# *British Lower Jurassic Stratigraphy*

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# Chapter 8

# The Hebrides Basin

## INTRODUCTION

*N. Morton*

### Geological Setting

The Hebrides Basin is one of a series of Mesozoic extensional basins, extending from Spitzbergen and Greenland in the north to Portugal in the south, which evolved during the early stages of opening of the North Atlantic Ocean (Trueblood and Morton, 1991; Morton, 1992a). These were mainly half-grabens, with alternating polarity of faulted margin on the west (including Hebrides) or east. The Hebrides Basin ceased being part of the system after the Jurassic Period, with basin inversion in Early Cretaceous times, when the main tilted fault-block structures were formed. It then became part of the Thulean volcanic province during Palaeocene times so that most of the Jurassic sequence is intruded by dykes and sills. These caused only local baking, but near the main plutonic centres of central Skye, Ardnamurchan and Mull, thermal metamorphism has occurred.

Lower Jurassic rocks crop out on various islands of the Inner Hebrides and on some neighbouring parts of the western coast of the Scottish mainland (Figure 8.1), in part preserved because of an overlying protective cover of Palaeogene plateau basalt lavas. More spectacularly, two small isolated outcrops, on Rum and Arran, owe their preservation entirely to large-scale downward movements within or on the margins of Tertiary igneous complexes. On a regional scale the rocks form a series of westerly- to north-westerly-tilted fault-blocks cut by two main sets of faulting. Both are downthrown predominantly to the east, with a small number of very large NNE–SSW-trending faults of mainly Early Cretaceous age (Morton, 1992b), and a large number of generally smaller NNW–SSE- to NW–SE-trending faults which are of Palaeogene age.

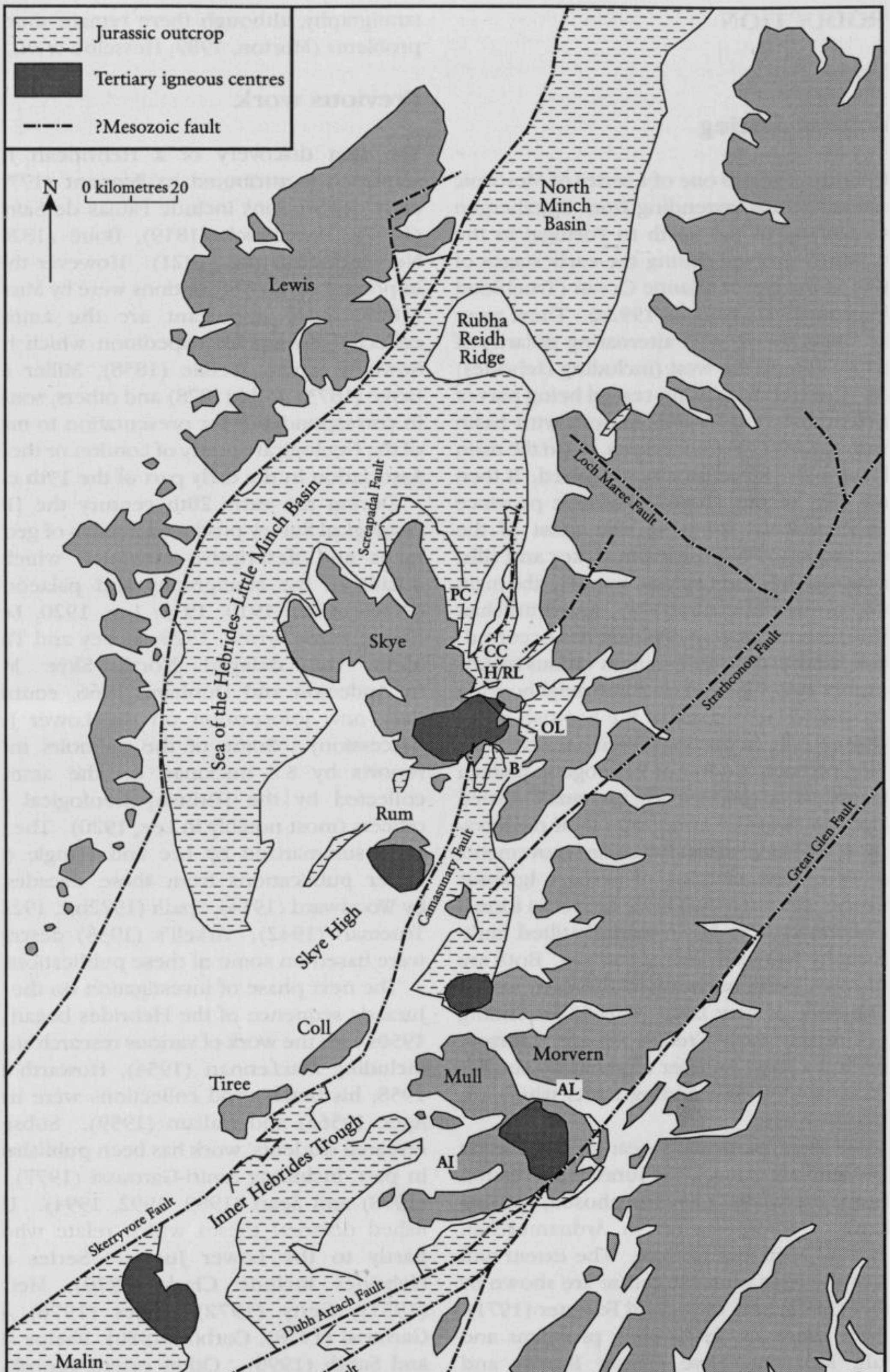
In some areas, particularly near the Palaeocene plutonic igneous centres, the Jurassic succession has been thermally metamorphosed, posing problems of interpretation in Ardnamurchan and parts of Mull and of Skye. The extent and effects of the Skye plutonic centre are shown by Thrasher (1992) and Taylor and Forester (1971). Elsewhere there are fewer such problems and in Mull, Morvern, Skye, Pabay, Raasay and Applecross there are excellent outcrops of Lower Jurassic sediments with normal diagenetic alteration, enabling reasonable syntheses of the stratigraphy, although there remain unresolved problems (Morton, 1989; Hesselbo *et al.*, 1998).

### Previous work

The first discovery of a Hebridean Jurassic sequence is attributed to Pennant (1774) and early descriptions include Faujas de Saint-Fond (1797), Macculloch (1819), Boué (1820) and Necker-de-Saussure (1821). However the most important early contributions were by Murchison (1829, more important are the ammonites collected during his expedition which became Sowerby types), Geikie (1858), Miller (1858), Bryce (1873), Judd (1878) and others, sometimes in correspondence for presentation to meetings of the Geological Society of London or the British Association in the early part of the 19th century.

During the early 20th century the [British] Geological Survey produced a series of geological maps and descriptive memoirs, which gave details of the stratigraphy and palaeontology (Peach *et al.*, 1910, 1913; Lee, 1920; Lee and Bailey, 1925; Tyrrell, 1928; Richey and Thomas, 1930; the delayed North Skye Memoir by Anderson and Dunham, 1966, contributed little new information on the Lower Jurassic succession). Some of the memoirs included reports by S.S. Buckman on the ammonites collected by the [British] Geological Survey officers (most notably in Lee, 1920). The results were summarized by Lee and Pringle (1932). Other publications from these decades were by Woodward (1914), Spath (1922b,c, 1924), and Trueman (1942). Arkell's (1933) descriptions were based on some of these publications.

The next phase of investigation on the Lower Jurassic sequence of the Hebrides began in the 1950s with the work of various research students, including MacLennan (1954), Howarth (1956, 1958; his brachiopod collections were used by Ager, 1956a) and Hallam (1959). Subsequent research students' work has been published only in part, including Amiri-Garoussi (1977), Oates (1978) and Searl (1989, 1992, 1994). Unpublished doctoral theses which relate wholly or partly to the Lower Jurassic Series of the Hebrides include Clark (1970), McCallum (1971), Getty (1972), Oates (1976), Amiri-Garoussi (1978), Corbin (1980), Phelps (1982), and Smith (1996). Other recent contributions on the Hebridean Lower Jurassic sequence include Nicholson (1978), Hesselbo *et al.* 1998), Morton (1999a,b) and Farris *et al.* (1999).


Jurassic outcrop
Tertiary igneous centres
?Mesozoic fault
N
0 kilometres 20
Lewis
North Minch Basin
Rubha Reidh Ridge
Sea of the Hebrides–Little Minch Basin
Screapadal Fault
Loch Maree Fault
PC
CC
H/RL
Skye
OL
B
Strathconon Fault
Rum
Camasunary Fault
Great Glen Fault
Skye High
Coll
Morvern
Mull
Tiree
AL
AI
Inner Hebrides Trough
Skerryvore Fault
Dubh Artach Fault
Malin Basin
Colonsay Fault

◂**Figure 8.1** Map of the Jurassic (including Lias Group) outcrop in western Scotland, showing the locations of the GCR sites, indicated in bold, as follows: **AI** – Aird na h-Iolaire; **AL** – Allt Leacach; **B** – Boreraig to Carn Dearg; **CC** – Cadha Carnach; **H** – Hallaig; **OL** – Ob Lusa to Ardnish; **PC** – Prince Charles' Cave to Holm; **RL** – Rubha na Leac. After Hesselbo *et al.* (1998).

These established the Hebrides as a significant area to be included in European or even global syntheses of Lower Jurassic stratigraphy, for example Hallam (1967a), Sellwood (1972), Getty (1973), Phelps (1985), Donovan (1990), Howarth (1992), Page (1992), Dommergues *et al.* (1994) and Hesselbo and Jenkyns (1998).

Syntheses and summaries of the Hebrides Jurassic System are given by Hudson and Morton (in Hemingway *et al.*, 1969 – field guide), Cope *et al.* (1980a – on correlations), Hudson (1983), Morton (1987, 1989, 1992b – on basin evolution), Hallam (1991), Bradshaw *et al.* (1992 – on palaeogeography), and Morton and Hudson (1995 – field guide). The setting and stratigraphical evolution of the Hebridean Lower Jurassic succession was described by Morton (1990) and in the broader context of British Lower Jurassic sequence stratigraphy by Hesselbo and Jenkyns (1998).

## Stratigraphical Framework

The Lower Jurassic rocks of the Hebrides are predominantly siliciclastics and the stratigraphical evolution of the area was different from that of Yorkshire, Somerset or Dorset. Therefore a different scheme of lithostratigraphical nomenclature (Figure 8.2) has been developed. Many of the names (now called formations) derive from Judd (1878), Woodward (1897) or other 19th century authors and were used by the [British] Geological Survey. The more recent revisions concern mainly the lower part of the Lower Jurassic succession or revision of spelling of place-names, and these are incorporated in the following summary.

1. For the Triassic (to lowermost Jurassic in the north) 'New Red Sandstone' continental red-beds, wider use of the name **Stornoway Formation** (Steel and Wilson, 1975) was suggested by Morton and Hudson (1995). The type section is near Stornoway and the best Inner Hebridean section, at **Rubha na' Leac** on Raasay, is described by Morton and Hudson (1995).
2. The marine 'Rhaetic' (only in the south) was identified with and named the **Penarth Group** (e.g. Cope *et al.*, 1980a). The type section lies outside the Hebrides, but the best Hebridean section is in Gribun, western Mull, included in the **Aird na h-Iolaire** GCR site report.
3. The Hettangian to Lower Sinemurian succession of Mull and Morvern, previously classified with the Broadford Beds, is developed in alternating limestone–mudstone facies identical to the Blue Lias Formation of south-west England Oates (1978) proposed using the same name, **Blue Lias Formation**, and this has been generally, though not universally, accepted. The Blue Lias Formation passes laterally through intermediate sandy limestones and shales, seen in northern Ardnamurchan, south-west Raasay and Sconser in Skye into the lithologically varied unit traditionally called the 'Broadford Beds'. The type section lies outside the Hebrides, but details of the best Hebridean section are given in the **Allt Leacach** GCR site report: see also Hesselbo *et al.* (1998).
4. The name 'Broadford Beds' has been applied to the lower part of the Lower Lias since the 19th century, and subdivision into a lower more calcareous unit and a higher more siliciclastic unit widely used. Restriction in use of the name 'Broadford Formation' to only the lower unit was proposed by Hesselbo *et al.* (1998), but to avoid confusion the new name **Breakish Formation** was introduced and defined by Morton (1999b). The type section east of Broadford is described in the **Ob Lusa to Ardnish Coast** GCR site report.
5. The upper unit of the former Broadford Beds was included within an expanded Pabay (see below) Shale Formation by Hesselbo *et al.* (1998). However, Morton (1999a) argued that there is a basin-wide mappable lithological distinction (cf. Hesselbo *et al.*, 1999) between the traditional 'Pabba Shales' and the upper unit of the 'Broadford Beds' and suggested the name **Ardnish Formation** for the latter. This has been adopted by the [British] Geological Survey in the revised Broadford and Raasay 1:50 000 maps. The most important sections of the

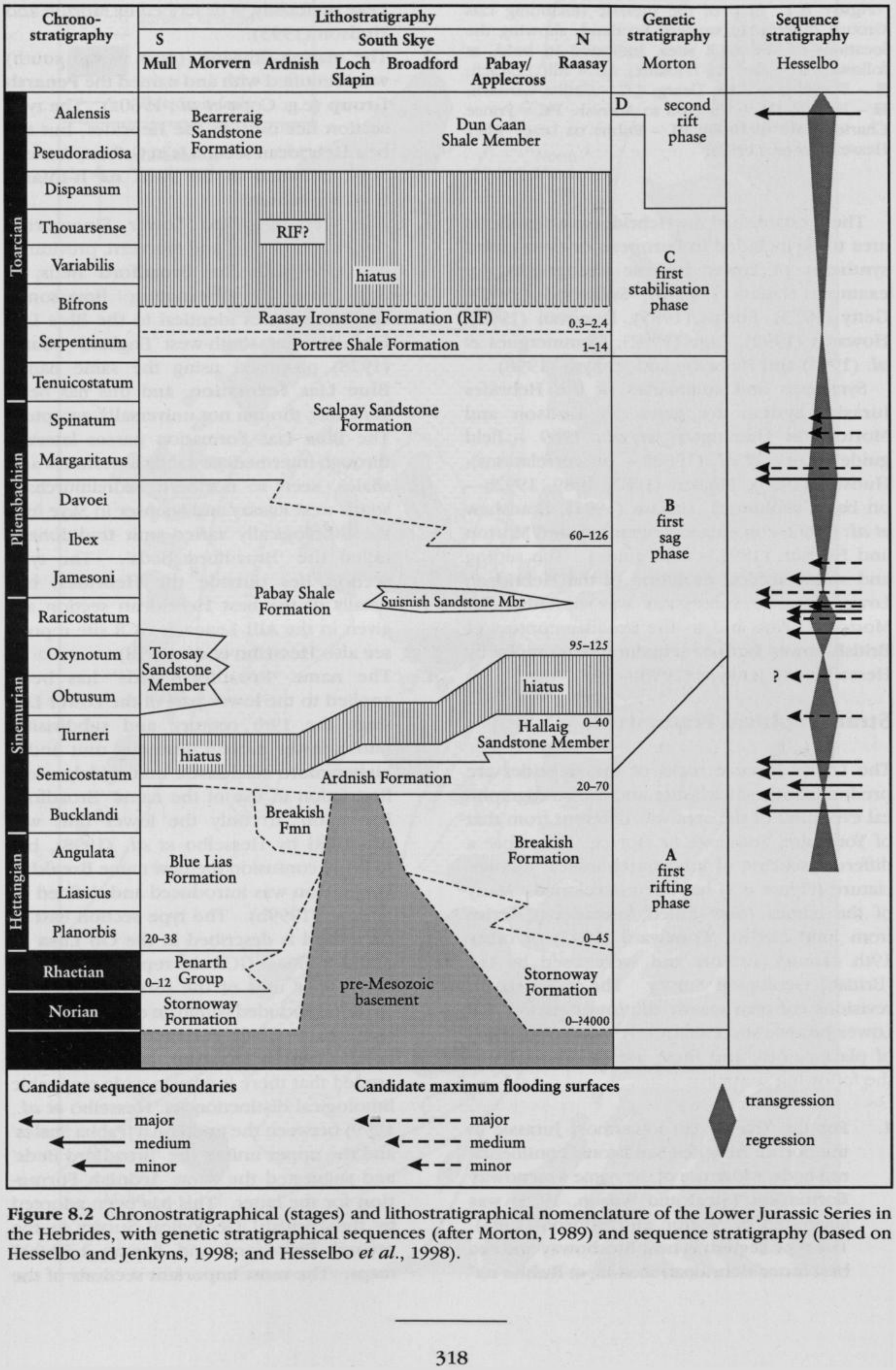



**Figure 8.2** Chronostratigraphical (stages) and lithostratigraphical nomenclature of the Lower Jurassic Series in the Hebrides, with genetic stratigraphical sequences (after Morton, 1989) and sequence stratigraphy (based on Hesselbo and Jenkyns, 1998; and Hesselbo *et al*., 1998).

formation are described in the **Ob Lusa to Ardnish Coast** and **Boreraig to Carn Dearg** GCR site reports. The **Hallaig Sandstone Member** designated by Hesselbo *et al.* (1998) is used for the upper more sandy part of this formation. The type section of the member lies outside the GCR sites, but is described by Morton and Hudson (1995) and Hesselbo *et al.* (1998).

6. The 'Pabba Shale' was named after the Isle of Pabay, but the anglicized names used by the original authors were the versions then current. The original spelling has been used more recently by the Ordnance Survey (and other official bodies) and adopted as appropriate for lithostratigraphical nomenclature as **Pabay Shale Formation**. The type section has not been defined, but is likely to be designated in the **Boreraig to Carn Dearg** GCR site. More sandy units within this formation are recognized by Hesselbo *et al.* (1998) as the **Suisnish Sandstone Member** (Skye, Raasay) and the **Torosay Sandstone Member** (Mull). The classic Allt Fearns section on the Isle of Raasay (Getty, 1973; Page, 1992) is not included in a GCR site, but is described in Morton and Hudson (1995), while the section on Pabay is described by Hesselbo *et al.* (1998).
7. Similarly, the 'Scalpa Sandstone', named after the Isle of Scalpay, has been amended to **Scalpay Sandstone Formation**, but the most appropriate type section is on the Isle of Raasay; see Howarth (1956) and the **Rubha na' Leac**, **Cadha Carnach** and **Hallaig Shore** GCR site reports.
8. The lower shaly part of the Upper Lias was named 'Portree Shales' in Lee (1920) after the capital town of the Isle of Skye (Portree, from Gaelic *Port-an-Righ* = King's harbour). This is retained as **Portree Shale Formation** and the type section is defined and described in the **Prince Charles' Cave to Holm** GCR site report.
9. The shales pass up into the 'Raasay Ironstone', named after the Isle of Raasay, almost everywhere in the Hebrides where the strata are exposed, justifying recognition of a **Raasay Ironstone Formation** even though it is frequently less than 1 m thick. The type section at the opencast mine on the Isle of Raasay is not included in any of the GCR sites, but is described in Morton and Hudson (1995).
10. The uppermost Lower Jurassic succession is classified lithostratigraphically as part of the Bearreraig Sandstone Formation, notably the **Dun Caan Shale Member**. This unit is described in the Middle Jurassic GCR volume under the Gualann na Leac and Bearreraig GCR site reports (Cox and Sumbler, 2002), and included here in the **Cadha Carnach** GCR site report.

The standard ammonite zonal and subzonal scheme for the Liassic of north-west Europe (Dean *et al.*, 1961; modified in Cope *et al.*, 1980a; and revised by Page, 2003) is readily applicable to the Lower Jurassic sequence of the Hebrides, as shown by Hesselbo *et al.* (1998). Indeed two index species have their type localities in the Hebrides. Except for the middle and upper Toarcian successions, nearly all zones and subzones can be recognized in at least one locality. Some localities yield detailed faunal sequences and are of international significance for Lower Jurassic ammonite biostratigraphy, as indicated in the next section.

## Locality Descriptions

Only brief descriptive notes on the most important features or potential of the various localities are given here, for further details see the appropriate [British] Geological Survey memoir, or other references indicated. All the localities are shown on Figure 8.1.

### *Arran*

The island of Arran is not strictly part of the Hebrides, but is included here for completeness. Two small poorly exposed outcrops of Lower Lias shales and decalcified mudstones are known, preserved by spectacular, accident in Palaeocene vent agglomerates as a result of collapse of caldera walls. Ammonites of the Planorbis (Trueman, 1942) and Angulata zones occur in separate places, and elsewhere marine 'Rhaetic' shales and limestones and Upper Cretaceous chalk, thermally metamorphosed (Tyrrell, 1928). Comparisons may be made with Antrim in Northern Ireland where Lias up to Valdani Subzone is known *in situ* under Upper Cretaceous strata, and derived fragments from the Spinatum Zone and Lower Toarcian Substage are known from the Cretaceous basal conglomerate (Wilson and Robbie, 1966; Wilson and Manning, 1978). A greater lateral extent of at least Lower Liassic rocks than might otherwise be expected is proved here.

### *Mull*

Outcrops of Lower (and the lower part of Middle) Jurassic rocks are mostly along the southern and eastern coasts of Mull, but in many areas, especially around Loch Don, the rocks are thermally metamorphosed to varying degrees. Exceptions include the remote outcrops of basal Lias in Gribun (**Aird na h-Iolaire** GCR site) and the important Upper Sinemurian to Lower Pliensbachian shore sections of Carsaig Bay (the original type locality of *Ammonites Jamesoni* Sowerby) (Oates, 1976; Hesselbo *et al.*, 1998). Middle and upper parts of the Lias (and up to Upper Bajocian) occur in the Loch Don area (Lee and Bailey, 1925), but structural complications and thermal metamorphism sometimes make interpretation difficult. Higher parts of the Jurassic sequence are cut out by unconformity beneath the Upper Cretaceous sediments and Palaeocene basalt lavas (except for a surprising outcrop of Lower Kimmeridgian shales, see Morton, 1989). Isolated small outcrops of Lias occur in northern Mull.

### *Morvern*

Lower Lias (up to Upper Sinemurian) occurs on both sides of Loch Aline on Movern, but the best sections are in streams to the east (MacLennan, 1954; Oates, 1976; Hesselbo *et al.*, 1998), including the **Allt Leacach** GCR site. The Hettangian and Lower Sinemurian (to Lyra Subzone) successions are developed in classic Blue Lias Formation facies with spectacular *Gryphaea* beds, overlain unconformably by the Upper Sinemurian Pabay Shale Formation. Jurassic rocks above the Oxynotum Zone are missing beneath the Upper Cretaceous unconformity (Lee and Bailey, 1925).

### *Ardnamurchan*

There are excellent Lower Jurassic outcrops on both the northern and southern coasts of Ardnamurchan, but thermal metamorphism has limited the stratigraphical value of some. A transitional 'sandy Blue Lias' facies is noteworthy on the northern coast (Oates, 1976) and coral beds correlated with Skye. Outcrops in the Kilchoan area of Pabay Shale and Scalpay Sandstone formations are generally too metamorphosed to be informative, but there are important small outcrops of Toarcian strata on the coast, including the only recorded evidence for possible post-Bifrons Zone ammonites in the Raasay Ironstone Formation (Richey and Thomas, 1930).

### *Rum*

No in-situ Jurassic sequence occurs on Rum because it forms part of a central basement ridge uplifted during Early Cretaceous times (the westward dip results in an outlier of Trias in the north-west). However a sliver of metamorphosed Jurassic limestones, presumably of the Blue Lias or Breakish formations, occurs in the ring-fault of the Palaeocene granophyric and ultrabasic plutonic complexes (Emeleus in Craig, 1983) and proves former continuity across the Camasunary Fault (see Morton, 1992b).

### *Skye*

Outcrops of Lower Jurassic rocks occur in several parts of Skye, the most extensive forming a broad stretch between Broadford and Loch Eishort. The oldest beds dated by ammonites in this part of the Hebrides belong to the Angulata Zone, and are underlain by transitional 'Passage Beds' and the continental red-beds of the Stornoway Formation. This has been re-interpreted (Morton, 1999b) as suggesting that the uppermost parts of the 'New Red Sandstone' in this area probably belong to the Hettangian Stage. There are extensive excellent outcrops of the Breakish and Ardnish formations east of Broadford, especially in coastal sections including the **Ob Lusa to Ardnish Coast** GCR site, and north of Loch Eishort, including the **Boreraig to Carn Dearg** GCR site, which are important for the Hettangian to Sinemurian stratigraphy of the Hebrides. Outcrops of the Pabay Shale Formation are less good around Broadford, but there are significant excellent stream and cliff sections on the north side of Loch Eishort, in the Boreraig to Carn Dearg GCR site (Peach *et al.*, 1910; Spath, 1922b; Trueman, 1942; Hallam, 1959; Oates, 1976, 1978; Hesselbo *et al.*, 1998). From Loch Eishort northwards to Loch Slapin the Ardish Formation overlaps older Mesozoic strata to rest unconformably on the Ordovician Durness Limestone at Camas Malag and Torrin (Nicholson, 1978; Farris *et al.*, 1999), but the

Breakish Formation again occurs north of Torrin east of the head of Loch Slapin. On the west coast of Loch Slapin outcrops of the higher parts of the Lower Jurassic succession occur on the east coast of the Strathaird Peninsula (Morton and Hudson, 1995). Outcrops of Breakish Formation (in transitional 'sandy Blue Lias' facies), Ardnish Formation and the lower part of the Pabay Shale Formation occur south of Loch Sligachan, south-west of Sconser, but the rocks are slightly metamorphosed and strongly faulted. Smaller outcrops of Blue Lias (or Breakish) Formation occur locally under the Upper Cretaceous and Palaeocene unconformity west of the basement ridge on the north shore of Soay Sound and west of Camasunary, while the Breakish, Ardnish and Pabay Shale formations crop out north of Camasunary. Higher parts of the Lower Jurassic succession are also well exposed in excellent coastal cliff exposures on the eastern coast of the Trotternish Peninsula in northern Skye, south and north of Portree, the latter in the **Prince Charles' Cave to Holm** GCR site.

### *Pabay*

The low island of Pabay gives its name to the Pabay Shale Formation, but in fact only the upper part of the formation is exposed in the excellent coastal outcrops (Sellwood, 1972; Oates, 1976; Hesselbo *et al.*, 1998). The locality is internationally significant as the type locality of *Platypleuroceras brevispina* (see Spath, 1922b).

### *Scalpay*

The coastal outcrops of the 'name locality' of the Scalpay Sandstone Formation and of part of the Pabay Shale Formation on the south-east coast of the island of Scalpay have not been studied recently and only limited information is available (Peach *et al.*, 1910).

### *Applecross*

The faulted Jurassic outlier in the remote village of Applecross is stratigraphically restricted to the Hettangian to lowermost Sinemurian Breakish Formation, mainly in sedimentologically unusual carbonate facies, exposed in stream and coastal sections (Lee, 1920; Hallam, 1959; Searl, 1989, 1992, 1994; Hesselbo *et al.*, 1998; Morton, 1999b).

### *Raasay*

The renowned Jurassic outcrops in the southern half of the Isle of Raasay owe their preservation, at least in part, to an overlying intrusive sheet of granophyre, but thermal metamorphism from this and other minor intrusions is fortunately limited. There are several superb stream, cliff and coastal exposures of all parts of the Lower Jurassic sequence. The contrast between the carbonate Breakish Formation and siliciclastic Ardnish Formation (with sandy Hallaig Sandstone Member) is well illustrated at Hallaig on the east coast (Hallam, 1959; Morton and Hudson, 1995; Hesselbo *et al.*, 1998; Morton, 1999b) and transitional 'sandy Blue Lias' facies at Suisnish in the south-west (Morton and Hudson, 1995). The Allt Fearns section in the Pabay Shale Formation is of international importance for biostratigraphy, especially in the very thick Raricostatum Zone (Getty, 1972, 1973; Oates, 1976; Donovan, 1990; Page, 1992; Dommergues *et al.*, 1994; Morton and Hudson, 1995). Important cliff sections in the Scalpay Sandstone Formation were described by Howarth (1956) and yielded data on Lower Pliensbachian ammonites (Phelps, 1985), Upper Pliensbachian ammonites (Howarth, 1958) and brachiopods (Ager, 1956a): see also Morton and Hudson (1995) and Hesselbo *et al.* (1998). These are included in the **Cadha Carnach**, **Hallaig Shore** and **Rubha na' Leac** GCR site reports, the latter proposed as the type section for the Scalpay Sandstone Formation. Data on the Toarcian succession is more limited (Lee, 1920; Morton, 1965; Morton and Hudson, 1995). Outcrops of Portree Shale Formation are rare (see Cadha Carnach GCR site report) but the Raasay Ironstone Formation is well exposed in the type section at the old opencast workings north-east of Inverarish (Morton and Hudson, 1995), and marginal-facies outcrops are included in the the Cadha Carnach and Rubha na' Leac GCR site reports.

### *Gruinard Bay*

From the south side of Gruinard Bay to Loch Ewe there is a narrow strip of faulted Mesozoic rocks, but only limited outcrops of Lower Jurassic carbonates, presumed to be Breakish Formation (Peach *et al.*, 1913).

### *Shiant Isles*

The isolated Shiant Isles are composed mainly of dolerite intrusions, but baked Jurassic shales with Toarcian ammonites (Portree Shale Formation?) also occur (Penn and Merriman, 1978).

## Stratigraphy

Two approaches to stratigraphical analysis of the Jurassic System of the Hebrides Basin have been employed by Morton (1987, 1989) and Hesselbo (Hesselbo and Jenkyns, 1998; Hesselbo *et al.*, 1998), genetic stratigraphy and sequence stratigraphy. These were used to emphasize, respectively, tectonic and sea-level controls of stratigraphical evolution. These are generally complementary, but there are significant differences of interpretation (Figure 8.2).

### *Genetic stratigraphy*

Analysis in terms of genetic stratigraphical sequences (Morton, 1989) has resulted in the recognition of three major sequences, plus a fourth which begins with the Aalensis Zone at the top of the Lower Jurassic succession but is mainly Middle Jurassic. Sequence boundaries were defined at major changes of facies, sometimes associated with a hiatus, and each sequence was found to be characterized by a distinctive style of stratigraphical architecture (thickness and facies variation through the basin). Integration of this data with information from analysis of the subsidence history (Morton, 1987) has enabled interpretation of the dynamic stratigraphical evolution of the basin. The results for the Lower Jurassic succession are summarized below and in Figure 8.2.

Sequence A began with an episode of lithospheric extension causing fault-controlled (especially on the western margin) differential subsidence resulting in the deposition of continental red-beds (Stornoway Formation) which onlap pre-Mesozoic basement. Continued subsidence and sea-level rise resulted in marine transgression in the south (Arran, Mull) during the latest Trias (Penarth Group) continuing northwards (Morvern, Ardnamurchan, Raasay) during early Hettangian times (Blue Lias Formation, Breakish Formation). Marine sedimentation did not begin in some areas in the north (Skye, Applecross) until middle or late Hettangian times (Breakish Formation) (Morton, 1999b). Renewed transgression and onlap also occurs at the base of the (Lower Sinemurian) Semicostatum Zone, most notably with the Ardnish Formation overlapping the older Mesozoic strata to rest unconformably on the Durness Limestone of the Loch Slapin area (Camas Malag-Torrin). The stratigraphical architecture of this sequence is characterized by great lateral variability of facies and thicknesses (see Morton, 1989, 1990 for details). These features are consistent with deposition during an episode of lithospheric extension resulting in differential subsidence at the surface.

Sequence B begins with a hiatus which can be identified but is of different ages in the various localities, although Morton's (1989) interpretation of a diachronous hiatus is questioned by Hesselbo *et al.* (1998). In Mull, Morvern and Ardnamurchan parts of the Semicostatum and Turneri zones are missing below the Pabay Shale Formation. In southern Skye (Loch Eishort) biostratigraphical evidence for the age of the Hallaig Sandstone Member is poor but possibly parts of the Turneri and Obtusum zones may be absent. On Raasay, especially at Hallaig, there is better evidence, with the top of the Hallaig Sandstone Member of Birchi Subzone age and the base of the Pabay Shale Formation of Oxynotum Zone (probably also subzone) age so that the Obtusum Zone and part of the Oxynotum Zone are missing. Above the hiatus there is a sharp reduction of grain size, and in most areas deposition begins with fine-grained organic-rich clays at the base of the Pabay Shale Formation. Onlap above a minor unconformity is also seen in Morvern (Oates 1976, 1978). The variations in facies and thickness seen in Sequence B are very much less than in Sequence A. Minor coarsening-up shale to sandstone cycles occur within an overall coarsening-up succession which includes the Pabay Shale and Scalpay Sandstone formations, but lateral variation in the shale–sandstone cycles has meant that the boundary between the two formations is drawn earlier in the north (Raasay and Skye) than in the south

(Mull). The changes in stratigraphical architecture, after a submarine hiatus, sharp reduction of the grain size of siliciclastic input, and onlap, are interpreted as resulting from a change in tectonic regime. Lithospheric extension and differential subsidence during deposition of Sequence A were replaced by broader and more uniform subsidence across the basin as a result of thermal and loading sag.

Sequence C is marked at the base by a sharp change of facies to dark organic-rich shales, the Portree Shale Formation. There does not appear to be a significant hiatus, at least at zonal level. The boundary is dated as at or close to the base of the Serpentinum Zone wherever ammonite faunas have been found, so that it appears to be isochronous throughout the basin. The Portree Shale Formation passes up gradationally into the Raasay Ironstone Formation, and the lateral extent and uniformity of facies in two such thin formations is remarkable. The Raasay Ironstone Formation shows evidence of condensation, with stromatolitic hardgrounds, and is succeeded by a major hiatus in which most of the Middle and Upper Toarcian sequence is missing. There is no apparent tectonic reason for the sequence boundary at the base of this sequence, and its isochronous nature together with precise correlation with similar deepening events in many other areas (Hallam, 2001) suggest that it was caused by a eustatic rise of sea level. The low thicknesses and hiatus development indicates that this sequence corresponds to a phase of basin and hinterland stabilization when subsidence and uplift were reduced, limiting accommodation space availability and siliciclastic sediment supply. Careful assessment of likely eustatic sea-level trends, compaction and other factors (Morton, 1987) suggests that there may even have been slight uplift of the basement during most of the Toarcian Stage. However, there is no evidence of emergence and only very local erosion of the Raasay Ironstone Formation.

Sequence D is mainly a Middle Jurassic sequence, so outside the scope of this volume. It is characterized by being very thick and highly variable in facies as well as thickness, indicating a new episode of renewed differential subsidence as a result of lithospheric extension. This began in very latest Early Jurassic times, because sediment accummulation recommenced with the top Toarcian Aalensis Zone, which is itself extremely variable; for example the thickness on Raasay increases from 9.1 m to 38.2 m over a distance of 3 km (Morton, 1965).

### *Sequence stratigraphy*

Hesselbo *et al.* (1998) re-measured and re-studied a number of the best Lower Jurassic sections in the Hebrides, publishing the first detailed measured successions for several decades. The stratigraphy was interpreted in the context of a wider study by Hesselbo and Jenkyns (1998) of Lower Jurassic secions in the Wessex, Bristol Channel and Cleveland basins as well as the Hebrides.

Four large-scale (second-order) transgressive–regressive cycles were recognized by Hesselbo *et al.* (1998), with boundaries in the Hallaig Sandstone Member, the Suisnish Sandstone Member and the Scalpay Sandstone Formation (see Figure 8.2). Hesselbo and Jenkyns (1998) interpreted the Hebrides Basin as exemplifying a proximal pattern of sedimentation, with expanded sections corresponding to sea-level rise or highstand, and condensed sections corresponding to relative sea-level fall or lowstand. The key medium-scale (third-order) sequence surfaces identified by Hesselbo and Jenkyns (1998) are shown on Figure 8.2. Two types are identified – candidate sequence boundaries, defined at unconformities or intervals of minimal accommodation space, and maximum flooding surfaces, recognized at condensed intervals in distal settings and maximum accommodation space in proximal settings. In each case major, medium or minor expressions can be distinguished, and these are shown on Figure 8.2.

## Palaeogeographical Evolution

Onshore evidence proves that subsidence in the Hebrides Basin started in the Triassic Period, and highly irregular topography resulted in deposition of conglomerates and breccias, mostly of local derivation, in a series of alluvial fans and mass-flow deposits. These pass laterally into fluvial sandstones and floodplain mudstones, and development of caliche in semi-arid conditions was widespread and frequent (Steel, 1977). There is no direct evidence for dating, but a late Triassic (?Norian) age is likely. Arran was at this time part of a separately evolving sedimentary basin, with evidence of lacustrine deposition in a more varied environment. During the latest Trias (Rhaetian) the marine transgression spread northwards from the south-west of the British Isles, to give marine conditions in Arran and as far north as Mull.

Dating events at the beginning of the Jurassic Period is hampered by limitations of biostratigraphical evidence – no Planorbis Zone ammonites are known north of Mull, and Liasicus Zone ammonites (*Franziceras*) only from eastern Raasay (Morton, 1999b). Ammonites from the Angulata Zone (*Schlotheimia*) are rare but more widespread (Applecross, Skye, Ardnamurchan, Morvern, Mull). Integrating facies and biostratigraphical evidence from other fossil groups (e.g. bivalves) with the ammonite dating indicates that renewed transgression spread marine conditions farther north, to Morvern, Ardnamurchan and Raasay during early Hettangian times, and to Applecross probably in mid-Hettangian times. However, in southern Skye (Broadford area) an Angulata Zone ammonite occurs not far above the base of the Breakish Formation. On the basis of correlations based on biostratigraphical and lithostratigraphical markers, Morton (1999b) interpreted a diachronous transgression and facies change from continental Stornoway Formation to marine Breakish Formation in the Skye area. Therefore the Penarth Group passes laterally into the Stornoway Formation, while the Blue Lias Formation in offshore areas (e.g. Mull, Morvern; Oates, 1976, 1978) passes laterally through a transitional more sandy facies (Ardnamurchan, south-west Raasay and Sconser; Oates, 1976; Morton, 1999b), or into Breakish Formation carbonates/shales (eastern Raasay), then near-shore Breakish Formation carbonates/sandstones (Applecross, southern Skye) and into the non-marine Stornoway Formation (Morton, 1999b). The sandstones represent offshore sand-bars, sometimes with wave-, tide- and possibly storm-action evident. The carbonates vary from oolites to coral beds (small patch reefs), *Liostrea* coquinas and calcilutites which may represent shallow lagoonal deposits, and there is diagenetic evidence for several periods of emergence near the basin margins at Applecross (Searl, 1989).

During the Semicostatum Zone there was a major change in the depositional environment, and final onlap of the topographic high related to the area of Cambro–Ordovician carbonates in the area north of Loch Slapin. In Raasay, Broadford, Loch Eishort, Mull and possibly Ardnamurchan, carbonate-dominated facies were replaced abruptly by ferrugineous association (Hallam, 1975) sandstones, siltstones and shales (Ardnish Formation) with at least one ironstone bed (Broadford) and *Gryphaea* beds. In the Broadford area three coarsening-up cycles from siltstone to sandstone to ironstone (or at least goethite ooliths present) can be recognized (Taylor, Cointet, unpublished reports; see Morton and Hudson, 1995). In the Skye and Raasay area a thicker sandstone (Hallaig Sandstone Member) was deposited in the Turneri Zone, while in Morvern slight tilting (presumably near the basin margin) resulted in the subsequent development of a local angular unconformity (Oates, 1976).

During Late Sinemurian times more uniform depositional environments occurred throughout the basin. The sediments were deposited on a mud- or silt-dominated shelf with local sand-bars (Pabay Shale Formation), and similar conditions continued into Early Pliensbachian times. Upward shallowing in Late Pliensbachian times resulted in the spread across the basin of extensive offshore sand-bars and sheet sands (Scalpay Sandstone Formation), influenced by tidal and storm activity (MacCallum, 1971; Oates, 1976). This continued into earliest Toarcian times.

The deepening event of the Early Toarcian Serpentinum Zone caused the establishment of deposition of shales (Portree Shale Formation) in partially anaerobic conditions below wave-base. This is the local expression of the widespread early Toarcian anoxic event (Jenkyns, 1988). Analysis of the subsidence history and stratigraphical architecture indicates that this rise of sea level postponed the development of 'basin-fill' conditions of stabilization in the Hebrides Basin, probably in a continuing marine environment, achieved during Early Toarcian times, with deposition of the Raasay Ironstone Formation.

There is no evidence from outcrops for any deposition having occurred during middle and most of late Toarcian times. Conversely there is evidence for only limited erosion in a few localities (e.g. Strathaird; see Morton, 1989), because the overlying Bearreraig Sandstone Formation rests everywhere on the Raasay Ironstone Formation even though this is very thin.

The top of the Lower Jurassic succession in the Hebrides is genetically part of the Middle

Jurassic Series, with a lithospheric extension event beginning in latest Toarcian times (Morton, 1987) resulting in renewed subsidence in the Hebrides Basin and rejuvenation of hinterland topography resulting in influx of large quantities of coarse siliciclastic sediment to form the Bearreraig Sandstone Formation, partly in tidal sand-wave environments (Morton, 1983).

## OB LUSA TO ARDNISH COAST, ISLE OF SKYE, HIGHLAND (NG 701 248–NG 676 245)

*N. Morton*

### Introduction

The Ob Lusa to Ardnish Coast GCR site lies on the foreshore on the eastern side of Broadford Bay on the Isle of Skye. Here an extensive low-lying area is underlain by Lower Jurassic sediments, including the Ardnish Peninsula, the crofting townships of Waterloo, Lower and Upper Breakish (part), and extending east to the Isle of Skye airfield and Ob Lusa (Figure 8.3). This GCR site is probably the best-known Lias section in the Hebrides Basin. It exposes one of the most extensive and readily accessible sections through the Hettangian and Lower Sinemurian succession of the region. It includes the type locality for the carbonate-dominated Breakish Formation, with its remarkable coral beds, and the more clastic-dominated Ardnish Formation, contrasting markedly with the correlative Blue Lias Formation developed across much of Britain. The Ob Lusa Coral Bed represents the only extensive development in the British Lias of isastraeid corals.

The Jurassic rocks in central Skye are folded into a broad syncline and anticline, of Tertiary age, but to the north and north-east these folds die out and on either side of Broadford Bay the rocks show the simple north-westward tilting which is typical of most of the Hebridean Jurassic sequence. The low dips and extensive coastal outcrops expose large bedding surface areas that provide excellent opportunities to study the typical facies and faunas of the Lower Lias of the northern Hebrides. These include coral beds and oolitic ironstones as well as a variety of carbonates and siliciclastic sediments, some of which are richly fossiliferous. The best outcrops, giving almost continuous successions through more than 75 m of Hettangian (Angulata Zone) to Lower Sinemurian (Semicostatum Zone) strata occur in and adjacent to the Ob Lusa to Ardnish Coast GCR site, on the east side of Broadford Bay, between Ob Lusa (NG 701 248) and the Ardnish Peninsula (NG 676 245 for GCR site, but extending south-west to Waterloo – NG 660 235) (Figure 8.3).

The Lower Lias of the Broadford area of central Skye has a long history of investigation, most notably by Judd (1878) and the [British] Geological Survey (Peach *et al*., 1910). More recent accounts with detailed measured sections include those by Hallam (1959), Searl (1992, 1994), Morton and Hudson (1995) and Hesselbo *et al*. (1998). The outcrops in this area are the most easily accessible Jurassic outcrops in the Hebrides. They are also the most frequently studied, by generations of geologists at all levels of experience – amateurs and tourists on holiday, students on field classes and professional geologists on field studies. An excursion guide is given by Morton and Hudson (1995).

Broadford is the type area of the Broadford Beds, the lithostratigraphical name introduced by Woodward (in Peach *et al*., 1910) for the lowest marine Jurassic succession in the Hebrides. More recent revisions of the lithostratigraphical nomenclature by Oates (1978), Hesselbo *et al*. (1998, 1999) and Morton (1999a,b) are discussed below. The GCR site includes the type section of the carbonate-dominated Breakish Formation, the lowest part of the marine Lower Lias in this area. Named after the township of Breakish, the type section is defined as the headland on the west side of Ob Lusa with the base at NG 6998 2492 and the top at NG 6972 2512 (Morton 1999b). The succeeding strata are clastic-dominated and crop out extensively on the Ardnish Peninsula, particularly in the coastal areas. It is not yet formally defined but is termed here the 'Ardnish Formation'. The base is seen in a small inlet on the south side of the peninsula (NG 6796 2422) but the top is not seen in the peninsula.

### Description

The Broadford area is part of one of the Hebrides tilted fault-blocks, formed during early Cretaceous times (Morton, 1992b), and the beds dip at low angles generally of less than 10° to the north-west. The outcrop is cut by numerous small faults of Palaeogene age, most with a

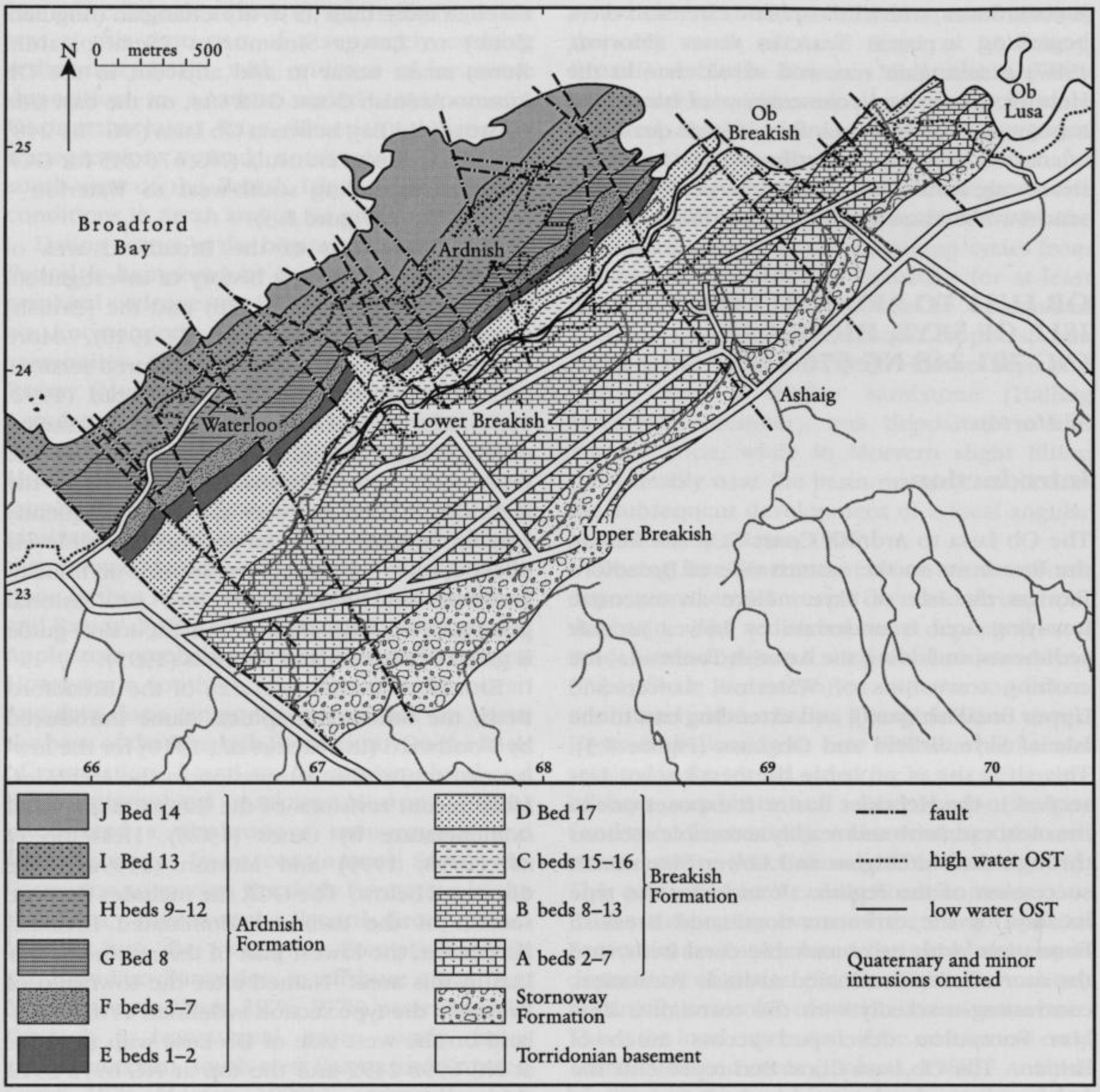



**Figure 8.3** Geological map of the Ob Lusa to Ardnish area, eastern part of Broadford Bay, Isle of Skye. The GCR site includes the coastal outcrops from Ob Lusa west to the eastern parts of Ob Breakish and the Ardnish Peninsula. After D.J. Taylor, 1981, BSc thesis, Birkbeck College.

north-west–south-east trend and a downthrow of only a few metres to the north-east. Numerous minor intrusions include dolerite sills, sometimes intruded along particular stratal surfaces, and dolerite and felsite dyke-complexes, sometimes associated with the minor faults. These cause only very local baking of the sediments, but in addition to the effects of burial diagenesis (Searl, 1994) the area is close enough to the Palaeogene plutonic centre of central Skye to have suffered slight thermal metamorphism (Lewis *et al*., 1992).

Detailed measured sections through the Jurassic succession at the site are given by Morton and Hudson (1995) and by Hesselbo *et al*. (1998). Though differing in detail of individual beds, most can be reconciled as shown in Figures 8.4 and 8.5. The succession, traditionally classified as 'Broadford Beds', always divided into two units, is now formally recognized as two formations.

The lower, carbonate-dominated, unit, the Breakish Formation, was variously termed the 'infra-Lias' by Judd (1878), the 'Lower Broadford

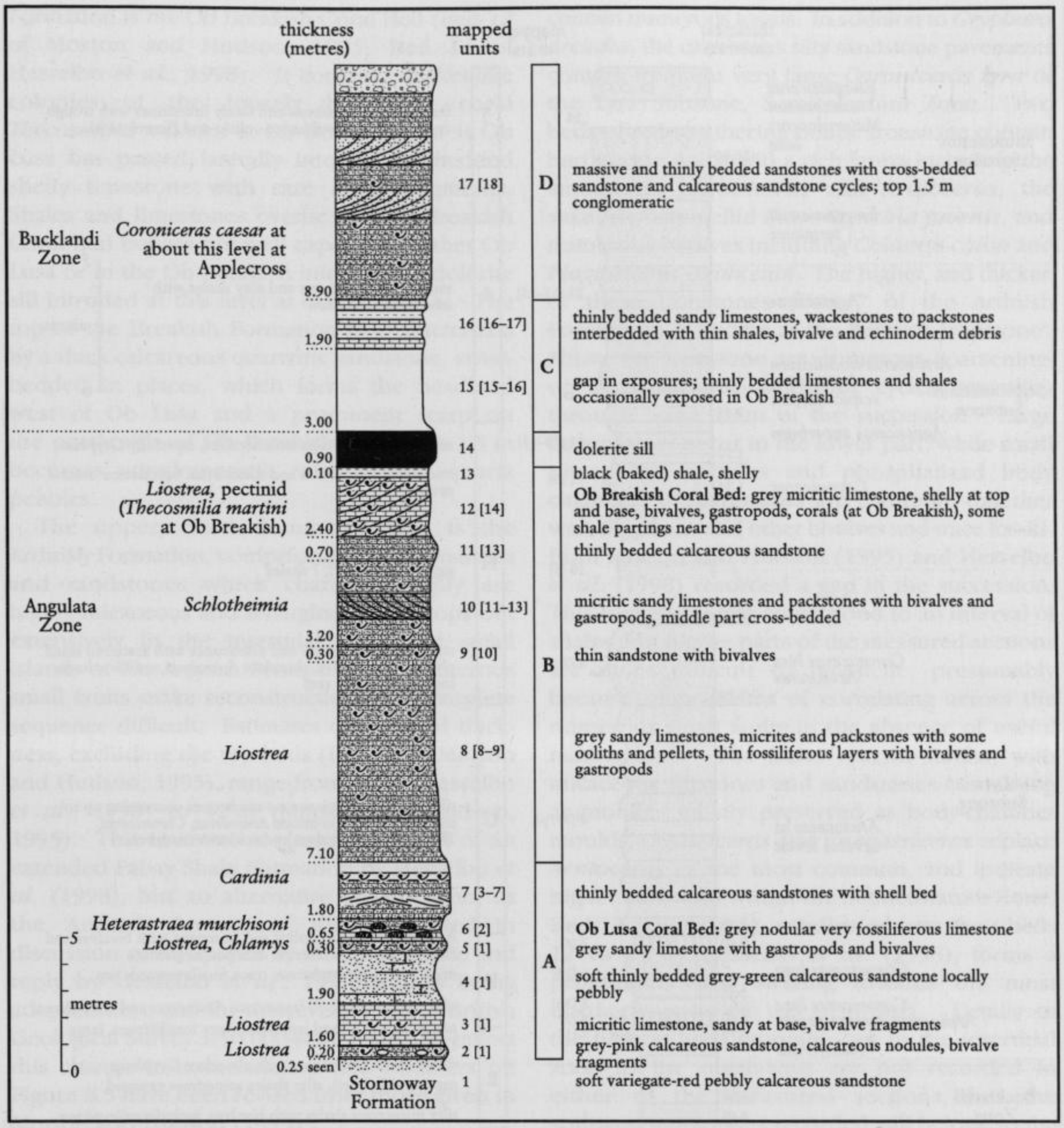



**Figure 8.4** Succession through the Breakish Formation at Ob Lusa (NG 6998 2492 to NG 6972 2512). After D.J. Taylor and C. Cointet, modified from Morton and Hudson (1995). The bed numbers of Hesselbo *et al.* (1998) are shown in square brackets.

Beds' by Hallam (1959), and the 'Broadford Formation' (in a more restricted sense) by Hesselbo *et al.* (1998). In the light of subsequent discussion it was re-named as the 'Breakish Formation' in its present sense, by Morton (1999b). The best section (Figure 8.4) lies on the west side of Ob Lusa where the unit is 34 m thick, but the succession can be correlated in detail across to the Ashaig Burn and Breakish (Figure 8.3). The base is seen only at Ob Lusa (between beds 1 and 2 of Morton and Hudson, 1995): and is not exposed elsewhere. The Breakish Formation contains several distinctive beds which form useful marker horizons. The Ob Lusa Coral Bed (Bed 6 of Morton and Hudson, 1995; Bed 2 of Hesselbo *et al.*, 1998) contains numerous subspherical colonies of the compact colonial coral *Heterastraea*

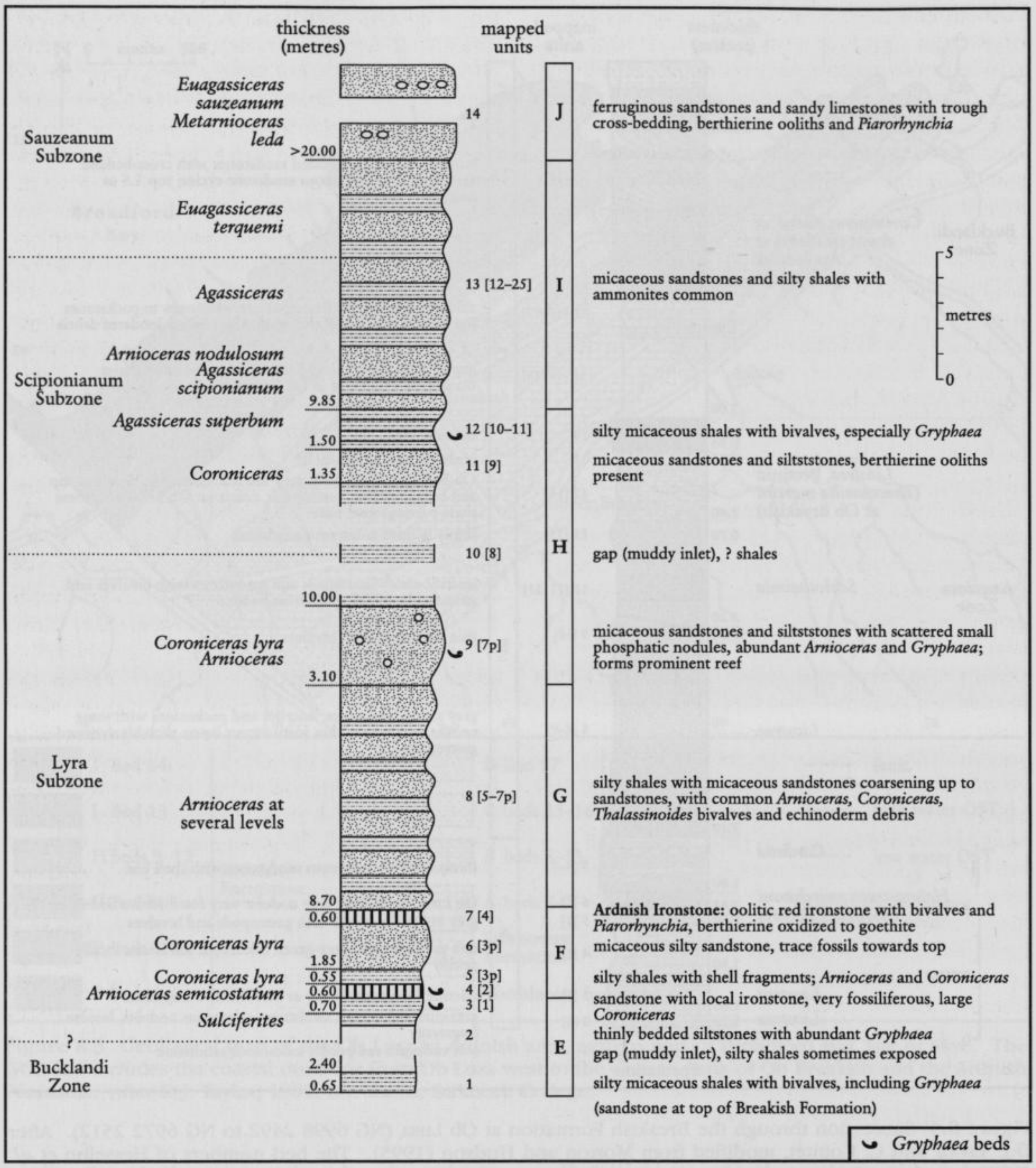



**Figure 8.5** Succession in the Ardnish Formation in the Ardnish Peninsula. After D.J. Taylor and C. Cointet, modified from Morton and Hudson (1995). Bed numbers have been revised to start the base of the Ardnish Formation as Bed 1 (= Bed 18 of Morton and Hudson, 1995). The bed numbers of Hesselbo *et al.* (1998) are shown in square brackets.

*murchisoni*, many of them *in situ*, together with bivalves, especially *Liostrea* and various pectinids, and gastropods. However, the coral bed has suffered severely from over-collecting in recent years and little in-situ material can now be seen (MacFadyen, 2001). The overlying beds show hummocky cross-stratification and a wave-sorted shell bed with *Cardinia*. Oates (1976) found the only ammonite recorded *in situ* in these beds, a *Schlotheimia* sp. about 3 m below the top. It indicates a late Hettangian, Angulata Zone, age. Near the top of the Breakish

Formation is the Ob Breakish Coral Bed (Bed 12 of Morton and Hudson, 1995; Bed 14 of Hesselbo *et al.*, 1998). It contains thicket-like colonies of the loosely branching coral *Thecosmilia martini* at Ob Breakish, but at Ob Lusa has passed laterally into a cross-bedded shelly limestone with rare coral fragments. Shales and limestones overlie the Ob Breakish Coral Bed but are not well exposed at either Ob Lusa or in the Ob Breakish inlet, with a dolerite sill intruded at this level at both localities. The top of the Breakish Formation is characterized by a thick calcareous quartzitic sandstone, cross-bedded in places, which forms the headland west of Ob Lusa and a prominent scarp on the north side of Ob Breakish. The top 1.5 m becomes conglomeratic, with mainly quartz pebbles.

The upper, clastic-dominated unit is the Ardnish Formation, comprising shales, siltstones and sandstones which characteristically are highly micaceous and ferruginous. It crops out extensively in the intertidal zone and small islands of the Ardnish Peninsula, but numerous small faults make reconstruction of a complete sequence difficult. Estimates of the total thickness, excluding the top beds (Bed 31 of Morton and Hudson, 1995), range from 36 m (Hesselbo *et al.*, 1998) to 42 m (Morton and Hudson, 1995). This unit was re-classified as part of an extended Pabay Shale Formation by Hesselbo *et al.* (1998), but an alternative classification, as the 'Ardnish Formation', was suggested in discussion of this paper by Morton (1999a, and reply by Hesselbo *et al.*, 1999) and is being adopted here and for the revision of the British Geological Survey 1:50 000-scale maps. To reflect this change in nomenclature bed numbers on Figure 8.5 have been revised from those given in Morton and Hudson (1995).

In a small inlet on the south side of the Ardnish Peninsula (NG 6796 2422) outcrops of the basal beds of highly micaceous silty shales vary according to the state of the beach. Hesselbo *et al.* (1998) recorded a gap of 5–6 m (plus their Bed 1), but on different occasions this has been much less (beds 1 and 2 with a smaller gap). The facies change to highly micaceous sediments, and the incoming of *Gryphaea arcuata*, marks the base of the Ardnish Formation. However, dating of this boundary to the basal Sinemurian Bucklandi Zone (after Hallam, 1959) or to the Semicostatum Zone is uncertain. The overlying beds 4 to 7 (Figure 8.5) contain numerous fossils. In addition to *Gryphaea arcuata*, the calcareous silty sandstone pavements contain frequent very large *Coroniceras lyra* of the Lyra Subzone, Semicostatum Zone. Two beds of red-weathering oolitic ironstone contain berthierine ooids and a rich fauna including the ammonites *Coroniceras* and *Arnioceras*, the small rhynchonellid *Piarorhynchia juvenis*, and numerous bivalves including *Chlamys calva* and *Plagiostoma giganteum*. The higher, and thicker, of these ironstones (Bed 7 of the Ardnish Formation) is known as the 'Ardnish Ironstone'. Above the ironstone are numerous coarsening-up shale–siltstone–sandstone cycles extending through some 10 m of the succession. Large *Coroniceras* occur in the lower part, while small phosphatic nodules and phosphatized body chambers of *Arnioceras* are common, together with *Gryphaea* and other bivalves and trace fossils. Both Morton and Hudson (1995) and Hesselbo *et al.* (1998) recorded a gap in the succession. This is presumed to correspond to an interval of shales, but higher parts of the measured sections are more difficult to reconcile, presumably because of problems of correlating across the numerous small faults in the absence of useful marker beds. The facies remain similar, with micaceous siltstones and sandstones containing ammonites mostly preserved as body-chamber moulds. *Agassiceras* and *Euagassiceras* replace *Arnioceras* as the most common, and indicate higher subzones within the Semicostatum Zone. Bed 13 (Figure 8.5), subdivided into their beds 12 to 25 by Hesselbo *et al.* (1998), forms a prominent scarp striking towards the most northerly point of the peninsula. Details of the highest beds cropping out in the intertidal zone to the north-west are not recorded in either of the measured sections, but the youngest ammonites recorded still belong to the Semicostatum Zone.

## Interpretation

Lithostratigraphical subdivision of the traditional Broadford Beds into two units is now accepted by consensus by those who have worked on this part of the Hebridean Jurassic sequence in recent years, with the lower unit being re-named the 'Breakish Formation' (Morton, 1999b). However, lithostratigraphical classification of the upper unit, as part of an enlarged and revised Pabay Shale Formation (Hesselbo *et al.*, 1998) or as a separate Ardnish Formation is not yet agreed. The latter is used here and has been adopted for the revision of the British Geological Survey maps.

The age of the succession and correlation with other sites has been discussed by Morton (1999b). Trueman (1942) concluded, largely on the basis of the bivalve faunas, that the Ob Lusa Coral Bed and overlying strata up to the Ob Breakish Coral Bed belonged to the Angulata Zone. The *Schlotheimia* found 3 m below the Ob Breakish Coral Bed (Oates, 1976) at least partly confirm this. The two coral beds are useful marker beds that can be correlated to Applecross, where Lee (1920) recorded *Schlotheimia* cf. *montana*, indicating the Angulata Zone, from near the level of the Ob Lusa Coral Bed. Although neither coral bed can be recognized at Hallaig on Raasay, an oolite marker bed below the Ob Lusa Coral Bed at Applecross is present at Hallaig though not in the Broadford area. These marker bed correlations support the interpretation that the base of the Breakish Formation in the Broadford area falls within the Angulata Zone, and hence is younger than the base of the formation at Applecross and Hallaig. Consequently the upper part of the continental red-bed facies (Stornoway Formation) in the Broadford area is interpreted as Jurassic in age.

The sandstones above the Ob Breakish Coral Bed in Applecross yielded a *Coroniceras coronaries* to Lee (1920), since re-identified as *Coroniceras caesar*, a form characteristic of the middle part of the Conybeari Subzone (Morton, 1999b). Consequently, the upper part of the Breakish Formation in Ob Lusa and Ob Breakish is also interpreted as belonging to the Bucklandi Zone. However, the precise position of the Hettangian–Sinemurian boundary remains uncertain. The Breakish Formation can be traced south-westwards from Ob Lusa towards Heaste and Loch Eishort, with both coral beds recognized though the sandstones become generally coarser grained.

In the succeeding Ardnish Formation ammonites are fairly common throughout the sequence. However, most frequent are small- to medium-sized body chambers of *Arnioceras* which are of only limited biostratigraphical value. Hence, although the whole of the formation exposed in the Ardnish Peninsula can be assigned to the Semicostatum Zone, the precise positions of the base of the zone and of subzonal boundaries remain less certain. Beds 3–6 are characterized by common large (> 35 cm diameter) *Coroniceras lyra* (Lyra Subzone). A large (> 40 cm diameter) specimen of *Agassiceras superbum* was found in Bed 12 on the north coast of Ardnish, indicating the Scipionianum Subzone, while *Euagassiceras* occurs in the upper part of Bed 13 and above and indicate the Sauzeanum Subzone. Elsewhere in Skye (Loch Eishort) and on Raasay (Hallaig) the Ardnish Formation, as used here (cf. Hesselbo *et al.*, 1998), encompasses younger strata, including the Hallaig Sandstone Member, which range up to the Turneri Zone.

The Breakish Formation in the Ob Lusa to Ardnish Coast area consists of limestones and clean (non-muddy) sandstones, with only subordinate shales. They are interpreted as having been deposited in generally shallow marine, near-shore environments with varying input of siliciclastic sand from adjacent land areas. This produced pure carbonates, especially the coral beds, when siliciclastic input was low, and quartz sandstones or sandy limestones when siliciclastic input was higher. Most beds contain stenohaline fossils, such as bivalves, gastropods and echinoderms, as well as the corals, indicating deposition in fully marine conditions. Cross-bedding in some beds, notably the top sandstone and the Ob Breakish Coral Bed at Ob Lusa, indicate deposition by marine tidal currents. Hummocky cross-stratification, indicative of the influence of storms, occurs in the beds above the Ob Lusa Coral Bed.

A characteristic feature of most of the succeeding Ardnish Formation is the almost ubiquitous occurrence of detrital mica. Lithologies range from micaceous shales through siltstones to sandstones, which tend to be muddy rather than the purer quartz sandstones of the Breakish Formation. The two formations provide a classic example of the contrasts between Hallam's (1975) ferruginous and calcareous facies associations. Berthierine ('chamosite') ooliths occur in several beds in the lower part of the succession (Searl, 1992) and are sufficiently abundant in two of these towards the base of the formation for them to be termed 'ironstones'. At several levels metre-scale coarsening-up cycles occur.

Fossils occur throughout but are abundant only in some beds, with layers rich in *Gryphaea arcuata* being especially characteristic. The faunas consistently include stenohaline groups such as ammonites and echinoderms indicating deposition in normal marine salinity. The sediments were deposited in an offshore shelf environment below or close to wave-base. Because the upper part of the succession is missing, the upward change to sandstones is less fully developed in Ardnish than elsewhere in Skye or Raasay.

## Conclusions

The Ob Lusa to Ardnish Coast GCR site includes the foreshore parts of two main areas of outcrop separated by the Isle of Skye airstrip (construction of which obscured some outcrops between). The two areas are complementary in showing different parts of the Hettangian to lower Sinemurian succession in the classical facies of the northern Hebrides Lower Lias.

Ob Lusa and the headland to the west shows the best and most accessible section of Hettangian to basal Sinemurian sediments in the Hebrides, and is the type locality of the Breakish Formation (formerly the 'Lower Broadford Beds'). Sedimentological interest lies in the mixing and alternation of shallow marine carbonates of various types and quartzose sandstones. Of greatest palaeontological interest is the Ob Lusa Coral Bed, with subspherical colonies, mostly 10 cm to 25 cm in diameter, of *Heterastraea murchisoni*. The upper part of the Breakish Formation is discontinuously exposed on both sides of Ob Breakish south of the Ardnish Peninsula. Outcrops of the Ob Breakish Coral Bed, with large masses of the branching colonial coral *Thecosmilia martini*, occur at high-water mark below the eastern end of Lower Breakish.

The Ardnish Peninsula, and especially the intertidal and supratidal shore zone and small islands at the eastern end included in the GCR site, shows very extensive outcrops of the lower Sinemurian Semicostatum Zone in the Ardnish Formation (formerly the 'Upper Broadford Beds'). The broad flat rocky platforms enable study of large areas of bedding plane in the micaceous silty shales, siltstones and silty sandstones. The Ardnish Ironstone and a lower, thinner bed are very fossiliferous iron-bearing oolites. Fossils include numerous ammonites, especially large *Coroniceras* in the lower part, and *Arnioceras* and *Agassiceras* in the upper part, together with epifaunal and infaunal bivalves, layers with abundant *Gryphaea*, and brachiopods locally.

## HALLAIG SHORE, ISLE OF RAASAY, HIGHLAND (NG 588 396–NG 591 390)

*N. Morton*

### Introduction

The Hallaig Shore GCR site is the finest of the very few exposures to show the transition from the Pabay Shale Formation into the Scalpay Sandstone Formation, a part of the succession almost never exposed in the Hebrides. The site is of key importance for dating the apparently diachronous junction between the two formations. The ammonite succession is well documented and enables detailed correlations to be made with the predominantly argillaceous Pliensbachian successions in southern England.

The area immediately north of the abandoned crofting township of Hallaig on the Isle of Raasay, including the Hallaig Shore GCR site (Figure 8.6), is underlain by a large rotational landslip. This consists mainly of the thick sandstones of the (Aalenian–Bajocian) Bearreraig Sandstone Formation and the (Pliensbachian–basal Toarcian) Scalpay Sandstone Formation. Décollement is in the lower part of the (Sinemurian–lower Pliensbachian) Pabay Shale Formation, which has been squeezed out so that the apparent thickness of this part of the formation is much reduced. The sole of the landslip lies on the top sandstone bed (Sinemurian Turneri Zone) of the Hallaig Sandstone Member of the Ardnish Formation, which forms the top of the cliff north of Hallaig waterfall (NG 5940 3870) and a scarp feature across the beach 200 m to the north (NG 5926 3887). Locally, very small masses of in-situ basal Pabay Shale Formation (Sinemurian Oxynotum Zone) can be observed on top of the sandstone.

In the southern part of the landslip, around Hallaig township and Creag nan Cadhaig, it is not possible to establish a coherent stratigraphy and a chaotic arrangement of small blocks is apparent in the few outcrops. The eastern edge of this part of the landslip, along the northern part of the Hallaig Burn, the top of the cliff north of the waterfall and on the shore to the north is still active and subject to erosion. Elsewhere, it is more stable and there is no evidence of significant movement in historical times; for example, the enclosure wall and foundations of the former crofts remain largely intact.

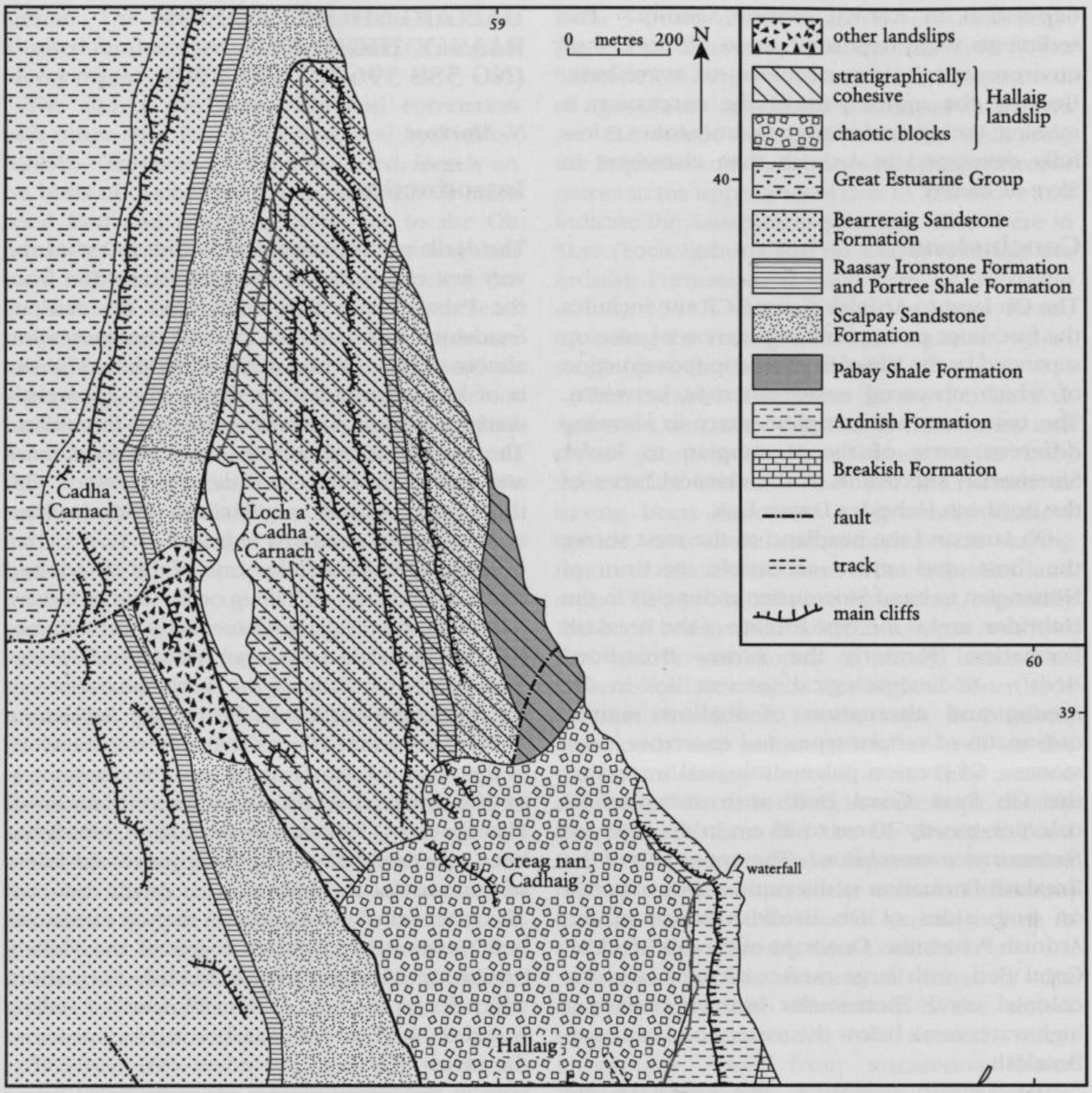



**Figure 8.6** Map of Hallaig and the Hallaig Shore area, showing the main topographic features, the limits of the Hallaig landslip and the location of the GCR site. Selected dip arrows shown indicate the effects of the rotation associated with the landslip. The probable position of the Portree Shale and Raasay Ironstone formations, which are not exposed, is interpolated.

In the northern part of the landslip the various parts of the succession have generally maintained their cohesion and relative stratigraphical positions, although displaced from their original positions and rotated through some 25° (see below). Consequently the upper part of the Pabay Shale Formation exposed on the shore (NG 5907 3909), dips WNW beneath the Scalpay Sandstone Formation, which forms the lower cliff overlooking the shore (NG 5883 3952) southwards to north of Creag nan Cadhaig (NG 5890 3907). The Bearreraig Sandstone Formation forms the higher scarp, to the west of a broad ledge interpreted to mark the position of the Portree Shale and Raasay Ironstone formations. On the western edge of the landslip it is possible locally to identify the Garantiana Clay Member and Cullaidh Shale Formation and map part of the Great Estuarine Group (Figure 8.6).

A description of the outcrops and lithologies, with a surprisingly brief faunal list, was given by Lee (1920). A more detailed measured succession was described by Howarth (1956) and further information about the ammonite succession was given by Phelps (1985). The sedimentary log by Hesselbo *et al*. (1998) is a composite of this site and that at the **Cadha Carnach** GCR site located 1 km to the north.

Lithologies throughout the succession vary between micaceous silty shales and sandstones, frequently with calcareous nodules or doggers, and some calcareous beds. Some beds are reasonably fossiliferous, with ammonites, bivalves and brachiopods dominant, though the distributions are usually discontinuous stratigraphically, so that precise positions of zonal or subzonal boundaries can rarely be defined.

## Description

The most important outcrops within the Hallaig Shore GCR site are in the intertidal part of the shore north of Hallaig. The first outcrops north of the top of the Hallaig Sandstone Member (at NG 5926 3885) are of fossiliferous dark shales, with numerous red-weathering calcareous nodules, comprising the main part of the Pabay Shale Formation. They are strongly affected by faulting and shearing in the base of the landslip so that their thickness is reduced and bedding is not preserved. Hence these outcrops are not stratigraphically useful. The southern edge of the GCR site (Figure 8.6) lies within this belt of deformed shales.

The first coherent beds, dipping at 40° to WSW, crop out in a small headland (NG 5914 3906) 260 m farther north and comprise dark-grey to black micaceous shales with calcareous nodules. The discrepancy of the dip and NNW–SSE strike here, compared with the regional strike and outcrops to the north, suggest that this outcrop is a separate landslipped block which is not in stratigraphical continuity with the main section described below.

The main section within the GCR site is 120 m farther north along the shore, extending some 400 m from NG 5904 3916 northwards to NG 5888 3958. The dip of the beds over this section is consistently close to 30° to the west and the strike close to north–south. Although the dip is significantly steeper than the regional dip (12° to 15° at Hallaig waterfall, for example), due to rotation during landslipping, there is stratigraphical continuity throughout the section, and the succession shown in Figure 8.7 does not include any structural breaks. The sediments are medium- to dark-grey micaceous shales with red-weathering calcareous nodules, gradually coarsening-up into muddy sandstones with calcareous lenticles and doggers.

The outcrops along the shore are separated, by a narrow emerged ('raised') beach platform, from the low cliff formed by the upper part of the Scalpay Sandstone Formation. The main part of this cliff is formed by massive sandstones (Bed 36 of Howarth, 1956, in the **Rubha na' Leac** GCR succession) but other beds can also be identified; for example, sandstones with doggers and with bands containing *Pseudopecten equivalvis* (Howarth's beds 28 to 30) near the southern end of the cliff. Some further rotational landslipping of certain blocks is indicated by higher dips, up to 40°, but the unbroken nature of the cliff line suggests that these movements are minor. Although this cliff lies within the GCR site, these strata have not been included in the measured succession (Figure 8.7).

The oldest strata seen within the GCR site are sheared black micaceous shales containing Raricostatum Zone *Echioceras* spp. and other fossils. However, these outcrops are not stratigraphically useful and undeformed strata of this part of the Pabay Shale Formation are exposed elsewhere on Raasay, notably in the Allt Fearns section 3 km to the south. Higher parts of the Pabay Shale Formation crop out in the small headland near the southern boundary of the GCR site, though they are also seen in the Allt Fearns section. No detailed measured succession is available and it is not at present possible to establish precise stratigraphical relationships with higher parts of the succession, described below. However, these outcrops are noteworthy because they are richly fossiliferous, yielding ammonites (*Polymorphites* cf. *angusta*, eoderoceratids and echioceratids), bivalves (including *Gryphaea mccullochi*, *Hippopodium ponderosum* and *Pleuromya costata*) and brachiopods (including *Spiriferina pinguis* and *Rimirhynchia anglica*). It appears that both Raricostatum and Jamesoni zone faunas may be present and that this outcrop represents strata below the described section. The position of the Sinemurian–Pliensbachian boundary remains to be established.

The main section, for which the site has been included in the GCR, is on the foreshore just to the north, though separated by a structural break. A detailed measured section re-drawn from data in Howarth (1956), Phelps (1985) and

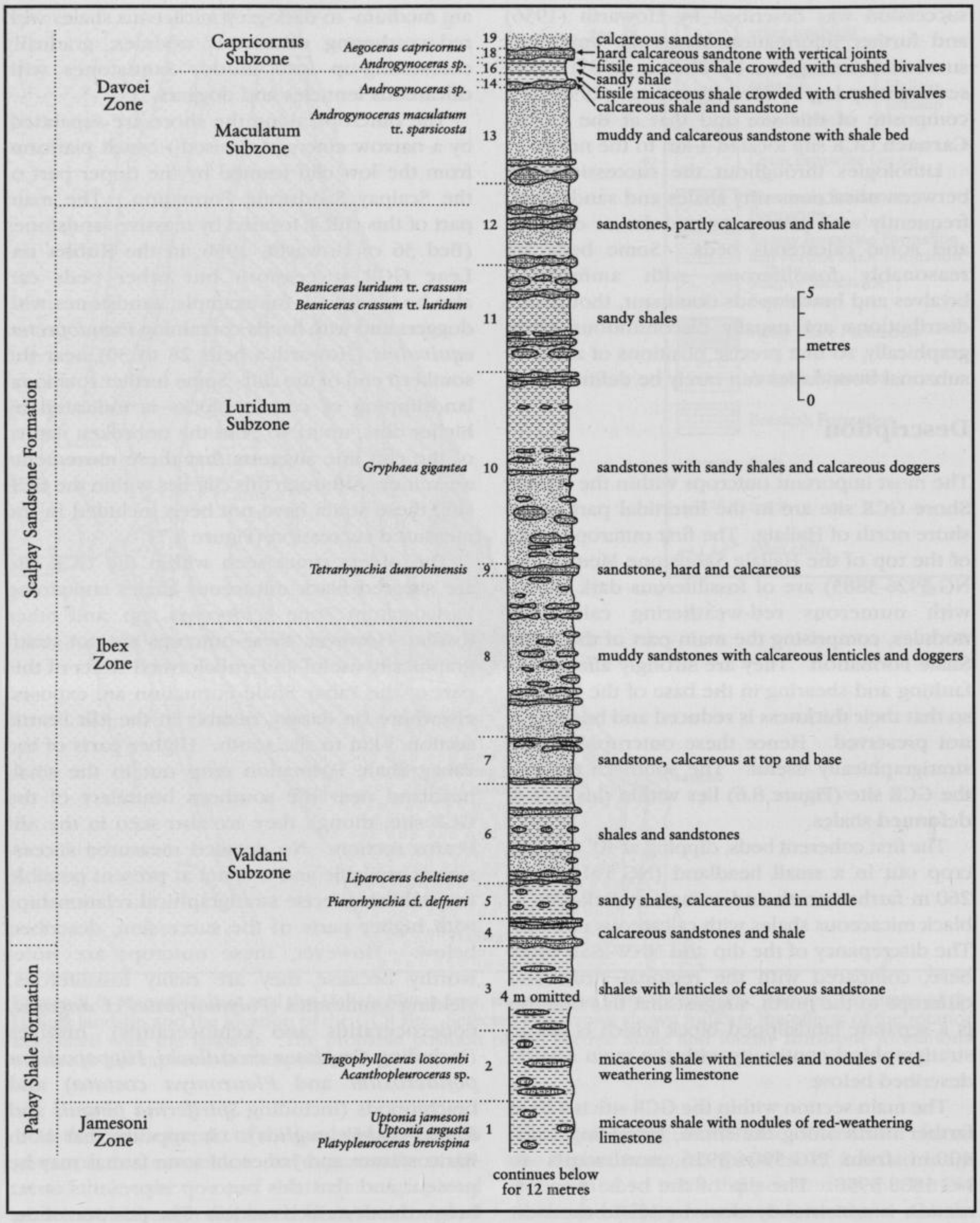



**Figure 8.7** Detailed succession of the uppermost Pabay Shale Formation and lower Scalpay Sandstone Formation, together with records of ammonites and some other key fossils. Bed numbers are those of Howarth (1956), on whose work this figure is mainly based, with additional information from Hesselbo *et al.* (1998) and Phelps (1985). Note that Bed 3 is 4 m thicker than shown here. The boundary between the Pabay Shale and Scalpay Sandstone formations is transitional but taken at the base of Bed 4. Beds 14 to 18 are distinctive marker beds allowing correlation with other sections on Raasay, including the GCR sites at **Rubha na' Leac** 1.5 km to the south, and **Cadha Carnach** 1 km to the north.

Hesselbo *et al.* (1998) is given in Figure 8.7. Note that only the upper part of Bed 1, which is about 12 m thick, is shown. Beds 1 and 2 are dark-grey micaceous, slightly silty, shales with nodules and lenticles of red-weathering, dark-grey to black, argillaceous limestone. Some of the nodules were formed at a very early stage of diagenesis, before compaction, while others appear to be later septarian nodules. Ammonites recorded by Howarth (1956), Oates (1976) and Phelps (1985) include Jamesoni Zone *Uptonia* and *Platypleuroceras* in Bed 1, Ibex Zone *Acanthopleuroceras* and *Tragophylloceras* in Bed 2. Bed 3 is a 7.62 m-thick succession of micaceous shales with thin lenticles of calcareous sandstone. Comminuted shell debris, mostly bivalve, occurs but no ammonites have been identified.

The base of the Scalpay Sandstone Formation was placed by Howarth (1956) at the first continuous sandstone, Bed 4. In such a transitional situation any lithostratigraphical boundary is arbitrary, so that Howarth's definition is accepted here, as it was by Hesselbo *et al.* (1998) even though elsewhere in the Hebrides it may be placed at biostratigraphically higher levels. Beds 5 to 10 vary between silty micaceous shales and muddy sandstones, with elongate calcareous doggers and thin beds of calcareous sandstone. Recognizable fossils are uncommon other than poorly preserved infaunal bivalves (*?Pholadomya* and *Pleuromya*), but bioturbation is pervasive. Exceptions are nodules with *Piarorhynchia* in Bed 5 and *Tetrarhynchia* in Bed 9, while parts of Bed 10 contain large specimens of *Gryphaea gigantea*. The position of the Valdani–Luridum subzonal boundary is uncertain. Silty shales characterize the upper part of Howarth's Bed 10 as well as Bed 11. Howarth (1956) listed *Androgynoceras maculatum* from Bed 11 but Phelps (1985) recorded specimens of *Beaniceras* transitional between *crassum* and *luridum* from this level, placing these beds in the Luridum Subzone (Ibex Zone) rather than Maculatum Subzone (Davoei Zone). Beds 12 and 13 show a return to mainly muddy sandstones with thin beds and doggers of calcareous sandstone and only minor silty shales. Phelps (1985) recorded *Androgynoceras* from Bed 13 and placed the base of the Maculatum Subzone (and Davoei Zone) in Bed 12. Feldmann *et al.* (2002) described a new species of crustacean, *Pseudoglyphea foersteri*, from a fallen block of fossiliferous Scalpay Sandstone Formation also containing *Aegoceras* cf. *brevilobatum* indicative of the Capricornus Subzone.

Near the top of the shore section Howarth (1956) identified a sequence of thin beds of calcareous sandstones and fissile micaceous shales. These dark fissile shales are crowded with crushed bivalves and are unusually distinctive within the otherwise homogeneous silty shale to muddy sandstone facies of the Scalpay Sandstone Formation. They are of great importance as marker beds, providing a lithostratigraphical correlation between this and other sections of the Scalpay Sandstone Formation on Raasay. The overlying sandstones of the main part of the Scalpay Sandstone Formation crop out in the low cliff overlooking the shore. However, these beds are better exposed elsewhere. As noted above, identification of the succession with beds seen south of Rubha na' Leac is usually straightforward.

## Interpretation

Within the Hallaig Shore GCR site itself only the upper part of the Pabay Shale Formation can be observed in stratigraphical succession, though undisturbed sections through the middle and lower parts of the Pabay Shale Formation can be seen farther south, in the Hallaig Burn and its tributaries south of Hallaig, and more especially in the classic Allt Fearns section 3 km to the south. Of the overlying Scalpay Sandstone Formation only the lowest 40 m is discussed here. Better sections through the main part of the formation can be found to the north (see **Cadha Carnach** GCR site report) and the south (see **Rubha na' Leac** GCR site report).

Ammonites occur only sporadically through the succession here and hence uncertainty surrounds some parts of the biostratigraphy. The southernmost shore outcrops in the GCR site consist of sheared shales with *Echioceras* and *Eoderoceras* of the Raricostatum Zone. In contrast to the succession in Allt Fearns Burn, where the four subzones of the Raricostatum Zone can be readily identified (Getty, 1973; Morton and Hudson, 1995), the thickness here has been greatly reduced by landslipping. The lowest stratigraphically coherent block of Pabay Shale Formation in the small headland (NG 5914 3906) has not been measured in detail so that the succession of faunas is not known. However, ammonites recorded include

*Polymorphites* cf. *angusta*, deroceratids and echioceratids suggesting that both the Raricostatum and Jamesoni zones may be present. A thin sandstone bed seen at about the zonal boundary in Allt Fearns has not been observed here.

The main section to the north exposes about 23 m of the uppermost part of the Pabay Shale Formation. In the upper part of Bed 1 *Uptonia* is abundant, including *U. jamesoni* and *U. angusta* (Howarth, 1956) indicating the Jamesoni Subzone, while *Platypleuroceras brevispina* may come from slightly lower (Oates, 1976), indicating the Brevispina Subzone. Bed 2 contains *Acanthopleuroceras* sp. and *Tragophylloceras loscombi* of the Valdani Subzone, so that the Jamesoni–Ibex zonal boundary is placed between beds 1 and 2. However, in the absence of diagnostic ammonites the position of the Masseanum Subzone here is unknown. The top 7.6 m of the Pabay Shale Formation (Bed 3) has not yielded any ammonites but is presumed to be still in the Valdani Subzone.

The lower part of the Scalpay Sandstone Formation contains very few ammonites so that the ages of most beds and the positions of zonal and subzonal boundaries are poorly constrained. The base of the formation, and strata up to Bed 8, are placed in the Valdani Subzone, with *Piarorhynchia* cf. *deffneri* in Bed 5. Phelps (1985) recorded *Liparoceras cheltiense* from this level and indicated Valdani Subzone (his fig. 3), although elsewhere (his fig. 9) he indicates the range of this species as extending into the lower part of the Luridum Subzone. The Valdani–Luridum subzonal boundary is tentatively placed in Bed 8, below the occurrence of *Tetrarhynchia dunrobinensis* in Bed 9. Phelps' (1985) record of specimens of *Beaniceras* transitional between *crassum* and *luridum* is consistent with a position in the middle–upper part of the Luridum Subzone (see his fig. 9). The Ibex–Davoei zonal (Luridum–Maculatum subzone) boundary is interpolated between the *Beaniceras* specimens in Bed 11 and *Androgynoceras* in Bed 13. The ammonite from this level was identified by Phelps (1985) as transitional between *A. sparsicosta* and *A. maculatum*, which is in the middle of the Maculatum Subzone. *Androgynoceras* ranges up into the base of the Capricornus Subzone (Phelps, 1985) so that the marker beds 14 to 18 may be close to the Maculatum–Capricornus subzonal boundary. Phelps (1985) recorded *Aegoceras capricornus* (Capricornus Subzone) from the lower part of Bed 19.

The overall succession at this site shows a gradual coarsening-up from uniformly micaceous silty shales typical of the Pabay Shale Formation into silty and muddy fine-grained sandstones of the Scalpay Sandstone Formation. Placing a lithostratigraphical boundary is arbitrary, and Howarth's (1956) unambiguous definition of the Scalpay Sandstone Formation as beginning with Bed 4 at this locality is accepted here.

The Pabay Shale Formation was deposited in normal marine conditions below wave-base. The abundance of detrital mica as flakes 2–3 mm across in this part of the formation suggests that transport from a nearby hinterland, identified from other evidence as the Scottish Highlands to the east, occurred via rivers and then tidal currents. However, there is no evidence for these inferred tidal currents having affected the sea floor depositional environment. By contrast, the occurrence of lenses of sand and comminuted shell-debris in Bed 3, presumably deposited in channels, indicates that the depositional environment shallowed to near or slightly above storm wave-base. Through the lower part of the Scalpay Sandstone Formation there is comparatively little lithological variation other than relatively subtle changes between muddy fine sandstone and silty mudstone. The most striking aspect of the lithology is the number of calcite-cemented beds and doggers, most formed late during diagenesis. The depositional environment was normal marine, close to or slightly above wave-base. Large fragments of driftwood suggest that the coastline and hinterland were not very distant.

## Conclusions

The most significant feature of the Hallaig Shore GCR site is in providing the only good section of the transition between the Pabay Shale and Scalpay Sandstone formations known in the northern part of the Hebrides Basin. In this section the base of the Scalpay Sandstone Formation is taken, following Howarth (1956), at the base of the first sandstone bed in a gradual coarsening-up sequence. This occurs in the Lower Pliensbachian Valdani Subzone of the Ibex Zone. This contrasts with the situation in Carsaig Bay (Isle of Mull) where there is a similar gradual coarsening-up but the base of the Scalpay Sandstone Formation is taken at an abrupt erosional base of a more massive sandstone (Oates, 1976) in the Upper Pliensbachian

Subnodosus Subzone of the Margaritatus Zone. From a palaeontological point of view the main interest of this section lies in the lower part, in which a good succession of ammonites from the upper part of the Jamesoni Zone and the lower part of the Ibex Zone can be established. A structurally separate section of a lower part of the Pabay Shale Formation is also exposed within the GCR site. This fossiliferous succession may span parts of the Raricostatum and Jamesoni zones, and, therefore, possibly the Sinemurian–Pliensbachian boundary.

## CADHA CARNACH, ISLE OF RAASAY, HIGHLAND (NG 582 392–NG 585 412)

*N. Morton*

### Introduction

The Cardha Carnach GCR site contains one of the best-documented and finest exposures through the Pliensbachian to basal Toarcian Scalpay Sandstone Formation. The site has also furnished important data on higher parts of the Lower Jurassic succession; the Lower Toarcian Portree Shale and Raasay Ironstone formations, and the uppermost Toarcian Dun Caan Shale Member of the Bearreraig Sandstone Formation. The 300 m-high cliff, Druim an Aonaich, towards the north in the GCR site, extends as an almost linear north–south feature from Dun Caan to Screapadal and dominates the east coast of the Isle of Raasay (Figure 8.8). It is one of the most spectacular British Jurassic exposures. It appears unrelated to any tectonic structures but has been interpreted as a product of glacial erosion (Chesher *et al.*, 1983). This also caused oversteepening of the slopes east of Dun Caan, leading to instability and the formation of the large Hallaig rotational landslip (see **Hallaig Shore** GCR site report). The southern part of Cadha Carnach, at the southern end of the GCR site, consists of later smaller landslipped blocks mainly of Middle Jurassic sandstones.

The southern part of Druim an Aonaich, north of Cadha Carnach, shows a clear tripartite division. The main vertical part of the cliff comprises the (latest Toarcian to Upper Bajocian) Bearreraig Sandstone Formation. Below there is a distinct sloping ledge developed on the Dun Caan Shale Member (Aalensis Zone), the Raasay Ironstone Formation (Serpentinum Zone) and the Portree Shale Formation (also Serpentinum Zone). These are exposed only occasionally,

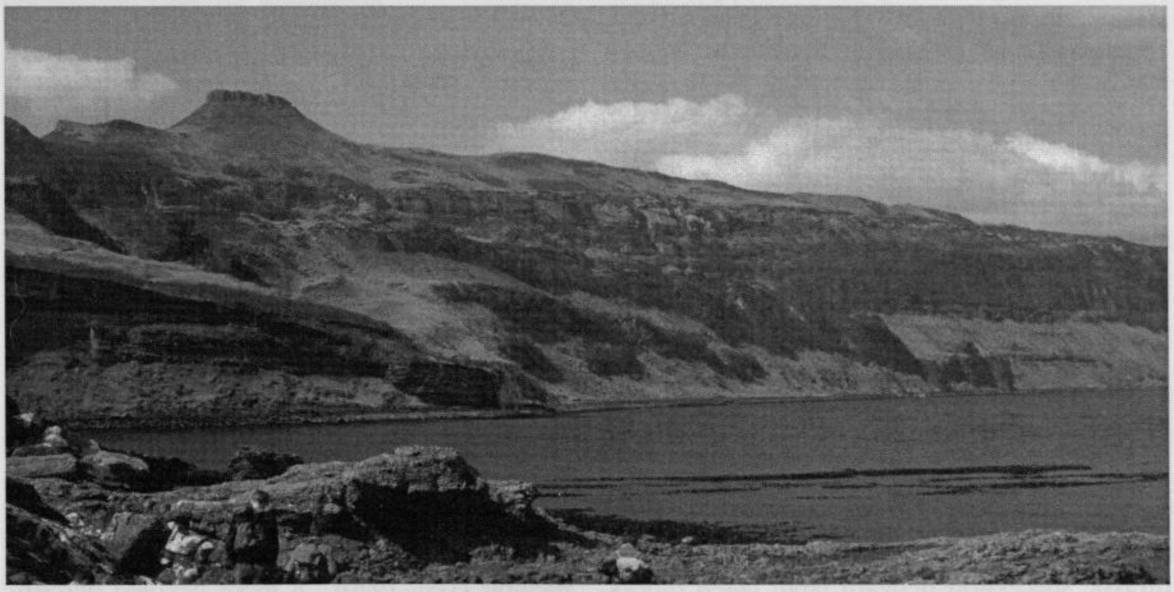


**Figure 8.8** View from Rubha na' Leac of the prominent peak of Dun Caan and the cliffs of Drum an Aonaich and Cadha Carnach. The main cliff is of Bearreraig Sandstone Formation above a slope developed on the Portree Shale and Raasay Ironstone formations, with the Scalpay Sandstone Formation forming the lower part of the cliff down to sea level. (Photo: N. Morton.)

being largely obscured by fallen blocks and scree from the massive units above, but a trench was excavated by the [British] Geological Survey, during the mapping of Raasay, to document the 'Upper Lias' succession. The steep slope below these units is formed by the Scalpay Sandstone Formation (here Davoei Zone to Tenuicostatum Zone). Although partly covered by vegetation, stream gullies expose a complete succession down to the foreshore.

Above the main cliff a ledge marks the position of the Garantiana Clay Member and the Cullaidh Shale Formation, both exposed at Cadha Carnach. To the west, gentler scarps and slopes are underlain by the various units of the Great Estuarine Group, cut by sills and capped by Palaeocene plateau basalts forming, within the GCR site, the summit of Dun Caan. On the western slopes of Dun Caan fragments of presumed Cenomanian greensand indicate the presence of a thin Upper Cretaceous sequence between the Jurassic and Palaeocene successions.

Useful sections through the Lower Jurassic succession can be seen at various points, notably towards the northern end of Druim an Aonaich (south of Screapadal) and towards the southern end. This southern section forms the Lower Jurassic part of the Cadha Carnach GCR site, named after the break in the cliff immediately east of Dun Caan. The Cadha Carnach GCR site was designated as a Lower Jurassic site largely because of the section through the (Pliensbachian to basal Toarcian) Scalpay Sandstone Formation, described by Howarth (1956, 1958) and Phelps (1985). However, important data can also be obtained (Lee, 1920) about the Portree Shale and Raasay Ironstone formations (both Lower Toarcian) and the (topmost Toarcian) Dun Caan Shale Member of the Bearreraig Sandstone Formation.

The eastern boundary of the Cadha Carnach GCR site lies between the in-situ strata of Druim an Aonaich and the Hallaig landslip. The western boundary is the top of the cliff, with a westwards extension at the southern end to include Dun Caan. The GCR site extends north to the edge of another landslip, which forms a shallow recess in the cliff and has buried the Lower Jurassic succession beneath large fallen blocks of the Bearreraig Sandstone Formation. Access to the site is difficult, involving a long walk (*c*. 7 km) from the end of the road at North Fearns.

## Description

Structurally the area is simple, comprising part of a large westerly tilted fault-block bounded to the west by the Screapadal Fault (see Morton and Hudson, 1995). Within the GCR site the strike of the beds is almost north–south, with dips between 13° and 21° to just north of west. The only fault within the site is an arcuate structure near the southern boundary, south of Cadha Carnach. Major dolerite and granophyre sills have been intruded into the Middle Jurassic sediments. The small granophyre sills represent the north-eastern edges of a large granophyre sheet which covers much of southern Raasay, while the dolerite sills are part of the extensive suite of sills which are prominent features in Trotternish, Isle of Skye. Minor dolerite dykes are confined to Cadha Carnach itself.

The Scalpay Sandstone Formation forms the steep slope in the lower part of the cliff and the foreshore but is accessible in steep parallel stream gullies (NG 585 404) which were described by Howarth (1956, section 7; marked as 'section' on Figure 8.9), Phelps (1985) and Hesselbo *et al.* (1998). The strata can be traced northwards along the shore and slope to almost the northern boundary of the GCR site (NG 586 411). The base of the Scalpay Sandstone Formation is below sea level within the site, but crops out on the foreshore farther north (NG 5864 4249).

Exposures of the Portree Shale and Raasay Ironstone formations are more limited along the narrow steep ledge above the Scalpay Sandstone Formation, but have been recorded at several locations (NG 5848 4026, NG 5851 4054 and NG 5853 4091). During the [British] Geological Survey mapping of Raasay, R. Tait excavated a trench (at NG 5847 4022; marked as 'trench' on Figure. 8.9) through the Dun Caan Shale Member (Bearreraig Sandstone Formation), the Raasay Ironstone Formation and the Portree Shale Formation, which yielded important information about the succession (Buckman in Lee, 1920) which has not been superseded.

The succession in the Scalpay Sandstone Formation of the Cadha Carnach area was first described in the [British] Geological Survey memoir (Lee, 1920). A more detailed description of the section was given by Howarth (1956) and this has served as the basis for more recent accounts (Phelps, 1985; Hesselbo *et al.*, 1998). The succession reproduced here (Figure 8.10) is

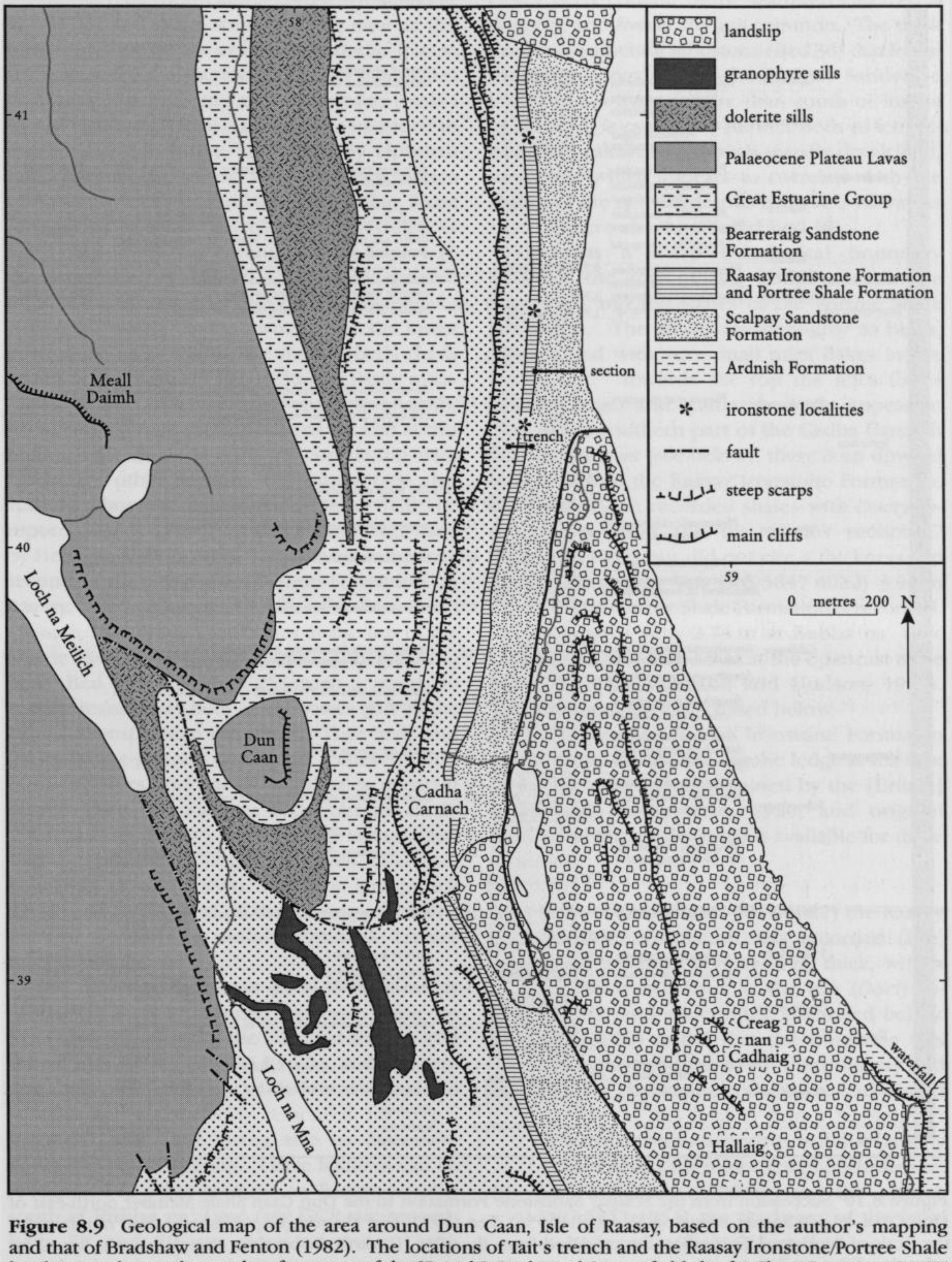



**Figure 8.9** Geological map of the area around Dun Caan, Isle of Raasay, based on the author's mapping and that of Bradshaw and Fenton (1982). The locations of Tait's trench and the Raasay Ironstone/Portree Shale localities to the north are taken from part of the [British] Geological Survey field slip for Sheet Inverness 31NW.

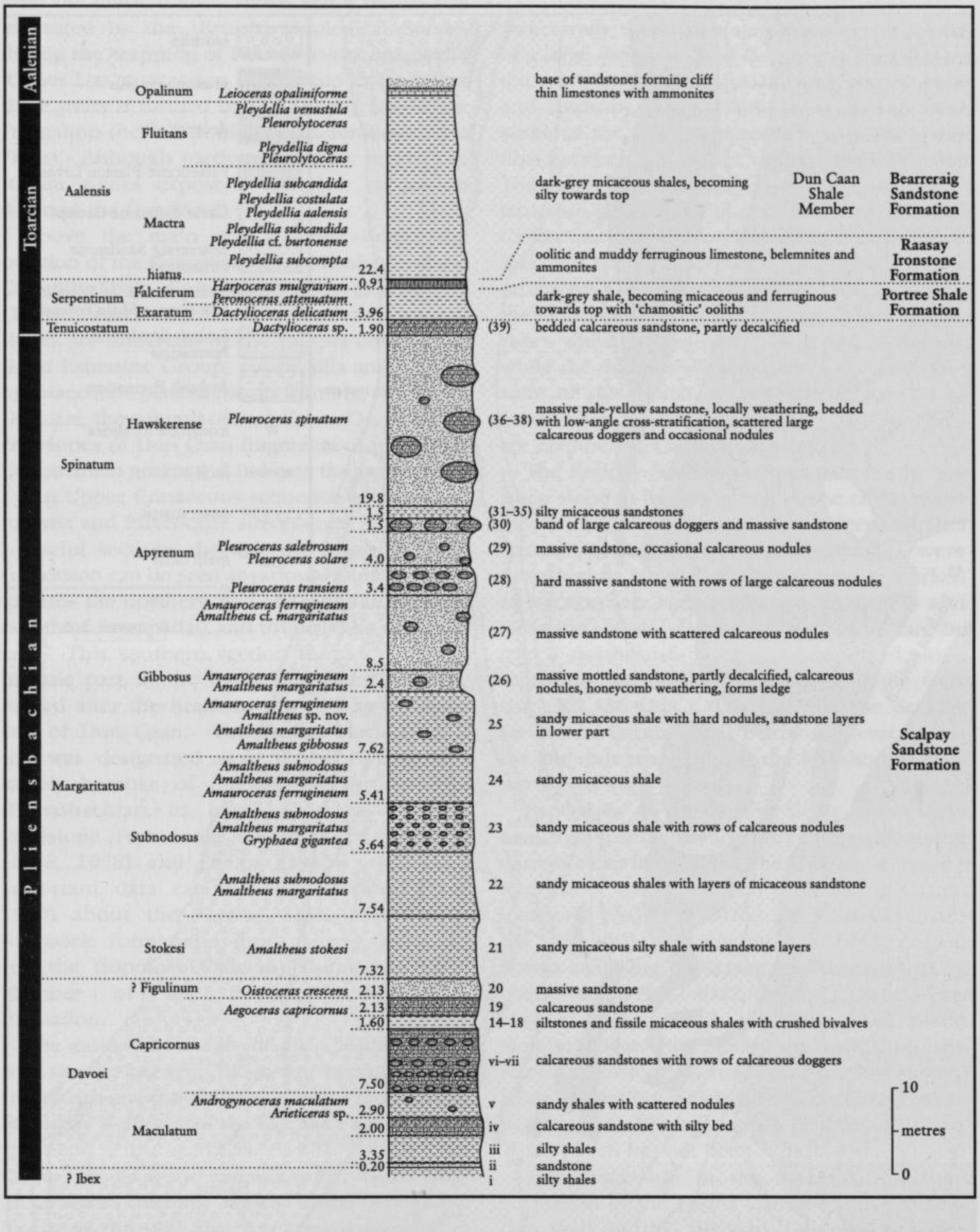



**Figure 8.10** Succession from the Scalpay Sandstone Formation to the Dun Caan Shale Member north-east of Dun Caan, Isle of Raasay, based on Howarth (1956), Lee (1920) and Morton (unpublished). Bed numbers for the Scalpay Sandstone Formation are modified from those of Howarth, in brackets where this was based on other localities on Raasay.

based mainly on Howarth's descriptions, with additional data from Phelps (1985), Hesselbo *et al.* (1998) and other sources. The base of the formation lies below sea level and the lowest strata exposed on the foreshore are silty shales or muddy siltstones and thin sandstones (beds i to v of Howarth, 1956). These were included in the Scalpay Sandstone Formation by Howarth but represent part of a transitional series between the Scalpay Sandstone and Pabay Shale formations (see also discussion in Hesselbo *et al.*, 1998). They may belong, at least in part, to the Ibex Zone (see below). These beds coarsen up into the overlying Davoei Zone sandstones of Howarth's beds vi and vii, which form the lower part of the cliff. Distinctive marker beds (beds 14–18 of Howarth, 1956), including fissile micaceous shales crowded with crushed bivalves, occur some 6 m above the base of the cliff at this section and are important for correlation with Howarth's other sections on Raasay (see also **Hallaig Shore** and **Rubha na' Leac** GCR site reports). Beds 14 to 25 of this section were used by Howarth (1956) as the basis for his composite section of the Scalpay Sandstone Formation on Raasay. Beds 19 and 20 form the first thick, massive, calcareous sandstones at the top of the Lower Pliensbachian succession. The overlying beds, Bed 21 up to Bed 25, mark a return to predominantly silty beds in the lower part of the Upper Pliensbachian sequence. Thin beds and lenses of fine-grained sandstone, scattered calcareous nodules and bands of nodules occur at several levels. Ammonites occur but are rarely abundant (see below) while Bed 23 is characterized by numerous large *Gryphaea gigantea*. Hesselbo *et al.* (1998) noted a sheeptrack developed at the level of the lower part of Bed 23, and this forms a useful identifiable feature on the hillside.

The more sandy upper part of the Scalpay Sandstone Formation forms a steeper slope, up to the ledge formed by the Toarcian shales. The lowest massive sandstone, Bed 26, is the exception. It is mottled by pervasive bioturbation and is softer and more poorly cemented, forming a recessed ledge and giving rise to distinctive honeycombe weathering. These features can be recognized in other sections on Raasay, notably south of **Rubha na' Leac** (see GCR site report). Beds 28 and 30 are more calcareous, with nodular bands of sandy limestone, and more fossiliferous with frequent *Gryphaea gigantea*, *Pseudopecten equivalvis*, ammonites and nests of brachiopods (especially rhynchonellids). Other beds contain more scattered calcareous doggers, and fossils are less common. The thick massive-weathering sandstone (Bed 36) that forms the main upper part of the Scalpay Sandstone Formation is thinner here than south of Rubha na' Leac. It is capped by thinner beds of ferruginous and calcareous, though usually decalcified, sandstone which appears to correlate with the higher of the two calcareous beds at Gualann na Leac (so here also numbered Bed 39).

There is a sharp lithological boundary between the top of the Scalpay Sandstone Formation and the shales of the Portree Shale Formation. The shales are dark-grey to black, fine grained with very small mica flakes in the lower part. Towards the top the mica flakes become larger and scattered ooliths appear so that, in the southern part of the Cadha Carnach GCR site at least (see below), there is an upward transition into the Raasay Ironstone Formation. Howarth (1956) recorded shales with *Dactylioceras* spp. from the top of his section 7 (NG 5850 4041) but did not cite a thickness. In the trench dug by Tait (NG 5847 4022) 3.96 m (13 ft) of the Portree Shale Formation is recorded. This compares with 2.74 m at Rubha na' Leac (NG 5983 3794) and 2.5 m at the opencast mine (NG 5718 3689) (Morton and Hudson, 1995). The ammonites are discussed below.

The succeeding Raasay Ironstone Formation also is rarely exposed along the ledge at the foot of the high cliff. Data obtained by the [British] Geological Survey (Lee, 1920, and original Geological Survey fieldslip) is available for three localities:

(i) In Tait's trench (NG 5847 4022) the Raasay Ironstone Formation was recorded (Lee, 1920) as about 0.91 m (3 ft) thick, with a belemnite-rich layer at the top (*Dactylioteuthis*) and ammonites, discussed below. Lee (1920) noted that the ironstone was much thinner than in southern Raasay and that the chamositic oolite there had passed laterally at this locality into a ferruginous limestone with carbonate ooliths (largely siderite) and only minor traces of chamosite.
(ii) Approximately 300 m to the north (NG 5851 4054) the thickness of the ironstone is reduced to 0.15 m (6 in.).
(iii) Near the northern end of the GCR site (NG 5853 4091) the Raasay Ironstone Formation is absent.

There is no evidence as to whether the northward thinning (from 2.4 m at the main opencast mine (NG 6690 3645) and 2.74 m at Rubha na' Leac (NG 5983 3794)) and disappearance of the Raasay Ironstone Formation is due to lateral change or to erosion before deposition of the Bearreraig Sandstone Formation (see Morton, 1989 for discussion).

The Raasay Ironstone Formation is succeeded by the Dun Caan Shale Member. The latter was proposed by S.S. Buckman, on account of the conspicuous feature these shales make below Dun Caan, and subsequently accepted by the [British] Geological Survey (Lee, 1920). Natural exposures of this part of the succession are rare and occur in small disconnected patches. Hence Tait's trench section (at NG 5847 4022) through about 23 m (75 ft) of strata, exposing the complete thickness of the shales, represents virtually the only source of information about the Dun Caan Shale Member (Lee, 1920) and must be considered its type section. Supplementary information was also obtained from another locality 'a few hundred yards further north, at Drium an Aonaich' (Lee, 1920). The shales are dark-grey to black and usually highly micaceous with occasional calcareous nodules and slight upward-coarsening. Ammonites, preserved flattened, are the most common fossils, with belemnites and occasional layers crowded with small bivalves (*Pseudomytiloides*, *Bositra*). The thickness was given by Lee (1920, p. 66, but cf. p. 42!) as 23 m (75 ft), but the top 1.2 m (4 ft) includes thin limestone beds. By comparison with the Beinn na Leac section (see Morton and Hudson, 1995) the latter would be excluded from the Dun Caan Shale Member and included in the Beinn na Leac Sandstone Member. Therefore the true thickness of the Dun Caan Shale Member is 21.8 m (71 ft) (see Morton, 1965; Morton and Hudson, 1995 for comparison with other localities).

## Interpretation

Within the Cardha Carnach GCR site a virtually complete succession can be seen from near the base of the Scalpay Sandstone Formation to near the top of the Bearreraig Sandstone Formation. However, the section is steep and parts are almost inaccessible (the southern end of the vertical cliff of the Bearreraig Sandstone Formation can be climbed by a steep gully on the northern corner of Cadha Carnach). Natural exposures of the Toarcian succession are rare, but the rocks can be exposed with a little effort and have been documented in the past (Lee, 1920).

Dating of the Scalpay Sandstone Formation in the Cadha Carnach section comes largely from the work of Howarth (1956, 1958), with some supplementary information about the lowermost part from Phelps (1985). The lowest beds (i and ii) have been placed in the Maculatum Subzone, but comparison with the **Hallaig Shore** GCR site suggests that they may be Ibex Zone. *Androgynoceras maculatum* and *Arieticeras* sp. in Bed v indicate the Maculatum Subzone, and *Aegoceras capricornus* in Bed 19 indicates the Capricornus Subzone, but the position of the subzonal boundary is uncertain. From beds 21 to 26, Howarth (1956) recorded a good succession of amaltheid faunas, summarized on Figure 8.10, indicating the presence of the Stokesi (Bed 21), Subnodosus (beds 22–24) and Gibbosus (beds 25–26) subzones. The age of Bed 27 is uncertain, though probably also Gibbosus Subzone since the lower part of Bed 28 contains early *Pleuroceras* (*P. transiens*) as well as *Amaltheus* from the lowermost Spinatum Zone (Apyrenum Subzone). The upper part of Bed 28 and beds 29–30 also yield Apyrenum Subzone *Pleuroceras*, but ammonites are rare in the overlying beds with only occasional *Pleuroceras spinatum* (Hawskerense Subzone) in the massive sandstone of Bed 36, which is thinner here than at Gualann na Leac (see **Rubha na' Leac** GCR site report). The lower calcareous bed (Bed 37) has not been recognized here.

The [British] Geological Survey (Lee, 1920) recorded specimens of *Dactylioceras*, indicating the Tenuicostatum Zone, from the top 1.8 m (6 ft) of the Scalpay Sandstone Formation. These records have been confirmed from elsewhere on Raasay, but the preservation is too poor for specific identification, so that subzonal attribution is not possible. The abruptness of the facies change to the overlying Portree Shale Formation suggests a hiatus representing part of the Tenuicostatum Zone, but this cannot be confirmed from the ammonite evidence.

Fewer details of facies and depositional environment are available than for the other Raasay GCR sites, but in general they appear similar. The Scalpay Sandstone Formation varies in grain size from silty shales to fine-grained sandstones. Three coarsening-up cycles can be identified here, as at Gualann na Leac, and are represented by beds i–20, beds 21–29, and beds 30–36. Both early- and late-diagenetic calcareous nodules and doggers occur. Fossils are scattered except for some nodules which are crowded with various types, especially brachiopods (see Ager, 1956a), and some layers with *Gryphaea* or *Pseudopecten*. Extensive bioturbation is evident throughout, though identifiable trace fossils are rare.

The Cadha Carnach GCR site includes some of the few localities on Raasay that expose the Portree Shale Formation, their value being enhanced by information gained from the exposure in Tait's trench. The thickness recorded here, 3.96 m, is greater than the 3 m at Gualann na Leac (see **Rubha na' Leac** GCR site report) or the 2.5 m at the opencast ironstone workings (Morton and Hudson, 1995), but is significantly less than on the Trotternish Peninsula of Skye (see **Prince Charles' Cave to Holm** GCR site report). At all these localities there is an abrupt facies change from sandstones to dark-grey shales, which become slightly coarser and more micaceous upwards. Towards the top, scattered chamositic ooliths are present, indicating an upward transition to the Raasay Ironstone Formation. No benthic fossils have been recorded, only ammonites and belemnites, suggesting deposition in an anoxic environment during an episode of sea-level rise. This correlates with the Exaratum Subzone global sea-level event identified by Jenkyns (1988; see Morton, 1989).

Buckman (in Lee, 1920) identified species of *Dactylioceras*, *Harpoceras* and *Peronoceras* in the material from Tait's trench, assigning the Portree Shale Formation to the Serpentinum Zone, with both the Falciferum and Exaratum subzones present. More recently these age assignments have been corrected on the basis of new collections made by Andrew B. Smith (of the Natural History Museum, London) at Bearreraig Bay and identified by Howarth (1992). This material suggests that only the Exaratum Subzone and possibly part of the Tenuicostatum Zone are represented in the Portree Shale Formation.

Above the Portree Shale Formation the Cadha Carnach GCR site exposes only a thinner more marginal facies of the Raasay Ironstone Formation than that seen at the type section in southern Raasay. Furthermore, the formation disappears completely towards the northern edge of the GCR site, although whether this is due to lateral thinning/facies change or to subsequent erosion before deposition of the Dun Caan Shale Member is unclear. Ammonites collected from the Raasay Ironstone Formation in Tait's trench were identified by Buckman (in Lee, 1920) as *Hildoceras bifrons* d'Orbigny (*non* Bruguière), *Dactylioceras* cf. *crassiusculosum* and, in the upper part, *Coeloceras dayi*. They were interpreted as indicating a Bifrons Zone, Commune Subzone, age but with the *Dactylioceras* possibly remanié, an age assignment accepted by Arkell (1933), Hallam (1967a) and Howarth (in Cope *et al.*, 1980a). However, material collected by Andrew Smith and identified by Howarth (1992) included *Harpoceras falciferum*, *Hildoceras laticosta* and *Dactylioceras toxophorum*, indicating the Falciferum Subzone, and *Cleviceras elegans* indicating the top of the underlying Exaratum Subzone. There is no evidence on Raasay of younger ammonites within the Raasay Ironstone Formation, which contrasts with the presence of Thouarsense Zone ammonites in Ardnamurchan (Howarth, 1992).

The Raasay Ironstone Formation at Cadha Carnach contains carbonate and siderite ooliths scattered in a fine-grained matrix. This contrasts with the more ferruginous, coarser-grained and sometimes cross-bedded ironstone seen at the main outcrops in southern Raasay (see also **Rubha na' Leac** GCR site report). Interpretation of the depth of the depositional environment of the Raasay Ironstone Formation regionally is controversial – above wave-base in places (with cross-bedding, stromatolites) or below wave-base in a deep-water environment. The latter seems more likely at Cadha Carnach. Deposition occurred during an interval of sediment starvation caused by sea-level rise (Hesselbo and Jenkyns, 1998) and/or tectonic stability (Morton, 1989). Supporting evidence includes the occurrence of a belemnite lag, with *Dactyloteuthis*, at the top of the ironstone.

Most of the fossils collected by Tait from the Dun Caan Shale Member were ammonites, which were submitted to S.S. Buckman (in Lee, 1920). Buckman's identifications were summarized in his table I (in Lee, 1920), together with the collector's detailed stratigraphy given in feet below a thin limestone bed crowded with ammonites (*Leioceras* 'spp.' which would now be classified as of the *L. comptum* group) belonging to the lower Aalenian Opalinum

Zone. This work has never been superseded or independently verified, but is probably reliable because Buckman had recently monographed (1887–1907) the ammonites of this age in southern England and hence was very familiar with the faunas even though those from Raasay are crushed. Selected species are recorded in Figure 8.10.

Within the Dun Caan Shale Member Buckman (in Lee, 1920) distinguished an upper Venustula Zone 4.9 m (16 ft) thick, and a lower Aalensis Zone proper 16.8 m (49 ft – should be 55 ft, corrected from table I) thick. In the appendix Buckman gave further details (table I and p. 67) and, comparing the Raasay succession with that in the Bridport Sand at Chideock, Dorset (Buckman, 1910), was able to identify three hemerae. Based on his identifications and comments on the faunas, the following characteristic morphological features can be recognized:

(iii) an upper Venustula Hemera (4.90 m) characterized by very finely ribbed ammonites in some of which 'bundling' of the ribs occurs, including *Pleydellia* (*Canavarina*) *venustula* and *Pleurolytoceras leckenbyi*.

(ii) A middle Digna Hemera (5.80 m) characterized by well-ribbed ammonites with clear separate ribs which curve onto the venter, including *Pleydellia* (*Canavarina*) *digna*, forms transitional from this to *P.* (*C.*) *steinmanni*, and *Pleurolytoceras leckenbyi*.

(i) A lower Cotteswoldia Hemera (11.00 m) characterized by ammonites with strong distant ribs which fade before the venter and also towards the aperture, including *Pleydellia* (*Cotteswoldia*) *subcandida*, *P.* (*C.*) *costulata*, *P. aalensis*, *P.* (*Walkericeras*) cf. *burtonense*, *P. subcompta*.

These faunal subdivisions of the Aalensis Zone on Raasay appear to be comparable with the subzones recognized in Spain by Goy and Ureta (1991), as shown here in Figure 8.10. The lowest *Pleydellia* appear to have been found less than 0.20 m above the Raasay Ironstone Formation, while belemnites of the *Megateuthis tripartitus* group occur immediately above the ironstone as well as higher. These confirm the occurrence of a major hiatus in the Toarcian succession of the Hebrides identified by Buckman (Morton, 1989). The top 1.2 m (4 ft) as described by Buckman contain the first *Leioceras* (*Cypholioceras*) *opaliniforme* (*sensu* Buckman) as well as *Pleydellia* (*Walkericeras*) *subglabrum*. They were placed in Buckman's Opaliniforme Hemera, now basal Aalenian Opalinum Zone. However, the shales at this level include some limestone beds which, in comparison with the Beinn na Leac section (see Morton and Hudson, 1995) would be included in the basal part of the Beinn na Leac Sandstone Member.

The lithology of the Dun Caan Shale Member is apparently uniform except for slight upwards coarsening and occasional shelly layers which suggest episodes of relative sediment starvation. It marks a return to deposition in a strongly subsiding basin, which at Cadha Carnach possibly lay below wave-base in a dysaerobic environment. This follows a long interval of stability which resulted in the Toarcian hiatus (see Morton, 1989).

## Conclusions

The Cadha Carnach GCR site makes available steep, but largely accessible, Lower and Middle Jurassic sections (excluding parts of the vertical cliff of the Bearreraig Sandstone Formation). The section in the Scalpay Sandstone Formation complements those farther south on Raasay, in the **Hallaig Shore** and **Rubha na' Leac** GCR sites. It is particularly important for the succession of Upper Pliensbachian ammonite faunas in the Margaritatus and lower Spinatum zones.

The GCR site is also of importance for understanding the Toarcian history of the Hebrides, especially the section exposed by the [British] Geological Survey in the trench excavated by Tait. The ammonites found there enabled S.S. Buckman to identify a major hiatus representing much of the Toarcian Stage, since confirmed as including the Bifrons to Pseudoradiosa (excluding Aalensis) zones. The ammonites collected from the Dun Caan Shale Member in the trench, the type section of this lithostratigraphical unit, were also identified and reported by Buckman. This collection, which has not yet been replicated, provides important evidence about the detailed succession of ammonite faunal horizons in Britain. It has also enabled comparisons to be made with the Iberian subzonal scheme.

## PRINCE CHARLES' CAVE TO HOLM, ISLE OF SKYE, HIGHLAND (NG 517 480–NG 519 515)

*N. Morton*

### Introduction

The Prince Charles' Cave to Holm GCR site is remote and poorly documented. The succession at the site includes a virtually complete uppermost Pliensbachian to Bajocian sequence of the Hebrides Basin and presents several differences from other correlative Hebridean successions. In particular the Portree Shale Formation is thicker and more complete here than elsewhere, and this site accordingly is proposed as the type section for the formation.

The east coast of the Trotternish Peninsula, from Portree north to Holm, is dominated by a high cliff composed of Jurassic sediments overlain by Tertiary lavas. The main part of the cliff consists of the Middle Jurassic Bearreraig Sandstone Formation, but from just south of Prince Charles' Cave (at NG 515 470) to south of Holm (at NG 520 507) the sea-cliff is formed by the Pliensbachian Scalpay Sandstone Formation (Figure 8.11). Above this is a ledge or slope formed by the softer Toarcian Portree Shale Formation, Raasay Ironstone Formation and the Dun Caan Shale Member of the Bearreraig Sandstone Formation. The latter is not described here, but was included in the Bearreraig GCR site report in the Middle Jurassic GCR volume (Cox and Sumbler, 2002). The Lower Jurassic GCR site described here includes most of the Lower Jurassic outcrop. From just over 1 km south of the GCR site at (NG 514 465), below Sithean Bhealaich Chumhaing, southwards to east of Torvaig (at NG 505 445) Jurassic rocks are hidden beneath scree and landslipped material. North of Holm the top of the Lower Jurassic sediments dips below sea level.

Lower Jurassic strata also crop out on the south side of Portree Bay, between Scorr Skerry (NG 504 428) and Scarf Caves (NG 511 427), north-east and south-east of Bein Tianavaig (NG 529 417 and NG 515 390), and on the foreshore at Braes (NG 520 366). These are the only outcrops of Lower Jurassic rocks in northern Skye outside of the GCR site and brief reference to them will be included in this account where appropriate.

In this GCR area the lowest part of the Lower Jurassic succession exposed is the upper part of the Scalpay Sandstone Formation (Upper Pliensbachian to basal Toarcian). The Portree Shale Formation (lower Toarcian) is much thicker here (the type section) than elsewhere on Skye or on Raasay. However, the Raasay Ironstone Formation is much thinner in Trotternish than on Raasay.

The structure of the area is simple,with dips of 5°–10° towards just north of west, so that the coast is exactly along-strike through the GCR site. There are no major faults and only a few minor NNW–SSE faults with displacements of 1 m or less have been observed. Some are associated with dykes, often eroded to form the caves such as Prince Charles' Cave, but these cause only very limited (< 1 m) baking of the adjacent sediments. The only substantial sill within the GCR site forms Holm Island and is intruded at the level of the Raasay Ironstone Formation, not seen here, for some 2 km to the south. This sill has thermally altered the Portree Shale Formation for 2 m below its base and the overlying Dun Caan Shale Member for about 3 m.

The Lower Jurassic rocks of the area were noted by Murchison (1829), and a description was given by Bryce (1873). However, there are only two significant published accounts of the stratigraphy of the Lower Jurassic succession in this GCR site, both [British] Geological Survey memoirs, by Lee (1920) and Anderson and Dunham (1966), although the latter adds little new information on the Lower Jurassic succession. The description and discussion given here are based mainly on unpublished work, including unpublished field observations and MSc theses by Bruce Farrer (1994) (on which descriptions of the Portree Shale and Raasay Ironstone formations are largely based) and Neville Brookes (1989), both at Birkbeck College. Murray Edmunds has also provided valuable unpublished information based on his collections and those of other amateur collectors who have visited the site. However, it is clear that further work is required to fully document this site.

The outcrops are difficult to access, involving a long walk across rough coastal terrain. They can be reached either from Bearreraig to the north (> 2 km to the northernmost outcrop) or from Torvaig to the south (4 km to the southernmost outcrop). Walking from the nearest point on the Portree–Staffin road, at the top of the hill south of Storr Lochs, and descending the

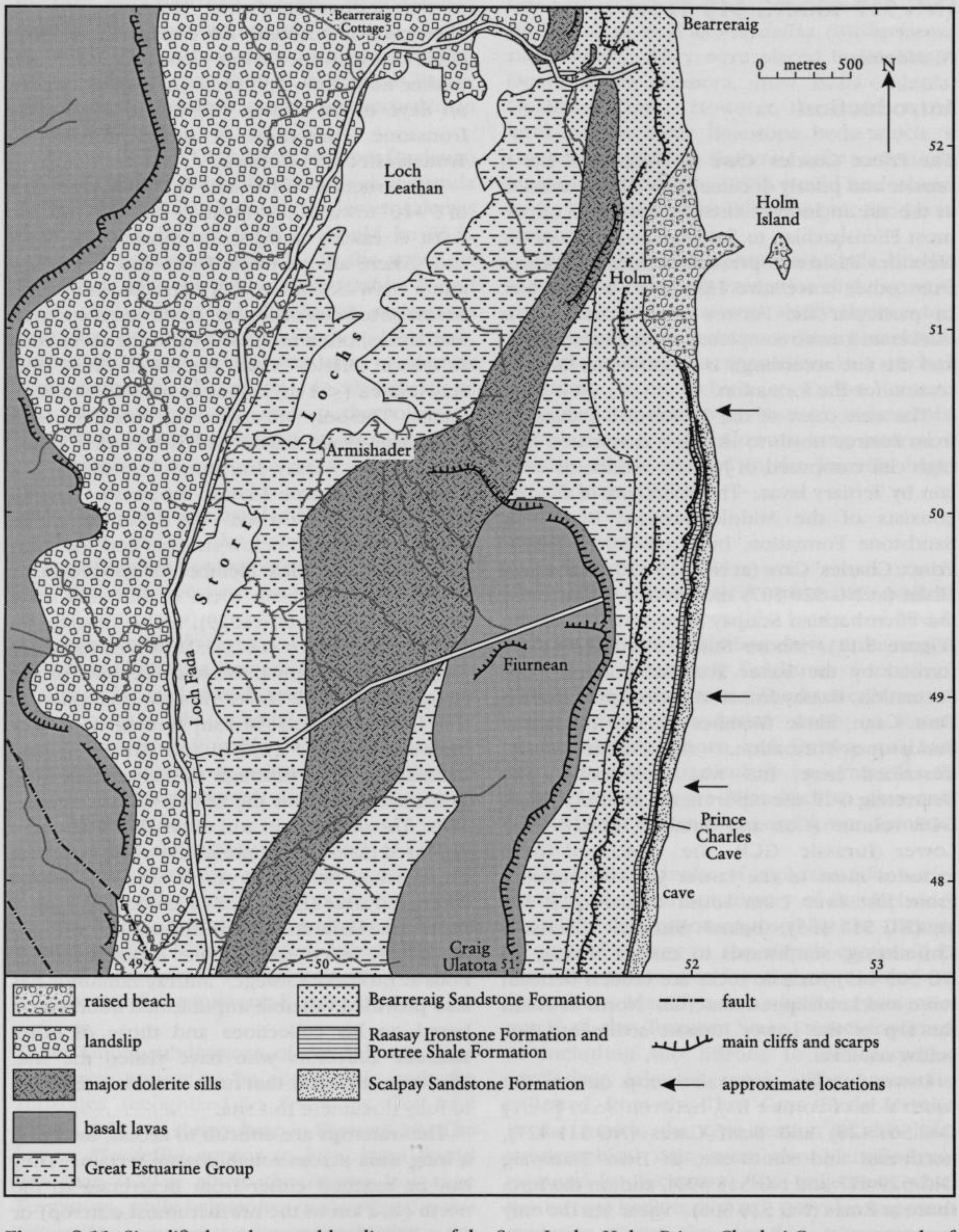



**Figure 8.11** Simplified geology and locality map of the Storr Lochs–Holm–Prince Charles' Cave area north of Portree, Trotternish, Isle of Skye, showing locations of the main sections (especially for the Toarcian Stage).

cliffs between Craig Ulatota and Fiurnean is inadvisable. In good weather conditions access by boat to the shore at Prince Charles' Cave is possible.

## Description

The Scalpay Sandstone Formation forms an almost continuous sea-cliff in the GCR site, especially around Prince Charles' Cave, but fallen blocks and the rough nature of the coast place practical limits on the sections that can be examined (Figure 8.11). The measured section and description given here are based on three selected sections:

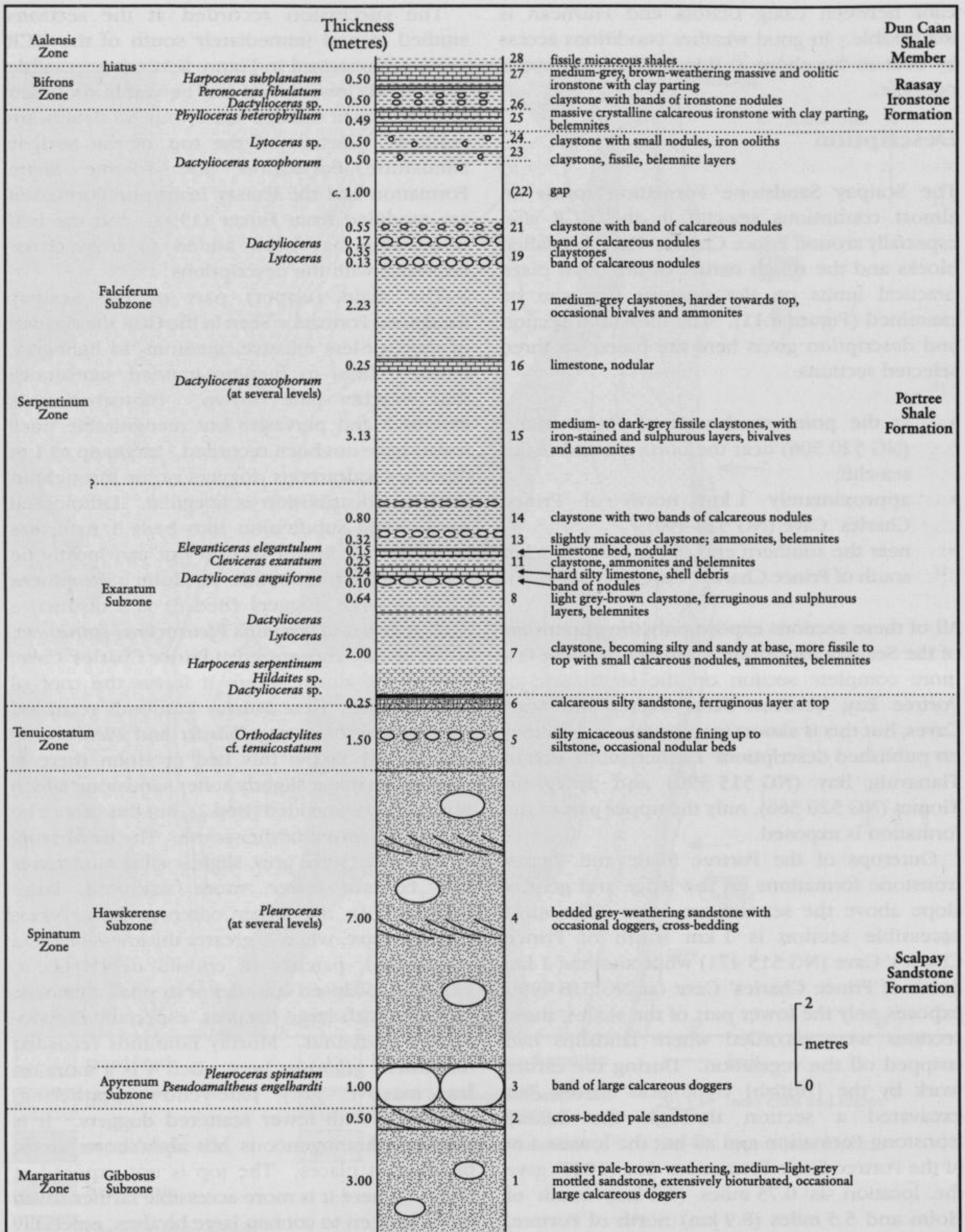
- at the point south-west of Holm Island (NG 520 506) near the northern end of the sea-cliff;
- approximately 1 km north of Prince Charles' Cave (NG 518 490);
- near the southern end of the sea-cliff, 1 km south of Prince Charles' Cave (NG 515 471).

All of these sections expose only the upper part of the Scalpay Sandstone Formation. There is a more complete section on the south side of Portree Bay, between Scorr Skerry and Scarf Caves, but this is almost inaccessible and there is no published description. Farther south, east of Tianavaig Bay (NG 515 390) and at Eilean Tioram (NG 520 366), only the upper part of the formation is exposed.

Outcrops of the Portree Shale and Raasay Ironstone formations on the ledge and gentler slope above the sea-cliff are rarer. The most accessible section is 1 km south of Prince Charles' Cave (NG 515 471) while another, 1 km north of Prince Charles' Cave (at NG 518 490), exposes only the lower part of the shales; these sections were recorded where landslips had stripped off the vegetation. During the earlier work by the [British] Geological Survey, Tait excavated a section through the Raasay Ironstone Formation and all but the lowest 4 m of the Portree Shale Formation. Lee (1920) gave the location as 0.75 miles (1.2 km) south of Holm and 5.5 miles (8.9 km) north of Portree, i.e. approximately halfway between Holm and Prince Charles' Cave (NG 520 500). The Portree Shale Formation also crops out just south of Holm but the shales here, though fossiliferous, have been baked by a thick dolerite sill (Figure 8.11).

The succession recorded at the sections studied in and immediately south of the GCR site is summarized in Figure 8.12. It is possible that slightly lower strata may be visible above sea level at Prince Charles' Cave, but no details are available. Details of the top of the Scalpay Sandstone Formation, the Portree Shale Formation and the Raasay Ironstone Formation are modified from Farrer (1994), and the bed numbering has been added to help cross-reference with the descriptions.

The main (upper) part of the Scalpay Sandstone Formation seen in the GCR site consists of more-or-less massive, medium- to light-grey, mottled, fine- to medium-grained sandstones that weather pale brown. Bioturbation is extensive and pervasive but recognizable trace fossils have not been recorded. Large, up to 1 m diameter, calcareous doggers occur throughout but their distribution is irregular. Lithological details, and subdivision into beds 1 to 4, are based on the Holm section but can mostly be recognized farther south. At Holm a prominent band of large doggers (Bed 3) is a distinctive marker bed and contains *Pleuroceras spinatum*. It can also be recognized at Prince Charles' Cave, and to the north where it forms the roof of an overhang. Here Murray Edmunds recorded *Pseudoamaltheus engelhardti* and *Pleuroceras spinatum*. Below this bed at Holm there is distinguishable a slightly softer sandstone which is clearly cross-bedded (Bed 2), but this cannot be readily separated farther south. The underlying strata (Bed 1) are grey, slightly silty, sandstones that contain fewer, more scattered, large doggers. In the larger outcrops near Prince Charles' Cave, where a greater thickness of strata is exposed, patches of crinoid debris occur, either as collapsed colonies or in small channels, together with large bivalves, especially *Pseudopecten equivalvis*. Murray Edmunds recorded *Amaltheus gibbosus* here. Bed 4 is a more-or-less massive, grey, pale-yellow weathering, sandstone with fewer scattered doggers. It is relatively homogeneous but also shows cross-bedding in places. The top is not exposed at Holm. Where it is more accessible farther south it can be seen to contain large bivalves, especially *Pseudopecten equivalvis*, some nests of brachiopods, notably *Tetrarhynchia tetrahedra*, belemnites and lenses of crinoid debris, mostly *Hispidocrinus schlumbergeri* with some *Balanocrinus donovani* (Simms, 1989). The belemnites do not show any preferred orientation, with



Thickness (metres)
Aalensis Zone
Dun Caan Shale Member
hiatus
Bifrons Zone
Harpoceras subplanatum 0.50
Peronoceras fibulatum
Dactylioceras sp. 0.50
Phylloceras heterophyllum 0.49
Lytoceras sp. 0.50
Dactylioceras toxophorum 0.50
c. 1.00
0.55
Dactylioceras 0.17
0.35
Lytoceras 0.13
Falciferum Subzone
2.23
0.25
Dactylioceras toxophorum (at several levels)
Serpentinum Zone
3.13
?
0.80
0.32
Eleganticeras elegantulum 0.15
Cleviceras exaratum 0.25
0.24
Dactylioceras anguiforme 0.10
Exaratum Subzone
0.64
Dactylioceras
Lytoceras
2.00
Harpoceras serpentinum
Hildaites sp.
Dactylioceras sp.
0.25
Tenuicostatum Zone
Orthodactylites cf. tenuicostatum 1.50
Hawskerense Subzone
Pleuroceras (at several levels) 7.00
Spinatum Zone
Apyrenum Subzone
Pleuroceras spinatum
Pseudoamaltheus engelhardti 1.00
0.50
Margaritatus Zone
Gibbosus Zone
3.00
Amaltheus gibbosus
28 fissile micaceous shales
27 medium-grey, brown-weathering massive and oolitic ironstone with clay parting
Raasay Ironstone Formation
26 claystone with bands of ironstone nodules
25 massive crystalline calcareous ironstone with clay parting, belemnites
24 claystone with small nodules, iron ooliths
23 claystone, fissile, belemnite layers
(22) gap
21 claystone with band of calcareous nodules
band of calcareous nodules
claystones
19 band of calcareous nodules
17 medium-grey claystones, harder towards top, occasional bivalves and ammonites
16 limestone, nodular
Portree Shale Formation
15 medium- to dark-grey fissile claystones, with iron-stained and sulphurous layers, bivalves and ammonites
14 claystone with two bands of calcareous nodules
13 slightly micaceous claystone; ammonites, belemnites
limestone bed, nodular
11 claystone, ammonites and belemnites
hard silty limestone, shell debris
band of nodules
8 light grey-brown claystone, ferruginous and sulphurous layers, belemnites
7 claystone, becoming silty and sandy at base, more fissile to top with small calcareous nodules, ammonites, belemnites
6 calcareous silty sandstone, ferruginous layer at top
5 silty micaceous sandstone fining up to siltstone, occasional nodular beds
4 bedded grey-weathering sandstone with occasional doggers, cross-bedding
Scalpay Sandstone Formation
2
metres
0
3 band of large calcareous doggers
2 cross-bedded pale sandstone
1 massive pale-brown-weathering, medium–light-grey mottled sandstone, extensively bioturbated, occasional large calcareous doggers
(sea level at Holm)

◂**Figure 8.12** Succession from the upper Scalpay Sandstone Formation to the Dun Caan Shale Member at Trotternish, north of Portree, Isle of Skye, based mainly on unpublished descriptions by Bruce Farrer (1994), observations by Morton (unpublished), and data from Murray Edmunds (unpublished) and Lee (1920). The composite section is based on three main localities: south of Holm (NG 520 506) (by Nicol Morton); between Holm and Prince Charles' Cave (approx. NG 518 490) (by Bruce Farrer) and south of Prince Charles' Cave (NG 515 471) (Bruce Farrer and Nicol Morton).

some even perpendicular to the bedding indicating the extent of bioturbation. Ammonites are rare but *Pleuroceras spinatum* occurs at several levels.

The top beds of the Scalpay Sandstone Formation are well exposed north of Prince Charles' Cave. Here Bed 4 becomes slightly finer grained and silty towards the top. The overlying Bed 5 continues the fining-up, from fine-grained sandstone at the base to a coarse micaceous siltstone. Occasional nodules occur and Murray Edmunds has recorded *Dactylioceras* (*Orthodactylites*) cf. *tenuicostatum* (more serpenticone than typical Whitby specimens). Bed 6 at the top of the Scalpay Sandstone Formation is a calcareous sandy siltstone with a strongly ferruginous layer at the top, and contains *Dactylioceras* sp.. In outcrops south of Portree Bay, east of Beinn Tianavaig and at Eilean Tioram, there is a bed of grey micaceous silty limestone crowded with small ammonites including *Dactylioceras toxophorum*, *Harpoceras serpentinum* and *Hildaites* sp. (M. Howarth, pers. comm., 1984). It is not clear whether this represents a bed within the Portree Shale Formation or Bed 6 at the top of the Scalpay Sandstone Formation. The grain size of the terrigenous component is significantly coarser than the argillaceous limestones which typically occur within the Portree Shale Formation. This, together with the observed field setting suggest that the latter is more likely, and is suggested here, but neither is conclusive and further work is required.

The base of the Portree Shale Formation (Bed 7) is overall a claystone, but becomes silty and even sandy towards the base and finer grained and more fissile towards the top. Small calcareous nodules occur in the top 0.5 m. Belemnites occur at several levels and there is a layer with *Dactylioceras* and *Lytoceras* 1 m above the base (see further discussion below). Bed 8 is a light grey-brown claystone with iron- and sulphur-staining, suggesting weathering of pyritic material. Belemnites occur but no ammonites. Bed 9 is a band of iron-stained nodules and Bed 10 is a silty nodular limestone with shell debris.

The overlying beds are light-, medium- or dark-grey claystones that mostly have a blocky fracture but locally are fissile, with some pyritic or iron- or sulphur-stained layers. There are several bands of calcareous nodules, some forming more continuous limestone beds, such as beds 12 and 16. Fossils generally are not abundant, but some bedding planes contain small thin-shelled bivalves and occasional belemnites. Ammonites are common in some layers, such as beds 11, 13, 15 and 19, but not throughout, and tend to be crushed. These include *Dactylioceras anguiforme*, *Cleviceras exaratum* and *Eleganticeras elegantulum*. Details of the ammonite succession, are discussed below.

The upward continuation of the succession, with a gap of about 1 m, can be seen in a parallel shallow gully 15 m to the south. The top beds of the Portree Shale Formation, beds 23 and 24, contain scattered iron-ooliths and some layers crowded with belemnites (also seen on Raasay at the main opencast workings, NG 5690 3645) and the ammonites *Dactylioceras* sp. and *Lytoceras*. The occurrence of scattered iron-ooliths indicates a transition into the overlying Raasay Ironstone Formation.

The base of the Raasay Ironstone Formation is taken at the first hard ironstone bed (Bed 25). At this locality the formation can be divided into three parts. The basal 0.49 m (Bed 25) consists of hard, massive, crystalline calcareous iron-stones or ferruginous limestones with a claystone parting. *Harpoceras subplanatum* was recorded by Farrer (1994). The middle part (Bed 26) is mainly claystone with two bands of ironstone nodules. Belemnites are abundant, especially in the top layer, while the ammonites recorded are *Harpoceras* sp. and *Peronoceras fibulatum* in the lower part and *Phylloceras heterophyllum* in the upper part. The upper part (Bed 27) is more similar to the ironstone seen in central

Raasay – a light- or medium-grey oolitic ironstone, weathering rusty-brown to yellow-brown.

The Raasay Ironstone Formation is overlain by a thick succession of dark-grey micaceous shales (Bed 28: only base shown in Figure 8.12) belonging to the Dun Caan Shale Member of the Bearreraig Sandstone Formation. No ammonites were recorded near Prince Charles' Cave, but *Pleydellia* sp., indicating the topmost Toarcian Aalensis Zone, occurs 5.5 m above the base at Holm (see Morton and Hudson, 1995).

## Interpretation

The Jurassic succession within the Prince Charles' Cave to Holm GCR site includes Lower and Middle Jurassic rocks ranging from Upper Pliensbachian to Upper Bajocian (and possibly Lower Bathonian) in age. In this account only the rocks up to lower Toarcian age are discussed. These are classified as the Scalpay Sandstone Formation, the Portree Shale Formation and the Raasay Ironstone Formation (Figure 8.12). Although the last two are very thin, they are lithologically distinctive through much of the Hebrides Basin, justifying formation status. The boundary between the mostly sandy Scalpay Sandstone Formation and the clays of the Portree Shale Formation is more gradational and less abrupt here than in Raasay or Strathaird. It is placed at the top of Bed 6 as described above. The topmost Toarcian (to lower Aalenian) Dun Caan Shale Member is excluded here because it is described in the Bearreraig GCR site report of the Middle Jurassic GCR volume (Cox and Sumbler, 2002).

Only limited lithostratigraphical information about the Scalpay Sandstone Formation in Trotternish is available. For example there is almost no description in the [British] Geological Survey memoir (Lee, 1920), contrasting with the situation on the Isle of Raasay where the formation is well described. For more detailed descriptions and discussions of this part of the successions see the **Rubha na' Leac**, **Hallaig Shore** and **Cadha Carnach** GCR site reports. The shales which succeeded the Scalpay Sandstone Formation, and below the Raasay Ironstone Formation, were named the Portree Shale (Formation) by the [British] Geological Survey (proposed by S.S. Buckman in Lee, 1920). The type locality, though not formally defined was clearly intended to be in the area of Prince Charles' Cave. In fact the best currently available section is south of the cave, 1 km south of the southern boundary of the defined GCR site (Figure 8.11). This section, at NG 515 471, is formally proposed here as the type section; the details on Figure 8.12 are mainly from this locality. The succeeding Raasay Ironstone Formation is much thinner on Trotternish than in southern Raasay. It has not been identified south of Portree Bay but does occur south of Prince Charles' Cave (Figure 8.12). Although there are few exposures to the north it can be traced to at least Bearreraig where a borehole (Lee, 1920) proved the ironstone to be slightly thicker than at the GCR site. There is a transition from the Portree Shale Formation, with the boundary traditionally taken at the first harder bed.

The oldest known ammonites within the area included in this account, which extends slightly south of the GCR site, are *Amaltheus gibbosus* from Bed 1 indicating the Gibbosus Subzone of the Margaritatus Zone. This would correlate Bed 1 with beds 25–27 of the succession south of Rubha na' Leac on Raasay. Bed 3, a band of large calcareous doggers, is a distinctive traceable unit characterized by the common occurrence of ammonites, especially *Pleuroceras spinatum* and *Pseudoamaltheus engelhardti*. These are characteristic of the Spinatum Zone, with the latter suggesting the Apyrenum Subzone, and correlation with beds 28–30 at Rubha na' Leac. Bed 4 contains *Pleuroceras spinatum* at several levels, but no other ammonites have been recorded confirming that this bed also belongs to the Spinatum Zone, Hawskerense Subzone according to Howarth (1958). This correlates with beds 36–37 at Rubha na' Leac and indicates that this part of the Scalpay Sandstone Formation is much thinner on Trotternish than on Raasay. The occurrence of *Dactylioceras* (*Orthodactylites*) cf. *tenuicostatum* in Bed 5 (M. Edmunds, pers. comm.) indicates that this bed belongs to the Tenuicostatum Zone, but identification of the subzone is not possible at present. It may be correlated with Bed 38 (undated) at Rubha na' Leac although it is finer grained (Figure 8.12). The top bed of the Scalpay Sandstone Formation, Bed 6 (Figure 8.12), is a distinctive more calcareous and ferruginous bed which therefore correlates with Bed 39 of the Raasay succession, and is again finer grained and more silty in Trotternish than on Raasay. *Dactylioceras* sp. is widely recorded and, although specific identity remains uncertain, correlation with the Tenuicostatum Zone has long been accepted (since Lee, 1920). However, if, as suggested above, the correlation with the silty limestone bed found south of Portree Bay is correct, then this dating must be revised because this bed contains ammonites of the Serpentinum Zone, *Dactylioceras toxophorum*, *Harpoceras serpentinum* and *Hildaites* sp.. This would indicate that the top of the Scalpay Sandstone Formation is slightly younger than previously thought (Howarth, 1992).

The most complete ammonite succession from the Portree Shale Formation was obtained by Tait from the trench excavated during the [British] Geological Survey field mapping. The ammonites were submitted to S.S. Buckman and were reported in the appendix in Lee (1920). The formation belongs almost entirely to the Serpentinum Zone, with the possible exception of the basal bed. The basal 4 m was not exposed by Tait. To date only *Dactylioceras* sp. and *Lytoceras* sp. have been found in Bed 7. Therefore the age cannot yet be independently verified as either Tenuicostatum Zone or, if the correlation of the top bed of the Scalpay Sandstone Formation is correct, Serpentinum Zone. The latter is provisionally adopted here. In the overlying beds 8–13 ammonites, including *Eleganticeras elegantulum*, *Cleviceras exaratum* and *Dactylioceras anguiforme*, are common. These are characteristic of the Exaratum Subzone of the Serpentinum Zone (Howarth, 1992).

The position of the boundary between the lower Exaratum Subzone and the higher Falciferum Subzone is placed near the base of Bed 15 (Figure 8.12), which equates with the level between 4.8 m and 5.8 m above the base of the formation identified by Buckman (in Lee, 1920). Higher beds contain mainly *Dactylioceras* spp., which are less reliable for dating, but are placed in the Falciferum Subzone.

Dating the Raasay Ironstone Formation with confidence has proven difficult because of poor preservation and limited numbers of ammonites recorded. Traditionally it has been placed in the Bifrons Zone, following Buckman's identifications of the ammonite fauna on Raasay. However, Howarth (1992) questioned the evidence for this and considered that all the ammonites he had seen were consistent with a Falciferum Subzone age. This was based on material collected on Raasay by Andrew Smith near the old mine buildings and confirmed subsequently from above the pier. However, both of these collections are from spoil tips that contain much shaly ironstone which may have come from the lower part of the formation, which is, therefore, certainly of Falciferum Subzone age. Those identified in Trotternish include *Harpoceras subplanatum*, *Peronoceras fibulatum*, *Dactylioceras* (*toxophorum*, teste Howarth), *Phylloceras heterophyllum*. However, Bruce Farrer identified in the middle bed (Bed 26) of the Raasay Ironstone Formation at Prince Charles' Cave *Harpoceras subplanatum* and *Peronoceras fibulatum*, together with *Dactylioceras* and *Phylloceras heterophyllum*. The first two, if confirmed by further work, are characteristic of the Bifrons Zone (Howarth, 1992). The allocation of part of the Raasay Ironstone Formation to the Bifrons Zone is supported by Murray Edmunds (pers. comm.) who found loose specimens of poorly preserved Bifrons Zone *Hildoceras semipolitum* near Prince Charles' Cave.

Detailed descriptions and interpretations of the facies and deposition of the Scalpay Sandstone Formation can be found in the descriptions of the three Raasay sites. The main difference in Trotternish seems to be that towards the top the formation becomes finer grained. The base of the succeeding Portree Shale Formation differs here from elsewhere in the Hebrides, in that there is some transition with fining-up in the basal bed as well as in the top of the Scalpay Sandstone Formation. The actual boundary is sharp but the lithological change is less extreme than elsewhere. This change in lithology reflects a marine flooding event and can be correlated with a global deepening event of the Serpentinum Zone (Hallam, 2001). The shales were deposited in a restricted distal marine environment. The occurrence of bivalves, mostly small thin-shelled genera, and the blocky fracture suggests that some benthos was present, but other layers are fissile and may have been deposited in anoxic conditions.

The Raasay Ironstone Formation in Trotternish differs in facies from the thicker developments seen in central Raasay (e.g. at the opencast workings). The crystalline ferruginous limestones may be more similar to the crinoidal facies seen at Gualann na Leac (see **Rubha na' Leac** GCR site report). The 'typical' facies is seen only in the uppermost Bed 27. The outcrops give little useful information about the controversial depositional environment of the ironstone. Fossils other than belemnites are rare, and even these are frequently worn or corroded.

## Conclusions

The cliffs along the shore of Trotternish from south of Prince Charles' Cave to Holm (Figure 8.11) show the most northerly extensive Lower Jurassic outcrops in the Skye area (excluding the limited outcrops in the Shiant Isles). However, through a combination of relative inaccessibility and poor exposure of the Toarcian shales the amount of data available about this area is very limited. It is clear that the descriptions given here could be improved with further determined fieldwork, and it is known that some amateur collectors have collections and data that are as yet unpublished.

At this site there are good outcrops of the upper part of the Scalpay Sandstone Formation and the faunas are similar to those documented on Raasay, with ammonite evidence for the Upper Pliensbachian Gibbosus, Apyrenum and Hawskerense subzones, and of the Lower Toarcian Tenuicostatum Zone. The facies are also similar, except that the boundary with the overlying Portree Shale Formation is more gradational and less abrupt than elsewhere in Skye and Raasay. However, the thicknesses are significantly less. The correlation and dating of the top calcareous bed of the Scalpay Sandstone Formation is unresolved. If the correlations suggested here can be verified by further work it may belong in the Exaratum Subzone rather than Tenuicostatum Zone. The Portree Shale Formation is not well exposed anywhere in the Hebrides, but the section south of Prince Charles' Cave is more complete and the formation much thicker than at other documented outcrops. This section is proposed here as the type section for the formation. Depending on resolution of the problem of the top bed of the Scalpay Sandstone Formation, the basal part of the Portree Shale Formation may still lie within the Tenuicostatum Zone rather than the Serpentinum Zone. The available ammonite faunas are not yet conclusive for independent verification. In the overlying shales both the Exaratum and Falciferum subzones have been identified; again the latter requires further proof. The few outcrops of the Raasay Ironstone Formation show a thinner more 'marginal' facies than at the type section of the formation in Raasay. The ammonites found to date in the middle part of the formation appear to conflict with Howarth's interpretation (based on Raasay material) of a Serpentinum Zone rather than Bifrons Zone age.

## RUBHA NA' LEAC, ISLE OF RAASAY, HIGHLAND (NG 600 381–NG 599 367)

*N. Morton*

## Introduction

The Rubha na' Leac GCR site exposes an almost complete Upper Pliensbachian section, including one of the thickest developments in Britain of the Spinatum Zone at the top of the Pliensbachian Stage. As such the site has been of enormous importance in the investigation of the evolution and migration of amaltheid ammonites.

Outcrops of the Scalpay Sandstone Formation in the Hebrides rarely expose more than a small part of the total thickness, most usually only the uppermost 10–20 m, as for instance along the eastern coasts of Strathaird and Trotternish. The section on the Isle of Scalpay, from which the formation was named, has not been described recently but is also incomplete, especially towards the top. The only area of the Hebrides with complete sections through the Scalpay Sandstone Formation and contiguous strata are on the eastern side of the Isle of Raasay.

The most accessible section on Raasay is on the north-east corner of Beinn na Leac, a faulted outlier of Middle and Lower Jurassic strata. Here most of the Scalpay Sandstone Formation is exposed on the foreshore and cliffs immediately south of the arcuate fault which defines the outlier. This fault intercepts the coast in a small bay (NG 5994 3802) south of Rubha na' Leac (Figure 8.13). Rubha na' Leac itself is composed of conglomerates and sandstones of the Stornoway Formation (Upper Triassic to basal Jurassic) so that the name given to the Lower Jurassic GCR locality is somewhat inappropriate. There are no details of this locality in the [British] Geological Survey memoir (Lee, 1920), but Howarth (1956, 1958) provided a detailed measured section as well as lists and descriptions of the ammonites. Ager (1956a,b, 1958) discussed and monographed the brachiopods, and Hallam (1967a) described the facies and gave a list of macrofossils from the upper part of the succession. A field guide to the localities is contained in Morton and Hudson (1995).

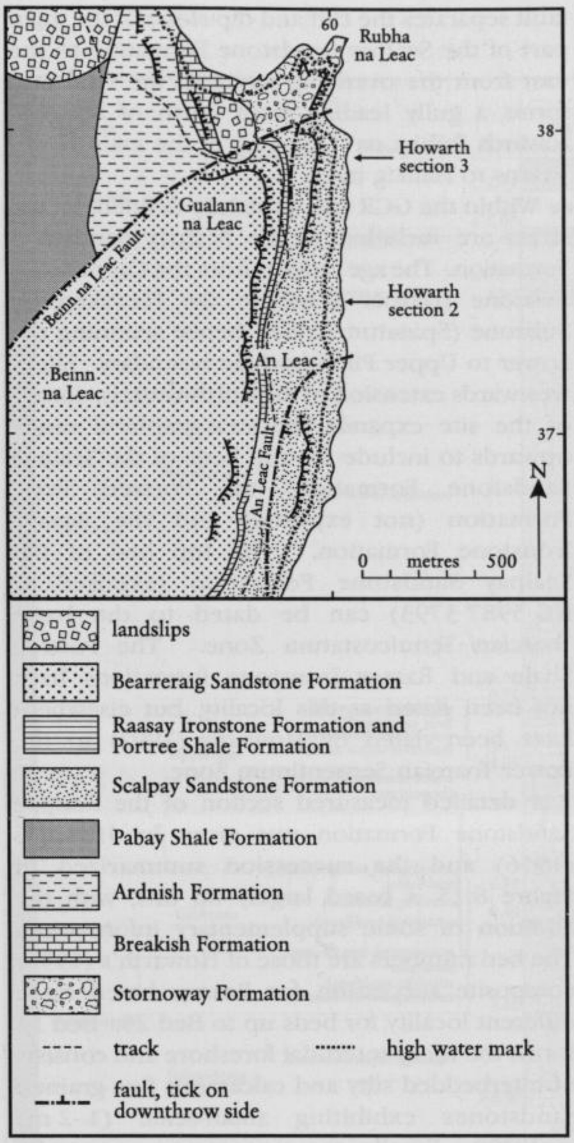



**Figure 8.13** Geological map of the northern part of Beinn na Leac and Rubha na' Leac area, showing the main topographic features and localities described in text. The boundary of the notified GCR site is also shown.

The most spectacular outcrop and section is at the northern end of the GCR site (Figure 8.14) where the main part of the Scalpay Sandstone Formation forms a cliff (from NG 5990 3794 to NG 6004 3788; section 3 of Howarth 1956, see Figure 8.13). Most beds are accessible *in situ* on the south side of the gully associated with the fault at the northern end of the cliff. The section continues upwards to just west of the defined boundary of the GCR site, to include the top beds of the Scalpay Sandstone Formation (at NG 5987 3793), the ledge formed by the Portree Shale Formation (not exposed), and the Raasay Ironstone Formation (exposed in an excavation at NG 5983 3794). This provides continuity of succession from the Lower Jurassic GCR site Rubha na' Leac into the Middle Jurassic GCR site Beinn na Leac (see Cox and Sumbler, 2002) and has therefore been included in this site description.

At the foot of the cliff, talus and large fallen blocks obscure the part of the succession between the cliff and the extensive outcrops on the foreshore. These fallen blocks can usually be identified with individual beds in the cliff and make available large easily accessible surfaces on which the facies and faunas can be examined. The obscured strata are exposed in an accessible section a short distance to the south, below An Leac (at NG 5999 3745; section 2 of Howarth, 1956).

An important outcrop occurs at the boundary between the talus slope and the rocky shore at NG 6001 3781 approximately 200 m south of the bay. Here the distinctive marker beds identified by Howarth (1956), which enable correlation with other localities, are exposed (see below).

South of An Leac, and still within the GCR site, the succession is repeated by the small arcuate An Leac Fault (see Figure 8.13) while landslipping of blocks makes it difficult to decipher the succession. Farther south along the shore from the area shown on Figure 8.13 towards North Fearns, lower beds of the Scalpay Sandstone Formation (including one with a large *Liparoceras*) and the transition into the Pabay Shale Formation can be observed but have not been documented.

## Description

Outcrops of the Scalpay Sandstone Formation occur in two main forms within the area of the Rubha na' Leac GCR site. The upper part of the formation, dominated by massive fine-grained sandstones, forms a cliff about 70 m high which is near-vertical or overhanging. The lower, more silty, part forms the rocky foreshore. Numerous very large fallen blocks abound at the foot of the cliff and on the foreshore, obscuring part of the succession, but are useful in complementing the in-situ outcrops. A lower cliff farther south, below An Leac, exposes the obscured middle part of the formation.

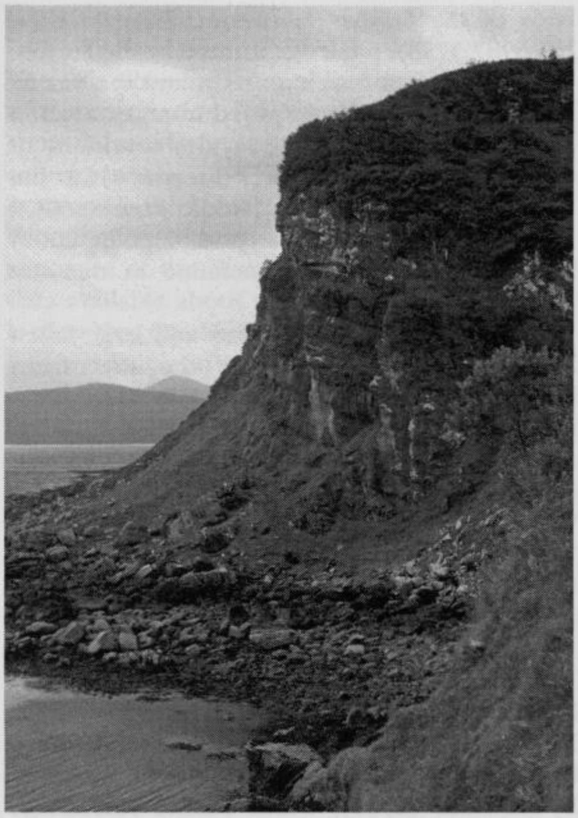


**Figure 8.14** Scalpay Sandstone Formation exposed in the cliff at Rubha na' Leac, Raasay. (Photo: N. Morton.)

The structure of most of the GCR site, north of An Leac (see Figure 8.13) is simple, with the beds dipping at less than 10° to just north of west. There is no evidence of faulting, even on a small scale, and the few minor basalt or dolerite intrusions cause only limited baking of sediments. The area lies near the northern limit of the regional thermal effects of the central Skye Palaeocene plutonic centre (Thrasher, 1992).

Towards the southern part of the GCR site the An Leac Fault (Figure 8.13) is an arcuate listric fault, smaller in scale (throw about 30 m down to east) but similar in character to the main Beinn na Leac Fault (estimated throw 300 m). Coherence of the succession has been maintained within the fault block, but rotational landslipping of blocks, indicated by steeper dips, becomes significant farther south. At the northern end of the GCR site a third small fault, with a downthrow of 4 m to the east but decreasing southwards, is interpreted as a branch of the main Beinn na Leac Fault (Figure 8.13), This fault separates the cliff and dip-slope of the main part of the Scalpay Sandstone Formation to the east from the overlying strata to the west and forms a gully leading from north of An Leac towards Rubha na' Leac east of the main North Fearns to Hallaig track.

Within the GCR site, as strictly defined, all the strata are included in the Scalpay Sandstone Formation. The age range is from the Capricornus Subzone (Davoei Zone) to the Hawskerense Subzone (Spinatum Zone), hence spanning the Lower to Upper Pliensbachian boundary. Slight westwards extension of the north-western corner of the site expands the stratigraphical range upwards to include the top beds of the Scalpay Sandstone Formation, the Portree Shale Formation (not exposed) and the Raasay Ironstone Formation. The top bed of the Scalpay Sandstone Formation (exposed at NG 5987 3793) can be dated to the basal Toarcian Tenuicostatum Zone. The Portree Shale and Raasay Ironstone formations have not been dated at this locality, but elsewhere have been dated by Howarth (1992) to the Lower Toarcian Serpentinum Zone.

A detailed measured section of the Scalpay Sandstone Formation was given by Howarth (1956) and the succession summarized in Figure 8.15 is based largely on this, with the addition of some supplementary information. The bed numbers are those of Howarth's (1956) composite succession for Raasay, based on a different locality for beds up to Bed 25. Bed 13 forms the rocky intertidal foreshore and consists of interbedded silty and calcareous fine-grained sandstones exhibiting small-scale (1–2 m) cyclicity. Fossils are uncommon, generally fragmentary, and dominated by infaunal bivalves, but *Aegoceras* sp., indicating the Capricornus Subzone, has been observed. Beds 14–18 were identified by Howarth (1956) as useful marker beds for correlation with localities farther north (see **Hallaig Shore** and **Cadha Carnach** GCR site reports). They include two characteristic fissile, laminated micaceous shales crowded with crushed bivalves, especially *Camptonectes* and *Plicatula*, but no ammonites. They are exposed in a small outcrop directly below the second crag of the cliff, about 200 m south of the bay, at the junction between the beach and the grassy talus slope just above normal high-tide level. The sandstones of beds 19–20, overlying the marker beds, are not well exposed though Howarth (1956) recorded *Oistoceras* sp. of the

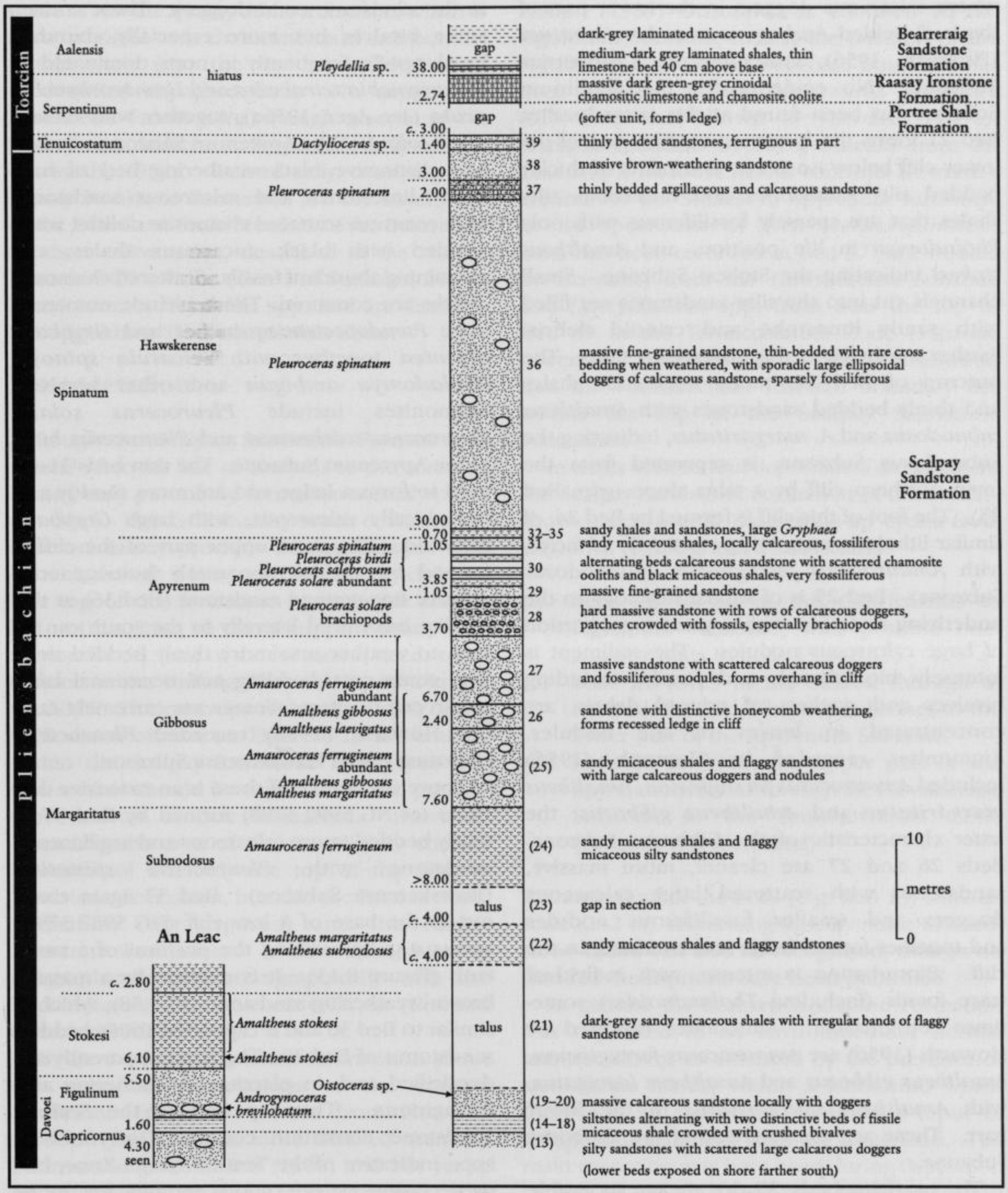



**Figure 8.15** Succession through the Scalpay Sandstone Formation, Portree Shale Formation (not exposed) and Raasay Ironstone Formation in the shore, cliffs and hillside south and south-west of Rubha na' Leac and the north-east corner of Beinn na Leac, partly modified from Howarth (1956). Bed numbers for the Scalpay Sandstone Formation are those of Howarth's composite measured succession, continued upwards, in brackets where this was based on other localities on Raasay.

Figulinum Subzone. Better outcrops occur farther south below An Leac (NG 5999 3745) where calcareous doggers in the lower part of the bed yielded *Androgynoceras brevilobatum* (Howarth, 1956), indicating the Capricornus Subzone. No evidence for the Figulinum Subzone has been found at this latter locality. Bed 21 forms the lower, accessible, part of the lower cliff below An Leac. It consists of thickly bedded silty sandstones and micaceous silty shales that are sparsely fossiliferous with only *Pholadomya* in life position, and *Amaltheus stokesi* indicating the Stokesi Subzone. Small channels cut into the silty sandstones are filled with sandy limestone and crinoid debris. Farther north this bed is covered by talus. The outcrop of Bed 22, sandy micaceous shales and thinly bedded sandstones with *Amaltheus subnodosus* and *A. margaritatus*, indicating the Subnodosus Subzone, is separated from the main northern cliff by a talus slope (gap, Bed 23). The foot of this cliff is formed by Bed 24, of similar lithology, suggesting continuity of facies, with *Amauroceras ferrugineum* (Subnodosus Subzone). Bed 25 is of similar lithology to the underlying beds but with a greater proportion of large calcareous nodules. The sediment is intensely bioturbated, and fossils, including bivalves and pockets of crinoid debris, are concentrated in lenses in the nodules. Ammonites recorded by Howarth (1956) included *Amauroceras ferrugineum*, *Amaltheus margaritatus* and *Amaltheus gibbosus*, the latter characteristic of the Gibbosus Subzone. Beds 26 and 27 are cleaner, more massive, sandstones with scattered large calcareous doggers and smaller fossiliferous nodules and together form a ledge and overhang in the cliff. Bioturbation is intense, with individual trace fossils (including *Thalassinoides*) sometimes recognizable. Ammonites reported by Howarth (1956) are *Amauroceras ferrugineum*, *Amaltheus gibbosus* and *Amaltheus laevigatus*, with *Amaltheus margaritatus* in the lower part. These are characteristic of the Gibbosus Subzone.

The overlying beds, 27–36, are not accessible in the main cliff, but can be reached by scrambling up the steep gully and grassy slope beside the northern end of the cliff (NG 5993 3799). However fallen blocks on the talus slope and foreshore can usually be identified to source. Bed 28 is a hard massive sandstone with rows of large calcareous doggers and patches crowded with fossils, usually in nodules which may occur in the sandstone or in doggers. These contain some bivalves but more especially abundant brachiopods, frequently in nests dominated by *Tetrarhynchia tetrahedra* and *Homoeorhynchia acuta* (see Ager, 1956a), together with *Pleuroceras solare* of the Apyrenum Subzone. Bed 30 is a distinctive black-weathering bed of hard sandy limestones and calcareous sandstones with common scattered chamosite ooliths, interbedded with black micaceous shales, and containing abundant fossils. Scattered chamosite ooliths are common. These include numerous large *Pseudopecten equivalvis* and *Gryphaea gigantea* together with *Plicatula spinosa*, *Pholadomya ambigua* and other bivalves. Ammonites include *Pleuroceras solare*, *Pleuroceras salebrosum* and *Pleuroceras birdi* of the Apyrenum Subzone. The thin beds 31–35 tend to form a ledge and are more muddy and only locally calcareous, with large *Gryphaea gigantea*. The main upper part of the cliff is formed by a thick apparently homogeneous massive fine-grained sandstone (Bed 36) at this locality, but traced laterally to the south can be seen to weather into more thinly bedded units with some cross-bedding and occasional large calcareous doggers. Fossils are extremely rare, but Howarth (1956) recorded *Pleuroceras spinatum* of the Hawskerense Subzone.

Above the main cliff there is an extensive dip-slope (at NG 5992 3790) formed by Bed 37, a thinly bedded, more calcareous and argillaceous sandstone with *Pleuroceras spinatum* (Hawskerense Subzone). Bed 37 again crops out at the base of a low cliff (NG 5987 3793) across a gully marking the position of a small fault (Figure 8.13). It is overlain by a massive brown-weathering sandstone (Bed 38), which is similar to Bed 36 and is capped by thinly bedded sandstones of Bed 39. The latter apparently are decalcified and, in places, red-weathering and ferruginous. This top bed of the Scalpay Sandstone Formation contains *Dactylioceras* spp., indicative of the Tenuicostatum Zone, but preservation is not good enough for more precise determination of species and age.

Above the low cliff there is the dip-slope of the top of the Scalpay Sandstone Formation, followed by a ledge that marks the position of the Portree Shale Formation. This is not exposed, but the thickness is estimated at 3 m.

The overlying Raasay Ironstone Formation is exposed in a small excavation (at NG 5983 3794) made to test the quality of the ironstone, which is here crinoidal with chamosite mud and ooliths. A thin shale near the top has yielded small unidentified rhynchonellids. No ammonites have been found here, though elsewhere on Raasay they indicate a Serpentinum Zone age (Howarth, 1992). Immediately overlying the Raasay Ironstone Formation are the basal beds of the Dun Caan Shale Member of the Bearreraig Sandstone Formation, described in the Middle Jurassic GCR volume (Cox and Sumbler, 2002). These contain *Pleydellia* spp. and are dated to the uppermost Toarcian Aalensis Zone.

## Interpretation

Although the Scalpay Sandstone Formation is named after the Isle of Scalpay, to the south of Raasay, only part of the formation actually crops out there. This GCR locality south of Rubha na' Leac on Raasay provides a more suitable type section, though it has yet to be formally defined. The top of the formation is seen (see above) but not the base, so that a supplementary type section for the base of the formation needs to be defined in the **Hallaig Shore** GCR site 2 km to the NNW. The outcrops within the limits of the GCR site as shown on Figure 8.13 are entirely within the Scalpay Sandstone Formation, and this section should be regarded as the primary type section of that formation. However, extending the area of the site slightly enables inclusion of not only the top of the Scalpay Sandstone Formation, but also the Portree Shale Formation (not exposed) and the Raasay Ironstone Formation. It also links this site geographically and stratigraphically with the Middle Jurassic Beinn na Leac GCR site (Cox and Sumbler, 2002).

By far the most important information about the ages and correlations of the Scalpay Sandstone Formation comes from Howarth (1956). This is much more detailed than the information given in Lee (1920) and has yet to be superseded by more recent studies. The ammonites listed in Figure 8.15, and the positions of the zonal and subzonal boundaries are based largely on those in Howarth (1956), though with some modifications and additions. Dating of Bed 13 to the Capricornus Subzone (Lataecosta Subzone of Howarth, 1956) can be confirmed by a field identification, by M.J. Oates, of a specimen of *Aegoceras* sp.. According to Phelps (1985) *Oistoceras* is confined to the Figulinum Subzone, so that the position of the Figulinum–Capricornus subzonal boundary has been adjusted slightly downwards in Figure 8.15 from that shown by Howarth (1956). Material collected by Nicol Morton from An Leac and from loose blocks confirms Howarth's records for the Stokesi to Apyrenum subzones. In-situ specimens of *Pleuroceras spinatum* have also been recorded in Bed 37 (not studied by Howarth) from the Hawskerense Subzone and *Dactylioceras* spp. from near the top of Bed 39 in the Tenuicostatum Zone (subzone uncertain), confirming Lee's (1920) conclusion that the Pliensbachian–Toarcian boundary lies within the top of the Scalpay Sandstone Formation.

In terms of facies and depositional environment the Scalpay Sandstone Formation at this locality shows three overall coarsening-up cycles from siltstones to fine-grained sandstones:

(i) beds 13 to 20 in the Capricornus to Figulinum subzones, with possible brief anoxic events in beds 15 and 17;
(ii) beds 21 to 29 in the Stokesi through to Subnodosus and Gibbosus subzones to the lower part of the Apyrenum Subzone.
(iii) beds 30 to 39 in the upper part of the Apyrenum Subzone through the Hawskerense Subzone to the Tenuicostatum Zone (subzone not identified).

Within several of the beds (e.g. Bed 13) smaller-scale (1–2 m) coarsening-up silty shale to sandstone cycles can also be recognized, though no detailed descriptions have been published.

In general the Scalpay Sandstone Formation was deposited in an environment of normal marine salinity, as indicated by the presence of stenohaline fossils, within a basin into which there was an apparently continuous input of terrigenous sediment from the hinterland. The main exception may have been during deposition of Bed 30, which is unusually fossiliferous and contains chamosite ooliths, perhaps indicating relative condensation and reduced terrigenous input. Sediment was re-distributed from presumed deltaic sources by marine currents and finer-grained parts of the formation were deposited in an environment below normal wave-base. The occurrence of small channels (e.g. in Bed 21) suggests that the sea floor was, at times, above storm wave-base. Cross-bedding can be observed in some places in the sandstone units, notably in Bed 36, suggesting the influence of tidal currents.

Above the Scalpay Sandstone Formation on Raasay there is evidence of an abrupt deepening event, defined as a sequence boundary by Morton (1989), to the black shales of the Portree Shale Formation, dated by Howarth (1992) as Exaratum Subzone. It is likely that part of the Tenuicostatum Zone is represented by a hiatus, though this remains unproven. The Portree Shale Formation forms a grassy ledge at this locality and does not crop out, so that no information can be given other than its estimated thickness of 3 m.

The shales pass up into the Raasay Ironstone Formation, representing another coarsening-up cycle. The age of the ironstone, previously placed in the Bifrons Zone, was revised by Howarth (1992) to the top of the Exaratum Subzone of the Serpentinum Zone. The main interest of this locality for the Raasay Ironstone Formation is the lateral facies change compared with the type section of the formation in central Raasay, 3 km to the south-west. At the main opencast mine in central Raasay the formation consists of thinly bedded and cross-bedded chamosite oolites with ammonites and belemnites, deposited in a shallow marine environment above wave-base (see Morton and Hudson, 1995). On Beinn na Leac it passes into largely crinoidal limestone with a chamositic mud matrix and scattered ooliths deposited below wave-base. The thickness increases slightly from 2.40 m to 2.74 m. The presence of *Pleydellia* spp. in the basal beds of the Dun Caan Shale Member, indicating the uppermost Toarcian Aalensis Zone, is evidence for a major hiatus with most of the Toarcian succession missing above the Raasay Ironstone Formation.

## Conclusions

The cliffs and foreshore south of Rubha na' Leac furnish the best section in the Hebrides through most of the Scalpay Sandstone Formation, while to the west outcrops of overlying strata occur. The succession, in the upper part of the Lower Pliensbachian and the Upper Pliensbachian sequence, is complete at subzonal level and thick, especially in the Hawskerense Subzone. However, although fossils are reasonably common, they are discontinuously distributed through the succession, so that precise positions of zonal and subzonal boundaries are uncertain. The site is of great value as an example of Lower Jurassic shallow marine siliciclastic facies, contrasting markedly with the other classic correlative successions of the Dorset and Yorkshire coasts. The succession is typically representative of an early Jurassic subsiding basin sufficiently near to a land area for sedimentation to be almost entirely siliclastic. The outcrops and large fallen blocks provide excellent illustrations of shallow marine silt to fine-sand deposition just below or above wave-base, with intense bioturbation being pervasive.

From a palaeontological perspective the most striking feature is the abundance of large bivalves, and especially of *Pseudopecten equivalvis*, together with *Gryphaea gigantea* (both epifaunal), and infaunal bivalves such as *Pleuromya costata* and *Pholadomya ambigua*, often in life position (see Hallam, 1967a, for a more detailed faunal list). The site is of both national and international significance for its ammonite and brachiopod faunas in particular. It was demonstrated by Howarth (1958) to be of great importance for the biostratigraphy, evolution, taxonomy and palaeobiogeography of the ammonite family Amaltheidae, which dominates the Upper Pliensbachian Substage of Britain. Examples of evolution documented here include the *Amaltheus margaritatus* to *Amaltheus laevigatus* lineage, and *Amaltheus gibbosus* through *Pleuroceras transiens* to *Pleuroceras solare*. Brachiopods are also abundant in some beds, usually occurring in large numbers in 'nests'. *Tetrarhynchia tetrahedra* and *Homoeorhynchia acuta* are dominant, but other significant species include *Grandirhynchia grandis* and *Zeilleria quadrifida*. The palaeobiogeographical significance of these was discussed by Ager (1956a), who recognized a distinctive Hebrides Province for Spinatum Zone brachiopods.

Immediately west of the northern limit of the GCR site as defined, the stratigraphical relationships of the Scalpay Sandstone Formation to the overlying Jurassic up to Lower Bajocian succession can be seen. The Pliensbachian–Toarcian boundary can be identified but the characteristic ammonite faunas are separated by 4 m of unfossiliferous strata.

## AIRD NA H-IOLAIRE, ISLE OF MULL, ARGYLL AND BUTE (NM 404 287)

*N. Morton*

### Introduction

The sections at the Aird na h-Iolaire GCR site expose a succession from late Triassic terrestrial facies, through the quasi-marine Penarth Group, into the fully marine basal Jurassic Blue Lias Formation facies. As such it is one of only two occurrences of basal Jurassic marine deposits known in Scotland. This is a key site in palaeogeographical reconstructions and for correlation with Lower Jurassic sections in southern Britain. Proven basal Jurassic (lower Hettangian Planorbis Zone) and uppermost Triassic (Norian–Rhaetian) marine sediments are recorded in western Scotland from only two areas; in the Central Ring Complex of the Isle of Arran in south-west Scotland (but see Cope *et al.*, 1980a), and in the south-western part of the Isle of Mull. Only the latter is geographically part of the main area of the Hebridean Jurassic System; palaeogeographically the Arran outcrops may have closer links to Northern Ireland than to the Hebrides Basin. The significance of the Aird na h-Iolaire GCR site in the British Lower Jurassic sequence is that it represents the most northerly outcrop known of the transition between uppermost Triassic and basal Jurassic marine strata, with Planorbis Zone ammonites. This is graphically illustrated by Hesselbo *et al.* (1998). Although the Planorbis Zone has been assumed to be present elsewhere, such as in Applecross (Hallam, 1959), this remains unproven and generally the lowest proven ammonite zone within the Hebridean region north of Mull is the Angulata Zone.

Most of the Isle of Mull is geologically dominated by Palaeocene igneous rocks, including a thick pile of plateau basalt lavas. Exceptions are the Ross of Mull Peninsula and the area around Loch Don in the south and south-east respectively. Elsewhere there are, in places, narrow strips of Mesozoic and older rocks which can be seen along the coast below the basalts. One such area is the Ardmeanach Peninsula, including the Aird na h-Iolaire GCR site (Figure 8.16). Here, between Rubha na h-Uahma (NM 402 279) and Gribun (NM 454 351), Triassic and Lower Jurassic sediments, resting unconformably on Moine schists and overlain unconformably by Upper Cretaceous sediments, occur along the coast below a high cliff of the Palaeocene volcanic rocks. However, most Jurassic outcrops are obscured by landslips from the basalt scarp or are covered by scree and there are few in-situ sections.

The Triassic succession in this area comprises two formations. The Stornoway Formation, consisting of conglomerates overlain by sandstones with calcretes (cornstones), rests unconformably on an uneven surface of Moine Schists. The unfossiliferous red-beds of the Stornoway Formation are overlain by pale-coloured calcareous sandstones, dark sandy limestones and thin layers of black shale containing marine bivalves, including *'Chlamys' valoniensis* and *Rhaetavicula contorta*. These beds are classified in the Penarth Group and, together with a locality on the edge of the Central Ring Complex of Arran, provide the only proof of marine Rhaetian in Scotland. Other localities such as Loch Aline (Morvern) have different bivalve faunas and are of uncertain age.

The Lower Jurassic sediments, classified by Oates (1976, 1978) as part of the Blue Lias Formation, can be seen *in situ* in only two areas on the Ardmeanach Peninsula of Mull (Figure 8.16), at the Aird na h-Iolaire GCR site (NM 403 287) and in Allt na Teangaidh east of Balmeanach Farm, Gribun (NM 451 333). This account will deal with both areas, but concentrate on the defined GCR site at the former locality, because it is the more completely known even though it is much more difficult to access in, aptly named, 'The Wilderness'. The descriptions are based on the [British] Geological Survey memoir (Lee and Bailey, 1925), a PhD thesis (Oates, 1976) and information provided by Michael Oates, Gert Bloos and Geoff Warrington.

The lithostratigraphical terminology used here follows that in Cope *et al.* (1980a), which included use of Penarth Group for the 'Rhaetic' and Blue Lias Formation for the Lower Lias (following Oates 1976, 1978), but with Stornoway Formation used for the rest of the so-called Trias 'New Red Sandstone' following Morton and Hudson (1995).

Access to Aird na h-Iolaire by walking is best achieved by following a footpath westwards from Tavool House (NM 439 271) but remaining above the sea-cliff past the fossil trees and Rubha na h-Uamha to regain the shore south of Aird na h-Iolaire (M. Oates, pers. comm.).

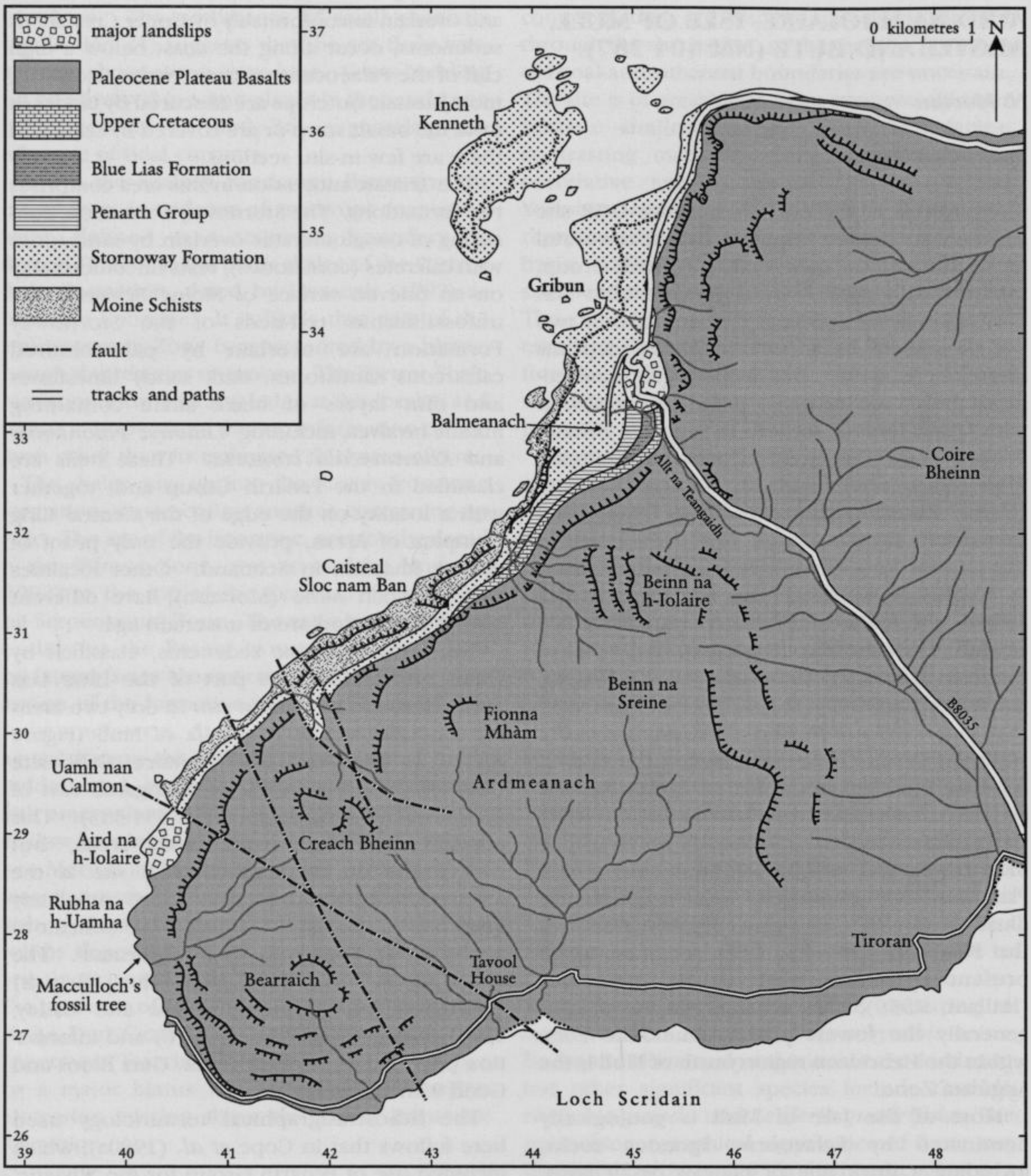



**Figure 8.16** Simplified geology and topography map of the western part of the Ardmeanach Peninsula, western Mull. The two main localities discussed, Aird na h-Iolaire and Allt na Teangaidh, Gribun, are indicated.

## Description

The outcrops of the Lower Jurassic sediments at the Aird na h-Iolaire GCR site are usually obscured by scree and landslipped material where the high scarp of the Palaeocene lavas has slipped on the soft Mesozoic sediments beneath. Oates (1976) identified two episodes of scree formation, with the earlier scree including, in addition to basalt, blocks of Mesozoic sedimentary rocks which included, in places, Blue Lias Formation limestone and shale with the

Hettangian ammonite *Psiloceras* or with lower Sinemurian *Gryphaea arcuata*, together with Upper Cretaceous greensand, white sandstone and silicified chalk (see Lee and Bailey, 1925; Oates, 1976). The younger scree contains only basaltic material.

At Aird na h-Iolaire, apparently in-situ Lower Jurassic sediments crop out on the foreshore and in a low cliff at the foot of the scree slope on both sides of the point NM 402 288. The beds are almost horizontal but the sections are not continuous and do not show completely the stratigraphical relationships with older or younger strata. An alternative, though less likely, possibility is that the outcrops may be a more coherent part of the larger Aird na h-Iolaire landslip.

This area of Mesozoic sediments is bounded to the north by a NW–SE-trending fault which cuts the west coast of the Ardmeanach Peninsula at Uamh nan Calmon (NM 405 293) and the south coast near Tavool House (NM 439 271) (Figure 8.16). North of the fault the Palaeocene basalts rest on a thin development (*c.* 3 m) of the Stornoway Formation which lies unconformably on Moine Schists. Upper Cretaceous sediments are not mapped by the [British] Geological Survey until 3 km to the north-east (at NM 434 313), near where they overstep the Penarth Group southwards to rest directly on the Stornoway Formation (Figure 8.16). Therefore, the Uamh nan Calmon Fault must have a significant pre-Palaeocene downthrow to the south-east. The overstep by the Upper Cretaceous sediments on both sides of the fault, and comparisons with the Camasunary and related faults in the Skye area, suggests that the main movement is likely to be of a pre-Late Cretaceous age (Morton, 1992b). Although mapped by the [British] Geological Survey as cutting the Palaeocene lavas, there is evidence neither for significant displacement of these nor of a topographic feature south-west of Creach Bheinn. By contrast several NNW–SSE faults (Figure 8.16) do displace the lavas and are associated with topographic features.

A coherent stratigraphical succession for the Aird na h-Iolaire area is possible only for short sections in the lower part of the Mesozoic sequence. However, the overall succession here can be reconstructed based on information shown on the [British] Geological Survey map (Sheet 43, Iona) and published by Lee and Bailey (1925).

| | | |
|---|---|---|
| **Paleocene:** | basalts (not differentiated here) | |
| **Upper Cretaceous:** | silicified chalk (Turonian) | |
| | white sandstone (?Cenomanian) | |
| | greensand (?Upper Albian–Cenomanian) | |
| **Lower Jurassic:** | Blue Lias limestones and shales with Gryphaea (Sinemurian) | |
| | Blue Lias shales and limestones with *Psiloceras* and *Liostrea* | *c.* 8 m |
| **Triassic:** | Penarth Group sandstones and shales (Rhaetian) | 5.80 m |
| | Stornoway Formation sandstones with conglomerates and cornstones (undated) | *c.* 6 m |
| base not seen | | |

There are no coherent sections in the higher beds, so no estimates of thickness can be given. A more detailed lowermost Jurassic succession at Aird na h-Iolaire, based on Oates (1976) and Lee and Bailey (1925), is shown in Figure 8.17. The strata exposed on the foreshore, partly obscured by mobile beach boulders, are silty bioturbated sandstones (Bed 2) capped by a more calcareous sandstone (Bed 3). These beds are extensively bioturbated but contain only plant remains. Lee and Bailey (1925) recorded 5.8 m of similar strata, with a 0.3 m-thick bed of red mudstone below (Bed 1). The boundary with the overlying beds is obscured by beach debris (Oates, 1976).

In a low cliff at the foot of the scree slope the lowest overlying beds observed are hard calcareous shaly sandstones (beds 5a–c). These become less sandy upwards and pass into alternating soft silty shales and thin argillaceous micritic limestones (beds 5d–j) crowded with *Liostrea hisingeri*, together with poorly preserved other bivalves including *Modiolus hillanus*, in the lower part but with a more diverse fauna, including more variable and more gibbous *Liostrea*, *Cardinia concinna*, *Plagiostoma succinta* and *P.* cf. *giganteum*, in the upper part. The thickness indicated by Lee and Bailey (1925; 2.4 m) is greater than that given by Oates (1976; 1.27 m). Above a soft, brown, silty, micaceous shale are alternating beds of fine-grained, slightly micaceous shales and argillaceous micritic limestone (beds 7–25). The similarity of facies between this part of the succession and the Blue Lias Formation of England and Wales led Oates (1976, 1978) to extend this lithostratigraphical term to part of the Lower Lias of the Hebrides. A detailed measured section for the Blue Lias Formation at

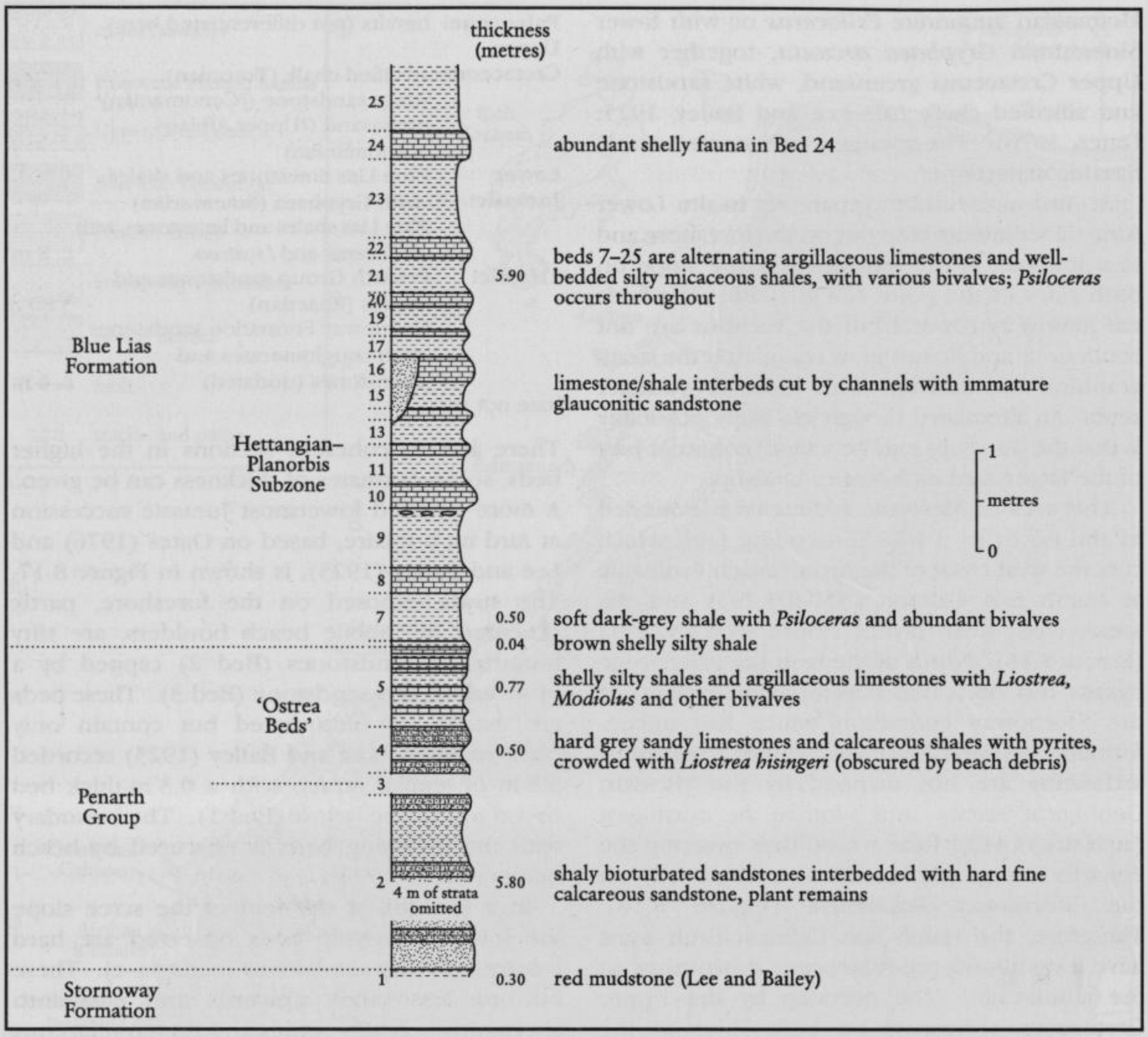



**Figure 8.17** Uppermost Triassic and lowermost Jurassic measured succession just south of Aird na h-Iolaire, based mainly on Oates (1976) with additional data from Lee and Bailey (1925) and Oates (1976). The bed numbering is added here for reference.

Aird na h-Iolaire was given by Oates (1976), and this forms the basis for Figure 8.17 with the addition of numbers for the individual beds because these can be matched in detail with photographs (figs 2 and 5) in Oates' thesis (1976). The fauna is more diverse, especially near the top of the section in Bed 24 (Figure 8.17), with ammonites including *Psiloceras planorbis* (see below) of the Planorbis Subzone, and bivalves including *Cardinia*, *Modiolus*, *Pholadomya*, *Pinna* and *Plagiostoma*. Oates (1976) also described sandstone channels cutting the shales and limestones and resulting also in disruption of bedding.

Higher Jurassic strata are not seen *in situ* or in stratigraphical continuity with the Hettangian strata. However, Lee and Bailey (1925) recorded fallen blocks in the landslip which suggest the presence of two higher units:

(i) grey shales and limestones with *Psiloceras*, *Liostrea hisingeri* and a 'gryphaeid form' of *Liostrea*, of lower Hettangian age;

(ii) limestones with typical *Gryphaea arcuata*, *Plagiostoma giganteum* and *Unicardium cardioides*, interpreted as from low in the Sinemurian Stage.

No evidence has yet been found for the presence of Hettangian strata higher than the Planorbis Zone.

From the cliff above Caisteal Sloc nam Ban (at NM 435 317) northwards into the Gribun area and Inch Kenneth, the Stornoway Formation increases dramatically in thickness and the Penarth Group re-appears below the Upper Cretaceous sediments and Palaeocene lavas. In the Gribun area there is an extensive raised beach area underlain mainly by the Stornoway Formation. East of the Balmeanach Farm, in Allt na Teangaidh where the slope begins to steepen (NM 452 332), the Stornoway Formation is overlain by the Penarth Group and black shales of the Lower Jurassic Series. The latter were not described by the [British] Geological Survey but descriptions are given by Oates (1976). This small area of Jurassic sediments does not appear to extend north or south of the Allt na Teangaidh valley.

The Gribun area shows better Triassic sections, both in the Stornoway Formation and the Penarth Group, than are seen at Aird na h-Iolaire. In the latter Manson (in Lee and Bailey, 1925) recorded fish scales and bivalves typical of the 'zone of *Rhaetavicula contorta*', i.e. Rhaetian. There appear to be significant differences between the Rhaetian strata here compared with Aird na h-Iolaire, but details of these are outside the scope of this review. The top of the Rhaetian and the overlying Jurassic were described by the [British] Geological Survey as obscured. However, Oates (1976) described small exposures of Blue Lias Formation facies (confirmed by G. Warrington, pers. comm.) in the banks of the Allt na Teangaidh. The section is not as useful as that at Aird na h-Iolaire, so that only additional facies or faunas at Gribun are commented on here. Oates (1976) described one facies not seen at Aird na h-Iolaire. This is a bed, 0.8 m thick, of light-grey, laminated shales which contain a rich, but low-diversity, bivalve fauna dominated by small, up to *c.* 7 mm in length, specimens of *Modiolus* sp. associated with *Lingula*. The *Modiolus* were interpreted as dwarfed and the fauna as possibly indicating an interval or reduced salinity. The stratigraphical relations of this bed to the Blue Lias Formation of the Planorbis Subzone at Aird na h-Iolaire is uncertain. From an outcrop stratigraphically higher than the laminated shales, Oates (1976, 1978) figured a specimen of *Caloceras ? johnstoni*, indicating the presence of the Johnstoni Subzone, and hence evidence for faunas younger than the Planorbis Subzone of Aird na h-Iolaire.

## Interpretation

The unfossiliferous conglomeratic and sandy 'red-beds' of the Stornoway Formation, at the base of the Mesozoic succession in the Hebrides, are everywhere undated by direct evidence. Other than the palaeomagnetic evidence in the Stornoway area used by Storetvedt and Steel (1977) to correlate these beds with the 'New Red Sandstone', rather than the Old Red Sandstone or Torridonian, only their conformable position below dated Lower Jurassic strata tentatively supports assignment to the Upper Triassic sequence (Morton, 1989). In Skye (Morton, 1999b) the top of the formation is thought to be Hettangian in age, but in the Ardmeanach area of Mull it is overlain by dated Rhaetian and basal Hettangian strata.

Transitional beds between the clearly continental Stornoway Formation and the clearly marine Lower Jurassic (Blue Lias Formation or Breakish Formation) sediments are widespread in the Hebrides. Those in the Ardmeanach Peninsula of Mull differ in two main aspects. The first is that the fauna, dominated by bivalves, includes species such as '*Chlamys*' *valoniensis* and *Rhaetavicula contorta*, which are typical of the Penarth Group of England and Wales. The second is that they are overlain by dated basal Jurassic sediments of the Planorbis Subzone. Similar strata elsewhere in the Hebrides, even in Morvern, tend to be more sandy and have a different bivalve fauna. In some areas at least, they may be of Hettangian age (Morton, 1999b).

Overlying the 'Ostrea Beds' at Aird na h-Iolaire is a 5.80 m-thick succession of interbedded shales and limestones (Figure 8.17) with a more diverse bivalve fauna and, more significantly, ammonites. This was placed in the Blue Lias Formation by Oates (1976, 1978) and correlated with the Pre-Planorbis Beds of England and Wales (see also Hesselbo *et al.*, 1998). The ammonites occur throughout but Oates (1976, 1978) allocated all of his material to one species *Psiloceras planorbis*, index fossil of the basal Jurassic Planorbis Subzone of the Planorbis Zone.

For the [British] Geological Survey, Manson (in Lee and Bailey, 1925) carried out bed-by-bed sampling. The ammonites were submitted to S.S. Buckman who identified several species of *Psiloceras* reported (in Lee and Bailey, 1925) as 'indicat[ing] a zonal succession with tachygenesis of wider umbilication'. Gert Bloos (pers. comm., February 2001) has suggested that, if the identifications can be confirmed, the detailed succession in the Planorbis Subzone of Mull could be one of the most complete in Britain. Further work on the British Geological Survey and Michael Oates' collections, preferably with collection of new material, is required.

The equivalent strata do not appear to be well exposed in the Allt na Teangaidh section, from where Oates (1976) figured a specimen of *Caloceras ? johnstoni* indicating the presence of the Johnstoni Subzone, the upper subzone of the Planorbis Zone. The facies, fauna and possible palaeoenvironmental significance of the bed with dwarfed *Modiolus* from lower in the section were compared by Oates (1976) with an interval in the Johnstoni Subzone of the Stowell Park Borehole in Gloucestershire.

The Triassic to Lower Jurassic succession exposed here represents a clear palaeoenvironmental transition from terrestrial to marine. The basal beds are locally derived breccias deposited by flash-floods near an alluvial fan setting. The overlying conglomerates include lenticles of cross-bedded pebbly sandstones and were deposited in a braided fluvial environment. Some pebbles in this unit are of more distant origin and include clasts of Durness Limestone from a considerable distance to the west (Lee and Bailey, 1925). In the Gribun and Inch Kenneth area the upper part of the formation is dominated by pale-coloured calcite-cemented sandstones, with frequent development of calcretes (cornstones). The formation varies enormously in thickness on the Ardmeanach Peninsula, as elsewhere in Mull and the Hebrides, from over 60 m at Inch Kenneth, opposite Gribun, to 3 m south of Gribun. It was deposited in a terrestrial alluvial fan to braided floodplain environment in a predominantly semi-arid climate which resulted in evaporation of groundwater to form the subsoil calcretes (Steel, 1974a,b).

The sandstones in the lower part of the Penarth Group here, especially at Aird na h- Iolaire, are hard, grey, micaceous calcareous sandstones with silty shales. The absence of fossils other than plant remains, and the extensive bioturbation, suggests a marginal-marine environment. The succeeding sandy limestones and shales with pyrite and abundant *Liostrea hisingeri* are overlain by beds with a different and more diverse bivalve fauna. Oates (1976) compared these beds with the Pre-Planorbis Beds of England and Wales and both are classified here as the 'Ostrea Beds'. They record the latest Triassic marine transgression across this area, as in England and Wales. At Allt na Teangaidh the shales and limestones are thicker (Manson in Lee and Bailey, 1925, recorded 15 beds) and have a more diverse fauna of Rhaetian bivalves and fish scales. There appear to be significant differences of detail between the Allt na Teangaidh and Aird na h-Iolaire sections, although both environments were marine and below wave-base.

The Blue Lias Formation at this locality was described by Oates as his 'Blue Lias Facies Type 1', characterized by a low carbonate content and fine-grained mud sediment. The limestones are argillaceous with mostly sharp, planar bedding surfaces. The shales are softer, dark in colour with small detrital mica flakes and strongly compacted, though not laminated. Differential compaction is evident (Oates, 1976). Fossils are unevenly distributed through the sediment, but generally more abundant in the limestones, especially the uppermost limestone of Bed 24. Ammonites of one or more species of *Psiloceras*, including *P. planorbis*, were reported both by Lee and Bailey (1925) and Oates (1976) as occurring throughout; in the limestones they are preserved with the body chambers filled with sediment and uncrushed but the phragmocones hollow and crushed. The bivalves are mostly disarticulated but unbroken and include infaunal and epifaunal elements such as *Cardinia*, *Pholadomya*, *Modiolus* and *Plagiostoma*. The semi-infaunal genus *Pinna* occurs at several levels, but always preserved parallel to bedding. In addition fragments of indeterminate pectinid bivalves, cidaroid radioles, crinoid ossicles, the ostracod *Ogmaconcha* and lignite fragments are reported. The disarticulation of the bivalves and absence of lamination suggest extensive bioturbation of the sediment, though no recognizable trace fossils have been identified. Deposition was clearly below wave-base in a fully marine environment, but not in anoxic conditions. Depth of depositional environment and distance from shore cannot be deduced solely from the nature of the limestone–mudstone interbeds. However, these interbeds are cut by two small sandstone-filled channels eroded into the shale (Oates, 1976). The sandstones are immature and glauconitic and have longitudinal flute casts at their base. Disruption of the limestone–mudstone beds is interpreted by Oates as due to contemporaneous local deposition of more porous sand subsequently influencing carbonate deposition, rather than a product of compaction effects. The field evidence indicates that the channels are aligned east–west and they may represent tidal washout structures associated with rip currents (Oates, pers. comm.). Such an interpretation implies that deposition was not in deep water and not far from the shore, in a restricted tidally influenced basin.

Strata in the Allt na Teangaidh section at Gribun are less clearly exposed so that few comparisons can be made. However, Oates (1976) described light-grey laminated shales with apparently dwarfed *Modiolus* which are unlike any of the shales in the Aird na h-Iolaire section. It is possible that they are younger in age (Johnstoni Subzone). Oates' (1976) suggestion of local near-shore development of a lagoonal environment with slightly reduced salinity would be consistent with the suggestion above of a restricted basin.

Overall, the presence of marine basal Jurassic and quasi-marine Penarth Group strata on Mull contrasts with the situation on Skye and Applecross to the north, where the lowest ammonite-bearing strata can be assigned to the Angulata Zone. It suggests that these northern areas were emergent during late Triassic and earliest Jurassic times, while the presence there of calcareous sandstones with coral-bearing horizons suggests shallower-water deposition in late Hettangian and early Sinemurian times, in contrast with the more typical Blue Lias Formation facies farther south.

## Conclusions

The greatest significance of the Aird na h-Iolaire GCR site is in being almost the only outcrop in Scotland known to show a good fossiliferous section through basal Jurassic sediments with lowermost Hettangian, Planorbis Subzone, ammonites. The detailed ammonite succession merits further investigation. In the wider context of the Ardmeanach Peninsula (i.e. taking account also of the outcrops farther north around Gribun) the area also demonstrates evidence for:

1. Differential subsidence with stratigraphical thickening and lateral facies change during late Triassic times, both in the Stornoway Formation and in the Penarth Group.
2. Late Triassic (Rhaetian) transgression into the southern part (at least) of the Hebrides Basin resulting in deposition of marine Rhaetian sediments that can be dated biostratigraphically in the black shales and limestone of the Penarth Group.
3. Evidence that the Blue Lias Formation sediments, normally interpreted as deposited in an offshore environment, were in this area deposited in a more restricted basin where the shoreline of the Scottish landmass was not far distant.
4. The NW–SE Uamh nan Calmon Fault in the south-western part of the Ardmeanach Peninsula is a Mesozoic fault with pre-Late Cretaceous movement. The contrasts of succession and facies in the Rhaetian and Hettangian sediments between Aird na h-Iolaire and Gribun may suggest that earlier phases of movement could also have occurred.

# BORERAIG TO CARN DEARG, LOCH EISHORT, ISLE OF SKYE, HIGHLAND (NG 599 155–NG 622 164)

*M.J. Oates*

## Introduction

Boreraig was a small settlement, abandoned at the time of the (late 18th to early 19th century) 'Highland Clearances'. The shoreline below the degraded walls of the old blackhouses and the cliffs (Dun Boreraig) and hillside (Beinn Bhuidhe) above have been carved from a complete sequence of rocks of the lower Lias Group, and the Breakish, Ardnish and Pabay Shale formations, although exposure is more limited than in other localities, such as Applecross and around Broadford, where less complete sequences are present. The Loch Eishort cliffs have been largely ignored by previous workers. Arkell (1933) stated that the cliffs here are thermally metamorphosed by Tertiary igneous activity although this is not actually the case. A composite section can be effectively measured from separate outcrops at Boreraig.

The geology of this area of Skye was investigated in the mid-19th century by Geikie (1858) with brief descriptions of some of the Lias Group fossils by Wright (in Geikie, 1858). Further details were published by Peach *et al*. (1910), including a summary section of the Pabay Shale Formation of the Loch Eishort area. A measured section of the lower part of the succession here, traditionally termed the 'Broadford Beds' but now referred to the Breakish and Ardnish formations, was published by Hallam (1959). The work of Oates (1976) formed the basis of the detailed sections published by Hesselbo *et al.* (1998), with amendments to the lithostratigraphical nomenclature and boundaries of the latter based on the comments of Morton (1999a), as outlined in the beginning of this chapter. A brief review and summary log of the site appeared in Hesselbo and Jenkyns (1998) and in Hesselbo and Coe (2000). Hesselbo *et al.* (1998) assigned separate sequences of bed numbers to their Broadford Formation (32 beds), lower Pabay Shale and Hallaig Sandstone Member (71 beds), and the remainder of the Pabay Shale and the Suisnish Sandstone Member (87 beds). These correspond closely to the Breakish, Ardnish and Pabay Shale formations of the present account and the bed numbers are assigned here appropriate prefixes (B, A and P respectively) to distinguish them. Thus the full succession is numbered here as beds B1–B32, A1–A71 and P1–P87 (see Figure 8.18). Oates (1976) and Hesselbo *et al.* (1998) established that the Raricostatum Zone here is exceptionally thick and that the site may be suitable for designation as the type locality for the Pabay Shale Formation.

The entire Loch Eishort section is free from any significant structural complication, and along its length only a gentle south-westerly dip is evident. This brings the Suisnish Sandstone Member to shore level at Rubha Suisnish, where it has been worked for stone in historical time, and in which is eroded a large sea-cave.

Access to Loch Eishort is not practically difficult, but it is a long walk from the nearest road at either the head of Loch Slapin, or Heaste. A reasonable footpath is present from Suisnish down the cliff to the foreshore, passing over a prominent picrite dyke of the Tertiary Skye volcanic centre. Tides, in general, are not a factor in accessibility, except for the promontory with the best Obtusum Zone outcrop.

## Description

A small marine inlet obscures the base of the Breakish Formation, which overlies red-beds of presumed Triassic or earliest Jurassic age. The succeeding section can be divided into three decametre-scale cycles of peloidal limestone and sandstone. The middle cycle may be a faulted repetition of the lower cycle but, owing to incomplete exposure, this cannot be verified although the successions within each cycle are sufficiently different as to suggest this is unlikely. Although fossil debris is abundant in the Breakish Formation, no ammonites have been found at this site. Keystone vugs and early vadose cement fabrics have been identified in some of the lower limestone beds, with examples from Bed B3 being figured by Hesselbo and Coe (2000). Two fine-grained quartz sandstone beds (B11 and B18) show hummocky cross-stratification.

The actual contact of the Breakish and Ardnish formations is obscured but Hallam (1959) noted the presence of scattered pebbles at the top of his Bed 7 (Bed B32 of this account). At the base of the Ardnish Formation, behind the obvious waterfall where Allt na Peighinn descends to the beach at Boreraig (NG 623 163), a more argillaceous sequence with thin mudstone beds and an abundance of *Gryphaea arcuata* (Bed 8 of Hallam, 1959; Bed A1 of this account) shows a marked similarity to classic Blue Lias Formation facies, such as seen at the Allt Leacach GCR site. The lower part of the Ardnish Formation is a little over 35 m thick here and is dominated by mudstones and argillaceous, micaceous, sandstones that become coarser and more massive upwards. This part of the succession is well exposed along the foreshore and low cliffs of Dun Boreraig, although it is suspected that significant repetition of the succession by extensional faulting may have caused its thickness to be overestimated by Hallam (1959). Both mudstones and sandstones are thoroughly bioturbated with a fully marine fauna including bivalves, brachiopods and ammonites. Hallam (1959) recorded *Arnioceras* aff. *semicostatum* throughout the Ardnish Formation with *Coroniceras lyra* in the lower two-thirds and *Pararnioceras* aff. *parthenope* in the upper third (Hesselbo *et al.*, 1998).

The upper part of the Ardnish Formation forms a distinct lithostratigraphical unit, the Hallaig Sandstone Member, which is just over 45 m thick at this site. It is similar to the underlying beds, but less argillaceous and continues an upward trend to more clean-washed sandstones. Nowhere is its base exposed in the area but a topographic depression at the appropriate level suggests more easily weathered and eroded, possibly muddier, sediments up to 10 m thick. The member comprises well-cemented,

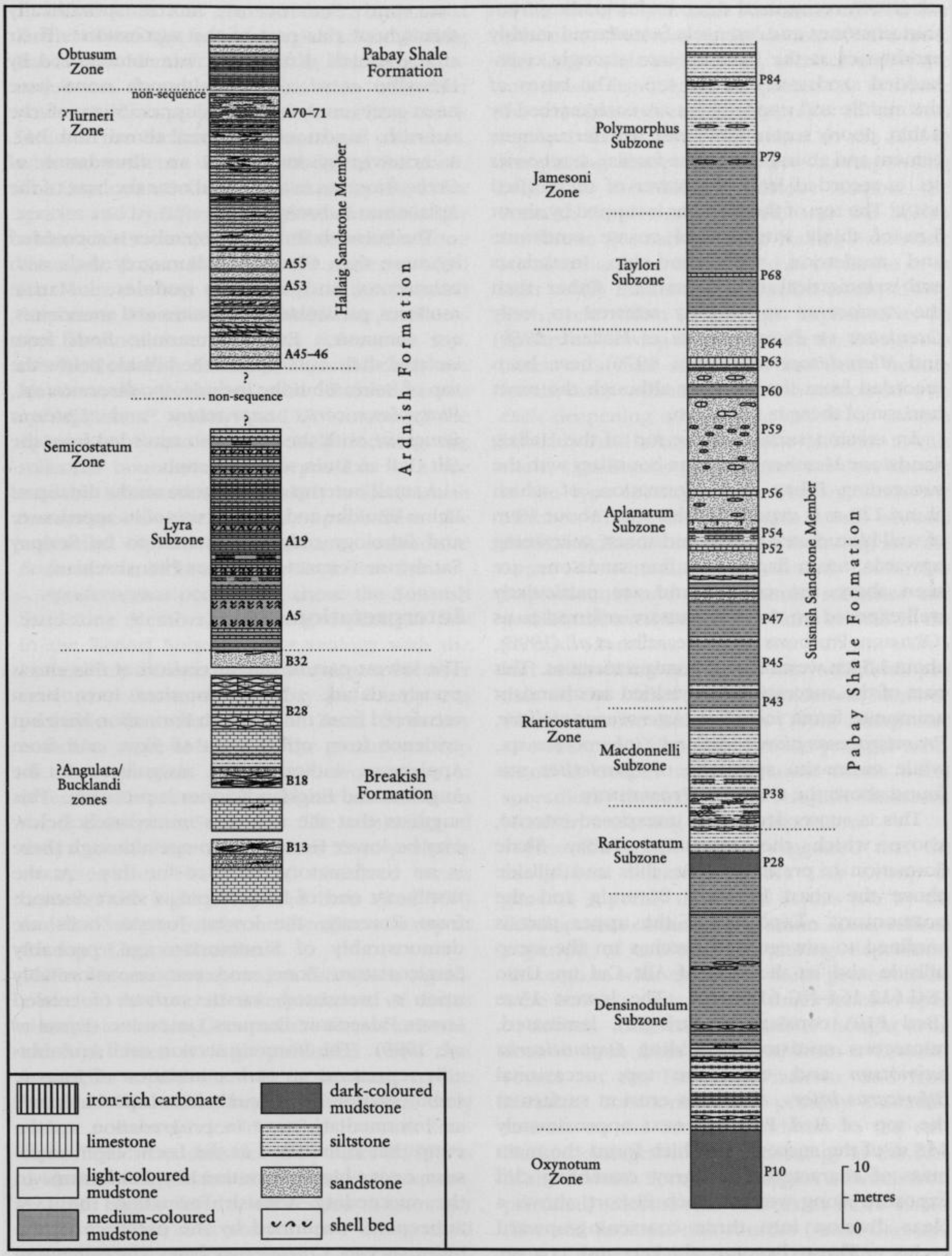



**Figure 8.18** Composite section through the Lias Group exposed at the Boreraig to Carn Dearg GCR site, Loch Eishort. After Hesselbo *et al.* (1998).

fine- to medium-grained sandstone. Hesselbo *et al.* (1998) recognized three cycles grading from thin siltstones and intensely bioturbated muddy sandstones at the base up into strongly cross-bedded sandstones at the top. The bases of the middle and upper cycles are each marked by a thin, poorly sorted sandstone with ferruginous cement and abundant marine fossils. *Arnioceras* sp. is recorded from the lower of these (Bed A50). The top of the member is capped by about 5 m of thinly interbedded coarse sandstone and mudstone, with mud-chip intraclasts and symmetrical ripple marks. Other than the *Arnioceras* sp. already referred to, only *Caenisites* (= *Euasteroceras* of Hallam, 1959) and *Microderoceras* (Oates, 1976) have been recorded from the member although the exact horizon of these is unknown.

An erosion surface at the top of the Hallaig Sandstone Member marks the boundary with the succeeding Pabay Shale Formation, of which about 220 m is exposed at this site. About 10 m of well-bioturbated sandy mudstones, coarsening upwards into a flaggy, very fine sandstone, are seen above the contact and are particularly well-exposed on the promontory, referred to as 'Obtusum Promontory' in Hesselbo *et al.* (1998), about 1.5 km west of the Boreraig settlement. This part of the succession has yielded an abundant ammonite fauna including *Asteroceras stellare*, *Promicroceras planicosta* and *Xipheroceras* sp., while an ex-situ specimen of *Eparietites* was found above the Obtusum Promontory.

This is succeeded by an unexposed interval, above which the remaining Pabay Shale Formation is present in the cliffs and hillside above the coast between Boreraig and the promontory. Exposure of the upper part is confined to unvegetated patches on the steep hillside and in the bed of Allt Cul an Duin (NG 612 164–NG 611 165). The lowest 13 m (Bed P10) consists of dark-grey, laminated, micaceous mudstones yielding *Oxynoticeras oxynotum* and, near the top, occasional *Bifericeras bifer*. Above an erosion surface at the top of Bed P10 the next approximately 145 m of the succession, which forms the main mass of characteristically grey, crumbling cliff exposure along western Loch Eishort, shows a clear division into three coarsening-upward cycles. These become thicker and coarser towards the top, culminating in the 85 m-thick Suisnish Sandstone Member (beds P30–P64), for which the Loch Eishort section is the type locality. Ammonites, mainly various echioceratid taxa and *Eoderoceras*, occur sporadically throughout this part of the succession. Their stratigraphical distribution was summarized by Hesselbo *et al.* (1998), although none have been recovered from the upper 50 m of the Suisnish Sandstone Member, above Bed P47. A noteworthy marker is an abundance of *Orthechioceras* in a thin bed near the base of the Aplanatum Subzone.

The Suisnish Sandstone Member is succeeded by more than 40 m of medium-grey shale with calcareous and sideritic nodules. Marine molluscs, particularly belemnites and ammonites, are common. Ex-situ ammonite finds from isolated shale outcrops on the hillside below the top of Beinn Bhuidhe include *Apoderoceras* sp., *Platypleuroceras caprarium* and *Uptonia jamesoni*, with the latter also recorded from the Allt Cuil an Duin stream section.

A small outcrop of sandstone marks the top of Beinn Bhuidhe and, on the basis of its appearance and lithology only, is assumed to be Scalpay Sandstone Formation (Upper Pliensbachian).

## Interpretation

The lowest part of the succession at this site is poorly dated. No ammonites have been recovered from the Breakish Formation here but evidence from other areas of Skye, and from Applecross, indicates that assignment to the Angulata and Bucklandi zones is probable. This suggests that the red-beds immediately below may be lower Hettangian in age although there is no confirmatory evidence for this. At the north-east end of Loch Slapin, a short distance from Boreraig, the lowest Jurassic beds are demonstrably of Sinemurian age, probably Semicostatum Zone, and rest unconformably upon a brecciated, karstic surface of eroded Lower Palaeozoic Durness Limestone (Farris *et al.*, 1999). The Boreraig section itself undoubtedly represents an earlier initiation of Jurassic sedimentation but, nonetheless, is probably still an intermediate stage in progradation up the ramp that culminated at the Loch Slapin exposure, or at a higher elevation as yet unknown. In the succeeding Ardnish Formation the Lyra Subzone is confirmed by the presence of the index species, *Coroniceras lyra*. The remaining subzones of the Semicostatum Zone are unproven but may perhaps be present in the lower part of the Hallaig Sandstone Member and an unexposed 10 m gap beneath. However, ex-situ *Caenisites* and *Microderoceras* indicate a Turneri Zone age for at least part of the Hallaig Sandstone Member. There is clearly a non-sequence above this since the abundant ammonite fauna from the succeeding beds indicate the Stellare and Denotatus subzones, with no evidence for the Obtusum Subzone. The Oxynotum Subzone, indicated by the index species and by *Bifericeras bifer*, is succeeded by a characteristic sequence of Raricostatum Zone ammonite faunas indicating the presence of all four subzones up to the top of the Suisnish Sandstone Member. *Crucilobiceras* indicates the Densinodulum Subzone; *Echioceras* spp. the Raricostatum Subzone; *Leptechioceras* the Macdonnelli Subzone; and *Paltechioceras aplanatum*, *P. oosteri* and *P. aureolum* the Aplanatum Subzone. Precisely locating the subzonal boundaries is not possible with the available information, particularly in the Suisnish Sandstone Member which, apart from the normally Aplanatum Subzone ammonite *Eoderoceras*, lacks any other diagnostic forms.

*Apoderoceras* occurs just above the Suisnish Sandstone Member, indicating a position low in the Taylori Subzone. By analogy with the successively thinner Suisnish Sandstone Member sections to the north, on Pabay and Raasay, it is probable that the Jamesoni Zone boundary coincides more-or-less with the gradational top of this sandstone. *Platypleuroceras* occurs at several levels around 20 m higher and indicates the Polymorphus Subzone. The remainder of the Jamesoni Zone and the Ibex Zone probably occupies the 60–70 m of obscured strata between the highest exposed beds (Bed P87) and the Scalpay Sandstone Member outcrop at the top of Beinn Bhuidhe.

The succession exposed at this site is significant for the overall interpretation of facies changes in the Lias Group of the Hebrides Basin, although there is little published work that is specific to the site. Near the base, in the Breakish Formation, keystone vugs and early vadose cement fabrics identified in some limestone beds were considered by Searl (1989) as evidence of deposition in a littoral environment. A little higher in the succession hummocky cross-stratification is seen in two fine-grained quartz sandstone beds (beds 11 and 18), indicating deposition in shallow marine conditions influenced by storm waves. The change from the cleanwashed sandstones of the Breakish Formation to the somewhat muddier sandstones of the succeeding Ardnish Formation are a further indication of increasing depth below wave-base. The larger-scale sedimentary architecture of the succession has been interpreted as evidence for transgressive–regressive cycles of at least regional extent, with Hesselbo *et al.* (1998) recognizing three main cycles corresponding broadly to the Hallaig Sandstone Member, the Suisnish Sandstone Member, and the Scalpa Sandstone Formation. The Hallaig Sandstone Member has been interpreted as estuarine or at least tidally influenced (Hesselbo *et al.*, 1998). Each cycle within it has been explained as an upward-shallowing sequence while the ferruginous bases, with their ammonites and other marine fossils, mark sediment starvation associated with each deepening event. The extent of erosion beneath the Hallaig Sandstone Member at this site is significantly greater here than on Raasay, at the type locality of the Hallaig Sandstone Member. There the ammonite faunas beneath the Hallaig Sandstone Member extend up into the upper Semicostatum Zone, certainly confirming Scipionianum and Resupinatum subzones and possibly the overlying Turneri Zone as well. In the Suisnish Sandstone Member the sediment is finer and sedimentary structures less well-developed than in the earlier Hallaig Sandstone Member, which Hesselbo and Jenkyns (1998) interpreted as evidence for deposition of the younger sandstone in deeper water. Marine fossils occur sporadically throughout the Suisnish Sandstone Member, indicating marine deposition.

Hesselbo *et al.* (1998) suggested that the exceptional thickness of the Lias Group in general, superbly illustrated at this site by the development of the Raricostatum Zone, reflects a period of active rifting during deposition, although to what extent the faults present today were active in early Jurassic times remains open to debate. The sediment itself is thought to be derived both from the west, from a Lewisian source on the Hebrides Platform, and from Moinian, Torridonian and possibly Dalradian sources on the Scottish landmass to the east. Marked changes in clay mineralogy at the base of the Ardnish Formation suggest a switch from proximal, smectite-rich sources to more distant illite and kaolinite-rich sources (Amiri-Garoussi, 1977), either as a result of drowning of the irregular basement as the transgression proceeded or as a consequence of exhaustion of the original sources.

## Conclusions

The combined exposures at this GCR site afford an almost continuous Hettangian through to Lower Pliensbachian sequence. It is noteworthy for the splendid exposures of the Pabay Shale Formation, with the development of major sandstone units highlighting the large-scale cyclicity of the succession. The Raricostatum Zone, within the Pabay Shale Formation, is substantially thicker at this site than at any other in Britain.

## ALLT LEACACH, LOCH ALINE, HIGHLAND (NM 692 454)

*M.J. Oates*

## Introduction

The Sound of Mull is famed for its attractive Tertiary volcanic and Moinian basement scenery. Along the NE shores of the Sound of Mull, however, between Rubha na Ridire and the narrow entrance to Loch Aline, a noticeably different style of cliff architecture is evident. This identifies the outcrop of a Carboniferous to Cretaceous sequence, variably preserved beneath a horizontal cap of Palaeocene basalt belonging to the Mull Tertiary igneous centre (Figure 8.19).

Included within this sequence is a more-or-less complete Hettangian to mid-Sinemurian Lias Group succession. These Jurassic rocks are most accessible in a series of stream sections which expose the bedrock beneath an extensive scree that otherwise obscures the lower cliff section. These cliffs no longer experience active marine erosion, being protected by the '6 foot' emerged ('raised') beach, a relatively recent effect of post-glacial isostatic re-adjustment. The most complete sections are accessible in stream beds around the shores of Loch Aline itself, particularly on its south-east side. Of these Allt Leacach provides the best exposure, although not all beds can be examined at close quarters without either a top rope or taking unnecessary risks in scaling the lowest waterfall during a period of low runoff. Unlike many south Hebridean Jurassic outcrops, this area is largely unaffected by Tertiary igneous-related thermal metamorphism, excepting only the immediate vicinity of intrusive sills and dykes.

The horizontal beds of the lower Lias Group here span an interval from within the Angulata Zone, at the base, up to the Obtusum Zone immediately beneath the unconformity with overlying Cretaceous sediments. The lithostratigraphical divisions are a lower Blue Lias Formation overlain by the Pabay Shale Formation. The Blue Lias Formation, as elsewhere, comprises an alternating, decimetre-scale, series of argillaceous limestone with silty shale. The Pabay Shale Formation consists predominantly of coarser, heavily bioturbated clastics. Diligent searching has yielded many ammonites that have proven crucial to establishing the biostratigraphy of the succession.

Although Allt Leacach has been designated the principal GCR site for this area, it should not be considered in isolation. Beds higher than those exposed in Allt Leacach are accessible in Allt Mor, 2 km to the south (NM 700 435) and the slight unconformity between the Blue Lias and Pabay Shale formations can be demonstrated only by comparing the relevant sections in adjacent streams. Similarly, bed variation within the Blue Lias Formation becomes apparent only from examination of all of the principal sections

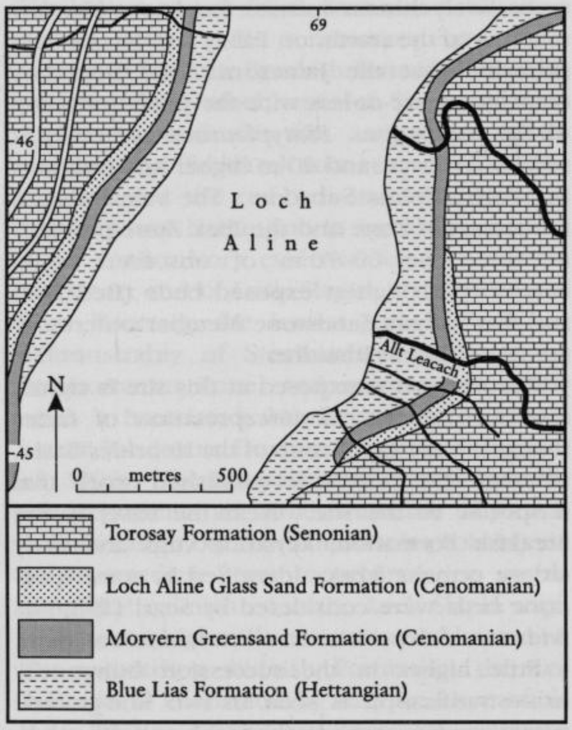



**Figure 8.19** Geological sketch map of Loch Aline and Allt Leacach.

around Loch Aline. This variation involves a breakdown of the regular periodicity in the bedding, and an increase in limonite and coarse bioclastic material towards the north-east, possibly indicating the proximity of a contemporary coastline. As the most complete section in the area of outcrop, it forms a useful reference section, against which the other stream and trackside exposures in the Loch Aline area may be compared. The site was first noted by Judd (1878), with further details of the section recorded by MacLennan (1954). Other references to the site are found in Arkell (1933), Lee and Bailey (1925) and Richey and Thomas (1930), with a summary graphic log included in Copestake and Johnson (1989). More detailed accounts have been published by Oates (1976, 1978) and Hesselbo *et al.* (1998).

## Description

The principal section is that exposed in the degraded cliff line at Allt Leacach (Figure 8.20), the name being a Gaelic allusion to stone slabs. A total of 62 m is exposed in three major waterfalls and the stream beds joining them. The section is more-or-less horizontally bedded and unfaulted. The strata exposed are grouped into two formations, the Blue Lias Formation and the Pabay Shale Formation (Figure 8.21). Nowhere is the base of the Blue Lias Formation seen around Loch Aline. At Allt Leacach *Schlotheimia similis* appears in Bed 5, 2 m above the lowest beds observed in the stream, and is abundant through the next 7 m of strata up to Bed 17. Only a small indeterminate schlotheimiid is recorded below this level, in the lower part of Bed 4. A specimen of *Schreinbachtites* sp. (recorded as *Vermiceras* in Hesselbo *et al.*, 1998) was found at the top of Bed 10. The ratio of shaley mudstone to limestone in this part of the succession increases upwards to a thick mudstone unit well exposed at the base of the lowest waterfall, but both the limestones and mudstones in this lower part of the formation are poorly fossiliferous.

No ammonites have been recovered from an interval of more than 11 m above the last *Schlotheimia*. The first appearance of *Gryphaea arcuata* is in Bed 28. Above this level both limestones and mudstones are significantly more fossiliferous than lower in the succession; crinoid debris is common in the limestones

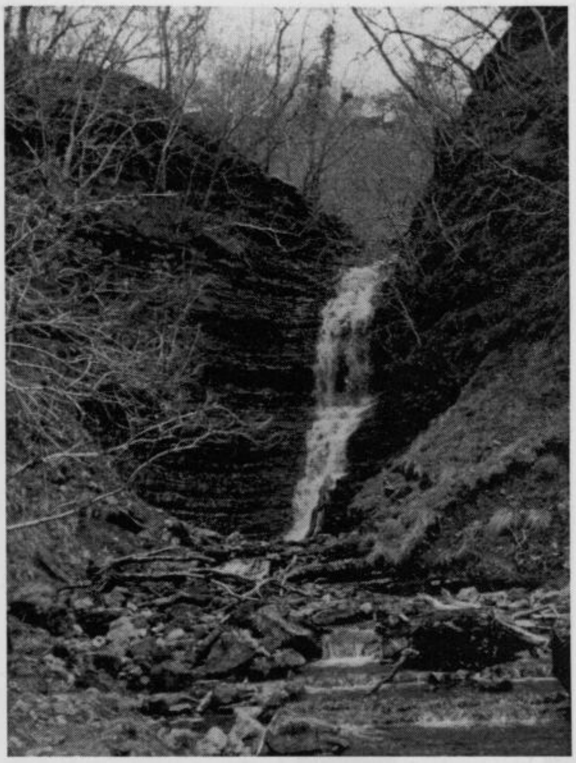


**Figure 8.20** The lower cascade at Allt Leacach, showing typical limestone–mudstone alternations of the Blue Lias Formation. The mudstone-dominated Bed 30 is represented by the conspicuous undercut about halfway up the cascade. (Photo: M.J. Simms.)

while *Gryphaea* is abundant throughout. Foreshore exposures on the opposite, western, shore of Loch Aline were the source of specimens of *Gryphaea* used in MacLennan and Trueman's (1942) study of morphological variation in this species. *Metophioceras conybeari* has been recorded from the base of Bed 37, with *Coroniceras* cf. *rotiforme* in beds 42 and 44, abundant *Coroniceras kridion* in Bed 47, and a single fragment of *Epammonites latisulcatus* from about the middle of Bed 47. *Arnioceras* sp. is present in beds 52 and 53, just below the first appearance of *Oxytoma inaequivalvis*. A thin, lenticular, limonitic bed is present in Bed 40 and is an important marker bed.

The junction of the Blue Lias and Pabay Shale formations is well exposed in the sloping stream bed above the lowest waterfall. The top of the Blue Lias Formation weathers red while *Gryphaea* shells are occasionally truncated at the contact between the two formations. The Pabay Shale Formation comprises a more-or-less

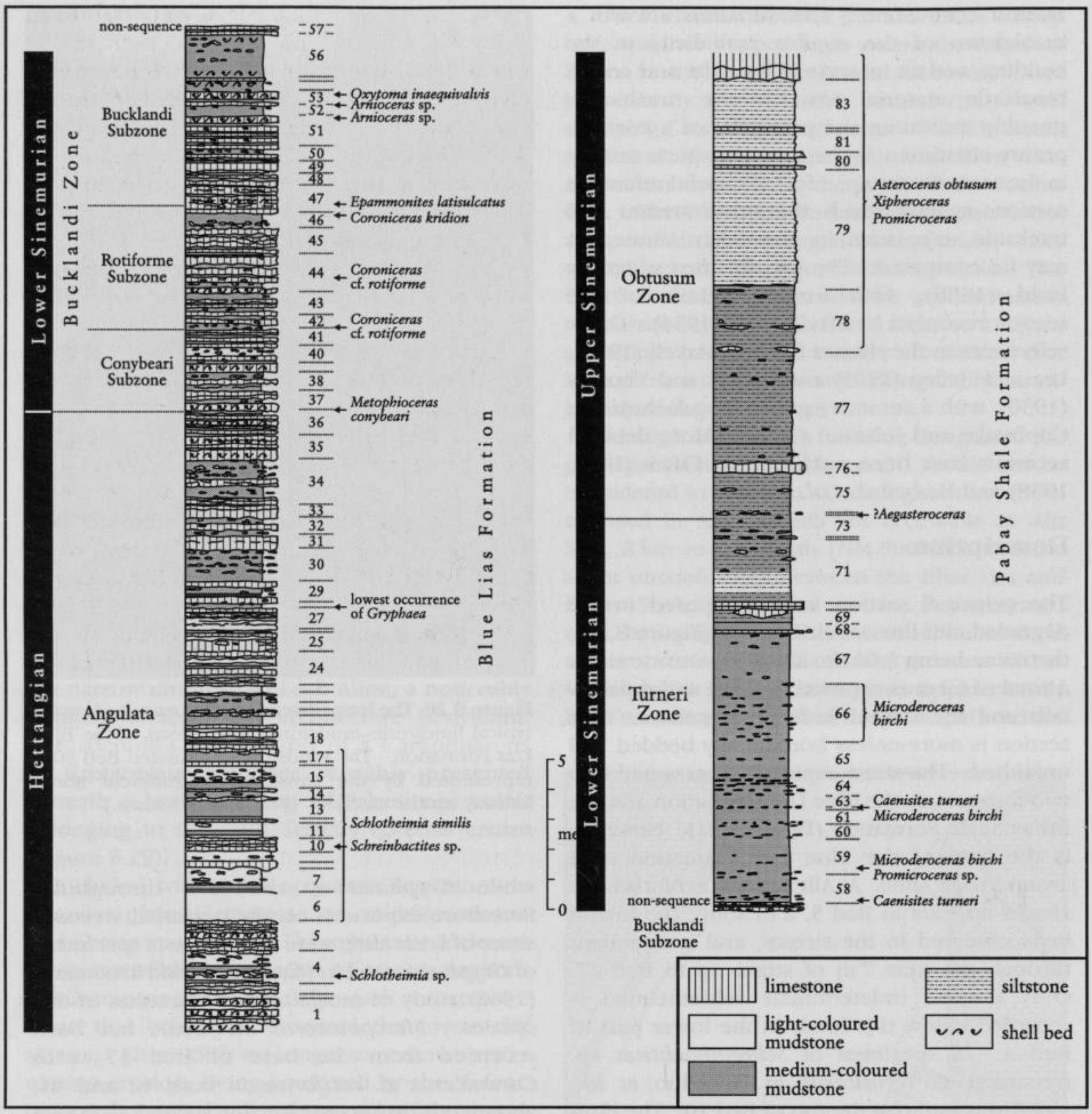



**Figure 8.21** Section through the Blue Lias and Pabay Shale formations exposed in Allt Leacach. After Hesselbo *et al.* (1998).

continuous series of bioturbated silts and sands with occasional nodular beds and thin sandstones. *Caenisites turneri*, *Microderoceras birchi* and *Promicroceras* are abundant in laminated mudstones in the lowest 9 m (beds 58 to 67). The base of the sandy limestone of Bed 68 has a slightly erosional character and is succeeded by further laminated mudstones and thin sandstones that have yielded *Promicroceras*, *Xipheroceras* and *Asteroceras obtusum*. A single *Aegasteroceras* fragment was found in the middle of Bed 72. In Allt Leacach only 28 m of the Pabay Shale Formation is preserved beneath the unconformity at the base of the Cretaceous succession. The somewhat sandy nature of the upper part of the Pabay Shale Formation here led Arkell (1933) to refer to this part of the succession as the 'Loch Aline Sandstone'. This term has never otherwise been adopted; partly because it is somewhat of a misnomer and also because of possible confusion with the Cretaceous silica sand that is mined on the west side of Loch Aline.

## Interpretation

The lowest 9 m of the Blue Lias Formation exposed here clearly lies entirely within the Angulata Zone, with *Schlotheimia similis* suggesting a level (*similis* Biohorizon) low in the Complanata Subzone. Higher levels in this zone remain unproven, although *Schreinbachtites* is typically a late-Angulata Zone genus (Depressa Subzone; see Figure 1.3, Chapter 1). Hesselbo *et al.* (1998) placed the Hettangian–Sinemurian boundary at the level of the first appearance of *Gryphaea arcuata*, although this species is known to extend down into the Angulata Zone. At present the base of the Bucklandi Zone, and Sinemurian Stage, must be drawn at the first appearance of *Metophioceras conybeari*, in Bed 37, indicating the Conybeari Subzone. The base of the succeeding Rotiforme Subzone is placed at the base of Bed 42, marked by the first appearance of *Coroniceras* cf. *rotiforme*, with *Coroniceras kridion* in Bed 47 indicating the *kridion* Biohorizon towards the top of the subzone. The boundary with overlying Bucklandi Subzone is tentatively placed a little higher in Bed 47, indicated by *Epammonites latisulcatus*. The occurrence of *Arnioceras* in beds 52 and 53 is definite evidence for a level above the Rotiforme Subzone, but is not conclusive proof of the Semicostatum Subzone.

There is convincing evidence, both here and in adjacent exposures, for a minor unconformity between the Blue Lias and Pabay Shale formations. The iron-stained top to the Blue Lias Formation and the presence of *Gryphaea* truncated by erosion is the most direct evidence, but it is also suggested by the absence of any definite evidence for the Semicostatum Zone here. However, progressively younger beds within the Blue Lias Formation are found to the south. In the Allt Mor stream section, little more than 2 km to the south, a 1.8 m-thick series of bedded crinoidal limestones not seen in Allt Leacach (Hesselbo *et al.*, 1998) has yielded *Coroniceras lyra* and *Arnioceras falcaries* indicating the basal Semicostatum Zone, Lyra Subzone.

Abundant *Caenisites turneri* and *Microderoceras birchi* in the laminated mudstones above the unconformity suggest that the basal Pabay Shale Formation is no older than the Birchi Subzone of the Turneri Zone, which continues up into the succeeding sandy mudstone. The precise boundary with the succeeding Obtusum Zone is uncertain but is provisionally placed below the occurrence of *Aegasteroceras* in Bed 74. However, *Aegasteroceras* is characteristic of levels relatively high in the Obtusum Zone (upper-Stellare and Denotatus subzones) and so its apparent presence here, below *Asteroceras obtusum*, requires confirmation. The presence of *Asteroceras obtusum*, *Xipheroceras* and *Promicroceras* from beds 78 upwards to the sub-Cretaceous erosion surface suggest that no level higher than the Stellare Subzone is present at this site. However, in nearby Allt Mor a single specimen of *Oxynoticeras oxynotum* 10 m below the sub-Cretaceous unconformity proves the existence of the Oxynotum Zone in the Morvern area.

The development here of the Hettangian and basal Sinemurian in typical Blue Lias Formation facies contrasts with the thick bioclastic limestones of the Breakish Formation developed elsewhere in the Hebrides Basin, such as at the **Ob Lusa to Ardnish Coast** GCR site. By analogy with the **Pant y Slade to Witches Point** GCR site in south Wales, where there is a clear lateral transition from marginal bioclastic limestones to more basinal limestone–mudstone alternations typical of the Blue Lias Formation, the succession in the Morvern area suggests deposition in water slightly deeper than elsewhere in the Hebrides Basin. The preservation, to the south, of progressively younger strata beneath the Pabay Shale Formation unconformity and the transition, north of Loch Aline, from typical Blue Lias Formation to a more marginal facies suggests a tectonic component to controls on deposition in this area, with the sea floor tilted higher to the north than to the south. Currents passing across this erosion surface at the top of the Blue Lias Formation may have encouraged colonization by filter-feading benthos such as crinoids, leading to the accumulation of the crinoid-rich bioclastic limestones of the Semicostatum Zone to the south of Allt Leacach. The abrupt change in facies between the Blue Lias and Pabay Shale formations reflects a eustatic sea-level rise which affected the whole of the Hebrides Basin.

## Conclusions

The exposures in the Allt Leacach Burn are the finest of several in the Morvern area. The limestone–mudstone alternations of the Hettangian and basal Sinemurian part of the succession closely resemble typical Blue Lias Formation farther south in Britain and contrast with the more marginal facies of the Breakish Formation at other GCR sites in the Hebrides Basin. The site shows clear evidence of a minor unconformity between the Blue Lias and succeeding Pabay Shale formations, and of both tectonic and eustatic controls on deposition.