the type locality of the Kildonnan Member (Lealt Shale Formation) on the coast north of Kildonnan, Isle of Eigg (for bed numbers, see Figure 6.12). (After Emeleus, 1997, fig. 12.)

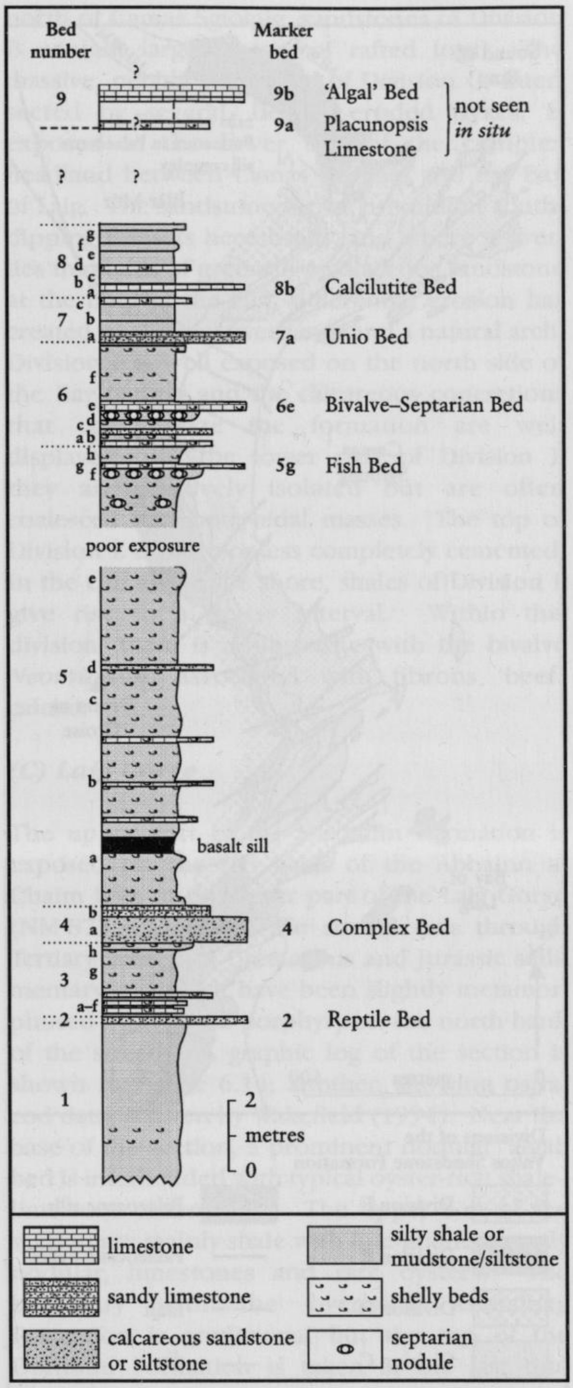

Figure 6.12 Graphic section of the Kildonnan Member at its type locality. (After Emeleus, 1997, fig. 13.) Bed numbers follow Wakefield (1991).

Valvata and '*Cylindrobullina*'; *Unio* occurs less abundantly. There is limited in-situ exposure of this bed, which was discovered by Hugh Miller in 1845 (recorded posthumously in Miller, 1858), but it is readily recognizable as loose blocks that are weathered red. The bed has yielded disarticulated, black plesiosaur bones (Newman in Persson, 1963; Benton and Spencer, 1995), and fish teeth and scales are consistently present. In the overlying silty mudstone (Bed 3), there are shell layers and thin shell-beds with gastropods, as in Bed 2, together with *Viviparus* and small *Praemytilus*; the latter becomes increasingly abundant, though specimens remain small (probably juvenile), in the upper part of the bed, which includes, at its top, large articulated specimens of *Unio*. The most useful marker (Bed 4) in the lower part of the section comprises irregularly lenticular beds of coarse, calcite-cemented sandstone, some with rippled tops and mudcrack-fills at their bases, separated by shale lenses, overlain by a sandy molluscan biosparite composed mainly of small *Praemytilus*. The sandstones contain high proportions of worn phosphatic debris, and some of the shales contain small gastropods. Bed 5 is the thickest development (total *c.* 13.3 m) of silty shale in the section; it includes subordinate thin beds of siltstones, *Praemytilus* biosparites and fibrous 'beef' calcite. In the upper part, large *Praemytilus* cover entire bedding planes, and often show current lineation. The gastropod *Valvata* and ostracods are also present. The upper part of Bed 5 also contains ovoid septarian concretions, about 1 m across and 0.20 m thick with well-formed rhombic calcite crystals. A mixed assemblage of *Unio*, large *Viviparus* and *Praemytilus*, orientated at all angles with respect to the bedding, occurs in Bed 5f. Below the Shelter Stone (so-called because one can actually shelter within it), the overlying Fish Bed (Bed 5g), a thin shelly limestone crowded with hybodont shark teeth and fish scales, is exposed at the back of the beach resting directly on a concretion.

In the overlying beds, a heterodont bivalve (*Tancredia*?) replaces *Praemytilus* as the predominant bivalve, and fine-grained shales with *Neomiodon*, conchostracans and numerous ostracods also occur. Three marker beds (the Bivalve–Septarian Bed (6e), the Unio Bed (7a) and Bed 8b (a hard, blue-grey, unfossiliferous calcilutite)) in the upper part of the section help to correlate exposures. The last-named is the highest consistently exposed marker bed in this type section. The boundary with the overlying Lonfearn Member and the widespread algal stromatolite that usually occurs at the top of the Kildonnan Member are not continuously exposed here.

The GCR site covers a little under a kilometre of coastline, of which the type section of the Kildonnan Member described above occupies about 200 m. The remainder of the section includes other exposures of the Lealt Shale and of the overlying Valtos Sandstone formations but these are less well developed than elsewhere on the Isle of Eigg.

(B) Bogha na Brice-nis to Bay of Laig

According to Hudson (in Emeleus, 1997), the most conspicuous Mesozoic outcrops in the Small Isles are the cliffs of the Valtos Sandstone Formation in this part of the GCR site in north-west Eigg (Figure 6.10). The pale sandstone gives rise to pure white beach sands, the famous 'singing sands' of Camas Sgiotaig. The formation here has been divided into six informal divisions (A–F from below). Each of the divisions, except F, contains a sand body, generally coarsening-upwards, and usually capped by a coarse-grained, shelly, cemented unit representing reworking. A map showing the distribution of these divisions within the GCR site is shown in Figure 6.13. A cross-section of their lateral distribution is shown by Harris (1992, fig. 4) and Hudson (in Emeleus, 1997, fig. 15), and these also show the distribution of the five facies recognized within the formation by Harris (1992). These facies are (1) *Neomiodon* mudstone–siltstone; (2) coarsening-upwards sandstone, (3) coarse-pebbly sandstone including (3a) pebbly and (3b) thin-bedded, trough cross-stratified and coarse-grained; (4) wave-formed sandstone; and (5) *Neomiodon*-debris limestone. Graphic logs of six sections at intervals along the coastal exposure are given by Harris (1992).

At the northern end of the GCR site, the gradational contact of the Valtos Sandstone Formation and the underlying Lonfearn Member of the Lealt Shale Formation is exposed. Thin beds of strongly bioturbated sandstone appear intercalated with dark shales, which are intruded by thin and somewhat irregular sills. The proportion of sandstone beds increases, and sills decreases, upwards. On the shore platform south-east of Bogha na Brice-nis, prominent calcareous concretions in the upper part of Division A are well exposed on the shore, and

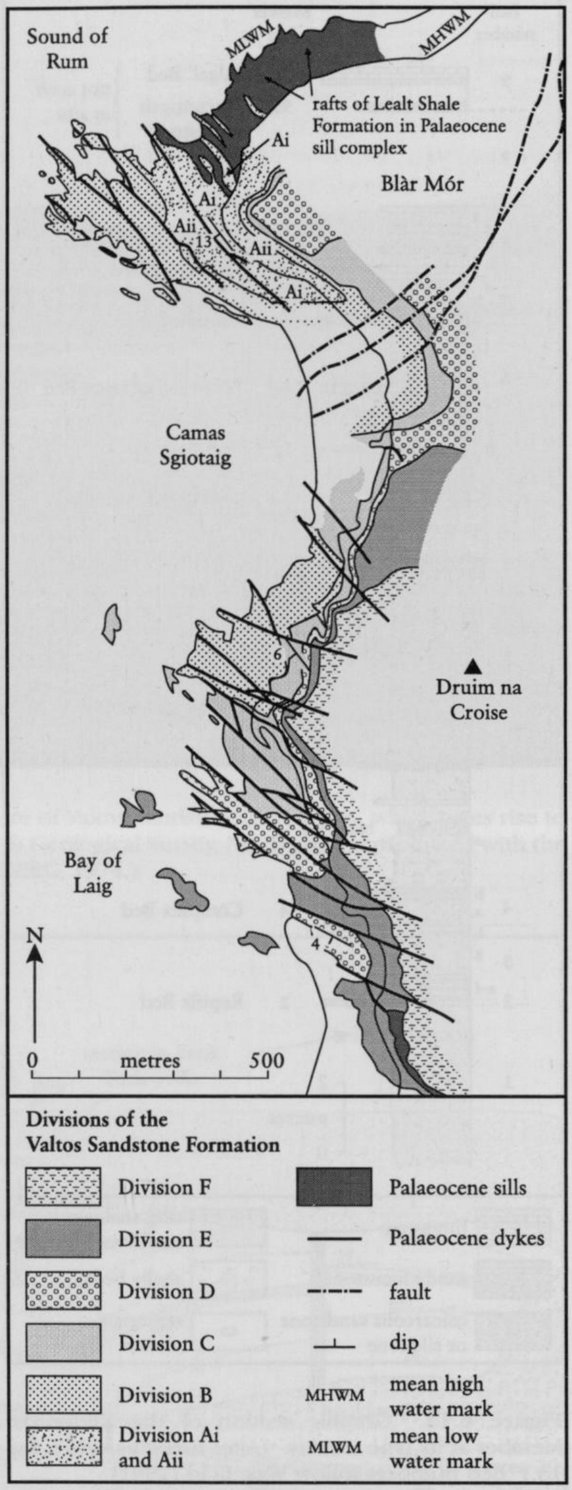

Figure 6.13 Outcrop map of the Valtos Sandstone Formation between Bogha na Brice-nis and Bay of Laig, Isle of Eigg. (After Emeleus, 1997, fig. 14.) Division letters follow Harris (1984).

north of Camas Sgiotaig, sandstones of Division B contain large masses of rafted logs. The massive, pebbly sandstone of Division C, intersected by several, deeply eroded dykes, is exposed in the lower cliff of the complex headland between Camas Sgiotaig and the Bay of Laig. The sandstone shows prominent south-dipping foresets hereabouts, and where it overlies thin beds of greenish argillaceous sandstone at the base of the cliff, differential erosion has created prominent overhangs and a natural arch. Division E is well exposed on the north side of the Bay of Laig and the calcareous concretions that characterize the formation are well displayed. In the lower part of Division E they are relatively isolated but are often coalesced into botryoidal masses. The top of Division E is more-or-less completely cemented. In the cliff above the shore, shales of Division F give rise to a grassy interval. Within this division, there is a biosparite with the bivalve *Neomiodon*, associated with fibrous 'beef' calcite.

(C) Laig Gorge

The upper part of the Duntulm Formation is exposed on the left bank of the Abhainn a' Chaim Loin in the lower part of the Laig Gorge (NM 873 875) where the stream cuts through Tertiary lavas into Cretaceous and Jurassic sedimentary rocks that have been slightly metamorphosed by a quartz porphyry on the north bank of the stream. A graphic log of the section is shown in Figure 6.14; another, showing ostracod data, is given by Wakefield (1994). Near the base of the section, a prominent nodular 'algal' bed is interbedded with typical oyster-rich shale–limestone alternations. The upper 5 m of the section are mainly shale with fine-grained, partly nodular, limestones and rare oysters. The boundary with the overlying Kilmaluag Formation is gradational but the top of the Duntulm Formation is taken at the last thin oyster-bearing limestone.

The Kilmaluag Formation comprises 6 m of shale–limestone alternations with an abundant ostracod and conchostracan (*Antronestheria*) fauna. The top limestone is dolomitic, and beneath the disconformable base of the Cretaceous Laig Gorge Sandstone, there is a shale. The outcrop of these beds above the south bank of the stream is sometimes obscured by vegetation, but can be easily exposed.

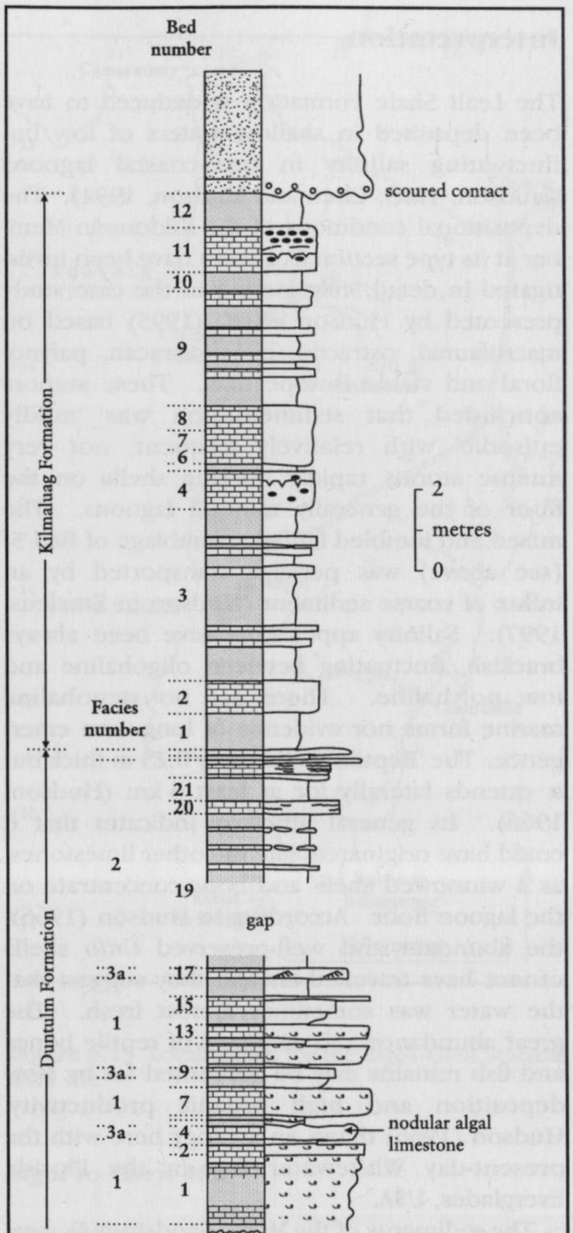

Figure 6.14 Graphic section of the Duntulm and Kilmaluag formations at Laig Gorge, Isle of Eigg. (After Emeleus, 1997, figs 17,18). Bed and facies numbers follow Andrews (1984, 1985).

Interpretation

The Lealt Shale Formation is deduced to have been deposited in shallow waters of low but fluctuating salinity in near-coastal lagoons (Hudson, 1983; Chen and Hudson, 1991). The depositional conditions of the Kildonnan Member at its type section (A above) have been investigated in detail, culminating in the case study presented by Hudson *et al.* (1995) based on macrofaunal, ostracod, conchostracan, palynofloral and stable isotope data. These authors concluded that sedimentation was 'mildly episodic' with relatively frequent, not very intense storms rapidly burying shells on the floor of the generally tranquil lagoons. The mixed and jumbled faunal assemblage of Bed 5f (see above) was perhaps transported by an influx of coarse sediment (Hudson in Emeleus, 1997). Salinity appears to have been always brackish, fluctuating between oligohaline and low polyhaline. There are no stenohaline marine forms nor evidence of long-term emergence. The 'Reptile Bed' is only 0.15 m thick but it extends laterally for at least 3 km (Hudson, 1966). Its general lithology indicates that it could have originated, like the other limestones, as a winnowed shell- and bone-concentrate on the lagoon floor. According to Hudson (1966), the abundant and well-preserved *Unio* shells cannot have travelled far and they suggest that the water was sometimes almost fresh. The great abundance and dispersal of reptile bones and fish remains may be accounted for by slow deposition and high organic productivity. Hudson (1966) draws an analogy here with the present-day Whitewater Bay in the Florida Everglades, USA.

The sediments of the Valtos Sandstone Formation have been interpreted by Hudson and Harris (1979) and Harris (1992) as representing a series of delta lobes built into the lagoons in which the Lealt Shale Formation had accumulated. As elsewhere in the Inner Hebrides Basin (see **Elgol–Glen Scaladal** GCR site report, this volume), heavy-mineral assemblages in the sandstones are garnet-poor, staurolite-rich and rutile-rich, which may indicate a significant though indirect input of sediment from the Dalradian rocks of the southern and eastern Highlands (possibly via the Old Red Sandstone, which may have extended into the hinterland of the basin). The coarsening-upwards sandstone facies, which is well displayed in the Bay of Laig section, is interpreted by Harris (1992) as indicating progradation of delta shoreline and interdeltaic lagoon shoreline systems. The wave-formed sandstone facies, which is also well developed here, represents wave reworking of fluvially supplied sand at the delta shoreline; the thicker, more complex sand-bodies of this facies are interpreted as the upper shoreface–foreshore of prograding delta shoreline systems (Harris, 1992). The shell-debris limestones, which, in places, cap divisions D, E and F (see B above), either indicate brackish-water transgressions of the lagoon shoreline or, where intercalated with the *Neomiodon* mudstone–sandstone facies, shell-debris sheets and shoals (Harris, 1992). Calcite concretions from the Bay of Laig section have been studied by Wilkinson (1992) who concluded that they grew at burial depths of 200–300 m, at temperatures of 31–46°C in pore waters of meteoric origin. The average concretion (*c.* 0.12 m diameter) grew in approximately 0.36–0.84 Ma, and their most likely nucleus was detrital *Neomiodon* shells.

The Duntulm Formation at Laig Gorge is dominated by *Praeexogyra* limestones (facies 1 of Andrews and Walton, 1990) and argillaceous limestones (facies 2 of Andrews and Walton, 1990). These are interpreted, respectively, as former shell-banks that have fallen apart, probably agitated by weak, wind-driven tides in shallow water, and shallow littoral carbonate–siliciclastic mud deposition probably in quiet water, leeward of the oyster-shell banks (Andrews and Walton, 1990). An algal bed (facies 3a of Andrews and Walton, 1990) occurs near the base of the exposure and correlates with Bed 31 in Straithaird (see **Elgol–Glen Scaladal** GCR site report, this volume). This is interpreted by Andrews (1986) as representing a supralittoral algal marsh to a shallow littoral algal stromatolite. Facies 2 limestones at the boundary of the Duntulm and Kilmaluag formations record the change from open, marine, brackish-water lagoons to closed, shallow, low-salinity coastal marginal lagoons with mud-dominated sedimentation and a restricted low-salinity biota of ostracods, conchostracans and gastropods (Andrews, 1985).

Conclusions

The Isle of Eigg GCR site includes the highly fossiliferous type section of the Kildonnan Member of the Lealt Shale Formation. This member records palaeoenvironments of low but fluctuating salinity and includes 'Hugh Miller's Reptile Bed', which features in the fossil reptile GCR networks (Benton and Spencer, 1995). The site also includes excellent exposures of the overlying Valtos Sandstone Formation, which represent the most conspicuous outcrop of Mesozoic rocks in the Small Isles, and a section across the boundary of the Duntulm and Kilmaluag formations. These formations represent a range of coastal lagoonal and deltaic depositional palaeoenvironments. The site is therefore an important one for stratigraphy, sedimentology, palaeontology, palaeoecology and palaeogeography.

ELGOL–GLEN SCALADAL, ISLE OF SKYE (NG 517 136–NG 519 154, NG 520 159–NG 520 168)

B.M. Cox

Introduction

The coastline from Port na Cullaidh to north of Glen Scaladal (Figure 6.15), on the west coast of Strathaird, southern Skye, exposes a virtually continuous section through the Great Estuarine Group together with the overlying Carn Mor Sandstone Member (Staffin Bay Formation) of Early Callovian age (see **North Elgol Coast** GCR site report, this volume). The exposure is interrupted for about 500 m to the west of Carn Mor by the Carn Mor landslip. The beds dip gently WNW so that, except for some repetition due to folding in the northern part of the exposure, the succession youngs from south to north. The exposures here include the type sections of the Elgol Sandstone Formation, and type/reference sections for the Cullaidh Shale and Kilmaluag formations. The cliffs are unstable and dangerous, especially below Carn Mor.

Description

The sections have been described by Morton and Hudson (1995) on which the following notes are largely based, together with additional information from Harris and Hudson (1980), Andrews (1985), Harris (1989, 1992) and Andrews and Walton (1990). The sections were also included in earlier field guides by Hudson and Morton (1969) and Bell and Harris (1986).

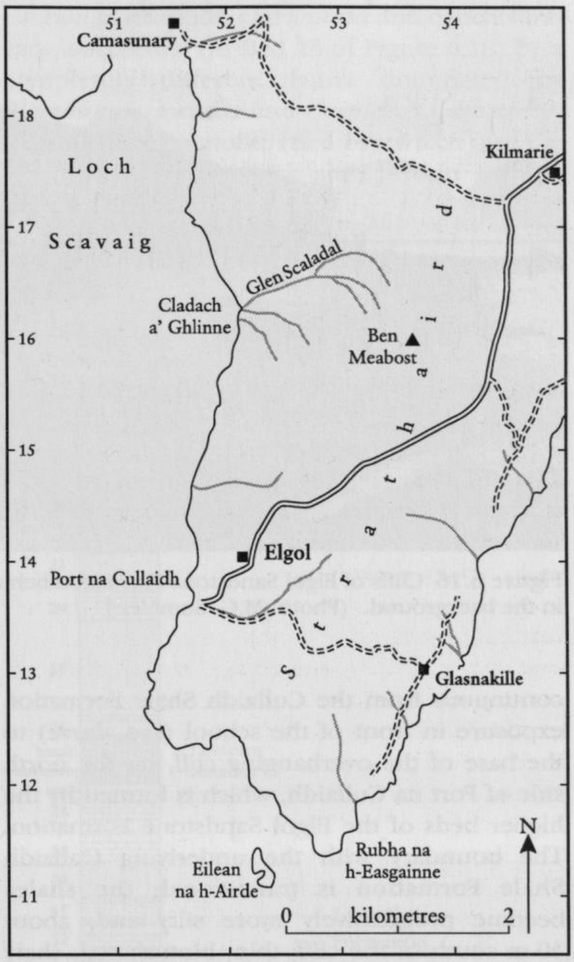

Figure 6.15 Locality map for the Elgol–Glen Scaladal GCR site.

Elgol to Carn Mor

The oldest strata, belonging to the Cullaidh Shale Formation, are exposed in a mobile storm beach immediately in front of Elgol school. The exposure (NG 517 137), normally of 1–2 m of dark shale intruded by thin, irregular, basaltic sills, varies with the state of the beach. The shale contains abundant cycloid and ctenoid fish (probably '*Leptolepis*') scales, and a sparse invertebrate fauna of gastropods (*Viviparus*? and tiny indeterminate specimens), bivalves (*Praemytilus*?) and rare conchostracans (*Euestheria* cf. *trotternishensis* Chen and Hudson, and *Neopolygrapta* sp.; Chen and Hudson, 1991). The base of the formation is not seen.

Exposure of the overlying Elgol Sandstone Formation (Figures 6.16 and 6.17) is nearly

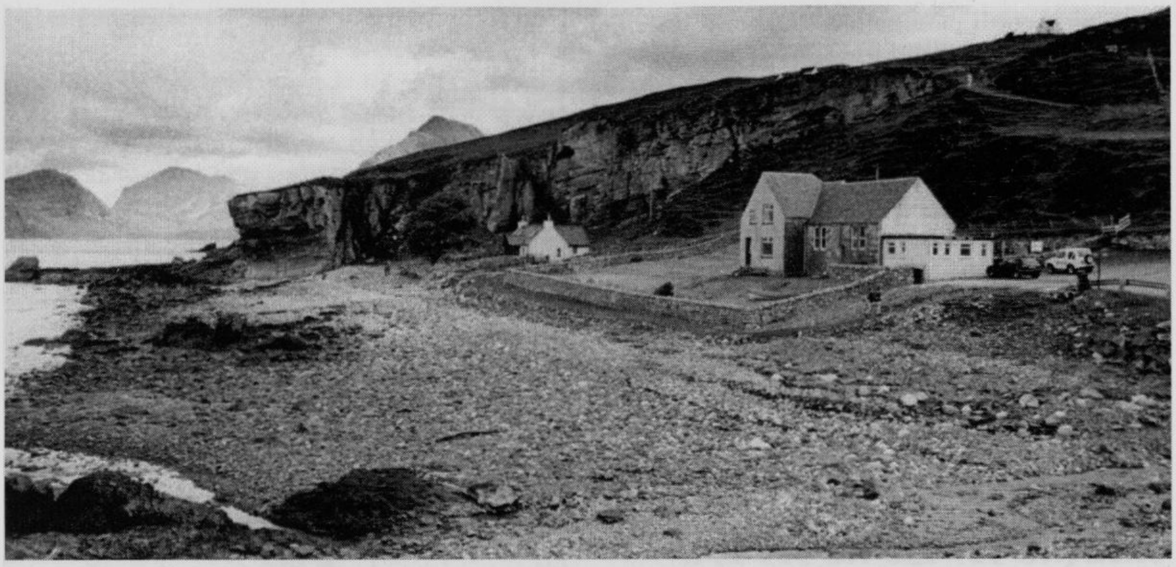

Figure 6.16 Cliffs of Elgol Sandstone Formation behind the school (centre right) at Elgol. The Cuillin Hills are in the background. (Photo: M.G. Sumbler.)

continuous from the Cullaidh Shale Formation exposure in front of the school (see above) to the base of the overhanging cliff, on the north side of Port na Cullaidh, which is formed by the higher beds of the Elgol Sandstone Formation. The boundary with the underlying Cullaidh Shale Formation is transitional; the shales become progressively more silty and, about 30 m south of the cliff, thin, bioturbated, shaly sandstone beds appear. Black, micaceous shales are intercalated with successively thicker, shaly sandstones that become progressively more intensively bioturbated upwards, culminating in shaly, fine-grained sands with pyrite nodules and a restricted assemblage of trace fossils, mainly *Planolites* (Harris, 1989). The sands gradually increase in proportion and thickness; first, and forming the main part of the cliff, there are white, fine- to medium-grained, pure, non-calcareous sandstones with well-developed honeycomb weathering under the overhang and with thin, lenticular, coarse-grained sand units. These are followed by moderately well-sorted, medium- to coarse-grained sandstones with large-scale (5 m amplitude), low-angle inclined surfaces dipping at between 4° and 7° to the south-east (these beds are seen in the N–S-trending cliff behind the school). These surfaces commonly have weak basal scours and show low-amplitude (less than 0.10 m) trough and tabular cross-stratification and complex palaeo-current flow directions. *Monocraterion* and indistinct *Thalassinoides*? burrows occur intermittently. Coarse- and very coarse-grained sands with granule and pebble lenses complete the sequence. These show trough and tabular cross-bed sets in the lower part with planar lamination preserved between numerous scour surfaces; in the upper part, there are two trough cross-stratified cosets capped by medium-grained sands with poorly defined planar-lamination. Moulds of large bivalves (probably *Unio*) in life orientation are seen on the surface of dipping slabs of the top sandstone exposed in front of a ruined cottage to the north of the main outcrop. The total thickness of the formation, which forms a distinct scarp traceable for *c*. 7 km to the north-west, is here 22 m.

The overlying Lealt Shale Formation is exposed in the next bay (NG 516 140–NG 516 144) to the north of the headland. It is predominantly argillaceous with numerous thin, mainly biosparite limestones, and yields an abundant, but restricted, fauna of bivalves, gastropods, ostracods and conchostracans. Its sharp contact with the coarse top of the Elgol Sandstone Formation is displaced by small faults. About 1 m above the base, there is a 0.30 m-thick bed of fine-grained sandstone, 0.30 m above which, the shales have yielded a well-preserved, fusainized fragment of the dipterid fern *Hausmannia* sp. This lower part of the Lealt Shale Formation (the Kildonnan Member) is dominated by the mytilid bivalve

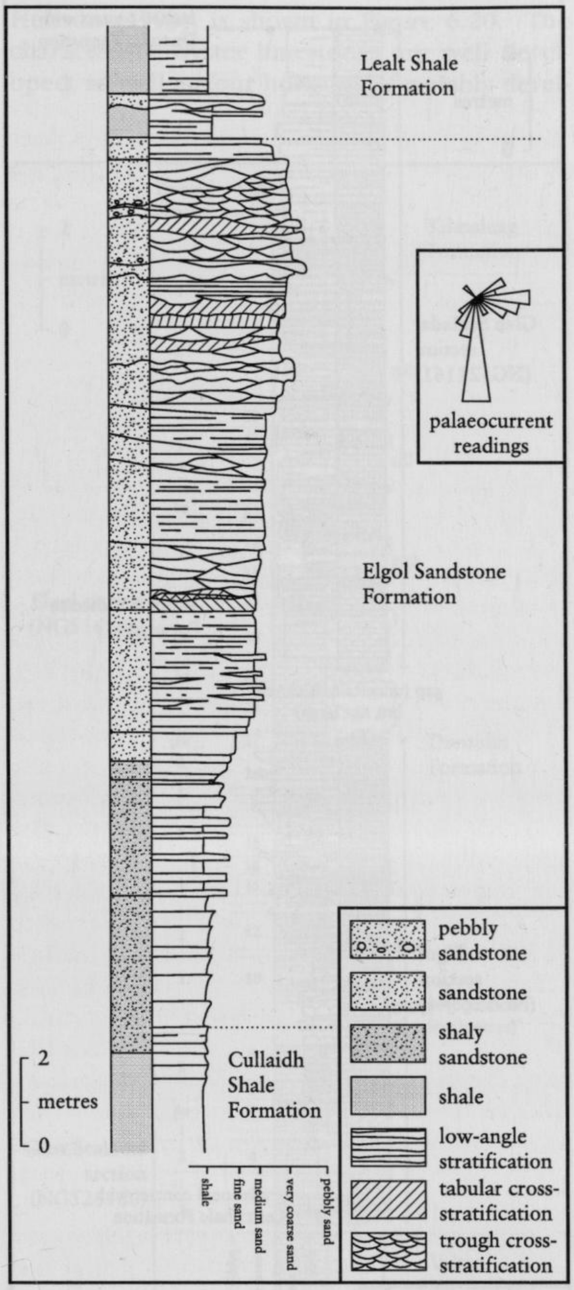

Figure 6.17 Graphic section of the Elgol Sandstone Formation at its type locality. (After Morton and Hudson, 1995, fig. 19.)

Praemytilus strathairdensis (Anderson and Cox). The upper part of the member, capped by a stromatolite bed, is exposed a few metres south of a small vent breccia outcrop that is conspicuous in the cliff but does not extend across the shore. These highest shales of the Kildonnan Member contain a fauna of *Praemytilus*, *Unio*, *Neomiodon*, neritid and probable ellobiid gastropods, *Darwinula* and conchostracans, succeeded (in Bed 13 of Figure 6.18) by a completely different fauna dominated by *Placunopsis socialis* and *Cuspidaria ibbetsoni*. The domal stromatolite (Bed 14), which caps the member, is 0.20 m thick and, in thin section,

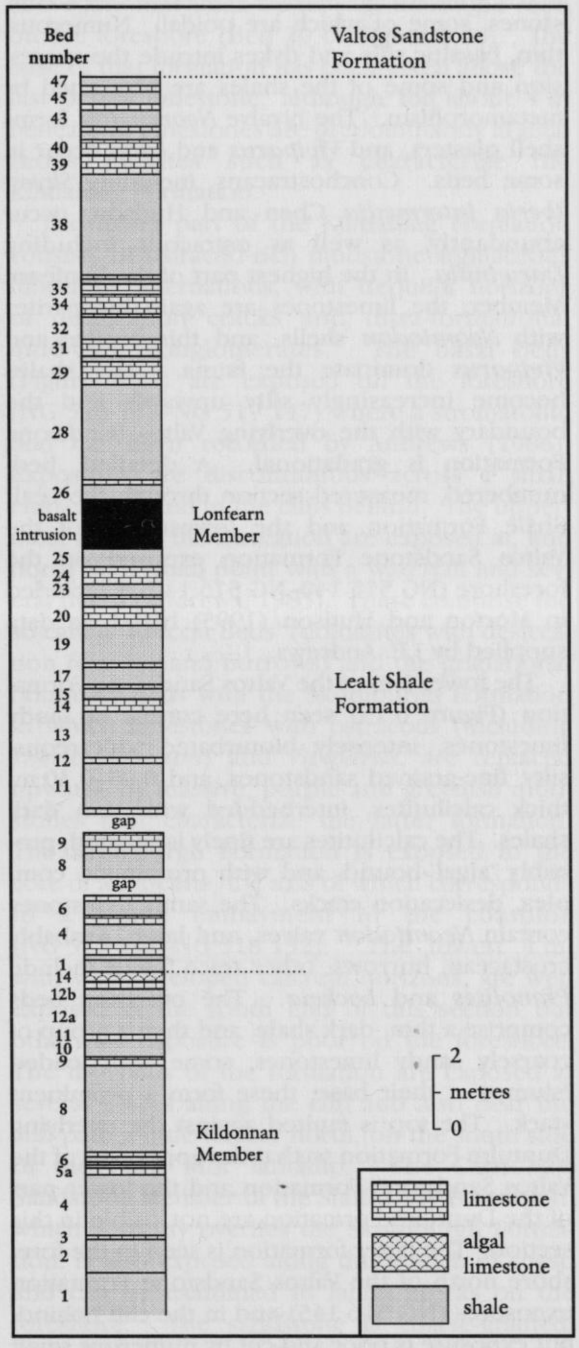

Figure 6.18 Graphic section of the Lealt Shale Formation on the coast north of Elgol, Isle of Skye. (After Wakefield, 1994, fig. 50.) Bed numbers follow Andrews (1984).

shows pseudomorphs after gypsum. The basal shales of the overlying Lonfearn Member, which is almost continuously exposed from here to a steep and projecting part of the cliff formed by a dyke complex, contain a fauna that also includes *Cuspidaria* as well as *Isognomon*, *Neomiodon* and ?*Viviparus*. Above this, the member comprises alternations of dark shales and thin limestones, some of which are ooidal. Numerous, thin, basaltic sills and dykes intrude the succession and some of the shales are blackened by metamorphism. The bivalve *Neomiodon* forms shell plasters, and *Viviparus* and *Unio* occur in some beds. Conchostracans, including *Skyestheria intermedia* Chen and Hudson, occur abundantly, as well as ostracods including *Darwinula*. In the highest part of the Lonfearn Member, the limestones are again biosparites with *Neomiodon* shells, and this bivalve and *Viviparus* dominate the fauna. The shales become increasingly silty upwards and the boundary with the overlying Valtos Sandstone Formation is gradational. A detailed, bed-numbered, measured section through the Lealt Shale Formation and the lowest part of the Valtos Sandstone Formation exposed on the foreshore (NG 515 140–NG 516 147) is included in Morton and Hudson (1995) based on data supplied by J.E. Andrews.

The lower 6 m of the Valtos Sandstone Formation (Figure 6.19) seen here consist of sandy limestones, intensely bioturbated, calcareous, silty, fine-grained sandstones, and 0.05–0.30 m-thick calcilutites, interbedded with thin dark shales. The calcilutites are finely laminated, probably 'algal'-bound, and with prominent, complex, desiccation cracks. The sandy limestones contain *Neomiodon* valves, and large, probably crustacean, burrows; other trace fossils include *Planolites* and *Lockeia*. The overlying beds comprise a thin, dark shale, and then a group of coarsely sandy limestones, some with loaded ?slumps at their base; these form a prominent stack. The top is faulted against the overlying Duntulm Formation so that the upper part of the Valtos Sandstone Formation and the lower part of the Duntulm Formation are not visible in this section. The latter formation is seen in the foreshore north of the Valtos Sandstone Formation exposures (NG 516 145) and in the cliff behind, but exposure is poor and cut by numerous small intrusions and small faults (Andrews and Walton, 1990, fig. 18). A graphic section, based on Andrews and Walton (1990) and Morton and

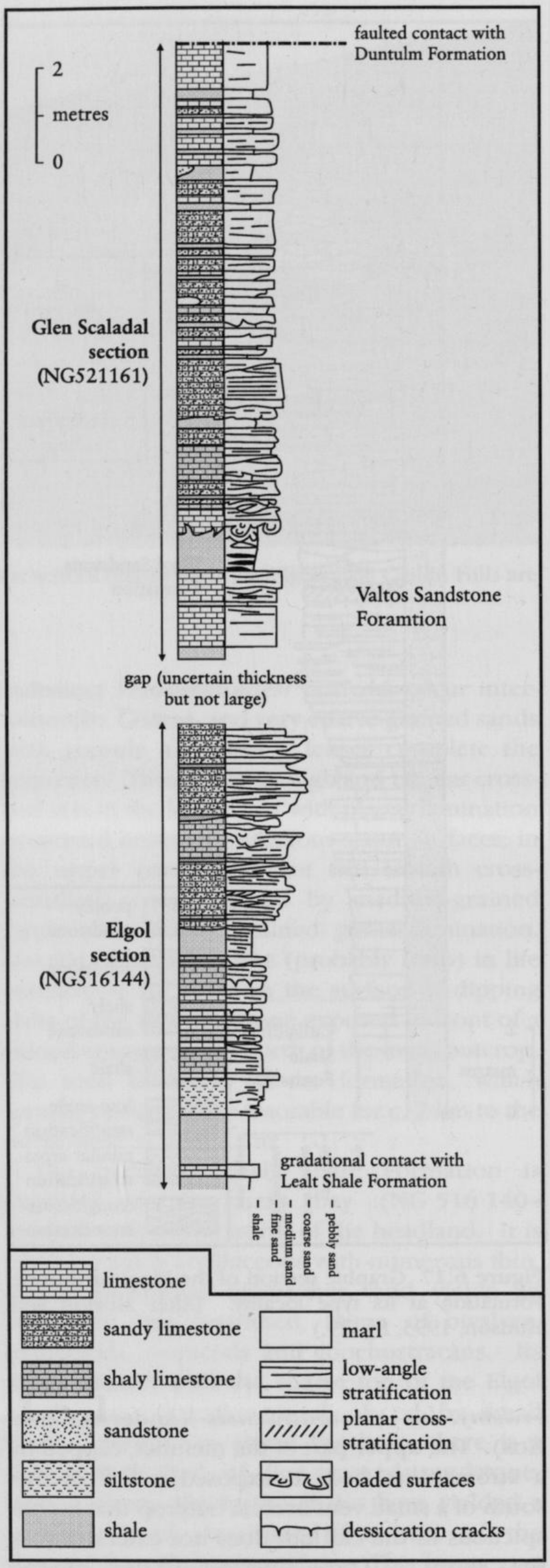

Figure 6.19 Graphic section of the Valtos Sandstone Formation on the coast north of Elgol, Isle of Skye. (After Morton and Hudson, 1995, fig. 20.)

Hudson (1995), is shown in Figure 6.20. The characteristic oyster limestones are well developed, as well as four horizons of variably devel-

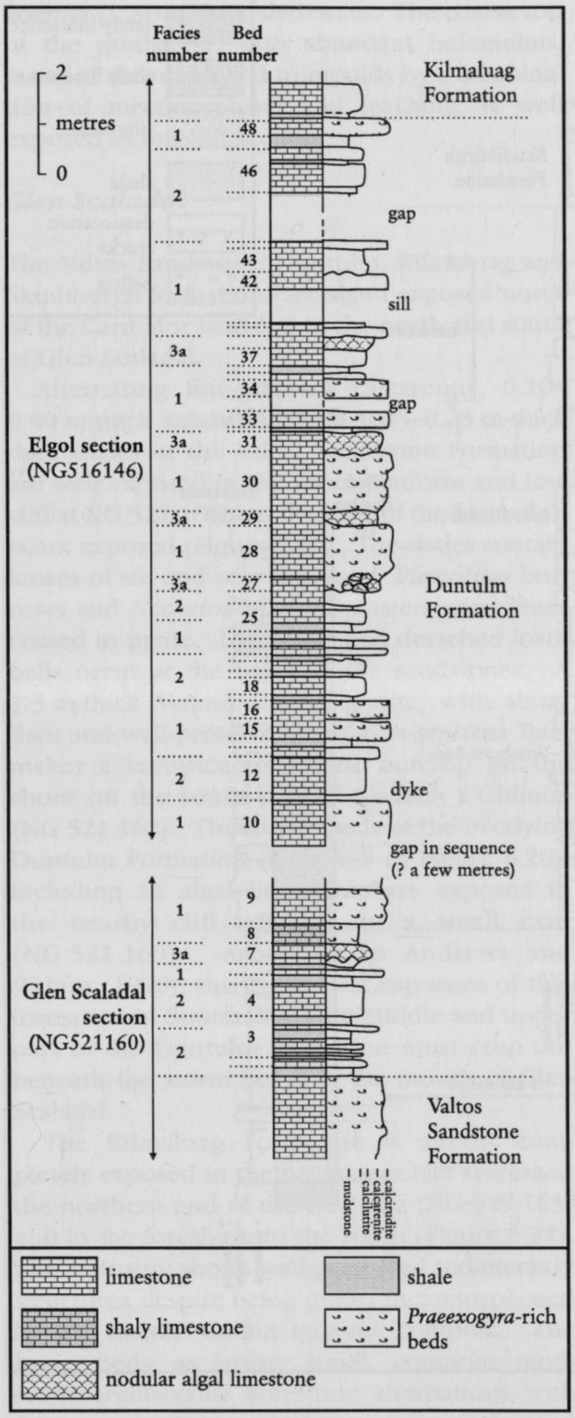

Figure 6.20 Composite graphic section of the Duntulm Formation at Elgol–Glen Scaladal. (After Emeleus, 1997, fig. 17.) Bed and facies numbers follow Andrews (1984).

oped nodular and stromatolitic algal limestone. Beds 10–29 of Andrews and Walton (1990) are best seen in the cliff, and beds 29–48, including the transition with the overlying Kilmaluag Formation, on the foreshore but, according to Andrews and Walton (1990), the algal limestone recognized by Anderson (1948) is easily located above the first thick oyster-rich limestone seen on the foreshore (Bed 20 of Figure 6.20). The base of that formation has been taken above the last oyster limestone, although for about 4 m beneath it, limestones are predominantly argillaceous micrites such as characterize the Kilmaluag Formation.

The lower part of the Kilmaluag Formation consists of ostracod-rich mudstone-argillaceous limestone alternations, with frequent horizons of desiccation cracks and intra-formational mud-clast conglomerates. The basal beds (Figure 6.21) are exposed on the foreshore (NG 516 146–NG 517 147) where a stromatolite bed has been recorded by Andrews (1986). Exposures are discontinuous across a small embayment and in the cliffs behind. The uppermost beds of the formation are exposed at, and north of, a small point with a waterfall and several dykes (Andrews, 1985). These comprise the so-called 'Breccia Beds' (dolomites with desiccation features and burrows) and the gradational boundary beds with the Skudiburgh Formation in which limestones with ostracods (including *Theriosynoecum*) and *Viviparus*, are replaced upwards by massive, purple and greenish mudstones that characterize the latter formation. The Skudiburgh Formation is exposed in the core of a syncline, the axis of which corresponds to a gentle embayment in the coastline (NG 517 147–NG 518 152). The lowest 4 m, with well-developed calcrete horizons, are well exposed at the south end of this section but otherwise exposure is poor on the foreshore. The top beds of the formation are exposed at several places along the cliff and also near the cliff path a little farther north, on the south side of the Carn Mor landslip. The Carn Mor Sandstone Member of the Staffin Bay Formation, which abruptly overlies the Skudiburgh Formation, is also exposed along this stretch of coast, and can be examined in fallen blocks on the foreshore. The sandstone is coarse-grained, with pebbles up to 30 mm, and bioturbated. *Thalassinoides* burrows extend down from the sandstone into the underlying mudstone of the Skudiburgh Formation. Clusters of

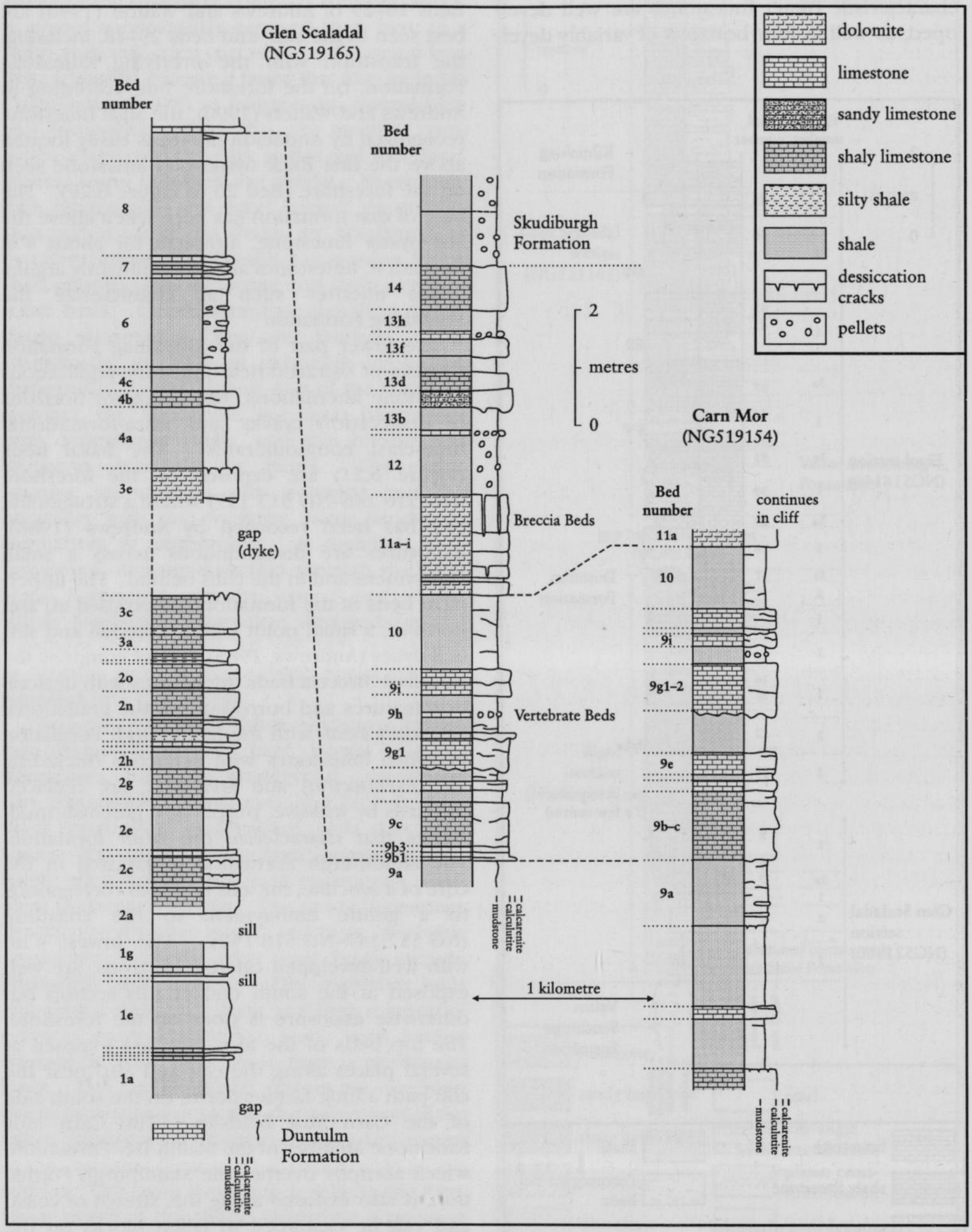

Figure 6.21 Graphic section of the Kilmaluag Formation, north of Elgol, Isle of Skye. (After Morton and Hudson, 1995, fig. 23.) Bed numbers follow Andrews (1984).

rhynchonellid brachiopods, identified by Sykes (1975) as *Thurmanella acuticosta* Childs, are locally conspicuous in the sandstone, and rare ammonites (*Kepplerites* (*Gowericeras*) *gowerianus* (J. de C. Sowerby) and *Proplanulites koenigi* (J. Sowerby)) also occur. The coarse top of the sandstone, with abundant belemnites, many of them reduced to moulds by a combination of metamorphism and leaching, is well exposed in the cliff section.

Glen Scaladal

The Valtos Sandstone, Duntulm, Kilmaluag and Skudiburgh formations are again exposed north of the Carn Mor landslip, to the north and south of Glen Scaladal.

Alternating fine-grained, calcareous, 0.10–0.40 m-thick sandstones and 0.05–0.25 m-thick dark shales of the Valtos Sandstone Formation are well exposed in the shore platform and low cliff at NG 521 160, but the base of the formation is not exposed (Figure 6.19). The shales contain lenses of silt and very fine sand, *Planolites* burrows and *Neomiodon* shell plasters sometimes coated in pyrite. Load casts and detached loadballs occur at the bases of the sandstones. A 1.3 m-thick *Neomiodon* biosparite, with abundant and well-preserved *Viviparus scoticus* Tate, makes a conspicuous karstic outcrop on the shore on the south side of Cladach a'Ghlinne (NG 521 162). The lowest beds of the overlying Duntulm Formation (beds 1–9 of Figure 6.20), including an algal limestone, are exposed in the nearby cliff adjacent to a small cave (NG 521 160). According to Andrews and Walton (1990), this is the best exposure of that formation in Straithaird. The middle and upper part of the Duntulm Formation must crop out beneath the storm beach at the mouth of Glen Scaladal.

The Kilmaluag Formation is almost completely exposed in the prominent cliff section at the northern end of the GCR site (NG 519 165) and in the foreshore to the south (Figure 6.21). The exposure shows well-preserved sedimentary structures despite being mildly metamorphosed by the nearby Cuillin igneous complex. The lower beds, as farther south, comprise mudstone–argillaceous limestone alternations with frequent horizons of desiccation cracks and intra-formational mud-clast conglomerates. These are overlain by distinctive, blue-grey, blue-weathering, hard limestones interbedded with calcareous siltstones and shales; individual limestones have irregular bases and contain bone fragments, *Viviparus* and ostracod valves, the last-named sometimes in rock-forming abundance. Concretions occur in some of the shales. This interval, known as the 'Vertebrate Beds', has yielded mammal and mammal-like reptiles (Savage, 1972; Waldman and Savage, 1972). The overlying Breccia Beds are predominantly dolomitic and weather brownish-yellow. The clasts are more dolomite-rich than the interstitial material and the cuboidal clasts show cryptalgal laminae. Conspicuous pipe-like structures, 40–70 mm across and up to 0.5 m deep, cut these breccias and are filled with similar, but finer-grained, material. The Breccia Beds are overlain by a mudstone with calcrete nodules and then by lithologies similar to the underlying Vertebrate Beds. The basal transition to the Skudiburgh Formation, with limestones being replaced upwards by purple and greenish mudstones, is well exposed in the low cliffs at NG 519 166. A bed-numbered graphic log of the Kilmaluag Formation here is given by Harris and Hudson (1980, fig. 9) and Morton and Hudson (1995, fig. 23).

Interpretation

According to Harris (1989), the shales of the Cullaidh Shale Formation represent deposition in an enclosed, probably stratified, water body (lagoon). They lack marine macrofauna, and palynofloras have largely been destroyed by Tertiary thermal metamorphism so that palaeosalinities remain uncertain. The boundary with the overlying Elgol Sandstone Formation is transitional and demonstrates the genetic relationship between the two formations, the Elgol Sandstone Formation representing delta-front sandstones, and the upper part of the Cullaidh Shale Formation, pro-delta mudstones. The Elgol Sandstone Formation in Straithaird forms a coarsening-upwards deltaic sequence, the sedimentology of which has been investigated by Harris (1989) who undertook detailed facies analysis. According to him, the coarsening-upward sandstones clearly represent shoreline progradation in a shallow water body (rootlets occur 5.5 m above the base). The minor fining-upward sequences indicate sediment supply by small channels flowing southwards. The channel sandstones contain fine-grained sediment drapes and probably had fluctuating discharge regimes. These sequences are interpreted by Harris (1989) as minor fluvial-dominated elongate deltas. Rootlets at the top of the sand bodies indicate plant colonization prior to abandonment and subsidence. The delta shoreline sands at the top of the Elgol Sandstone Formation that contain moulds of probable *Unio* demonstrate that by this time the basin probably contained freshwater; these sands probably also record minor wave reworking.

The restricted fauna of the overlying Lealt Shale Formation is indicative of generally brackish water but with fluctuating salinities. In particular, the boundary beds of the Kildonnan and Lonfearn members show a change from low- to high-salinity faunas; they include a stromatolite bed with pseudomorphs after gypsum, which indicate hypersalinity. The formation is interpreted as representing deposition in shallow water in near-coastal lagoons (Hudson, 1983; Chen and Hudson, 1991).

According to Harris (1992), the outcrops of the Valtos Sandstone Formation in Straithaird show major thickness and facies variations because they are sited near the margin of the Inner Hebrides Basin. The formation is only about 24 m thick (compared with *c.* 120 m in northern Skye; see **Valtos** GCR site report, this volume) and the major sand bodies that dominate the formation elsewhere are replaced by shell-debris limestones, desiccation-cracked and burrowed limestones and shales. The mineralogy also differs: the sandstones are quartzose and contain much less feldspar. Heavy-mineral assemblages are garnet-poor, staurolite-rich and rutile-rich; these probably indicate a significant though indirect input of sediment from the Dalradian rocks of the southern and eastern Highlands (possibly via the Old Red Sandstone, which may have extended into the hinterland of the basin). As elsewhere, pebbles are predominantly of vein quartz. The depositional environment of the Valtos Sandstone Formation is one of lagoonal deltas and interdeltaic lagoon shorelines (Harris, 1992). The characteristics of the limestones near Elgol (facies 5 and 7 of Harris, 1992) are indicative of low subsidence rates and low rates of clastic supply to the area. The desiccation cracks are indicative of periods of subaerial emergence of lagoon margin mudflats; the associated sandstones represent lagoon shoreline sand bodies, and the occurrence of *Neomiodon* in the sandy limestones marks brackish-water transgressions.

Detailed facies analysis of the Duntulm Formation suggests that it represents shallow lagoonal sediments (Hudson and Harris, 1979; Andrews and Walton, 1990). Most of the succession at the GCR site belongs to their lithofacies 1 ('*Praeexogyra* limestone–shales') and lithofacies 2 ('argillaceous limestones') and the algal limestones constitute their lithofacies 3a (Figure 6.20). According to Andrews and Walton (1990), lithofacies 1 is interpreted as probably representing former shell-banks that have 'fallen apart'; the preservation of articulated valves, and the mudstone matrix, militate against strong current reworking, and they were probably agitated by weak, wind-driven tides in shallow water. The argillaceous beds intercalated between the oyster beds are interpreted as inter-shell-bank muds. The clay minerals and silts were probably deposited in the lagoons as distal suspension detritus from small rivers. The limestones of lithofacies 2 probably represent shallow littoral carbonate–siliciclastic mud deposition. The bivalve faunas are identical to those from the inter-shell-bank muds of lithofacies 1 but colonization by oysters was prevented by the soft, muddy substrate. The impure carbonate muds that these beds represent possibly accumulated in quiet water, leeward of the oyster-shell banks that dampened currents. Lithofacies 2 limestones at the base of the formation indicate the final abandonment of the Valtos Sandstone Formation delta as the 'Duntulm transgression' began (Andrews and Walton, 1990). Grain-rich, chaotically bedded laminae alternating with micritic laminae are interpreted as episodic storm layers. Shallow burrowing bivalves and other burrowing organisms bioturbated the muddy substrates during periods of quiescence. The petrography and palaeoecology of the algal limestones of lithofacies 3a have been studied in great detail (Hudson, 1970; Andrews, 1986); the latter author interpreted them as supralittoral 'algal' stromatolites.

The Kilmaluag Formation exposed here belongs to the 'argillaceous limestone' facies of Andrews (1985). Lamination, which is common in the argillaceous limestones, is in places disrupted and domed suggesting that the beds are stromatolitic. Such domes are indicative of a shallow sublittoral to intralittoral depositional environment, which, for the formation as a whole, is deduced to be ephemeral lagoons, closed from the sea. According to Andrews (1985), the basal beds (1–9) represent a mud-dominated, low-salinity lagoon that alternated between clastic and carbonate mud deposition. The rhythmic alternation of muds and muddy carbonates probably reflects climatic control. Magnesium/calcium ratios probably varied during seasonal climatic changes. Mud-clast conglomerates formed when the lagoon evaporated to leave exposed vast mudflats that dried and cracked. The thicker limestones of the so-called 'Vertebrate Beds' have the lowest magnesium content in the Kilmaluag Formation of Straithaird and, according to Andrews (1985), may represent a wet climatic phase. He envisaged gastropods, ostracods and turtles flourishing while terrestrial vertebrate bone fragments accumulated on the muddy lagoon bed. Courses of desiccation breccias may be lagoon floor lags, reworked from the marginal flats, but the Breccia Beds themselves appear to represent the lagoon-marginal mudflats that existed during prolonged periods of exposure and desiccation. Cryptalgalaminates were cracked and partially reworked, accompanied by penecontemporaneous dolomitization. The upper part of the succession records a return to largely sublittoral, lagoonal environments. The recovery of a specimen of *Unio* (Andrews, 1985) probably indicates non-evaporated freshwater. Calcrete nodules, similar to those in the overlying Skudiburgh Formation, which occur amongst the highest beds of the Kilmaluag Formation, probably record the oscillatory transition from relatively extensive, coastal lagoons to smaller alluvial-plain lagoons, and eventually the coastal plain, terrestrial environments of the Skudiburgh Formation.

Conclusions

The Elgol–Glen Scaladal GCR site exposes virtually the entire Great Estuarine Group of Straithaird, southern Skye, and is the only site representing that region. It includes the type section of the Elgol Sandstone Formation, and type and reference sections for the Cuillaidh Shale and Kilmaluag formations. Although thermally metamorphosed and intruded by dykes and sills, the succession records all of the characteristic features of the component formations of the group in the Inner Hebrides Basin, which represent a range of coastal lagoonal and deltaic depositional palaeoenvironments (Figure 6.22). The site is therefore an important one for stratigraphy, sedimentology, palaeoecology and palaeogeography.

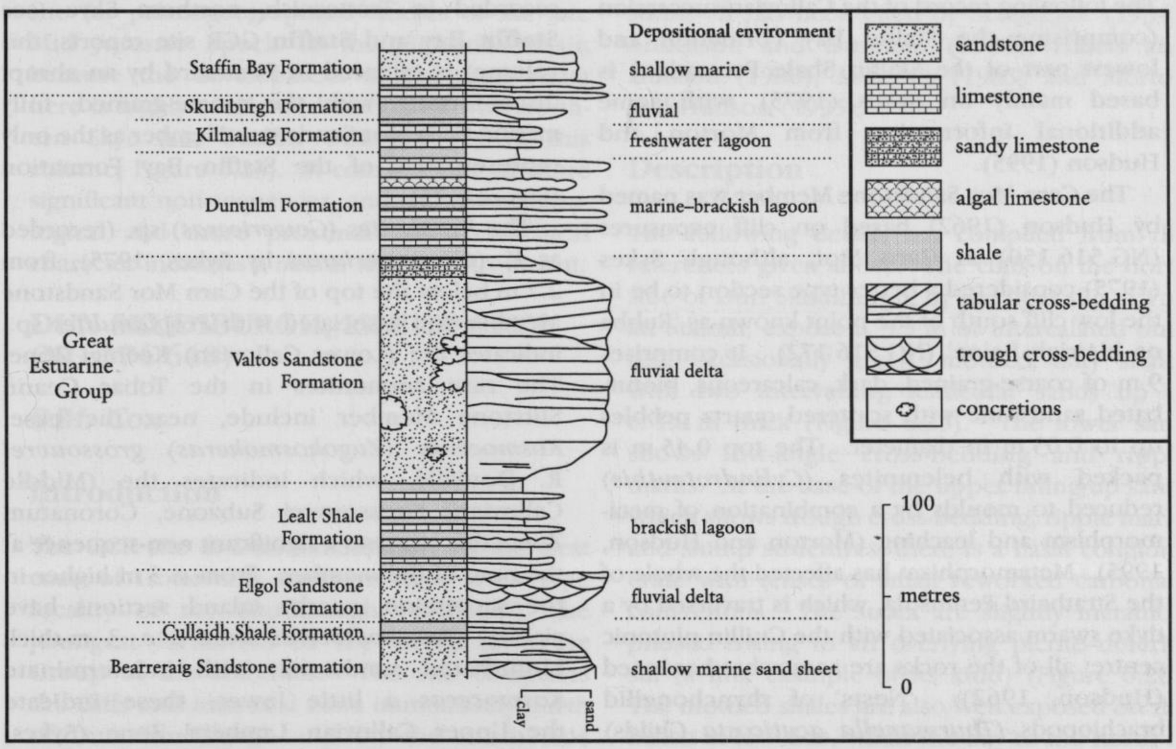

Figure 6.22 Main lithologies, fossils and depositional environments of the Great Estuarine Group of the Inner Hebrides. (After Hudson *et al.*, 1995, fig. 1.)

NORTH ELGOL COAST, ISLE OF SKYE (NG 520 165–NG 517 180, NG 516 150)

K.N. Page

Introduction

The most complete Callovian sections on the Straithaird Peninsula in south-west Skye are on the coast between 2.5 km and 4 km north of Elgol (*c.* NG 520 165–NG 517 180) (see Figure 6.15). A little farther south, other sections occur in the cliff at Carn Mor (NG 516 150) (Hudson, 1962; Turner, 1966; Sykes, 1975). The correlation of the sections in this area, which represent an unusual sandy equivalent of the predominantly muddy succession seen in northern Skye (see **Staffin** GCR site report, this volume), was briefly reviewed by Duff (1980). The site overlaps with, and continues northwards, the Bathonian GCR site known as '**Elgol–Glen Scaladal**' (see GCR site report, this volume), and includes the type section of the Carn Mor Sandstone Member.

Description

The following record of the Callovian succession (comprising the Staffin Bay Formation and lowest part of the Staffin Shale Formation) is based mainly on Sykes (1975), with some additional information from Morton and Hudson (1995).

The Carn Mor Sandstone Member was named by Hudson (1962) based on cliff exposures (NG 516 150) at Carn Mor, although Sykes (1975) considered a better type section to be in the low cliff south of the point known as 'Rubha na h'Airigh Baine' (NG 516 172). It comprises 9 m of coarse-grained, dark, calcareous, bioturbated sandstone with scattered quartz pebbles up to 0.03 m in diameter. The top 0.45 m is packed with belemnites (*Cylindroteuthis*) reduced to moulds by a combination of metamorphism and leaching (Morton and Hudson, 1995). Metamorphism has affected the whole of the Strathaird Peninsula, which is traversed by a dyke swarm associated with the Cuillin plutonic centre; all of the rocks are somewhat hardened (Hudson, 1962). 'Nests' of rhynchonellid brachiopods (*Thurmanella acuticosta* Childs) are locally conspicuous and rare ammonites (*Kepplerites* and *Proplanulites*) also occur. The base of the member is abrupt, with *Thalassinoides* burrows extending down into the mudstones of the Skudiburgh Formation (Great Estuarine Group) below.

The overlying Staffin Shale Formation is much coarser grained in Straithaird than Trotternish in northern Skye (see **Staffin** GCR site report, this volume) and, although Sykes (1975) retained the same formational name for the two areas, he proposed several new members for the succession in Straithaird of which only the lowest, the Tobar Ceann Siltstone, includes strata of Callovian age. These consist of *c.* 6 m of predominantly silty, poorly fossiliferous clays with scattered bivalves and rare ammonites (*Kosmoceras*). The principal exposures are along the foreshore north of Rubha na h'Airigh Baine although the type locality of this member is an inland gully section at NG 565 196.

Interpretation

The Staffin Bay Formation marks the transgression of the Callovian sea over the alluvium of the Skudiburgh Formation (Great Estuarine Group) (see **Elgol–Glen Scaladal** GCR site report, this volume). According to Morton and Hudson (1995), the gentle lagoonal transgression recorded in Trotternish, northern Skye (see **Staffin Bay** and **Staffin** GCR site reports, this volume) is replaced in Strathaird by an abrupt disconformity, with the coarse-grained, fully marine Carn Mor Sandstone Member as the only representative of the Staffin Bay Formation (Figure 6.23).

The *Kepplerites* (*Gowericeras*) sp. (recorded as *K.* (*G.*) *gowerianus* by Sykes, 1975), from 2.7 m below the top of the Carn Mor Sandstone Member and associated with *Proplanulites* sp., indicates the (Lower Callovian) Koenigi Zone. The rare ammonites in the Tobar Ceann Siltstone Member include, near the base, *Kosmoceras* (*Zugokosmokeras*) *grossouvrei* R. Douvillé, which indicates the (Middle Callovian) Grossouvrei Subzone, Coronatum Zone; this suggests a significant non-sequence at the base of the member. From *c.* 3 m higher in the succession, nearby inland sections have yielded *Quenstedtoceras* from a *c.* 3 m-thick bioturbated sandstone, with indeterminate *Kosmoceras* a little lower; these indicate the Upper Callovian Lamberti Zone (Sykes, 1975). Silts above this level have yielded ammonites indicative of the (Lower Oxfordian)

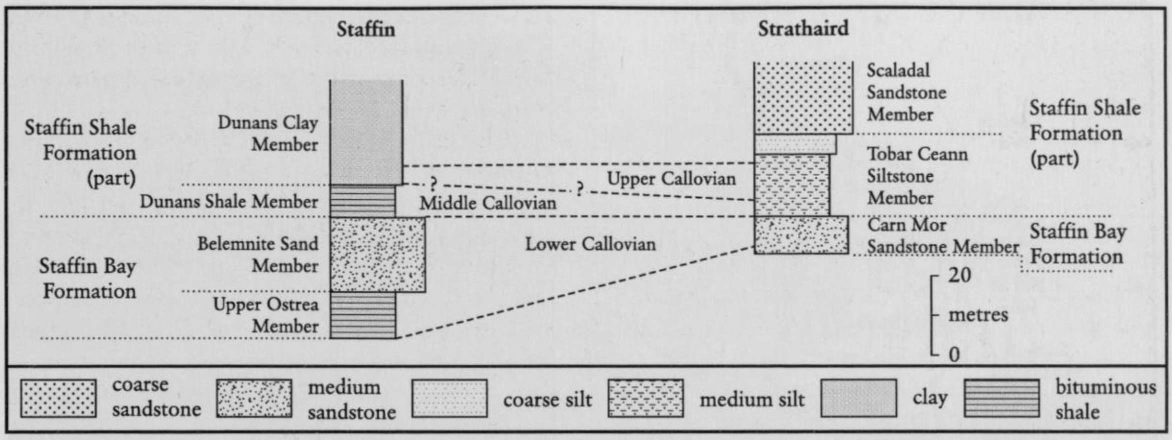

Figure 6.23 Correlation between the Callovian sections at North Elgol and **Staffin**. (After Sykes, 1975, fig. 7.)

Scarburgense Subzone, Mariae Zone and therefore the Callovian–Oxfordian stage boundary is indicated hereabouts.

Conclusions

The North Elgol Coast GCR site includes the type locality of the Carn Mor Sandstone Member of the Staffin Bay Formation. It is an important site for palaeogeographical studies of the late Mid Jurassic Epoch in the Hebrides Basin because the development of Callovian strata here is highly condensed compared with northern Skye (see **Staffin** GCR site report, this volume; Figure 6.23). It contains one or more significant non-sequences, and its coarser lithological and more proximal sedimentological character indicates a nearer shore environment.

DUN SKUDIBURGH, ISLE OF SKYE (NG 374 648)

B.M. Cox

Introduction

The GCR site at Dun Skudiburgh, on the west coast of Trotternish, northern Skye, is the type locality of the Skudiburgh Formation, the youngest formation in the Great Estuarine Group of the Hebrides. The site comprises the cliffs and intertidal zone immediately north of Dun Skudiburgh and on the north side of the Stack of Skudiburgh (Figure 6.24). The Skudiburgh Formation is consistently represented by mottled silty clays and, prior to Harris and Hudson (1980), was known as the 'Mottled Clays' (Anderson, 1948; Anderson and Dunham, 1966; Anderson and Cox, 1948). As elsewhere in Trotternish, the clays at Dun Skudiburgh contain sandy and silty intercalations (Andrews, 1985). The formation is nowhere fully exposed in Trotternish, and the exposed section at the GCR site is relatively short. It has been cited by Macgregor (1934), Anderson and Dunham (1966), Harris and Hudson (1980), Andrews (1985) and Morton and Hudson (1995).

Description

The following details are compiled from the references given above. The cliffs on the north side of Dun Skudiburgh, by the boat slip at Poll an Staimh, expose *c.* 3.5 m of intercalated buff-red, occasionally green, mottled, silty shales with two intervening lenticular sands up to *c.* 1.0 m thick (Figure 6.25). The lower sand shows low-angle cross-bedding and ripple marks. At the base of the upper fining-up sand, which shows trough cross-bedding, ripple marks and slump structures, there is a basal conglomerate with lenses of small reworked carbonate concretions. The strata are slightly metamorphosed owing to an overlying picrite–dolerite sill (a fine example of its kind) (Figure 6.26). The mottled shales are also well exposed on the beach at low tide, when the bay to the north of the GCR site exposes an unmetamorphosed succession.

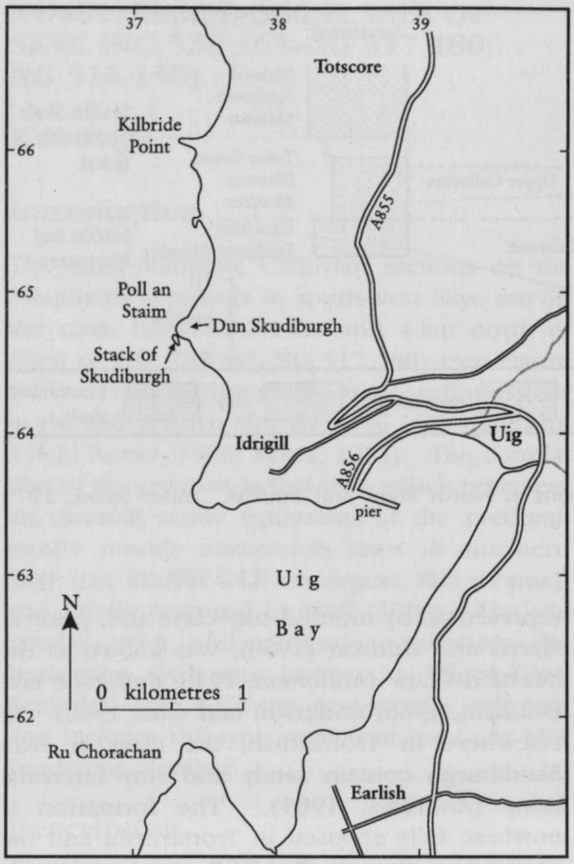

Figure 6.24 Locality map for the Dun Skudiburgh GCR site.

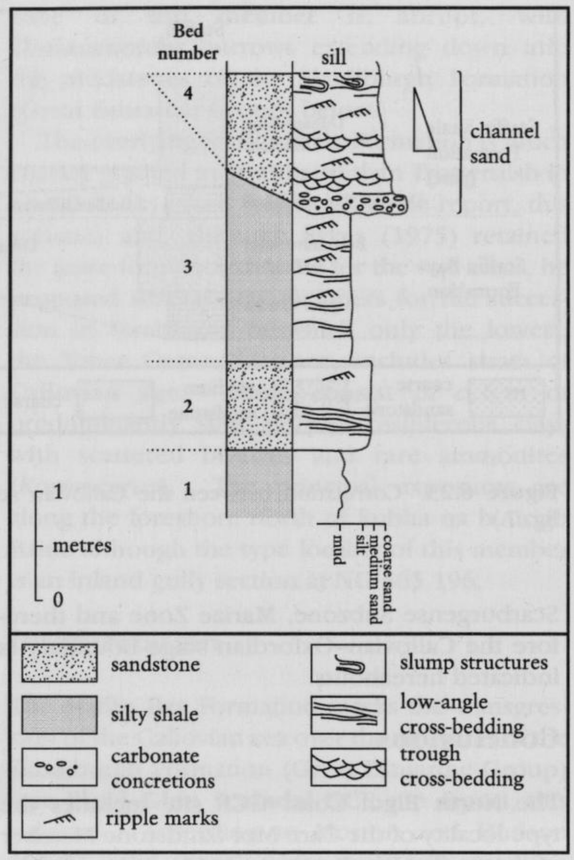

Figure 6.25 Graphic section of the Skudiburgh Formation at Dun Skudiburgh. (After Andrews, 1985, fig. 7.) Bed numbers follow Andrews (1984, 1985).

Interpretation

The depositional environments represented by the rocks of the Skudiburgh Formation have been investigated by Andrews (1985) on which the following notes are based. The succession is interpreted as alluvial in origin. The mottled, red, silty clays represent floodplain sediments with a water table, at the time of deposition, close to the surface. The red colouration, representing dehydrated iron hydroxides, could well have developed almost straight after deposition, the mottled horizons representing alternations between partial dehydration and reduction. In general, mottling is thought to occur only below the water table.

The coarse sandstone units seen at Dun Skudiburgh display the classic fining-upwards cycles and vertical transition of bedforms associated with river-channel deposits. The reworked carbonate concretions, which form a basal conglomerate to the upper channel sand, are believed to have been exhumed from the alluvial plain during channel migration. Carbonate concretions are usually sparsely and randomly distributed within the Skudiburgh Formation. They represent fossil nodular calcretes or caliches that occasionally coalesced to form more extensive, hardpan horizons. They are not algal nodules as suggested by Anderson (1948). Calcrete development requires a source of calcium carbonate and a low floodplain sedimentation rate; the formation of recent calcrete is favoured in a warm climate where there is limited seasonal rainfall. Their presence in the Skudiburgh Formation appears to indicate at least seasonal aridity. The appearance of reworked carbonate concretions at Dun Skudibugh led Macgregor (1934) and Anderson and Dunham (1966) to describe them as 'pebble beds'. Macgregor (1934) thought they were sufficiently different from other rocks in the area that he suggested they might be Cretaceous in age. The only fossil reported from

Figure 6.26 Low cliff exposure of the Skudiburgh Formation beneath the picrite–dolerite sill at Dun Skudiburgh. (Reproduced by kind permission of the Geologists' Association.)

the site is the freshwater bivalve *Unio* (Harris and Hudson, 1980); Andrews (1985) recorded plant debris in his lithological log of the section.

Conclusions

Although not complete, the Skudiburgh Formation is better developed at Dun Skudiburgh, its type locality, than at any other location in the Hebrides. The facies that can be studied there are of considerable palaeogeographical and sedimentological importance. The red-bed lithologies represent an alluvial plain, mudflat environment, which is unique within the onshore British Middle Jurassic succession; the sandstone with its basal conglomerate is indicative of a meandering river channel. Preceded by the oyster-dominated marine to brackish-water lagoonal sediments of the Duntulm Formation (see **Duntulm** GCR site report, this volume) and the lagoonal and mudflat sediments of the Kilmaluag Formation (see **Elgol–Glen Scaladal** GCR site report, this volume), the alluvial mudstones and sandstones of the Skudiburgh Formation represent the last part of the highest of the three major upward-regressive cycles that are recognized in the Great Estuarine Group of the Hebrides. These coastal plain, terrestrial environments were subsequently transgressed by the sea during Callovian times.

DUNTULM (CAIRIDH GHLUMAIG AND LON OSTATOIN) ISLE OF SKYE (NM 411 740–NM 406 733, NM 406 729–NM 408 727)

B.M. Cox

Introduction

The GCR site at Duntulm, on the west coast of northern Skye, includes the type section of the Duntulm Formation as well as exposures of parts of the underlying Valtos Sandstone and overlying Kilmaluag formations. The main section comprises two nearly continuous exposures in the bay (Cairidh Ghlumaig) south of the headland on which Duntulm Castle stands, but a section exposed in the Lon Ostatoin stream, about 1 km south of the headland, is also included (Figure 6.27). The stream section is separated from the coastal section by unexposed ground and by a fault. The sections have been described by Anderson (1948), Anderson and Dunham (1966), Hudson and Morton (1969), Hudson (1970), Harris and

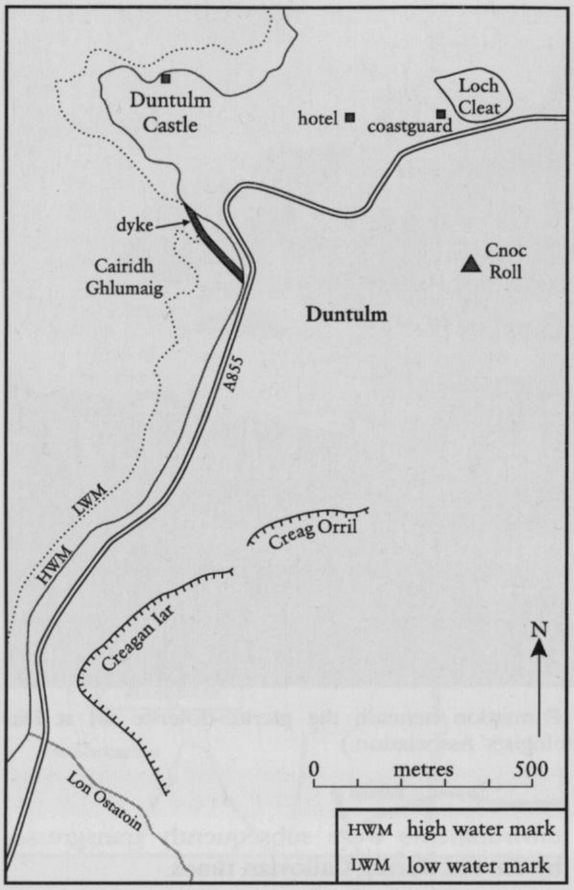

Figure 6.27 Locality map for the Duntulm GCR site. (After Morton and Hudson, 1995, fig. 35.)

Hudson (1980), Bell and Harris (1986), Andrews (1985), Andrews and Walton (1990) and Morton and Hudson (1995).

Description

Cairidh Ghlumaig foreshore

The following section and observations are largely taken from Morton and Hudson (1995); their section is itself based on Hudson (1970) and Harris and Hudson (1980) with additions by J.E. Andrews. The section starts immediately south of the headland. Beds 1–7 (4.1 m thick), which are strongly metamorphosed, are exposed in an 'apron' between the dolerite intrusion that forms the craggy headland, and an offshoot dyke that crosses the foreshore. From there, the succession up to Bed 39 (7.68 m thick), and dipping gently to the south, continues southwards within the bay (Figure 6.28); Bed 39 is conspicuous in the low cliff at the back of the storm beach. There is then a gap in the exposure for about 400 m until beds 40–55 (12.18 m thick) are exposed in another low cliff and the adjacent foreshore. The highest well-exposed bed is a conspicuous nodular algal limestone (Bed 54). The most striking feature of the Duntulm Formation is the monotypic shell beds, either limestones or shales, composed of the oyster *Praeexogyra hebridica* (Forbes). Graphic logs showing lithofacies and palynological data are given by Andrews and Walton (1990), which form the basis of Figure 6.29, Riding *et al.* (1991) and Wakefield (1994).

	Thickness (m)
Duntulm Formation	
55: Shale, silty, green-grey with three *c.* 10 mm-thick pale bands at 1.0 m, 1.2 m and 1.4 m below top; *Corbula* common; *Cuspidaria*, *Myophólas*, *Procerithium*, and plant fragments	3.40
54: Limestone, nodular, algal with various horizons of cryptalgal pelletal laminations; some pale micritic horizons of pelletal limestone	0.60
53: Shale with abundant *Praeexogyra*; harder limestone in middle	0.60
52: Limestone, wavy laminated, cryptalgal with some nodular algal pods	0.15
51: Shale and siltstone; undulose lamination with a few cryptalgal laminations	0.15
50: Shale and shaly limestone; abundant *Praeexogyra*	1.05
49: Shale, dark; no fossils	0.15
48: Shale, calcareous; abundant *Praeexogyra*	0.60
47: Limestone composed of *Praeexogyra* shells	0.23
46: Sandstone, fine grained, calcareous; *Praeexogyra*, *Placunopsis*, *Camptonectes*, *Corbula*, *Modiolus*, *Procerithium*, serpulids encrusting *Praeexogyra* shells, abraded shark teeth, echinoid spines, reworked *Pycnoporidium* colonies; some surfaces intensely bioturbated; *Thalassinoides*	0.30
45: Limestone, hard, laminated with partings; *Placunopsis*, *Modiolus*, *Corbula*, a few rare small *Praeexogyra*, some serpulids attached to *Praeexogyra* shells but not as commonly as in Bed 46; intensely bioturbated with *Pelecypodichnus*; some reworked, nodular, algal material; worm burrows	0.23
44: Shale, dark, abundant *Corbula*, *Placunopsis* and *Cuspidaria*, fish fragments	0.20
43: Limestone, grey, pelletal, small nodular algal heads on top surface; ?mudcracks	0.10
42: Shale, calcareous; *Praeexogyra* and small indeterminate bivalves	0.12
41: Mudstone, structureless, blue-grey, rusty-weathering; carbonaceous fragments and lignite abundant, otherwise no fossils	0.90
40: Shale, carbonaceous, laminated	seen to 0.90
Break in exposure; at most, only 1.0 m missing	
39: Shale, dark, abundant *Praeexogyra*	seen to 2.50
38: Shale, dark	0.30

Figure 6.28 Foreshore exposures of the Duntulm Formation in Cairidh Ghlumaig south of Duntulm Castle. (Photo: M.G. Sumbler.)

	Thickness (m)
37: Limestone, hard; *Praeexogyra*	0.20
36: Shale, dark; abundant *Praeexogyra*	0.30
35: Sandstone, hard, calcareous, very bioturbated with *Thalassinoides* and *Diplocraterion*; *Praeexogyra*	0.30
34: Limestone, sandy; *Praeexogyra*, shark-fin spines	0.15
33: Shale parting	
32: Sandstone, coarse grained; *Praeexogyra*	0.06
31: Sandstone, dark, argillaceous, ripple laminated; *Praeexogyra*; layer with *Praeexogyra* and *Kallirhynchia* at base	0.10
30: Limestone, nodular, algal, grey, with massive fabric	0.20
29: Shale parting	
28: Sandstone, hard, calcareous	0.15
27: Sandstone, soft, argillaceous, intensely bioturbated; *Praeexogyra* in patches only; *Kallirhynchia*, wood fragments	0.75
26: Sandstone, hard, calcareous; *Praeexogyra*	0.20
25: Shale parting	
24: Sandstone, hard, calcareous; abundant *Praeexogyra* and *Kallirhynchia*; reworked fragments of *Pycnoporidium*	0.15
23: Siltstone, ripple laminated; *Praeexogyra*, *Kallirhynchia*, *Myophola*s, *Corbula*, *Modiolus*, *Anisocardia* and fish fragments	0.15
22: Shale, dark; *Myopholas* and *Corbula* abundant; *Cuspidaria*, heterodont bivalves, *Procerithium*?, other gastropods crushed, *Praeexogyra* fragment, shark tooth and fish scales	0.60
21: Shale; *Praeexogyra* abundant	0.15
20: Limestone, nodular, algal, dark-grey, quite soft with irregular domes on top surface; well-preserved *Cayeuxia nodosa* Anderson and thin	

	Thickness (m)
20 (cont.): organic-walled tubes similar to modern *Schizothrix* (this bed often hidden by beach sand)	0.15
19: Shale with lenticular sand horizons; *Praeexogyra*	0.06
18: Sandstone, harder and softer beds, ripple marked; *Praeexogyra*, shark-fin spines, wood fragments	0.30
17: Sandstone, medium grained, in part calcareous; shale partings, 10 mm quartz pebbles; bioturbated with *Diplocraterion*	0.30
16: Sandstone, hard, medium-grained, better sorted than beds above	0.15
15: Shale and siltstone, dark; 20–40 mm-thick, calcareous sandstone layers; ripple laminated	0.70
14: Shale, silty; *Praeexogyra*	0.08
13: Sandstone, argillaceous and calcareous, shelly	0.15
12: Shale, silty	0.15
11: Sandstone, fine-grained; *Praeexogyra*	0.15
10: Shale, dark, silty, bioturbated with *Thalassinoides*; *Praeexogyra*? and hybodont sharks' teeth	0.45
9c: Shale, silty, not obviously fossiliferous	0.18
9b: Sandstone; *Praeexogyra* fragments	0.20
9a: Shale, dark, shelly, pyritic, ?baked by dyke; *Placunopsis*, *Modiolus*, *Cuspidaria*?, fish fragments	0.30
8: Shale, dark, discontinuously exposed; no obvious fossils	0.60
Section interrupted by dyke crossing foreshore	
Valtos Sandstone Formation	
1–7: Siltstones and mudstones with thin calcareous horizons baked by intrusion; *Neomiodon*, *Unio*; large mudcracks in upper part	4.10

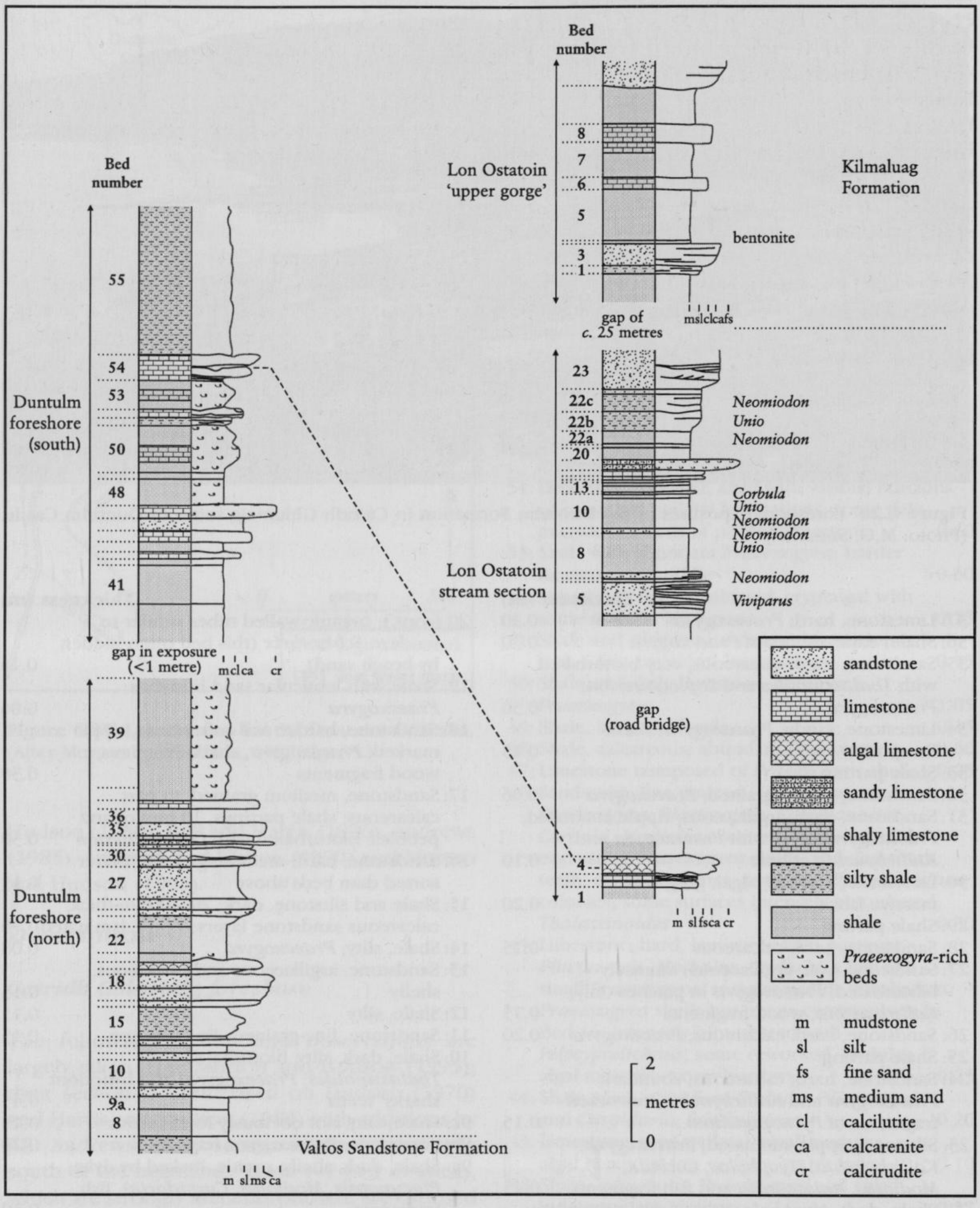

Figure 6.29 Graphic sections of the Duntulm and Kilmaluag formations exposed at the Duntulm GCR site. (After Andrews, 1985, fig. 3; and Morton and Hudson, 1995, fig. 36.) Bed numbers follow Andrews (1984, 1985).

Lon Ostatoin stream section

The stream exposes a good but discontinuous section of the Duntulm Formation, as well as part of the overlying Kilmaluag Formation. The beds are exposed in the south-eastern bank of the stream above and below the road bridge. According to Harris and Hudson (1980) and subsequent authors, the exposures immediately below the bridge on the seaward side include a probable correlative of Bed 54 of the coastal sections (Figure 6.29). Above the bridge, the succession mainly comprises mudstones and siltstones but a *Praeexogyra*-rich limestone (Bed 19) forms a small waterfall. The graphic log given by Andrews and Walton (1990) forms the basis of Figure 6.29; graphic logs showing respectively ostracod and palynological data were given by Wakefield (1994) and Riding *et al.* (1991). Farther up the stream, in what is described by Hudson and Morton (1969) and Morton and Hudson (1995) as the 'upper gorge' (NG 408 727), and after a gap in the succession of *c.* 25 m, an exposure shows *c.* 6 m of the upper part of the Kilmaluag Formation. The beds are predominantly shales, which are unusually rich in smectite, with some shaly limestones (Andrews, 1985). The freshwater gastropod *Viviparus*, conchostrachans and ostracods have been recorded (Hudson and Morton, 1969). Bed 4 of Andrews (1985) is a conspicuous 50 mm-thick, pale, grey-buff coloured, soft clay intercalated within otherwise dark-grey shales that are locally baked by the overlying dolerite sill.

Interpretation

Beds 1–7 of the foreshore section are assigned to the Valtos Sandstone Formation whose sediments are interpreted as being deposited in lagoonal deltas (Harris, 1992). According to this latter author, the mudcracks (desiccation cracks) recorded at Duntulm bear witness to a reduction in clastic supply and probably indicate reduced fluvial runoff. This reduction in clastic supply is associated with the incoming of marine bivalves (first *Placunopsis*, *Cuspidaria* and *Modiolus*, then *Praeexogyra*) which defines the base of the overlying Duntulm Formation (Morton and Hudson, 1995). The Duntulm Formation has the most diverse faunas of all of the formations in the Great Estuarine Group, and the effects of substrate can be most clearly recognized therein (Hudson, 1980; Andrews, 1987). It includes a number of features, such as the sandy beds 9b–19 with conspicuous burrows including *Thalassinoides* and wave-ripple marks, and the algal (cyanobacterial) nodular limestones (beds 20, 30 and 54), which together indicate marine brackish-water salinities (Hudson, 1963a,b). Above Bed 41, the faunas are as marine as any in the Great Estuarine Group, and include abundant dinoflagellate cysts (Andrews and Walton, 1990). In the Lon Ostatoin stream section, the beds yield a low-salinity fauna and flora including *Unio*, *Neomiodon*, conchostracans and *Botryo-coccus*, but just below Bed 19, in which *Praeexo-gyra* is abundant, the fossils, including dinoflagellate cysts, indicate a return to marine conditions. Above this, in beds 22–23, the fossil assemblage again indicates low-salinity conditions.

Detailed facies analysis suggests that the limestones, shales and siltstones of the Duntulm Formation were deposited as shallow lagoonal sediments (Hudson and Harris, 1979; Andrews and Walton, 1990). The sandstones probably represent small deltaic deposits (Andrews, 1987). Features such as mudcracks, algal limestones and lignite-rich mudstones have been interpreted as indicative of lagoon–marginal mudflat palaeoenvironments but the presence of the bivalves *Unio* and *Neomiodon* suggest that at times the lagoons temporarily became freshwater (Andrews, 1987 and references therein). Most of the succession at the GCR site belongs to lithofacies 1 ('*Praeexogyra* limestone–shales') of Andrews and Walton (1990), although the lowest beds constitute lithofacies 4 ('sandstones') and the algal limestones constitute lithofacies 3a. Lithofacies 1 is interpreted as probably representing former shell-banks that have 'fallen apart'. According to Andrews and Walton (1990), the preservation of articulated valves, and the mudstone matrix, militate against strong current reworking; they were probably agitated by weak wind-driven tides in shallow water. The argillaceous beds intercalated between the oyster beds are interpreted as inter-shell-bank muds. The clay minerals and silts were probably deposited in the lagoons as distal suspension detritus from small rivers. The sandstones of lithofacies 4 were possibly formed by the redistribution of fine sand from the delta-front environments. These more distal delta sands were mainly deposited in 'marine' open lagoonal settings where brachiopods, calcareous algae and serpulid worms were able to survive. The petrography and palaeoecology of the algal limestones of lithofacies 3a have been studied in great detail (Hudson, 1970; Andrews, 1986). The latter author interpreted them as supra-littoral algal marsh deposits to shallow littoral algal stromatolites. The micritic horizons of pelletal limestone recorded in Bed 54 probably represent storm-washed carbonate sediments between algal heads (Morton and Hudson, 1995).

The distinctive buff clay (Bed 4) recorded by Andrews (1985) in the Kilmaluag Formation seen in the 'upper gorge' of Lon Ostatoin is surprisingly unbaked and retains a soapy texture; preliminary X-ray diffraction work led Andrews (1985) to interpret it as a bentonite. According to Andrews (1987), it has a mineralogy of more than 85% smectite and vermiculite and is interpreted as a secondary bentonite, the alteration product of a redeposited volcanic ash. The source of this pyroclastic material may have been to the west of the depositional basin, and possibly associated with initial North Atlantic rifting.

Conclusions

This site includes the most important exposure and type section of the Duntulm Formation. The sections are the most fossiliferous, lithologically varied and accessible in that formation, which itself represents the most marine interval in the Great Estuarine Group of the Hebrides. The sections are amongst the best for studying the alternation of marine and freshwater facies in that group.

STAFFIN BAY, ISLE OF SKYE (NG 473 687–NG 474 693)

B.M. Cox

Introduction

The GCR site in the south-western corner of Staffin Bay on the east coast of northern Skye (Figure 6.30) includes exposures of the Skudiburgh Formation and the overlying basal beds of the Staffin Bay Formation (Upper Ostrea Member). It was primarily for these latter beds, thought to be Late Bathonian or Early Callovian in age (Sykes, 1975; Duff, 1980; Bradshaw and Fenton, 1982), that the site was included in the Bathonian GCR network. However, a more recent palynological investigation of the member at its type locality (Point 5 (NG 472 708) of Anderson and Dunham, 1966), *c.* 1.6 km north of the GCR site, suggests that it is Early Callovian in age (Riding, 1992). The exposures within the GCR site were described by Anderson and

Figure 6.30 General view of Staffin Bay looking north-west. The foreshore exposures on the far side of the bay comprise the GCR site. (Photo: M.G. Sumbler.)

Dunham (1966) as the most complete section through the Mottled Clays (now Skudiburgh Formation) in northern Skye, and Hudson (1962) referred to them as the best section of that unit on Trotternish. However, when Harris and Hudson (1980) came to formalize the lithostratigraphy, they considered the exposure at **Dun Skudiburgh** (see GCR site report, this volume), on the west coast of Trotternish, to be superior, although the exposed section there is shorter.

Description

The most detailed description of the beds specific to the GCR site (rather than Staffin Bay in general) is that given by Anderson and Dunham (1966). A large-scale map of the foreshore exposures within the site, which lies between Point 1 (NG 474 694) of Anderson and Dunham (1966) and the River Brogaig, had been produced earlier by Anderson (1948) and, although not easy to follow, gives a general idea of the outcrop pattern on the beach. According to Andrews (1984), Anderson must have mapped the foreshore during an abnormally low spring tide because at normal tides, the outcrop shown on Anderson's map of the Upper Ostrea Member, repeated by a strike fault at the bottom of the beach, cannot be seen (Figure 6.31).

The following section through the Upper Ostrea Member, measured on the foreshore

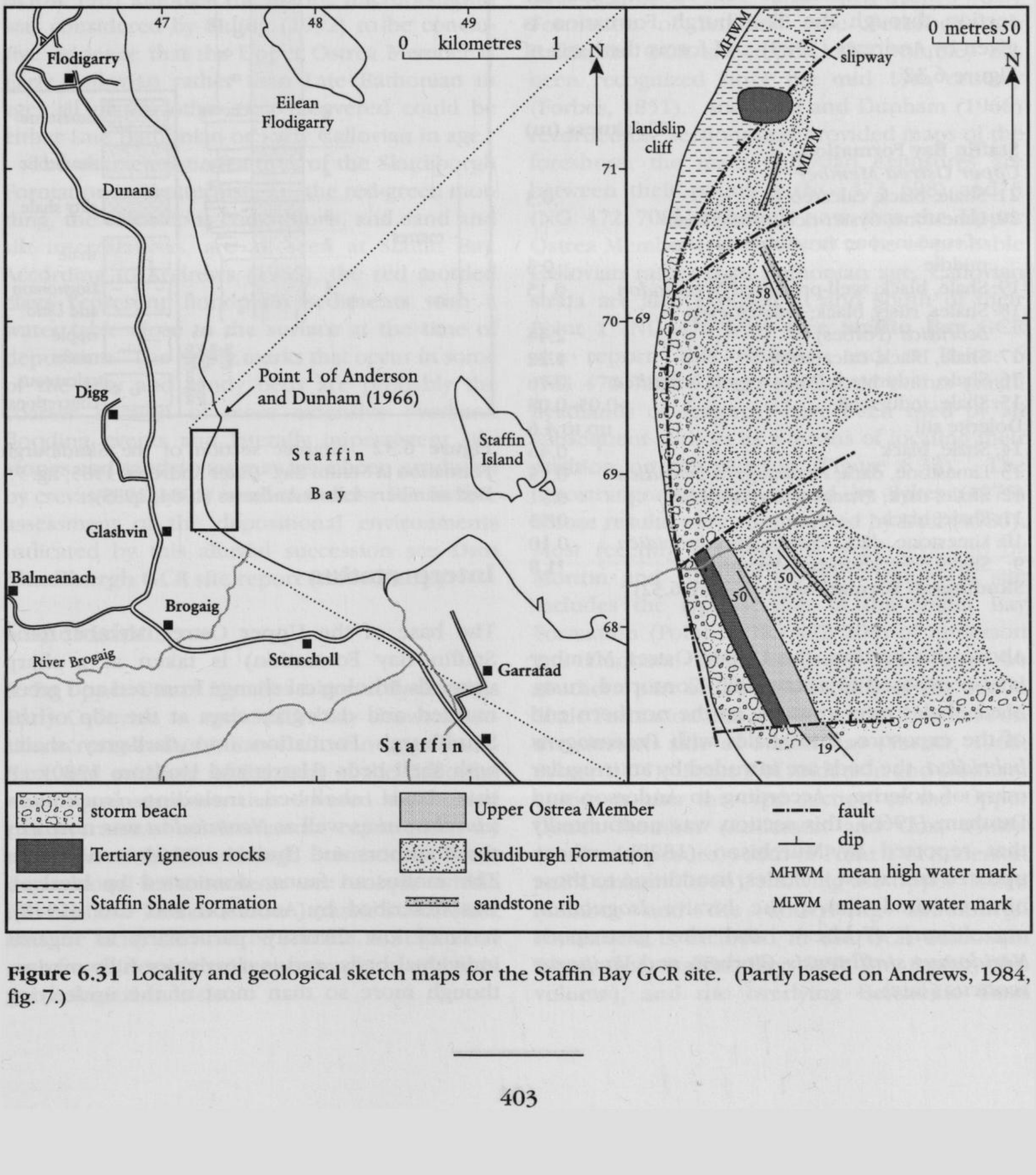

Figure 6.31 Locality and geological sketch maps for the Staffin Bay GCR site. (Partly based on Andrews, 1984, fig. 7.)

c. 366 m south of Point 1 (NG 474 694) where a wedge of sediments has been downthrown by bounding faults to the north and south, is taken from Anderson and Dunham (1966). The southern fault is small and displaces the Upper Ostrea Member by about a metre only. The northern fault has a greater throw, and brings the Upper Ostrea Member against the Skudiburgh Formation. Within a few metres, another nearly parallel fault brings the Skudiburgh Formation against Oxfordian strata. The measured section is interrupted first by a dolerite sill and then, near low water mark, by a strike fault that repeats the Upper Ostrea Member on the seaward side where, at very low tide, shales with *Neomiodon* can be seen (but see above). The beds dip steeply westwards at angles varying from 30° to 90°. A graphic section through the Skudiburgh Formation is given by Andrews (1985) and forms the basis of Figure 6.32.

	Thickness (m)
Staffin Bay Formation	
Upper Ostrea Member	
21: Shale, black, calcareous	0.3
20: Limestone, oyster-rich, sandy, layer of cone-in-cone structure near the middle	0.3
19: Shale, black; well-preserved *Neomiodon*	0.15
18: Shales, rusty, black; *Praeexogyra hebridica* (Forbes)	2.44
17: Shale, black, calcareous	1.22
16: Shale, indurated; *Praeexogyra hebridica*	0.76
15: Shale, indurated	0.05–0.08
Dolerite sill	up to 4.6
14: Shale, black	0.46
13: Limestone, dark; *Praeexogyra hebridica*	0.15
12: Shale, dark; *Praeexogyra hebridica*	0.91
11: Shale, black	0.53
10: Limestone, dark; *Praeexogyra hebridica*	0.10
9: Shale, grey; abundant *Neomiodon*	?1.8
Skudiburgh Formation (see Figure 6.32)	

Above this section, the Upper Ostrea Member is also exposed in a low cliff. Contorted, rusty, black shales pass upwards, at the northern end of the exposure, into shales with *Praeexogyra hebridica*; the beds are intruded by an irregular mass of dolerite. According to Anderson and Dunham (1966), this section was undoubtedly that reported by Murchison (1829b) whose updated faunal list includes, in addition to those bivalves cited above, the bivalve *Isognomon murchisoni* (Forbes), and the gastropods *Neridomus staffinensis* (Forbes) and *Viviparus scoticus* (Tate).

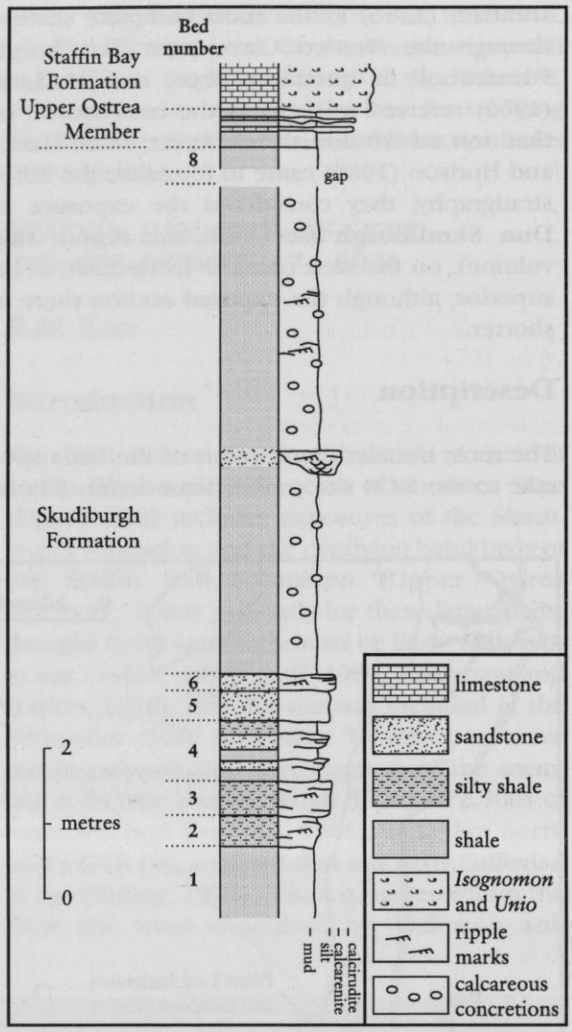

Figure 6.32 Graphic section of the Skudiburgh Formation at Staffin Bay. (After Andrews, 1985, fig. 7.) Bed numbers follow Andrews (1984, 1985).

Interpretation

The base of the Upper Ostrea Member (and Staffin Bay Formation) is taken at a sharp upwards lithological change from red and green mottled and dark-grey clays at the top of the Skudiburgh Formation into dark-grey shales with shell beds (Harris and Hudson, 1980). A thin basal shell-bed including *Isognomon murchisoni* as well as *Neomiodon* was noted by these authors and Hudson and Morton (1969). The molluscan fauna, dominated by bivalves, was described by Anderson and Cox (1948). It is of low diversity, particularly as regards individual beds, and is clearly not fully marine, though more so than most of the underlying

Great Estuarine Group (Morton and Hudson, 1995). Variations in faunal diversity between beds almost certainly reflect fluctuations in salinity. According to Morton and Hudson (1995), there have been no recent sedimentological or palaeoecological analyses but the depositional environment was probably a coastal lagoon. The palynofloras recovered by Riding (1992) from the member's type section, a little to the north of the GCR site, are dominated by miospores with lesser proportions of marine microplankton. The florules are of relatively low species-diversity with the dominance of just one or a few taxa; this is typical of marginal marine environments subject to salinity fluctuations. The presence of the dinoflagellate cyst *Rhynchodiniopsis cladophora* (Deflandre 1938) Below 1981 amongst the marine microplankton was considered by Riding (1992) to be conclusive evidence that the Upper Ostrea Member is Early Callovian rather than Late Bathonian in age; all of the other taxa recovered could be either Late Bathonian or Early Callovian in age.

The characteristic features of the Skudiburgh Formation in Trotternish, i.e. the red-green mottling, the calcareous concretions, and sand and silt intercalations, are all seen at Staffin Bay. According to Andrews (1985), the red mottled clays represent floodplain sediments with a water table close to the surface at the time of deposition. The ripple marks that occur in some of the silty and sandy beds are probably the coarser fraction of more extensive overbank flooding events and laterally impersistent siltstones and sandstones may have been produced by crevasse splays or small channels. For further assessment of the depositional environments indicated by this alluvial succession see **Dun Skudiburgh** GCR site report (this volume).

Conclusions

If the Upper Ostrea Member is correctly dated as Early Callovian in age, Staffin Bay shows a section across the Bathonian–Callovian stage boundary, and evidence of the start of the Callovian marine transgression that covered the coastal plain–terrestrial environments represented by the rocks of the Skudiburgh Formation. These depositional environments are unique within the onshore British Middle Jurassic succession, and the facies that can be studied at Staffin Bay are of considerable palaeogeographical and sedimentological interest.

STAFFIN, ISLE OF SKYE (NG 472 697–NG 471 710)

K.N. Page

Introduction

Callovian strata exposed at Staffin Bay, on the east coast of the Trotternish peninsula in northern Skye, form part of a classic Sub-Boreal–Boreal, Middle–Upper Jurassic sequence. Exposures are primarily on the foreshore between NG 471 710 and NG 472 697, and are accessible only at low tides; in addition, boulders and seaweed can affect the degree of exposure, at least seasonally. Despite these difficulties, the similarity between the argillaceous beds exposed here and the Oxford Clay Formation of England (see **Peterborough Brickpits** GCR site report, this volume) has been recognized since the mid 19th century (Forbes, 1851). Anderson and Dunham (1966) recorded the sections and provided maps of the foreshore; the main Callovian exposures are between their points 3 (NG 473 698) and 5 (NG 472 708), although now that the Upper Ostrea Member is considered to be of probable Callovian rather than Bathonian age, Callovian strata are also exposed at and south of their Point 1 (NG 474 694) (see **Staffin Bay** GCR site report, this volume) and at Point 6 (NG 470 712). These numbered points (small headlands or features) have been used by all subsequent authors as a means of locating their position on the outcrop (Figure 6.33). The lithostratigraphy was revised by Sykes (1975) whose results were summarized by Duff (1980). Most recently, the sections were reviewed by Morton and Hudson (1995). The GCR site includes the type section of the Staffin Bay Formation (Point 5 (NG 472 208) of Anderson and Dunham, 1966; Hudson, 1962) and the southern part of the type locality of the Staffin Shale Formation that is taken as the foreshore on the western side of Staffin Bay (Turner, 1966; Sykes, 1975). Point 5 of Anderson and Dunham (1966) is also the type section of the Upper Ostrea Member (Anderson and Cox, 1948). Another exposure, south of Point 1 of Anderson and Dunham (1966), showing the Upper Ostrea Member and the underlying Skudiburgh Formation, is included in the GCR Bathonian Block (see **Staffin Bay** GCR site report, this volume), and the overlying Belemnite Sand

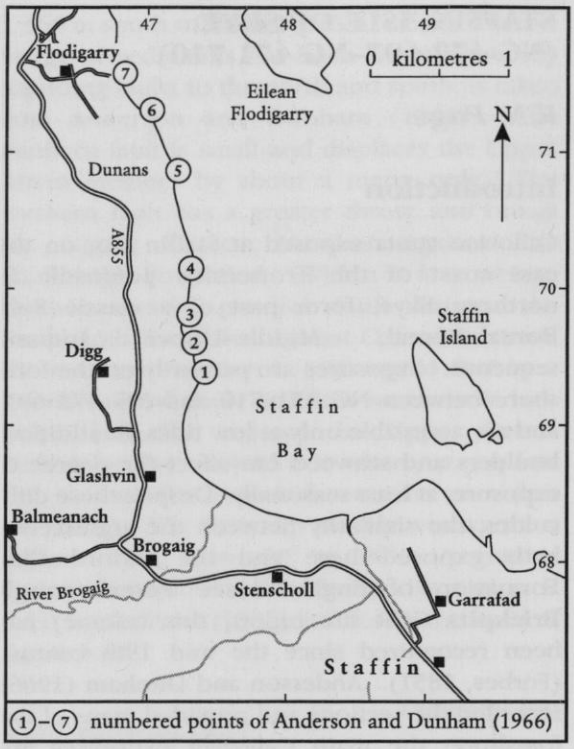

Figure 6.33 Locality map for the Staffin GCR site.

Member also has Staffin Bay as its type locality (Anderson and Cox, 1948). The Dunans Shale Member, at the base of the Staffin Shale Formation, was proposed by Sykes (1975) with, again, a type section at Point 5 of Anderson and Dunham (1966). The Dunans Clay Member was proposed by Sykes (1975) with a type section on the foreshore midway (NG 473 699) between points 3 and 4 of Anderson and Dunham (1966).

Description

The following section of the Callovian succession is based mainly on Morton and Hudson (1995); bed numbers for the Staffin Shale Formation are those of Sykes and Callomon (1979).

	Thickness (m)
Staffin Shale Formation	
Dunans Clay Member (part)	
SS6 (part): Clay, silty, grey-green; highly bioturbated by *Thalassinoides* and *Chondrites*; layers of lignite debris; phosphatic nodules; *Bositra buchii* (Roemer) at base only; sporadic nuculacean bivalves, belemnites and ammonites (*Kosmoceras* and *Quenstedtoceras*) above	2.20
SS5c: Siltstone, carbonate-cemented ('cementstone') with ammonites (*Kosmoceras* and *Quenstedtoceras*)	0.25
SS5b: Clay, silty; *Bositra buchii* common; ammonites (*Kosmoceras* and *Quenstedtoceras*)	0.45
SS5a: Siltstone, carbonate cemented ('cementstone')	0.25
SS4: Silts and silty clays, pale grey-green; profuse *Bositra buchii* at several horizons; several rows of phosphatic nodules; ammonites (*Kosmoceras*); base burrowed by *Chondrites*	1.90
Dunans Shale Member	
SS3: Shale, dark grey, bituminous, barren except for occasional belemnites	3.45
SS2: Shale, laminated, black, bituminous; *Lingula* and belemnites	0.45
SS1: Clay, shaly, medium- to dark-grey with layers of glauconitic silt burrowed by *Chondrites*; *Kosmoceras* at sharp base and at 0.85 m and 1.20 m above	?2.45
Staffin Bay Formation	
Belemnite Sand Member	
BS7: Limestone, red-weathering, hard, sandy, glauconitic and sideritic; white nodules in lower part; abundant belemnites (*Cylindroteuthis*)	0.25
BS6: Sandstone, soft, argillaceous; belemnites	0.30
BS5: Sandstone, hard, calcareous, glauconitic, pebbly; rubbly weathering with nodular *Spongeliomorpha suevica* (Reith); belemnites	0.20
BS4: Sandstone, massive, hard, calcareous; apparently unfossiliferous; sharp base	0.20
BS3: Soft, carbonaceous, shelly siltstones and fine-grained sandstones; top marked by hardground; ripple cross-lamination mostly disturbed by bioturbation; burrows outlined by carbonaceous laminae; bivalves including *Astarte* and *Camptonectes*, as well as '*Liostrea*' and *Neomiodon*	0.20
BS2: Limestone, hard, sandy with fine-grained matrix and carbonaceous fragments; bivalves (mostly disarticulated) and ammonites (*Cadoceras* and *Kepplerites*)	3.00
BS1: Soft, carbonaceous, shelly siltstones and fine-grained sandstones; small-scale ripple-bedding outlined by carbonaceous laminae; bivalves including '*Liostrea*', *Oxytoma*, *Pleuromya* and *Trigonia*	0.60
Upper Ostrea Member	
UO5: Shale, dark, very shelly with layers of mainly articulated bivalves; prominent shell-bed at top; bivalve fauna dominated by *Neomiodon* with occasional *Staffinella*	2.90
UO4: Siltstone, soft, shelly with carbonaceous streaks and ripple cross-lamination; *Neomiodon*?	1.20
UO3: Shale, dark, very shelly with shell beds some including *Praeexogyra hebridica* (Forbes); other bivalves including *Isocyprina*, *Isognomon*?, *Neomiodon*, *Staffinella* and *Vaugonia staffinensis* (Anderson and Cox)	4.55
UO2: Limestone, massive, hard, shelly with '*Liostrea*' and other bivalves	0.75
UO1: Shale, dark with harder pyritic layers including 0.08 m-thick basal shell-bed; fauna dominated by *Isognomon* and *Neomiodon*	1.80
Great Estuarine Group	
Skudiburgh Formation	

Interpretation

The molluscan fauna of the Upper Ostrea Member, dominated by bivalves, is of low diversity and indicative of brackish salinity conditions (Anderson and Cox, 1948; Hudson, 1963a,b). Palynofloras recovered by Riding (1992) from this section are dominated by miospores with lesser proportions of marine microplankton. The florules are of relatively low species-diversity with the dominance of just one or few taxa; this is typical of marginal marine environments subject to salinity fluctuations. The presence of the dinoflagellate cyst *Rhynchodiniopsis cladophora* (Deflandre 1938) Below 1981 amongst the marine microplankton was considered by Riding (1992) to be conclusive evidence that the Upper Ostrea Member is Early Callovian rather than Late Bathonian in age (Riding and Thomas, 1997); all other taxa recovered could be either Late Bathonian or Early Callovian in age. No ammonites are known from the member. The Belemnite Sand Member includes a more varied and marine bivalve fauna than the Upper Ostrea Member, and ammonites, albeit very rare, are also present. These include *Kepplerites* (*Gowericeras*) *galilaeii* (Oppel) and *Cadoceras* aff. *sublaeve* (J. Sowerby) in Bed BS2 indicating the Galilaeii Subzone (Koenigi Zone, Lower Callovian) (Figure 6.34). The incoming of abundant cylindroteuthid belemnites at the top of the member is comparable with their appearance at the base of the Calloviense Zone in southern England. A plesiosaur found in a loose boulder on the foreshore hereabouts is believed to have come from this member (Clark *et al*., 1993).

The Dunans Shale Member is poorly fossiliferous except for *Chondrites*-type burrows and *Lingula* in the more silty beds. Belemnites may also occur in the silty beds but ammonites are common only near the base of the member. These include abundant *Kosmoceras* (*Gulielmiceras*) *medea* Callomon (macroconch and microconch) in Bed SS1 (indicative of the Middle Callovian Medea Subzone, Jason Zone), and *K.* (*G.*) *jason* auctt. a little higher (Jason Zone and Subzone; Sykes, 1975; Morton and Hudson, 1995). The only ammonite evidence from the upper and greater part of the member is a specimen of *Erymnoceras* cf. *coronatum* (Bruguière) collected loose from a concretion (ex Bed SS3) indicating the Middle Callovian Coronatum Zone (possibly Obductum Subzone; Morton and Hudson, 1995). Ostracods and foraminifera also appear to be virtually absent (Sykes, 1975; Whatley, 1970).

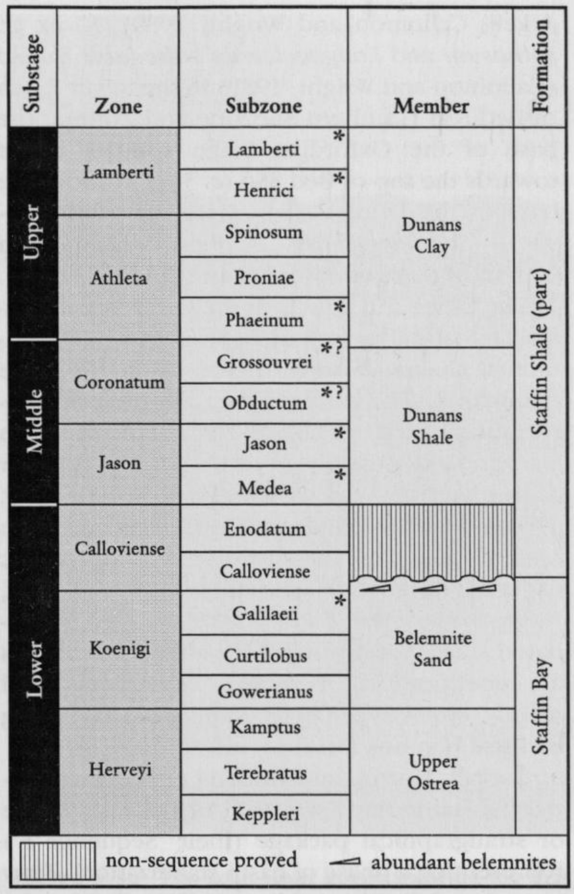

Figure 6.34 Main stratal divisions of the Callovian succession at Staffin. Not to scale. (* = presence of subzone indicated by ammonites.)

In the Dunans Clay Member, beds SS5a–c form a prominent marker horizon. Several layers are packed with the supposed hemipelagic bivalve *Bositra buchii*. The ammonite fauna is often abundant but typically crushed in the clays. Bed SS4, at the base of the member, has yielded *K.* (*Lobokosmokeras*) ex gr. *phaeinum* S.S. Buckman indicating the Phaeinum Subzone (Athleta Zone, Upper Callovian), although records by Turner (1966) suggest that *K.* cf. *grossouvrei* R. Douvillé of the topmost Middle Callovian Grossouvrei Subzone may also occur in this bed and hence, the Coronatum–Athleta zonal boundary. Higher levels have yielded species of *Quenstedtoceras* and *Kosmoceras* ex gr. *spinosum* (J. Sowerby) from Bed SS5b–c, indicative of the ?Henrici Subzone (Upper Callovian Lamberti Zone), and *Quenstedtoceras* ex gr. *lamberti* (J. Sowerby) (including *Q. grande*

Arkell; Callomon and Wright, 1989), *K.* ex gr. *spinosum* and *Longaeviceras holtedahli* Salfeld (Callomon and Wright, 1989) in the lower 2.2 m of Bed SS6 (Lamberti Subzone and Zone). The base of the Oxfordian Stage appears to lie towards the top of Bed SS6 (*c.* 5.05 m above the base of the Dunans Clay Member) as *Cardioceras* (*Scarburgiceras*) is present in the top 0.35 m of that bed (Morton and Hudson, 1995).

The facies and faunas of the Callovian succession at Staffin Bay indicate a progressive environmental change from restricted to open marine conditions. The Upper Ostrea Member was probably deposited in a coastal lagoon that was then transgressed possibly by an offshore sand-bar represented by the Belemnite Sand Member. The general lack of benthos in the Dunans Shale Member suggests that the sea floor was anoxic for much of the time, with only occasional, brief, more oxygenated phases indicated by bioturbated silts. The Dunans Clay Member indicates an amelioration of seabed conditions, and mainly well-oxygenated conditions favouring infaunal benthos (Morton and Hudson, 1995).

Overall, Morton and Hudson (1995) interpreted the Staffin Bay Formation as a thin sequence or stratigraphical package (their 'Sequence F') representing a phase of basin stabilization. They interpreted the abrupt change of lithology at the base of the overlying Staffin Shale Formation as marking a sequence boundary and a minor hiatus in sedimentation. They suggested that the relatively thin Callovian part of the overlying sequence indicated a continued phase of basin stabilization, followed by a renewed phase of subsidence in Oxfordian and Early Kimmeridgian times; sediment thicknesses of that age are much greater.

Conclusions

The Staffin GCR site includes the type sections of the Staffin Bay and Staffin Shale formations and of their Callovian component members. The sections are crucial to the understanding of the development of the Hebrides Basin during Mid to Late Jurassic times, and good overall age controls on the succession make close comparisons with other regions possible. Of note is the significant development of bituminous shale deposition in the Middle Callovian succession, especially in the Coronatum Zone, as elsewhere in Britain (see **Peterborough Brickpits** GCR site report, this volume).

VALTOS, ISLE OF SKYE (NG 523 601–NG 522 610, NG 528 622–NG 521 628, NG 517 638–NG 509 654)

B.M. Cox

Introduction

The GCR site known as 'Valtos' comprises three separate stretches of coast and a river section on the east side of Trotternish in northern Skye (Figure 6.35).

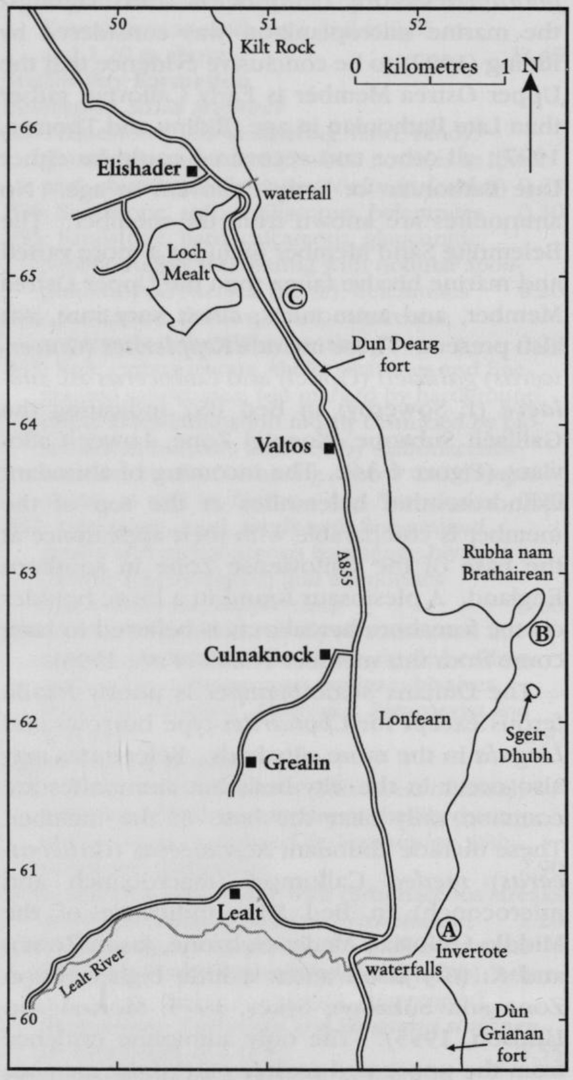

Figure 6.35 Locality map for the Valtos GCR site which comprises three separate localities. (A) Invertote and Lealt River; (B) Rubha nam Brathairean (Sgeir Dhubh to mouth of Lonfearn Burn); (C) Valtos to Mealt Falls.

(A) The most southerly locality (NG 523 601–NG 522 610) comprises a section in the Lealt River, and on the shore at its mouth at Invertote. It exposes a complete but discontinuous succession from the ?uppermost Bearreraig Sandstone Formation, through the overlying Elgol Sandstone Formation, Lealt Shale Formation (including its type section), and up into the lower part of the Valtos Sandstone Formation. Thick dolerite sills intrude the Lealt Shale Formation, and part of the succession is faulted.

(B) About 1.5 km farther north, foreshore and cliff exposures (NG 528 622–NG 521 628) around the promontory of Rubha nam Brathairean, between Sgeir Dhubh and the mouth of the Lonfearn Burn, show the most complete section of the Lealt Shale Formation and include the type section of its Lonfearn Member.

(C) A farther 1 km to the north, an almost continuous section through the Valtos Sandstone Formation is seen in the cliffs below Valtos and Dun Dearg to Mealt Falls (NG 517 638–NG 509 654), and is the type section for that formation.

Description

(A) Invertote and Lealt River

The sections here (e.g. see Figure 6.36) have been described by Anderson and Dunham (1966), Hudson and Morton (1969), Harris (1989) and Morton and Hudson (1995). The cliff to the south of the Lealt River at Invertote exposes the Elgol Sandstone Formation, which here is the basal formation of the Great Estuarine Group, overlying similar coarse sandy beds that are questionably assigned to the Bearreraig Sandstone Formation. The following section is based on Morton and Hudson (1995).

	Thickness (m)
Elgol Sandstone Formation	
7: Sandstone, coarse with erosional base and prominent planar cross-bedding	seen *c.* 0.30
?Bearreraig Sandstone Formation	
Rigg Sandstone Member	
6: Sandstone, fine- to medium-grained, uncemented; clay flasars; bioturbated (marked by carbonaceous wisps)	0.62
5: Sandstone, medium grained, wood fragments, mudstone clasts; abundant *Meleagrinella*, *Globularia*, *Procerithium*?; *Thalassinoides* and *Planolites*, especially at base	0.24
4: Shale, hard, black; thin siltstone layers increasing upwards	0.07
3: Sandstone, medium grained, calcareous and carbonaceous; nerineid gastropods, *Globularia*, *Grammatodon*?, *Pleuromya*; *Teichichnus*, *Planolites*; sharp base	0.48
2c: Shale, dark-grey	0.05
2b: Sandstone, grey, fine- to medium-grained; convoluted flame-structures at base	0.14
2a: Sandstone, grey, becoming more carbonaceous upwards; top 0.06 m with lignitic lenses	*c.* 1.90
1: Sandstone, mainly coarse-grained, cross-bedded in 0.20 m sets; foresets with carbonaceous laminae	seen to 6.00

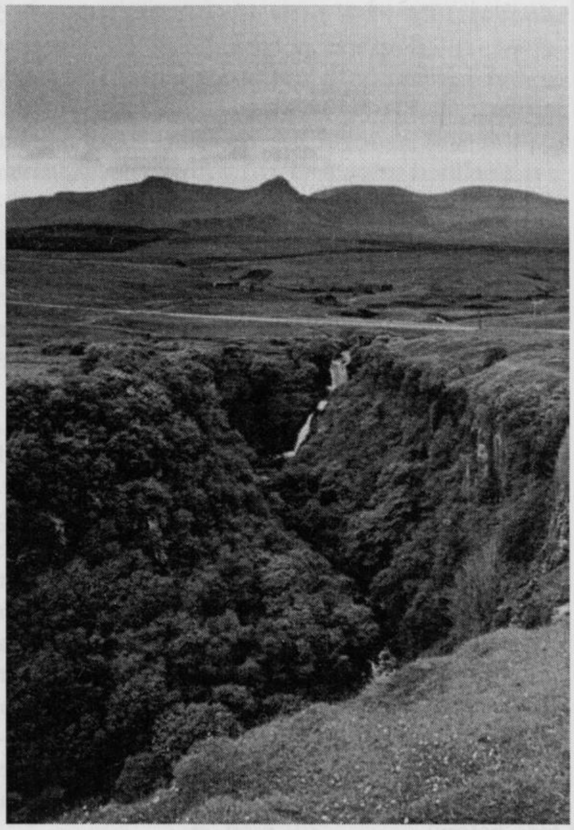

Figure 6.36 The Lealt River gorge showing the first waterfall (formed by a dolerite sill) below the road bridge. The upper part of the Lealt Shale Formation is exposed above the waterfall. (Photo: M.G. Sumbler.)

The Elgol Sandstone Formation at Invertote comprises a 1.5 m-thick burrowed sandstone overlain by two, complex, fining-upwards sequences with prominent scour-surfaces and lags of quartz pebbles (Harris, 1989). Trough and tabular cross-stratification (0.05–0.30 m) dominate the basal parts of these sequences and gives a complex polymodal palaeocurrent pattern with both northerly and southerly modes. The sequences also include planar lamination and a single large-scale (1.5 m) tabular set (inclined towards 160°) with mud drapes on foreset surfaces. The two sequences are separated by a laterally persistent mudstone with *Monocraterion* and branching *Thalassinoides*? burrows. Graphic logs of the Elgol Sandstone Formation close to the mouth of the Lealt River and on the foreshore 750 m to the north are given by Harris (1989).

The top of the Elgol Sandstone Formation, overlain by the Lealt Shale Formation, is well exposed near the mouth of the Lealt River. Between the shore and the road bridge over the river, two dolerite sills form waterfalls. The lower part of the Lealt Shale Formation is not well exposed here but the following section through the upper beds, as exposed between the road bridge and the first waterfall below it (Figure 6.36), is taken from Morton and Hudson (1995); only the upper part of the section is normally accessible. The bed numbers relate to the more complete sections in the Lonfearn area (see below).

	Thickness (m)
Lealt Shale Formation	
Lonfearn Member	
15: Shale, dark, fissile; conchostracans	0.60
14: Limestone, thin bedded, shelly; fibrous calcite, pyrite	0.08
11–13?: Shale, as Bed 15; conchostracans	1.50
10: Limestone, oosparite and intrasparite; ostracods; upper part massive oolite, lower part with partings and fibrous veins	0.20
9: Shale, dark, fissile; conchostracans, *Neomiodon*, ostracods	0.78
8: Limestone with coarse (2 mm) intraclasts; forming prominent regular bed (top of fall at low water)	0.24
3–7?: Shale, less fissile (very baked)	0.78
Limestone, thin-bedded, shelly, partings	0.26
Shale, dark, baked	0.90
Limestone, shelly	0.08
Shale, ?with thin limestones	*c.* 3.0
2: Limestone, coarsely shelly; base deformed by concretion growth below	0.19
1b: Shale, very shelly (*Isognomon*?, heterodont bivalves); concretions up to 0.12 m thick and 0.70 m diameter	0.07
1a: Shale, dark, irregular top and base	up to 0.35
Kildonnan Member	
12: *Stromatolite Bed*	
12c.: Limestone, laminated, irregular upper surface, weathering pale-grey	0.10
12b: Limestone, irregular, brecciated	up to 0.10
12a: Limestone, laminated, shelly; abundant *Placunopsis*, *Cuspidaria*	0.12
11: Shale, dark	0.90
10: Limestone, calcilutite; whole, small heterodont bivalves	0.09
9: Shale, hard, variably shelly; ostracods, fish scales and bone fragments 0.60 m from top; basal 0.20 m shelly with *Neomiodon*?, *Isognomon* or *Praemytilus*?	1.00
8: Limestone, coarsely shelly with jumbled shells; beneath it, 0.15 m thick and 0.70 m diameter septarian concretions with black calcite	0.02
7: Shale or mudstone, very baked, paler than above; conchostracans at 1.10 m below concretions	c. 3.50
Top of thick dolerite sill forming waterfall	

The overlying Valtos Sandstone Formation is seen higher up in the Lealt River (Harris, 1992), outside of the GCR site.

(B) Rubha nam Brathairean (Sgeir Dhubh to mouth of Lonfearn Burn)

The coastal exposures from south of Rubha nam Brathairean to the mouth of the Lonfearn Burn are the best sections of the Lonfearn Member of the Lealt Shale Formation, and constitute its type section. The underlying Kildonnan Member is here dominated by the ostracods *Limnocythere incerniculum* Wakefield and *Darwinula pulmo* Wakefield, the bivalve *Neomiodon brycei* (Tate), the conchostracan *Neopolygrapta lealtensis* Chen and Hudson, the gastropod *Viviparus scoticus* (Tate), as well as numerous fish and plant fragments (Wakefield, 1995). Its boundary with the Lonfearn Member is exposed at sea level in a small embayment south of Rubha nam Braithairean, behind dolerite skerries that extend south to Sgeir Dhubh (NG 526 625). The succession is similar to that described above in the Lealt River but the section is superior because the beds are not metamorphosed and are much more accessible (though not for those prone to vertigo). They have yielded rich ostracod and conchostracan faunas (Chen and Hudson, 1991) and a dinosaur footprint (Andrews and Hudson, 1984). The boundary with the overlying Valtos Sandstone Formation is exposed at the mouth of the Lonfearn Burn (NG 521 627) and in the lower part of the burn itself. Shales with desiccation cracks and conchostracans, which mark the top of the Lonfearn Member, pass gradually up into siltstones with *Neomiodon* (Harris and Hudson, 1980).

Graphic logs of the section are given in Harris and Hudson (1980) (which forms the basis of Figure 6.37) Riding *et al.* (1991) and Wakefield (1994, 1995).

(C) Valtos to Mealt Falls

The spectacular but treacherous cliffs below Valtos and Dun Dearg (see Figure 6.38), and northwards to the Mealt Falls, expose a fine and almost continuous section through the Valtos Sandstone Formation and constitute its type locality (Harris and Hudson, 1980). The total thickness of the formation in Trotternish is about 120 m and it has been divided into three informal lithostratigraphical units: a lower sandstone-dominated unit, a middle limestone–shale-dominated unit, and an upper sandstone-dominated unit (Harris, 1992). All but the base of the lower unit and top 20–30 m of the upper unit are exposed within the GCR site. The lower unit (*c.* 48 m thick) is almost continuously exposed between Valtos and Mealt Falls. It is dominated by cross-bedded, coarsening-upwards sandstones with intervening silty shales; calcite concretions are conspicuous. Escape structures, probably made by the ubiquitous *Neomiodon*, are also evident, and winnowed valves of that bivalve also dominate a coarse sandy to granular biosparite at the top of

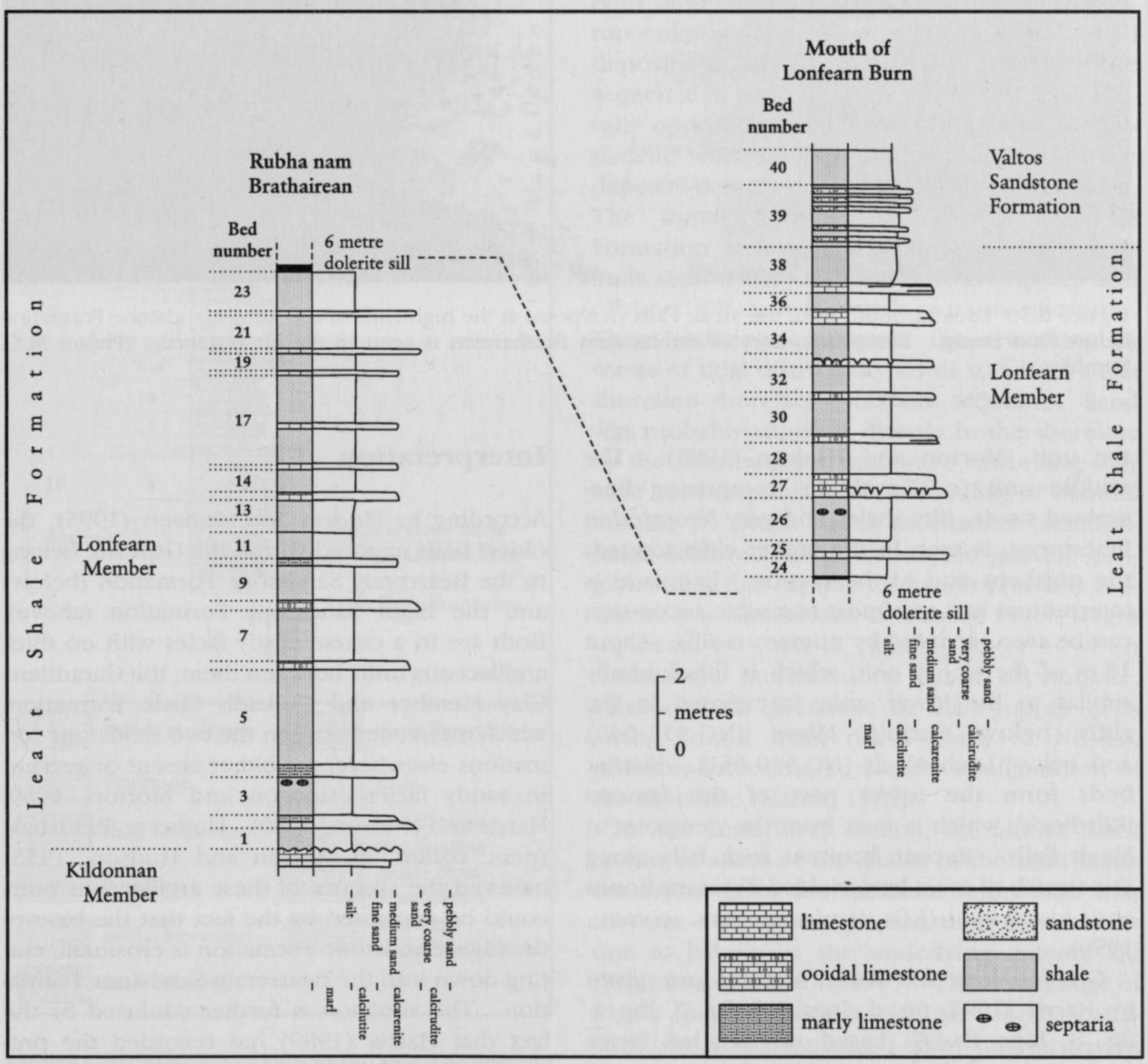

Figure 6.37 Graphic section of the Lonfearn Member (Lealt Shale Formation) at its type locality. (After Harris and Hudson, 1980, fig. 6.) Bed numbers follow Harris and Hudson (1980).

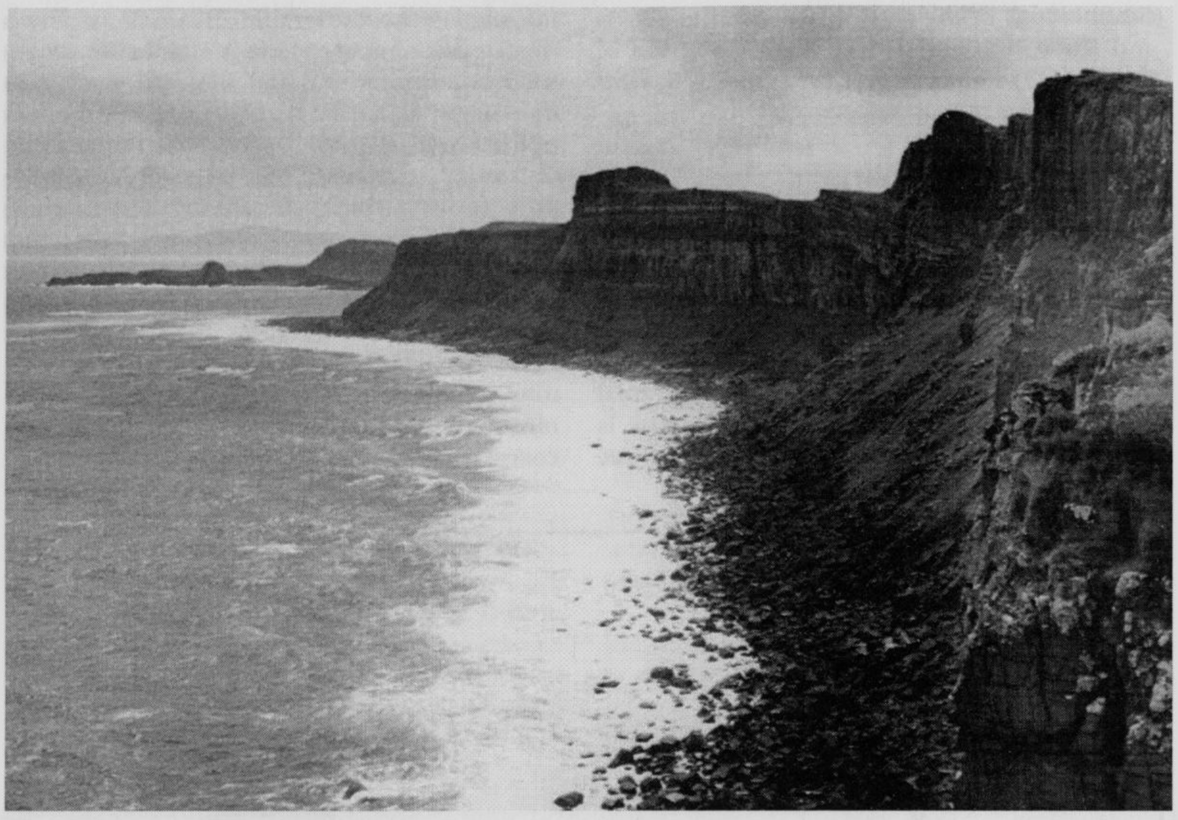

Figure 6.38 Looking south from the Mealt Falls viewpoint at the high cliffs of the Valtos Sandstone Formation below Dun Dearg. The promontory of Rubha nam Brathairean is seen in the far distance. (Photo: M.G. Sumbler.)

the unit (Morton and Hudson, 1995). The middle unit (*c.* 27 m thick), comprising fine-grained sands, silty shales and grey *Neomiodon* limestones, is seen in the higher cliffs towards the northern end of the section. Exposure is intermittent but an almost complete succession can be seen intruded by numerous sills. About 15 m of the upper unit, which is lithologically similar to the lower unit, is exposed in the cliffs below Carraig Mhor (NG 511 649) and below Loch Mealt (NG 510 651). Similar beds form the lower part of the famous 'Kilt Rock', which is seen from the viewpoint at Mealt Falls. Recent frequent rock falls along this stretch of coast have yielded dinosaur bones and footprints (J.D. Hudson, pers. comm., 1996).

Graphic logs for these sections are given by Harris (1992, fig. 6, logs 3,4; fig. 7, log 4; fig. 8, logs 4b,4,5) based on detailed facies analysis, but the composite log shown here in Figure 6.39 is based on Harris and Hudson (1980).

Interpretation

According to Morton and Hudson (1995), the oldest beds exposed within the GCR site belong to the Bearreraig Sandstone Formation (below) and the Elgol Sandstone Formation (above). Both are in a coarse sandy facies with no thick argillaceous units between them; the Garantiana Clay Member and Cullaidh Shale Formation, which intervene between the two sandstone formations elsewhere, are either absent or present in sandy facies (Hudson and Morton, 1969; Harris and Hudson, 1980). However, Bradshaw (pers. comm. in Morton and Hudson, 1995) believed the absence of these argillaceous units could be explained by the fact that the base of the Elgol Sandstone Formation is erosional, cutting down into the Bearreraig Sandstone Formation. The situation is further confused by the fact that Harris (1989) has recorded the presence of the Cullaidh Shale Formation at Invertote.

The exposures of the Elgol Sandstone Forma-

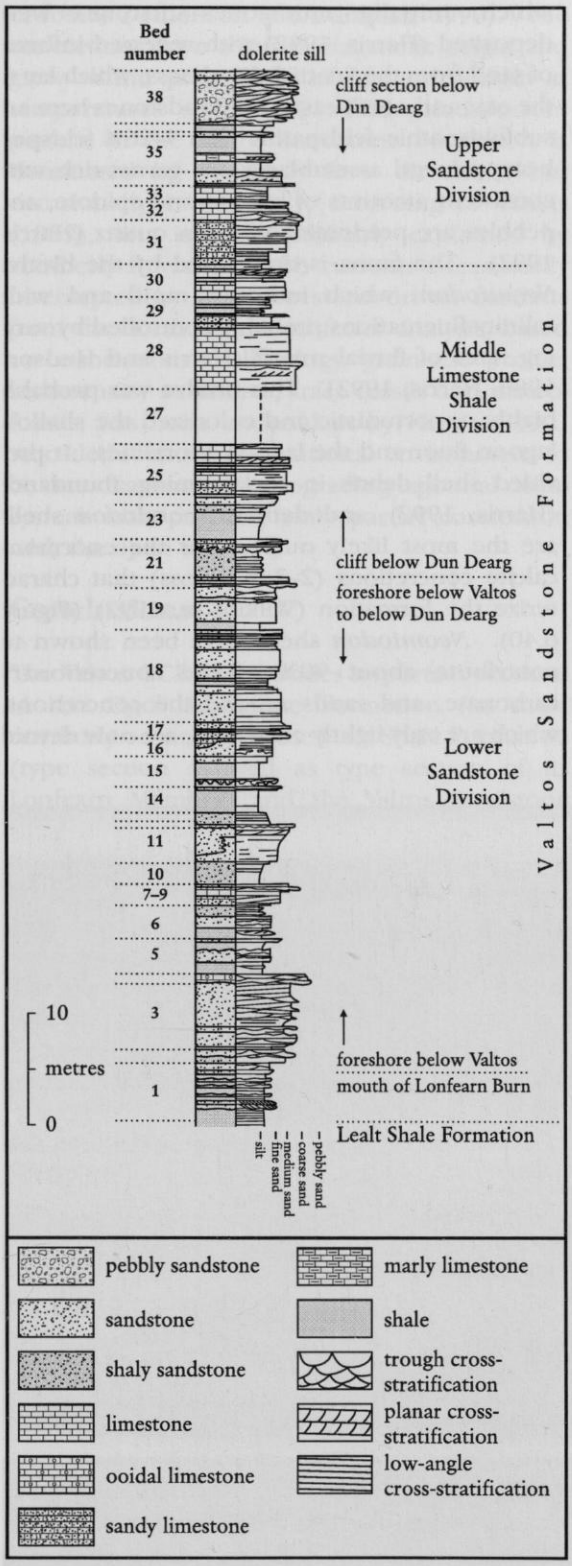

Figure 6.39 Graphic section of the Valtos Sandstone Formation at its type locality. (After Harris and Hudson, 1980, fig. 7.) Bed numbers follow Harris and Hudson (1980).

tion at Invertote are almost the most northerly occurrence of that formation whose sandstones are interpreted as delta-front deposits. Here, they represent tidal currents flowing in a distributary channel with subsequent progradation of the channel mouth by deposition from dominant basinward (southerly directed) ebb-tide and fluvial currents (Harris, 1989). This sequence of events resulted in erosion of channel and mouth-bar deposits, and subsequent deposition of fining-upwards sequences from fluctuating currents in laterally migrating tidal distributary channels and channel-mouth systems. Bi-polar palaeocurrent patterns indicate tidal currents and demonstrate the exchange of water with the open sea, and the occurrence of both large- and small-scale sedimentary structures may also be characteristic of tidal-channel deposits. According to Harris (1989), the sequence of grain sizes, structures and diametrically opposed palaeocurrent directions is comparable with the tidal channel and mouth-bar deposits described from the Recent Niger Delta. The upper part of the Elgol Sandstone Formation at Invertote is dominated by wave-built sedimentary structures (wave-ripples and offshore SW-inclined swash cross-stratification). These sediments represent the reworking by waves of tidal distributary sands to form a delta shoreline–shoreface–foreshore sequence. Sand was probably supplied directly to the shoreline by the distributaries, and wave reworking may have been responsible for the sealing of channel mouths by beach sands as channel abandonment occurred. The well-sorted granule conglomerates that cap the formation probably represent storm-generated backshore beach ridges separated by pools of standing water in which dark shale intercalations could accumulate. Palaeocurrent directions in these upper beds swing round from north–south to NE–SW, probably indicating an arcuate configuration of the shoreline (Harris, 1989).

In the Lealt River section, the almost black colour of some of the shales in the Lealt Shale Formation gives the mistaken impression that they are organic-rich; in fact, their blackness is due to baking by the underlying dolerite sill (Morton and Hudson, 1995). The assemblage of fossils (mainly bivalves with gastropods, ostracods and conchostracans) from this formation indicates deposition in shallow waters of low but fluctuating salinity in near-coastal lagoons (Hudson, 1983; Chen and Hudson, 1991). The

Lonfearn Member of that formation was formerly called the 'Estheria Shales' after a genus of conchostracan (Anderson, 1948; Harris and Hudson, 1980). The algal stromatolite limestone, the top of which marks the base of that member, is a widespread marker bed in the Hebrides. Its regular lamination and dome-like form are more characteristic of intertidal and subtidal stromatolites than of supratidal ones; however, the occurrence of gypsum pseudomorphs indicates hypersalinity and effectively rules out a subtidal environment (Hudson, 1970). According to Andrews and Hudson (1984), the bed in which a dinosaur footprint was discovered records a succession of peritidal environments on and around a carbonate mudflat. Horizons of desiccation cracks, such as those recorded at the top of the Lonfearn Member, indicate emergence (Hudson, 1983).

Deposition of the Valtos Sandstone Formation commenced with the inundation of the coastal mudflats, represented in the top beds of the Lealt Shale Formation, and resulted in the establishment of a shallow brackish-water lagoon in which, initially, mudstones–siltstones were deposited (Harris, 1992) with renewed influxes of sand from the Scottish Landmass, which lay to the east and north-east. The sandstones here are subfeldspathic–feldspathic with 5–26% feldspar; heavy-mineral assemblages are garnet-rich with consistent amounts of kyanite and epidote, and pebbles are predominantly vein quartz (Harris, 1992). The fauna is dominated by the bivalve *Neomiodon*, which indicates rapid and wide salinity fluctuations probably controlled by varying rates of fluvial runoff (Harris and Hudson, 1980; Harris, 1992). This bivalve was probably highly opportunistic and colonized the shallow lagoon floor and the lagoon shorelines. It provided shell debris in rock-forming abundance (Harris, 1992), and detrital *Neomiodon* shells are the most likely nucleus for the enormous calcite concretions (2–3 m across) that characterize the formation (Wilkinson, 1992) (Figure 6.40). *Neomiodon* shells have been shown to contribute about 90% of the concretionary carbonate, and sands around the concretions, which are only lightly cemented, are now devoid

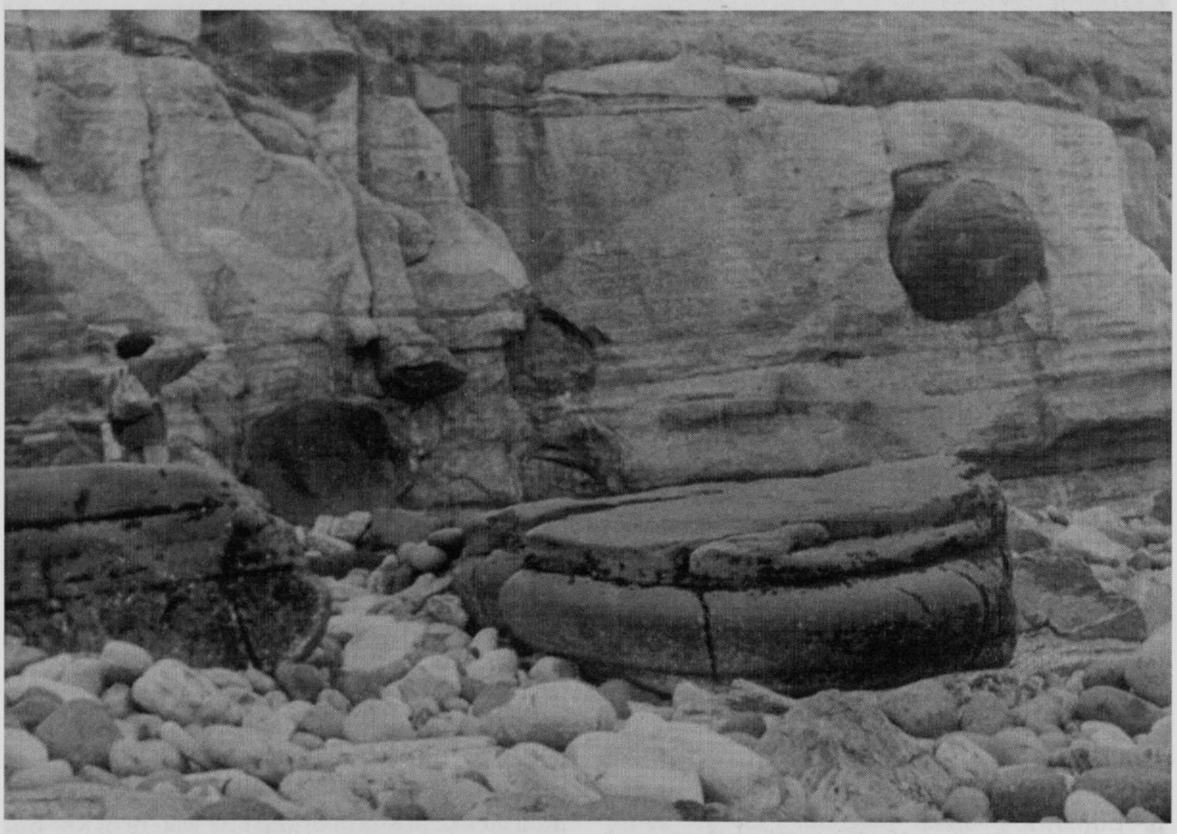

Figure 6.40 Concretions in the type section of the Valtos Sandstone Formation (formerly known as the 'Concretionary Sandstone Series'). (Photo: J.D. Hudson.)

of fossils (Wilkinson and Dampier, 1990). The concretions have a burial diagenetic origin and grew within pore fluids of meteoric origin at temperatures of 25–35°C. The palaeocurrent pattern in the Valtos Sandstone Formation is dominated by southerly flow directions but occasionally is northerly; according to Harris (1989), this is most probably explained by southerly fluvial and ebb currents occasionally interrupted by wind- or storm-driven currents from the north. Detailed facies analysis, based on associations of lithology, grain-size profile, sedimentary structures, trace fossils and macrofossils, has been undertaken by Harris (1992) who deduced the depositional environment to be one of a southerly prograding lagoonal delta-system with probably only partial connection with the open sea.

Conclusions

The Valtos GCR site includes important sections in the Elgol Sandstone Formation (its most northerly occurrence), the Lealt Shale Formation (type section as well as type section of its Lonfearn Member) and the Valtos Sandstone (type section) Formation. The Elgol Sandstone Formation represents delta-front deposits, the Lealt Shale Formation represents shallow-water near-coastal lagoon deposits, and the Valtos Sandstone Formation, a lagoonal delta-system. The site is therefore an important one for stratigraphy, sedimentology, palaeoecology and palaeogeography. It has also provided the first Scottish Jurassic dinosaur record.

BEARRERAIG BAY, ISLE OF SKYE (NG 520 545–NG 519 515)

N. Morton

Introduction

The Bearreraig Sandstone Formation forms the main part of the coastal cliffs on the eastern side of the Trotternish Peninsula on the Isle of Skye, from Ben Tianavaig on the south side of Portree Bay to Leac Treshnish (NG 524 528), 14 km north of Portree. The base of the formation can be seen on the east side of Ben Tianavaig (NG 515 425) and north of Portree, between Prince Charles' Cave (NG 512 466) and Holm (NG 519 505). Within the GCR site, north of Holm, the dip brings progressively higher beds down to sea level and the top of the formation reaches sea level at the mouth of the Lealt River (NG 522 603) (see **Valtos** GCR site report, this volume). Breaks in the cliff allowing access to the outcrop occur at Holm and at Bearreraig Bay (NG 518 527), the type section of the Bearreraig Sandstone Formation (Morton and Hudson, 1964; Morton, 1965, 1976). Bearreraig Bay became more readily accessible as a result of the construction of a small hydroelectric power station, completed in 1953, which included an access road from the main A855 Portree–Staffin road (at NG 506 526) across the dam to a small parking area at the top of the cliff (NG 517 524) (Figure 6.41). From here, a footpath to the

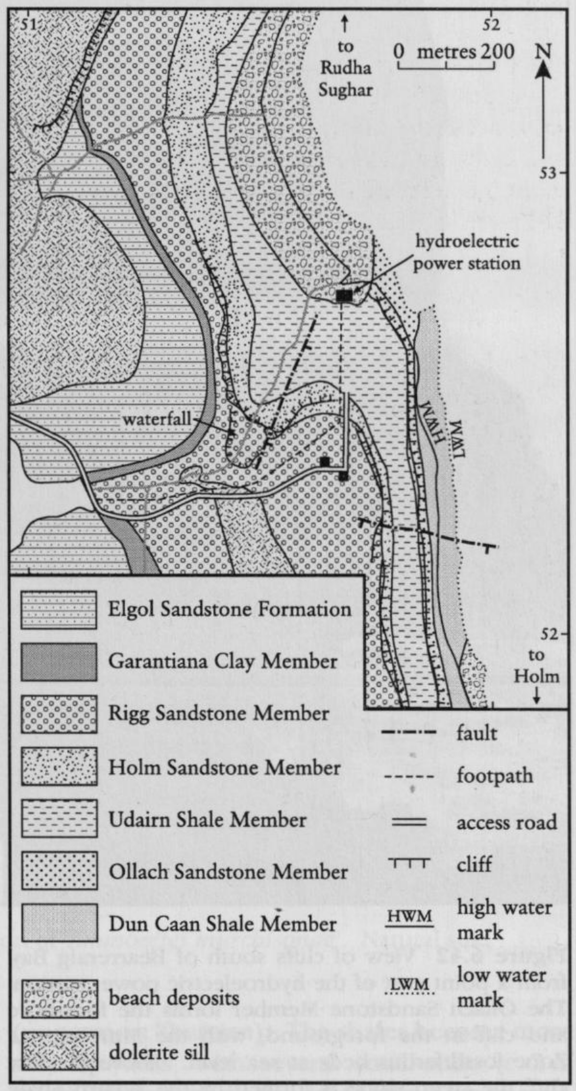

Figure 6.41 Geological map of Bearreraig Bay, Trotternish, Isle of Skye. (After Morton and Hudson, 1995, fig. 24.)

shore has been constructed recently, together with information panels on the geology. North and south of Bearreraig Bay, within the GCR site, outcrops of the Bearreraig Sandstone Formation occur in the cliffs. These are mostly too steep to be accessible, but provide large numbers of fallen blocks along the shore south of the bay and at Rudha Sughar north of the bay. Accessible outcrop sections through the Bearreraig Sandstone Formation can be seen in the Bearreraig Burn downstream from the dam (NG 513 524 to NG 516 527), and on the foreshore south of NG 518 527 (Figures 6.41 and 6.42). Details are given in Morton and Hudson (1995).

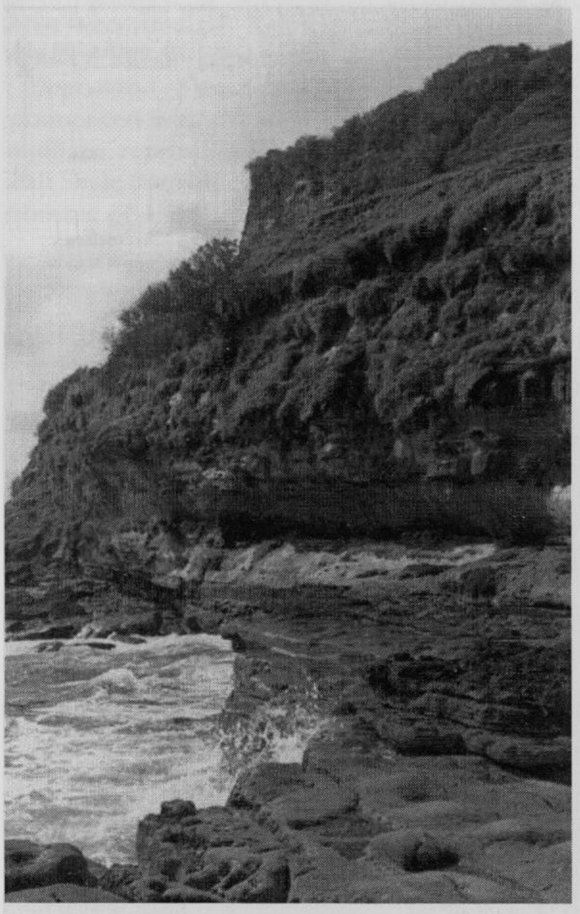

Figure 6.42 View of cliffs south of Bearreraig Bay, from a point east of the hydroelectric power station. The Ollach Sandstone Member forms the foreshore and cliff in the foreground, with the Murchisonae Zone fossiliferous beds at sea level. Above the low cliff, the steep slope is formed by the Udairn Shale Member and above this, the high cliff is formed by the Holm Sandstone and Rigg Sandstone members. (Photo: N. Morton.)

Bearreraig has long been known for its succession of Aalenian and Bajocian ammonite faunas. A visit by Murchison in 1826 resulted in the finding of an ammonite by Lady Murchison that became the type specimen of the species *Ludwigia murchisonae*, first named and figured by J. de C. Sowerby (1829) (Figure 6.43); it must have been found less than 0.5 km south of Bearreraig Bay, and therefore within the GCR site. The species is widely cited, and is the index taxon for one of the standard zones of the Aalenian Stage. The importance of Bearreraig Bay as an international reference section for Aalenian and Bajocian ammonites was established with the publication of the [British] Geological Survey memoir by Lee (1920), which included reports on the ammonites by S.S. Buckman; subsequent [British] Geological Survey work (Anderson and Dunham, 1966) added little new information. More recent work on the ammonite faunas has been undertaken by Morton (1965, 1971, 1972, 1973, 1975, 1976, 1983a,b, 1988, 1990), which has led to the section here being a candidate Global Standard Stratotype and Point for the Aalenian–Bajocian stage boundary. It has now been formally designated as an Auxiliary Stratotype Point for the base of the Bajocian Stage.

Description

The beds of the Bearreraig Sandstone Formation dip at 6° to just north of west. They are cut by two minor faults, with throws of 4 m and 2 m (Figure 6.41), the former easily recognized on the shore section where calcareous tufa is developed above the high water mark. They are also cut by several Tertiary dykes (not shown on the map) and two, thick, dolerite sills, one of which crops out in the Bearreraig Burn and pipeline cutting, but dies out northwards. A larger sill, with characteristic columnar jointing, cuts down through the highest part of the Bearreraig Sandstone Formation and caps the cliff north of Bearreraig Bay. Thermal metamorphism of the sediments by the intrusions is extremely local.

The succession in the Bearreraig Sandstone Formation is summarized in Figure 6.44; the lithostratigraphical terminology follows Morton (1976), combining older names proposed by Morton (1965), and Anderson and Dunham (1966). The basal 3.5 m of the formation are not exposed within the GCR site, but can be seen south of Holm (at NG 520 505) where, above

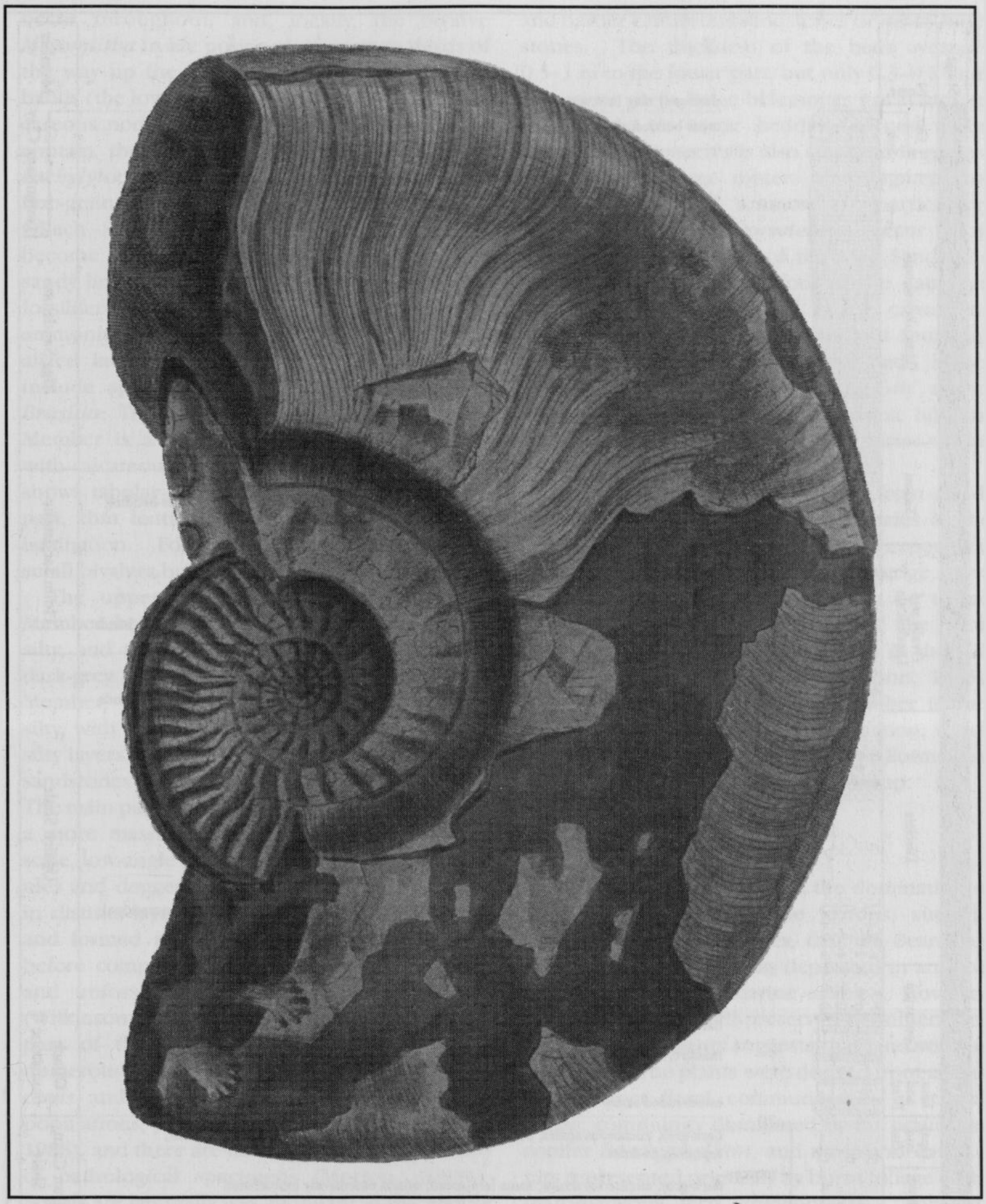

Figure 6.43 Sowerby's (1829) original illustration of '*Ammonites murchisonae*'. Natural size.

the Toarcian Raasay Ironstone Formation, there is a major hiatus and most of the Toarcian succession is missing. The basal beds of the Bearreraig Sandstone Formation are the micaceous shales of the Dun Caan Shale Member (uppermost Toarcian). The shales become more silty upwards, with several small-scale (*c.* 2 m thick) cycles, and are intensely bioturbated. Fossils are scattered, but include belemnites, occasional large fragments of driftwood, which

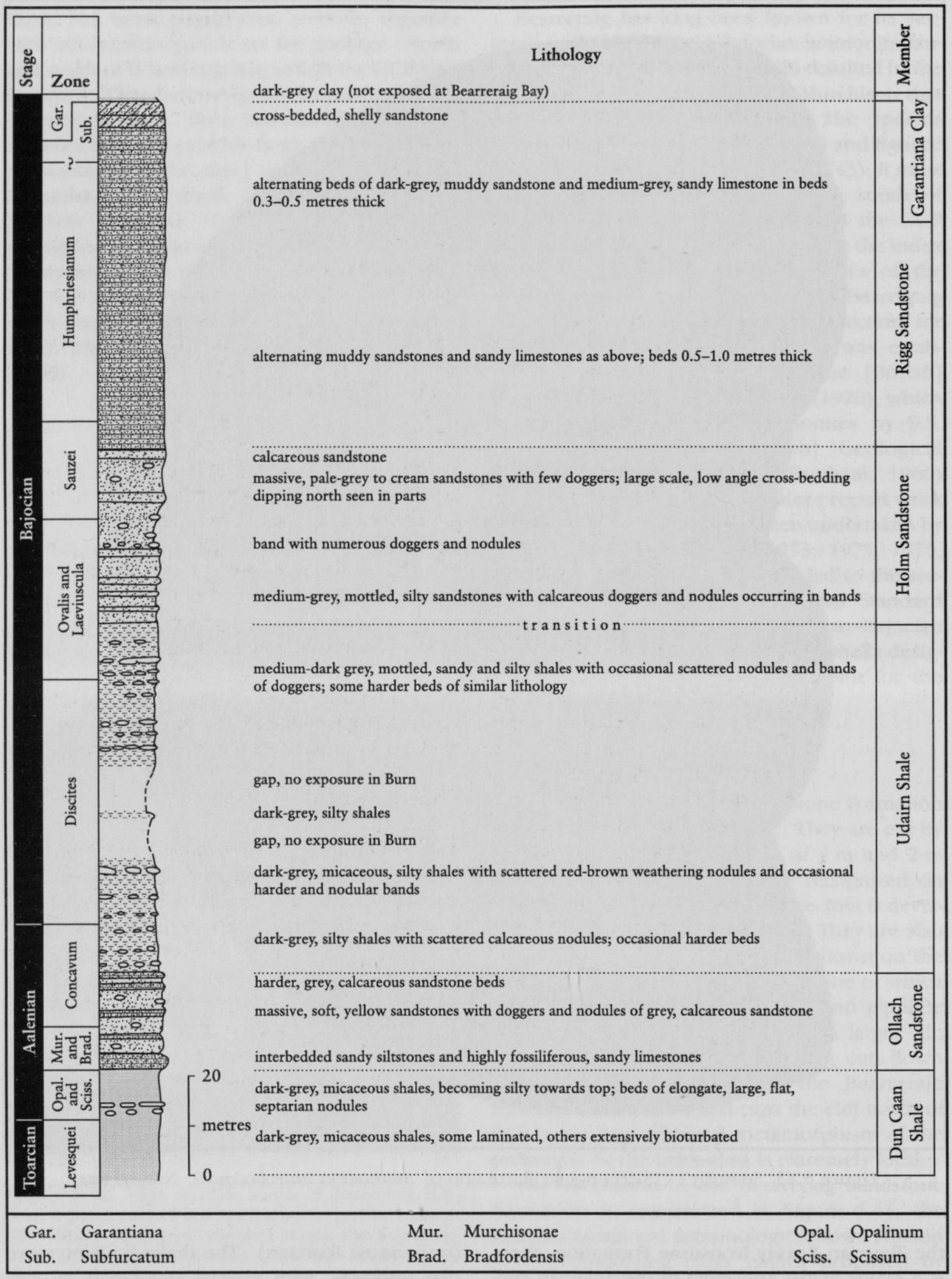

Figure 6.44 Schematic graphic log of the Bearreraig Sandstone Formation at Bearreraig Bay, showing litho-stratigraphical and chronostratigraphical subdivisions. More detailed bed-by-bed descriptions and measured successions can be found in Morton and Hudson (1995).

occur throughout, and, locally, the bivalve *Mesomiltha* in life position. About two thirds of the way up the Dun Caan Shale Member, two bands (the lower discontinuous) of elongate calcareous nodules form useful marker beds and contain the ammonoids *Leioceras* and large *Pachylytoceras*. The shales coarsen up into fine-grained silty sandstones at the base of the Ollach Sandstone Member. The beds also become more calcareous with several layers of sandy limestones, which, in patches, are highly fossiliferous and include predominantly juvenile ammonites, belemnites, bivalves, and permineralized land-plant fragments. The ammonites include species of the genera *Ludwigia* and *Brasilia*. The main part of the Ollach Sandstone Member is a more massive yellow sandstone with calcareous doggers and nodules. One bed shows tabular cross-bedding and, in the upper part, thin lenticles preserve ripple-drift cross-lamination. Fossils are less common, mostly small bivalves but with occasional ammonites.

The upper part of the Ollach Sandstone Member becomes darker in colour and more silty, and there is then a rapid transition into dark-grey micaceous shales of the Udairn Shale Member, which becomes progressively more silty, with interbedded harder, more calcareous silty layers. It grades up into paler mottled grey sandstones of the Holm Sandstone Member. The main part of the Holm Sandstone Member is a more massive, cream sandstone with large-scale, low-angle cross-bedding. Calcareous nodules and doggers occur throughout, sometimes in distinct layers; some are highly fossiliferous and formed at very early stages of diagenesis before compaction, others are generally larger and unfossiliferous, and formed much later (Wilkinson, 1991). The nodules in the lower part of the Udairn Shale Member contain numerous ammonites including both *Graphoceras* and *Hyperlioceras*. In the ammonite populations, juveniles again dominate (Morton, 1988), and there are unusually high proportions of pathological specimens (Morton, 1983b). Fossils are generally less abundant in the middle and upper parts of the Udairn Shale Member; in the Holm Sandstone Member, they occur mainly in some nodules.

There is a rapid transition from the Holm Sandstone Member into the overlying Rigg Sandstone Member, with interbedding of the two facies. The latter member consists of alternating beds of softer muddy or silty sandstones, and harder calcareous sandstones or sandy limestones. The thickness of the beds averages 0.5–1 m in the lower part, but only 0.3–0.5 m in the upper part. Large belemnites are common, particularly on some bedding planes. The bivalve *Camptonectes* is also common in places, together with large oysters and fragments of driftwood. Large ammonites, particularly *Stephanoceras* and *Dorsetensia*, occur occasionally. The top beds of the Rigg Sandstone Member, exposed at the foot of the dam, are thinly bedded, cross-bedded, coarse, calcareous sandstones with quartz granules and abundant comminuted shell-debris. These beds, sometimes referred to as the 'Bearreraig Grit', represent the northernmost and youngest limit of progradation of the cross-bedded facies of the Bearreraig Sandstone Formation.

The sharp lithological change from sandstones to the dark-grey or black shales of the Garantiana Clay Member is not now exposed at Bearreraig Bay. However, a distinct ledge marking the position of the shales can be traced northwards from near the foot of the dam. Outcrops can be seen farther south in the cliff below Fiurnean (Morton and Hudson, 1995), and here the Garantiana Clay Member is succeeded by the Cullaidh Shale Formation, which coarsens up into the Elgol Sandstone Formation, both part of the Great Estuarine Group.

Interpretation

There is clear evidence from the domination of the faunas by stenohaline groups, such as ammonites and belemnites, that the Bearreraig Sandstone Formation was deposited in an environment of normal marine salinity. However, the abundance of well-preserved permineralized land-plant fragments suggests that land was not far distant. The plants were derived from at least two distinct floral communities – a coastal-deltaic community dominated by the araucarian conifer *Brachyphyllum*, and an inland community represented primarily by burnt foliage of the matoniaceous fern *Phlebopteris*. The fine preservation of anatomical detail enables recognition of xeromorphic adaptations (unpublished work by R.M. Bateman, reported in Morton and Hudson, 1995).

The Bearreraig Sandstone Formation consists of three major coarsening-upwards cycles, and part of a fourth. The shales and siltstones in the lower parts of the cycles are generally extensively bioturbated and characterized by benthic assemblages typical of organic-rich soft-sediment sea floors below wave base (Morton, 1990). At the base of the first cycle, in the Dun Caan Shale Member, the most common bivalve is the lucinoid *Mesomiltha*, in life position, joined in the lower beds of the Ollach Sandstone Member by nuculids (especially *Nuculoma*), *Pleuromya*, small gastropods, etc. Discrete patches of crinoid debris indicate local disarticulation of crinoids without significant lateral transport, and bioturbation is interpreted as the main cause of disturbance of shell material before fossilization.

At the base of the second cycle, in the lower part of the Udairn Shale Member, the dominant bivalves are *Nuculoma variabilis* (J. de C. Sowerby), *Mesomiltha lirata* (Phillips) and *Grammatodon inaequivalvis* (Goldfuss). At the Aalenian–Bajocian boundary (see below), *Mytiloceramus polyplocus* (Roemer) appears and dominates the higher parts of the Udairn Shale Member (Morton, 1990) but the associated faunas, including the foraminifera (Gregory, 1990, 1991), indicate no apparent palaeoenvironmental change.

The silty shales typical of the lower parts of the cycles also contain calcareous nodules; in thin section, these are seen to comprise fine-sand grade, angular to subangular, quartz grains in a lime-mud matrix. The quartz grains are interpreted as having been washed into a depositional environment below wave base from a nearby higher-energy environment, and this interpretation is consistent with the abundance of well-preserved land-plant fragments.

The sandstones in the upper parts of the cycles show characteristics of deposition by the migration and build-up of offshore sand-bars in depths above wave base. Both the Ollach Sandstone and Holm Sandstone members consist of fine- to medium-grained sandstones, with small-scale ripple-drift cross-lamination and one cross-bedded unit in the Ollach Sandstone Member, and large-scale, low-angle cross-bedding in the Holm Sandstone Member. Cross-bedding dips are consistently towards the north. Marine fossils occur, particularly in calcareous nodules, and bioturbation is widespread. In the Holm Sandstone Member, the benthic faunas are dominated by the infaunal bivalves *Mesomiltha*, *Grammatodon* and *Pleuromya*, and some epifaunal bivalves such as *Oxytoma* and pectinids. In the upper part of the Ollach Sandstone Member, shelly lenticles are characterized by small bivalves such as *Meleagrinella*.

The succession of ammonite faunas enables the recognition of all of the zones, nearly all of the subzones and many of the ammonite biohorizons established in the Aalenian and Lower Bajocian strata of southern England (see Chapter 1). All of the Upper Bajocian zones are also recognized except for the Parkinsoni Zone, which has not been proved in the Hebrides.

Work on the succession of ammonite faunas across the Aalenian–Bajocian boundary (Morton, 1984, 1990, 1991, 1994) has led to Bearreraig Bay being recognized as an Auxiliary Stratotype Point for the base of the Bajocian Stage. The precise point is at the base of Bed U10, 12.27 m above the base of the Udairn Shale Member at the section beside the lower part of the pipeline (NG 5170 5271) (Figure 6.45). It is marked by the incoming of a distinctive faunal assemblage that includes *Hyperlioceras mundum* (S.S. Buckman), *H. furcatum* (S.S. Buckman) (macroconch) and *H. aspera* (S.S. Buckman) (microconch), as well as *Graphoceras limitatum* S.S. Buckman (macroconch) and *G. carbatinum* (S.S. Buckman) (microconch). Details of the succession are shown in Figure 6.46. The Aalenian–Bajocian boundary is also marked by the incoming of the bivalve *Mytiloceramus polyplocus*. This does not appear to be a local palaeoecological event, and comparison with other areas in Europe suggests that it may be of geochronological significance.

The palynostratigraphy of the succession at Bearreraig Bay has been documented by Riding *et al.* (1991), who established some marker events tied to the ammonite-based stratigraphy, although with a wide spacing between samples. A more detailed, closely sampled study of the Aalenian–Bajocian boundary was carried out by Gregory (1990, 1991) who established a major diversification of the foraminiferal fauna, with the incoming of several species of *Lenticulina*, *Nodosaria*, *Falsopalmula* and *Palaeomiliolina* in the uppermost part of the Aalenian Concavum Zone, below the base of the Bajocian Stage.

Conclusions

The GCR site at Bearreraig Bay includes the type section of the Bearreraig Sandstone Formation, which is the main lithostratigraphical unit in the Aalenian and Bajocian strata of the Hebrides Basin. The lithostratigraphical subdivisions (members) recognized here are restricted to

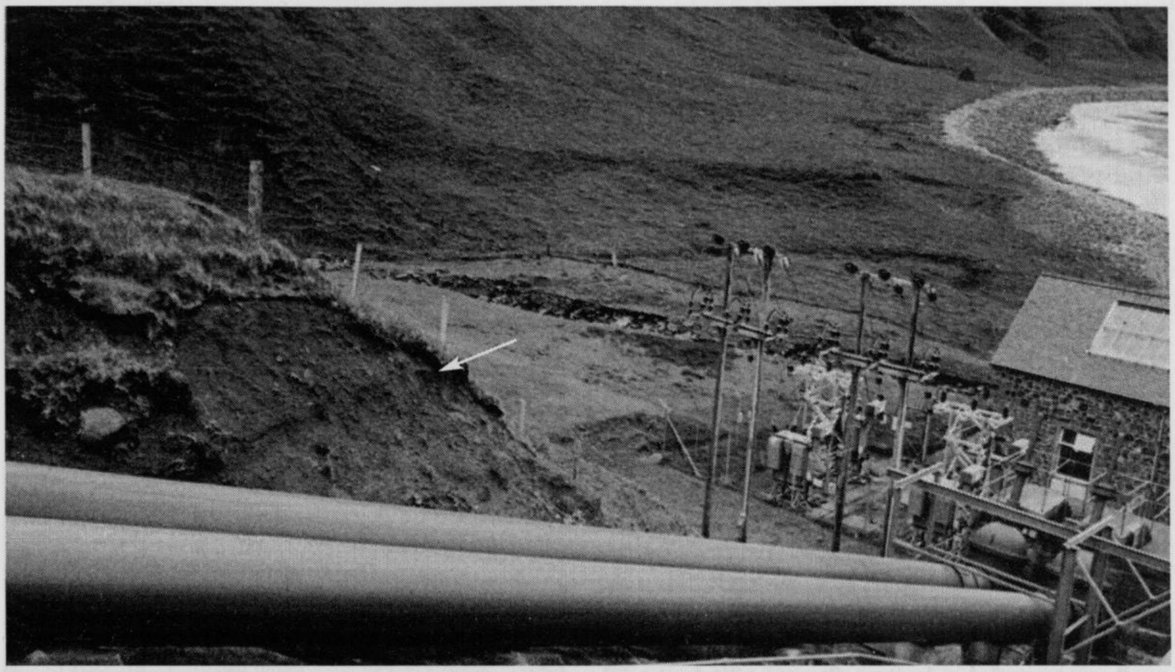

Figure 6.45 The Aalenian–Bajocian stage boundary section beside the pipeline at Bearreraig Bay. The boundary is taken at the base of the slightly harder bed (arrowed) which is Bed U10 of Figure 6.46. (Photo: M.G. Sumbler.)

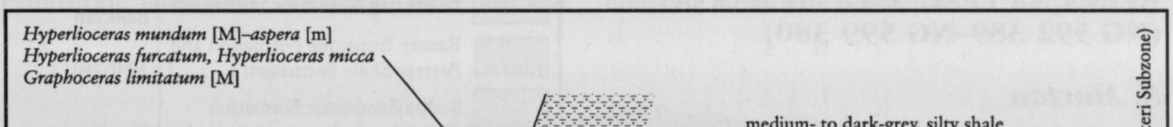

Figure 6.46 Details of the succession across the Aalenian–Bajocian boundary at the Auxiliary Stratotype Point at Bearreraig Bay (outcrop near bottom of pipeline cutting (NG 5170 5271). (After Morton and Hudson, 1995, fig. 28.) ([M] = macroconch; [m] = microconch.) Bed numbers follow Morton and Hudson (1995).

Trotternish in northern Skye; elsewhere, there are major facies changes and different subdivisions are used.

Bearreraig Bay is most widely known for ammonite faunas, which are abundant and well preserved in some parts of the succession. It is the type locality of the widely recognized and important Aalenian ammonite species, *Ludwigia murchisonae*. Of greater significance, Bearreraig Bay is an international reference section for Aalenian and Lower Bajocian ammonite faunas and their biostratigraphy. In particular, it has recently been selected as Auxiliary Stratotype Point for the base of the Bajocian Stage. The palynomorphs and foraminifera have also been investigated and provide additional biostratigraphical data for the Aalenian–Bajocian of the Hebrides Basin. Although the Aalenian–Bajocian sediments at Bearreraig Bay were deposited in a fully marine environment, they have yielded exceptionally well-preserved land-plant floras, which reveal unusual anatomical detail and palaeoecological information about adjacent land areas.

BEINN NA LEAC, ISLE OF RAASAY (NG 592 389–NG 599 380)

N. Morton

Introduction

The Bearreraig Sandstone Formation crops out extensively in the centre of the southern part of the Isle of Raasay, and forms the high cliffs on the eastern edge of the central part of the island. To the south-east of the main outcrop, a down-faulted outlier forms the upper part of the hill known as 'Beinn na Leac'. The fault that bounds Beinn na Leac is arcuate and can be seen in a small bay (NG 596 381), within the GCR site, from where it can be traced round the 'back' (west) of the hill (Figure 6.47) before reaching the coast again (NG 591 357) (though not exposed) at North Fearns. It appears to be a late listric fault related to glacial overdeepening of the sea east of Raasay, and there is clear evidence, from separated fault-scarp talus (e.g. at NG 584 364), of Holocene movement. Evidence of earlier, possibly synsedimentary, movement on a NNE–SSW fault, which could now be part of the Beinn na Leac Fault, is circumstantial.

The thick, often highly calcareous, sandstones of the Bearreraig Sandstone Formation, which

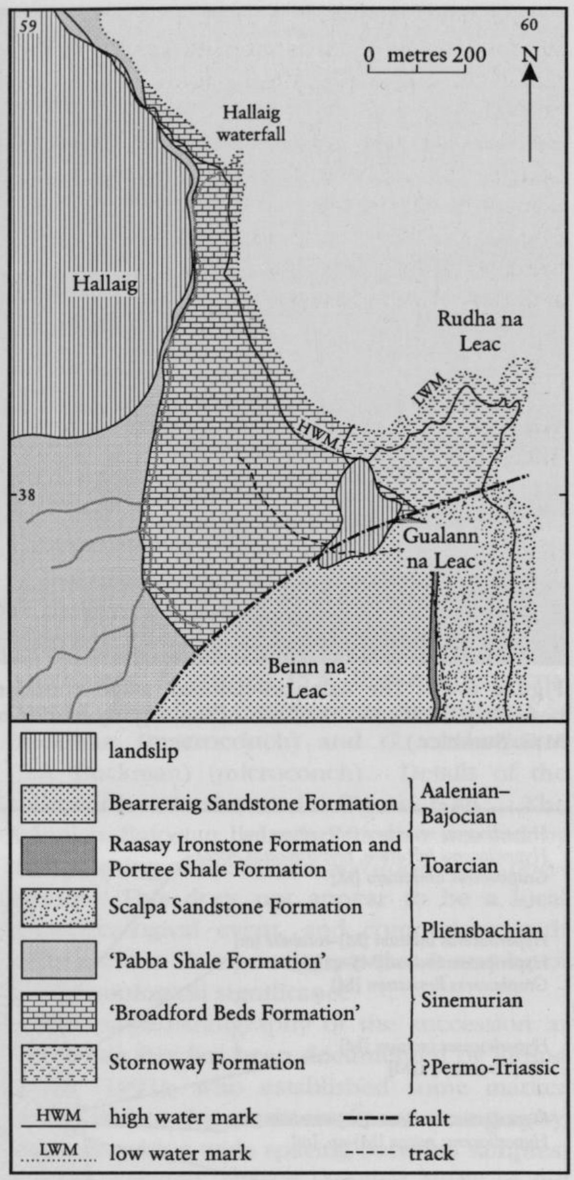

Figure 6.47 Geological map of the northern part of Beinn na Leac, Rudha na Leac and Hallaig, Isle of Raasay (Quaternary sediments and minor intrusions omitted). (After Morton and Hudson, 1995, fig. 9.)

form the upper part of Beinn na Leac, rest on thick Toarcian shales. As a result, landslips from the main scarp, and cambering of large blocks are common. The top of Beinn na Leac is also cut by large numbers of deep fissures caused by similar movements. The combination of acid peaty soil on the exposed top of the mountain with alkaline lime-rich soils in sheltered hollows and fissures has resulted in a great variety of micro-environments with varied floras.

The most important part of the Beinn na Leac site for Middle Jurassic stratigraphy is at Gualann na Leac (NG 599 379) on the north-eastern corner (Figures 6.48 and 6.49). Here, there is an excellent section through a major part of the Bearreraig Sandstone Formation, although it is discontinuous in the shales of the lower part. The base of the formation is seen at outcrop, but the top is missing because of erosion of younger sediments from the top of Beinn na Leac.

Description

The track along the east side of Beinn na Leac gradually ascends the succession from the Scalpa Sandstone Formation (Lower Jurassic, Pliensbachian) at North Fearns to the lower part of the Bearreraig Sandstone Formation at Gualann na Leac. The Scalpa Sandstone Formation forms the sea-cliffs below the track and the main part of the Bearreraig Sandstone Formation forms the rampart of high cliffs. The slopes between mark the position of the Toarcian shales and ironstone, including the Dun Caan Shale Member of the Bearreraig Sandstone Formation. However, there are few outcrops of this part of the succession, which is mostly covered by scree and landslipped material from the cliffs.

Below the bend in the track at Gualann na Leac, just south of the line of the Beinn na Leac Fault (Figure 6.47), the succession from the upper part of the Scalpa Sandstone Formation to the Bearreraig Sandstone Formation is exposed (Figure 6.48). The boundary between the Bearreraig Sandstone Formation and the Raasay Ironstone Formation (Toarcian) is abrupt and represents a hiatus with much of the Toarcian succession missing. The lowest 10 m of the Dun Caan Shale Member are well exposed and comprise very sparsely fossiliferous shales with a thin limestone near the base. Higher beds are rarely exposed until above the track where small discontinuous outcrops of micaceous shales with the ammonite *Pleydellia* occur. The shales pass up into a series of alternating silty shales and thinner calcareous siltstones or silty limestones. The first thin limestone bed is taken as the base of the Beinn na Leac Sandstone Member, of which this is the type section with a total thickness of 20.76 m. The basal limestone bed contains the ammonite *Leioceras*.

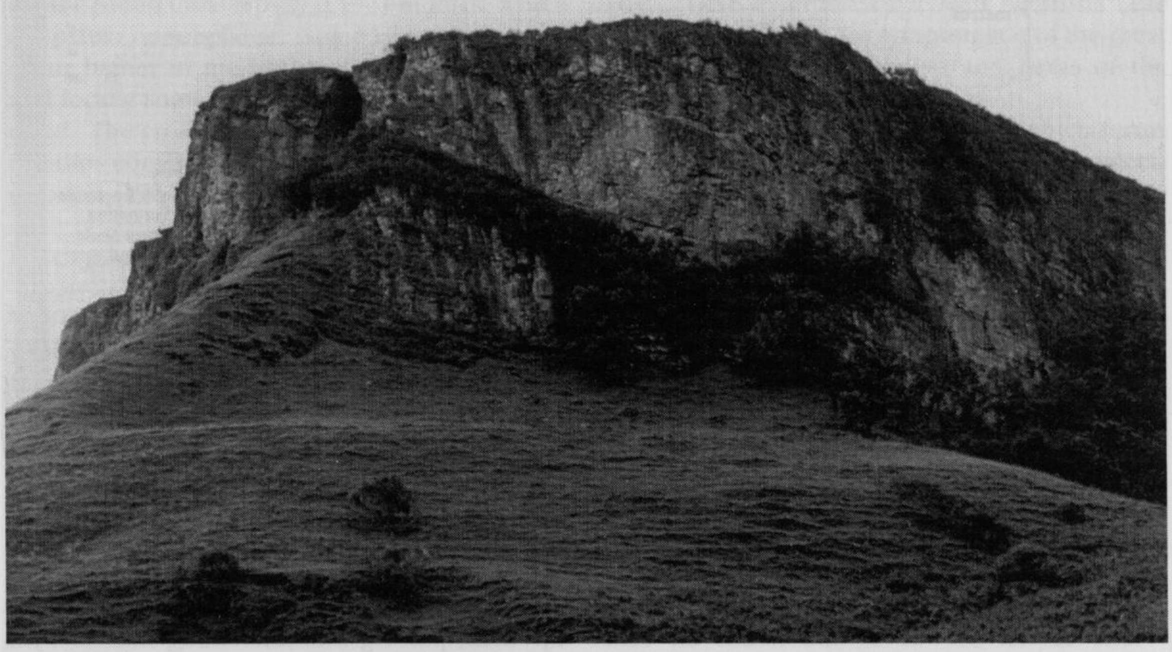

Figure 6.48 Gualann an Leac (northern face of Beinn na Leac). The grassy slopes in the lower left are the Dun Caan Shale Member above which, left of centre, are the steeper slopes, with ledges sloping down to right, formed by the Beinn na Leac Sandstone Member. The upper part of this member forms the lower third of the lower cliff, while the upper part of the lower cliff and the high cliffs behind are composed of the Raasay Sandstone Member. (Photo: N. Morton.)

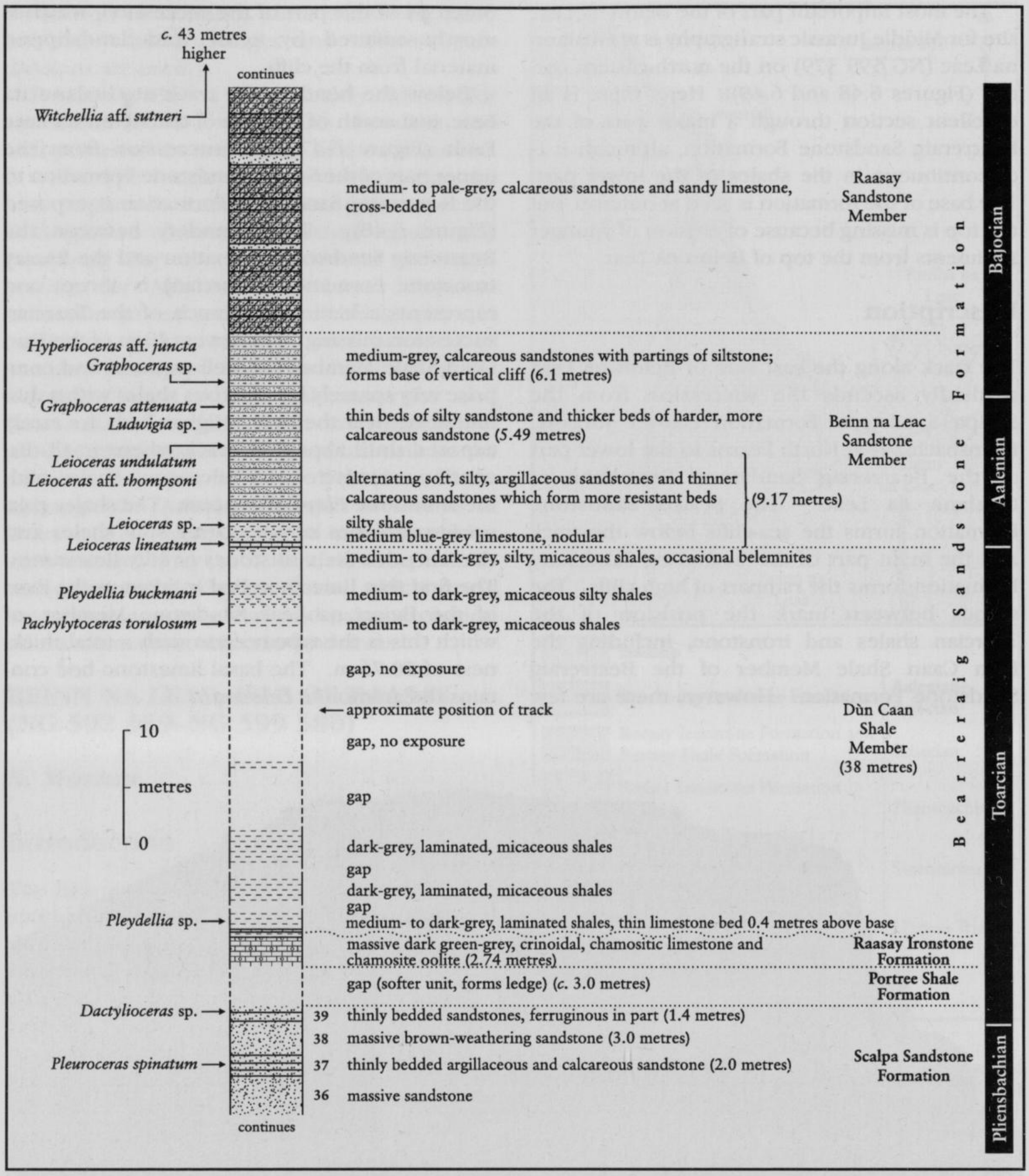

Figure 6.49 Succession from the top of the Scalpa Sandstone Formation (Lower Jurassic, Upper Pliensbachian) to the lower part of the Bearreraig Sandstone Formation (uppermost Toarcian, Aalenian and Lower Bajocian) at Gualann na Leac. (After Morton and Hudson, 1995, fig. 14.)

The lowest 9.17 m of the Beinn na Leac Sandstone Member consists of poorly fossiliferous alternating beds of soft silty sandstones and harder, more calcareous, silty sandstones. Rare *Leioceras* occur. The succession gradually becomes slightly coarser and more calcareous upwards, passing into alternating thinner beds of soft argillaceous sandstones and thicker calcareous silty sandstones and sandy limestones 5.49 m thick. These form a series of ledges on a steep but accessible slope at the foot of the cliff. Fossils become more common but tend to be concentrated in patches; they include species of *Leioceras*, *Ludwigia* and *Graphoceras* in different layers (Figure 6.48; Morton, 1965; Morton and Hudson, 1995), with belemnites and bivalves. The top 6.10 m of the Beinn na Leac Sandstone Member consist of thickly bedded, calcareous sandstones with thin silty partings, which form the lowest part of the vertical cliff. The outcrop is mostly inaccessible, but *Hyperlioceras* occurs in the lowest part of this unit.

The main part of the cliff at Gualann na Leac consists of cross-bedded sandstones and sandy limestones of the Raasay Sandstone Member, varying in colour from white or pale-grey to yellow and occasionally red. This unit forms the top of Beinn na Leac and the rampart of cliffs southwards, with an incomplete thickness of at least 140 m. The Raasay Sandstone Member consists of mixtures, in variable quantities, of shell-sand (derived mainly from bivalves, crinoids and bryozoans) and medium to coarse quartz-sand. Shell material is mostly comminuted and no longer identifiable, but one ammonite (*Witchellia* aff. *sutneri* (Branco)) was found at Gualann na Leac, 43 m above the base of the Raasay Sandstone Member. The sediments are thinly to very thinly bedded with cross-bedded units mostly 0.15–1 m thick, which are planar or subplanar. Some larger scale units occur higher in the Raasay Sandstone Member, and locally some trough cross-bedding is developed. The cross-bedding, corrected for regional tilt, dips consistently towards NNE to north-east (Morton, 1983a).

Interpretation

The Dun Caan Shale Member at Gualann na Leac probably belongs entirely to the Aalensis Subzone of the Upper Toarcian Levesquei Zone. Evidence for this in the lower beds is limited at Gualann na Leac, but is supported at other localities on the Isle of Raasay (Lee, 1920; Morton, 1965). The top of the Dun Caan Shale Member is defined at the change to the slightly coarser and more calcareous lithologies of the Beinn na Leac Sandstone Member. This is older at this locality (base of Opalinum Zone) than at **Bearreraig Bay** (see GCR site report, this volume), where the similar upward change to the Ollach Sandstone Member is placed at the base of the Murchisonae Zone. The Dun Caan Shale Member is exceptionally thick (38 m) on Beinn na Leac compared with only 9 m at the opencast ironstone mine (NG 569 365), 3 km to the west, and at the Inverarish Burn (NG 570 371) sections (Morton, 1965; Morton and Hudson, 1995), and *c.* 10 m in a section south-east of Loch na Mna (NG 584 382), 1.4 km to the west. These sections lie on the other side of the Beinn na Leac Fault, and it is possible that this fault may have been active during sedimentation.

The upwards coarsening from the Dun Caan Shale Member into the Beinn na Leac Sandstone Member on Beinn na Leac differs from that seen between the Dun Caan Shale Member and the Ollach Sandstone Member at **Bearreraig Bay** (see GCR site report, this volume) in three ways: firstly, the coarsening begins earlier (Opalinum Zone compared with Murchisonae Zone); secondly, the coarsening is less marked, with silty, fine-grained, calcareous sandstones or sandy limestones, but no massive sandstone; and thirdly, there is only one coarsening-up cycle through the Aalenian and into the Lower Bajocian succession, both of which are much thinner than at **Bearreraig Bay**. The sediments were deposited in a marine shelf below wave base, with extensive bioturbation but no evidence of current activity, on a sea floor that appears to have been firmer than at Bearreraig Bay. These differences between Beinn na Leac and Bearreraig Bay are symptomatic of the great lateral variation in thickness and facies of the Bearreraig Sandstone Formation.

The Raasay Sandstone Member, which forms the main part of the Aalenian–Bajocian succession on the Isle of Raasay, is typical of the cross-bedded facies of the Bearreraig Sandstone Formation. This facies, interpreted as the result of deposition in tidal sand waves (Morton, 1983a), spread diachronously northwards from southern Strathaird to south-eastern Raasay, then to western Raasay and southern Trotternish. At Gualann na Leac, the change from the normally bedded facies of the Beinn na Leac Sandstone Member to the cross-bedded facies of the Raasay Sandstone Member can be assigned, by means of ammonites, to between the Discites and Ovalis zones.

The cross-bedded facies of the Bearreraig Sandstone Formation consists of medium- to coarse-grained, quartz-rich, terrigenous sand that has been redistributed by strong tidal currents and mixed with autochthonous shell material. The tidal current directions are along the length of the Hebrides Basin, and the consistent NNE to north-east directions seen on Beinn na Leac are parallel to the Screapadal and Applecross Faults. These are interpreted (Morton, 1983a) as having been sufficiently active during deposition to influence sea-floor topography and control tidal current directions. The Beinn na Leac Fault has, for part of its length, a similar trend and, as during deposition of the Dun Caan Shale Member, may have been active during sedimentation.

Conclusions

The importance of the Beinn na Leac GCR site lies in the fact that it enables clear documentation of some of the lateral changes in the stratigraphy of the Bearreraig Sandstone Formation in this part of the Hebrides Basin. The succession of ammonite faunas does not provide a reference section for Aalenian–Bajocian biostratigraphy, but it enables most parts of the succession and, in particular, important facies changes to be dated and correlated with other localities. The most important features of the succession on Beinn na Leac are the thickening of the Dun Caan Shale Member in comparison with other localities on the Isle of Raasay; a single coarsening-up sequence in the Aalenian–Lower Bajocian succession and different facies development compared with **Bearreraig Bay** (see GCR site report, this volume); and ammonites that show that the change to cross-bedded facies occurs within the Discites and Ovalis zones, thereby calibrating one point in the diachronous spread of the cross-bedded facies of the Bearreraig Sandstone Formation. The section also shows the Toarcian–Aalenian and Aalenian–Bajocian stage boundaries.