British Upper Jurassic Stratigraphy (Oxfordian to Kimmeridgian)

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Chapter 5

Upper Jurassic stratigraphy in Scotland

INTRODUCTION

J.K. Wright

Outcrops of Oxfordian and Kimmeridgian rocks in Scotland are restricted to two sedimentary basins, the Hebrides Basin in the west and the Inner Moray Firth Basin in the east (Figure 5.1). Both are fault-bounded basins, formed to a large extent by normal movements on fault belts that have complex movement histories, and which are marked by the Minch and the Great Glen Faults respectively. In each basin, one Oxfordian section shows a thick sandy succession, which may be interpreted as near-shore (Elgol in the Hebrides Basin and Brora in the Inner Moray Firth Basin), while a second section in each basin (respectively Staffin and Balintore) shows a more argillaceous and probably deeper-water facies (Figure 5.2).

Due to their occurrence in fault-bounded basins, the various facies of the Oxfordian sediments in Scotland are often in marked contrast to those in England (Chapters 2–4). In the south, Oxfordian sediments were laid down in a wide epicontinental sea dominated on the shelves by shallow-water carbonate and fine-grained clastic sediments. There is little coarse-grained sediment derived from the rapid erosion of nearby substantial landmasses, the Yorkshire Passage Beds and the coarse Beckley Sand around Oxford being exceptions. In contrast,

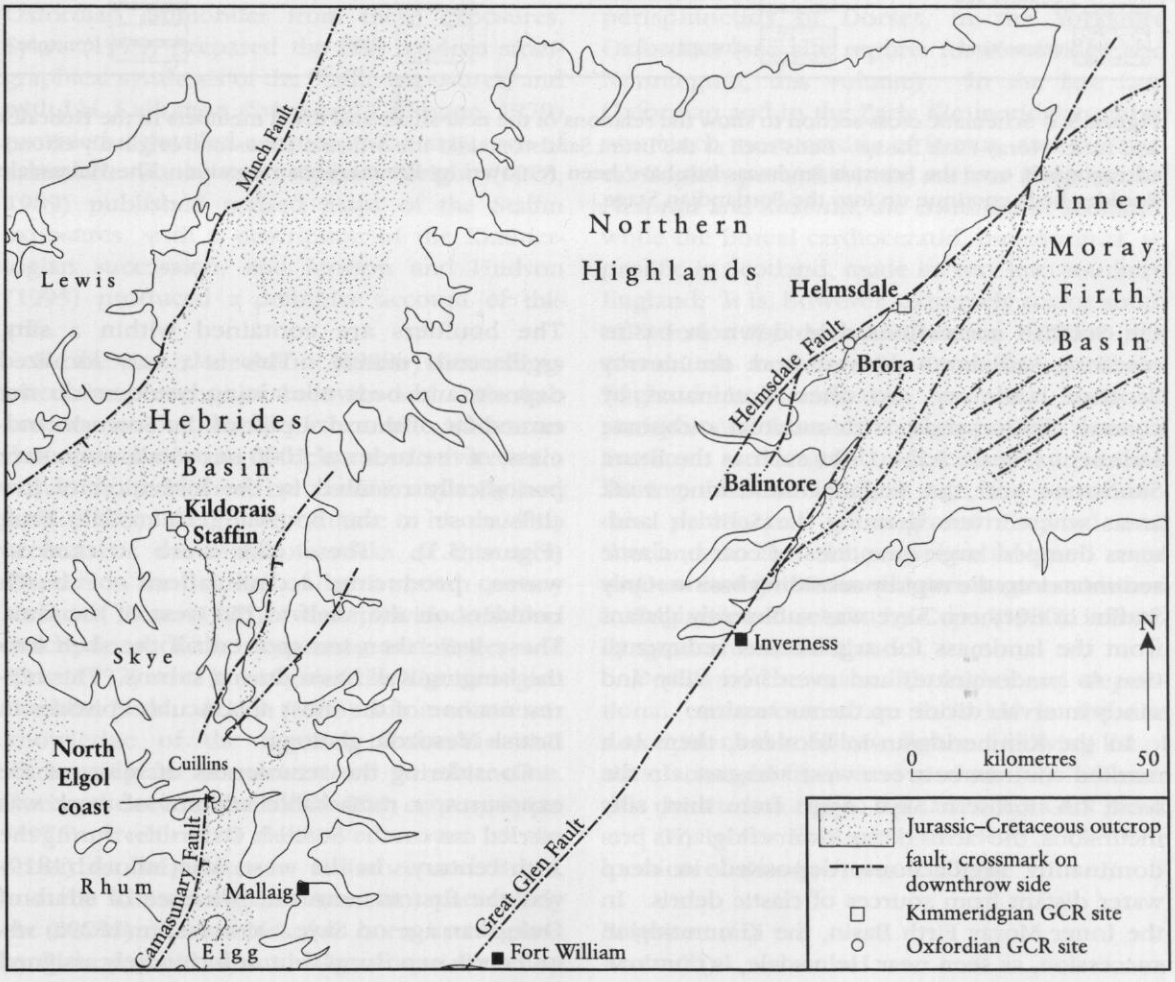

Figure 5.1 Map of northern Scotland, showing the principal Jurassic sedimentary basins and their structural controls, and the locations of Oxfordian and Kimmeridgian GCR sites. Based on BGS 1:1 500 000 Tectonic Map of Britain, Ireland and Adjacent Areas (1996) and BGS 1:1 000 000 Geological Map of the United Kingdom, Ireland and the Adjacent Continental Shelf (1991).

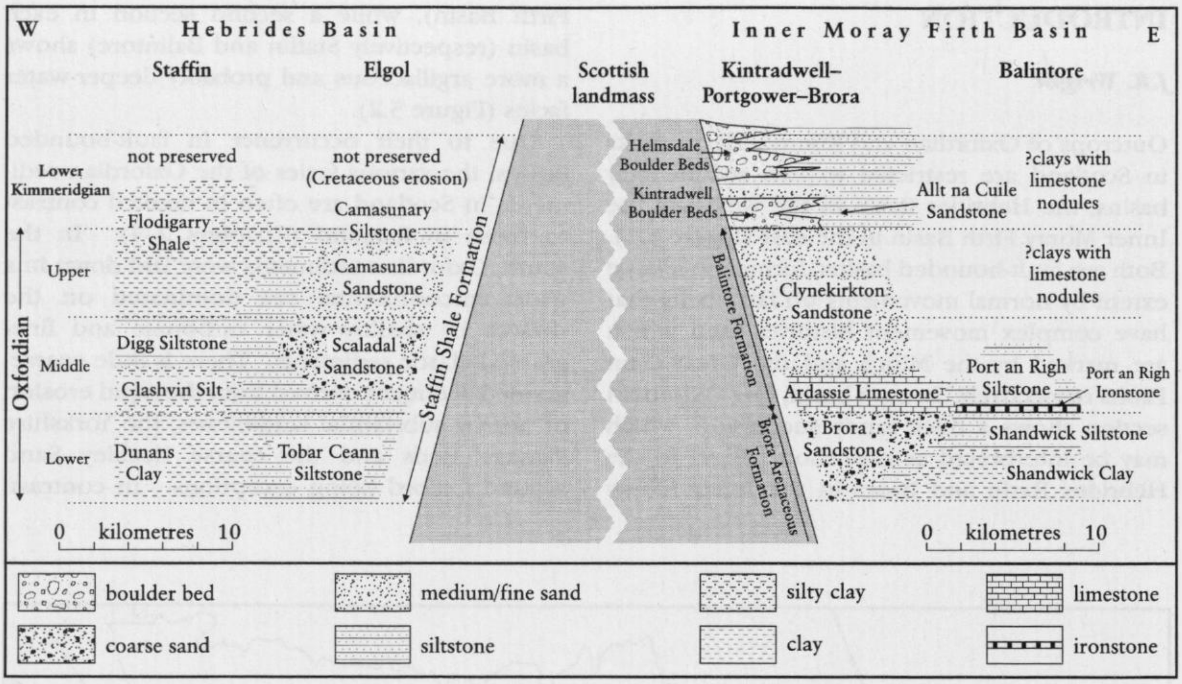

Figure 5.2 Schematic cross-section to show the relations of the near-shore and distal members in the Hebrides and Inner Moray Firth Basins. Beds such as the Brora Sandstone and the Ardassie Limestone originally extended eastwards over the Scottish landmass but have been removed by Kimmeridgian erosion. The Helmsdale Boulder Beds continue up into the Portlandian Stage.

the Scottish successions, laid down in basins receiving sediments derived from the nearby Scottish landmass, are often dominated by coarse, clastic sands, with minimal carbonate sediment (Figure 5.2). Units such as the Brora Sandstone and the Scaladal Sandstone mark areas where rivers draining the Scottish landmass dumped large quantities of coarse, clastic sediment into the rapidly subsiding basins. Only Staffin in northern Skye was sufficiently distant from the landmass for argillaceous sedimentation to predominate, and even here silty and sandy intervals divide up the succession.

In the Kimmeridgian in Scotland, there is a marked contrast between west and east. In the west, on northern Skye, apart from thin, silty incursions, the facies of the Kimmeridgian is predominantly argillaceous, deposited in deep water distant from sources of clastic debris. In the Inner Moray Firth Basin, the Kimmeridgian succession, as seen near Helmsdale, is dominated by the Helmsdale Boulder Beds, which comprise thick accumulations of coarse, bouldery debris derived from the rising Scottish landmass and dumped rapidly into the subsiding basin. The boulders are contained within a silty, argillaceous matrix. This is a very localized deposit, and beds containing boulders do not extend far offshore. Uplift of the Scottish landmass, of the order of 1000 m overall, must have periodically resulted in the formation of low cliffs close to the bounding Helmsdale Fault (Figure 5.1). These cliffs were attacked by waves, producing accumulations of beach boulders on the shelf to the west of the fault. These were then transported off the shelf into the hanging-wall basin during storms. This represents one of the most spectacular episodes in British Mesozoic geology.

Considering the remoteness of many of the exposures, a remarkable amount of work was carried out on the Scottish Oxfordian during the 19th century. In the west, MacCulloch (1819) was the first to note the presence of strata of Oxfordian age on Skye. Murchison (1829a) visited these exposures, but unfortunately assigned the Great Estuarine Series (and the overlying Oxfordian shales) to the Wealden Group. Forbes (1851) corrected this mistake, recording cardioceratids from these shales, which he equated with the Oxford Clay Formation of England. The major account of the Mesozoic rocks of western Scotland by Judd (1878), though interesting from a historical aspect, is of lesser importance in connection with the present account, as the only Oxfordian outcrops Judd visited were those on the Isle of Eigg.

The significant outcrops of Oxfordian strata on southern Skye were first recorded by Wedd (1910) in Peach and Horne's classic memoir. Hudson and Morton (1969) and Turner (1966, 1970) added to this earlier account, but it was Sykes (1975) who provided the definitive description.

MacGregor (1934) produced the first modern account of the Oxfordian rocks at Staffin. Anderson and Dunham (1966) published maps of the foreshore outcrops here, with sections and logs. Turner (1966, 1970) described Lower Oxfordian ammonites from these exposures. Sykes (1975) prepared the first modern stratigraphical synthesis of the Staffin exposures, and with J.H. Callomon (Sykes and Callomon, 1979) provided a detailed account of the sequence of ammonite zones seen there. Wright (1973, 1989) published revised maps of the Staffin exposures, with a description of the Kimmeridgian succession, and Morton and Hudson (1995) produced a definitive account of this area.

In the east, Murchison (1829b) first recognized the presence of Callovian and Oxfordian sections in the Moray Firth area. Numerous descriptions of parts of the succession were subsequently published by various authors, and Judd (1873) listed many of these in his masterly account of the Mesozoic rocks of this area. Workers in the first half of the twentieth century included Lee (1925), who provided further descriptions of the exposures, and Bailey and Weir (1932) who investigated the Kimmeridgian Boulder Beds. Arkell (1933) summarized our knowledge of the Scottish Oxfordian and Kimmeridgian as understood at that time. During the second half of the 20th century, Sykes (1975) produced a definitive account of the Oxfordian sequences at Balintore and Brora, and the Kimmeridgian succession, particularly the Boulder Beds facies, has been investigated by Pickering (1984) and Wignall and Pickering (1993).

Problems of correlation of the Scottish sequences with those of England have been largely resolved in recent years. In the Early Oxfordian, the typical cardioceratid succession of England is precisely represented in Scotland (Turner, 1966). In the Middle Oxfordian, the perisphinctids, upon which Callomon (1960) based the English subzonal succession, are less common, occurring abundantly only at certain horizons. The Scottish Middle Oxfordian is zoned by means of the Boreal cardioceratids, and as it has been possible to extend this Boreal zonation into England (Sykes and Callomon, 1979; Wright, 1997) the correlation with the perisphinctid-dominated sequences is reasonably well established.

In the lower part of the Scottish Upper Oxfordian, the perisphinctids of England, typified by those of the Dorset Clavellata Formation, are largely absent, but correlation is established by the common occurrence of the Boreal *Amoeboceras* of Scotland, and of the Sub-Boreal perisphinctids of Dorset, in the Yorkshire Oxfordian (see site reports for Newbridge and Nunnington, this volume). In the late Late Oxfordian and in the Early Kimmeridgian, there was much more mixing of faunas, and the typical English perisphinctids, such as *Ringsteadia*, *Pictonia* and *Rasenia*, are common in Scotland, while the Boreal cardioceratid *Amoeboceras*, so prolific in Scotland, made its way into southern England. It is, however, extremely scarce south of Swindon (Sykes and Callomon, 1979) so that correlation between Scotland and southern England is undertaken on the basis of perisphinctid faunas. Though prolific, those of Scotland are largely undescribed at present. During the Kimmeridgian Age, the perisphinctids proliferated throughout England and Scotland, so that the perisphinctid-based zonal sequence of the Kimmeridgian Stage established in England, and set out by Cope (1980), is readily applicable in Scotland.

Details of the main lithologies and depositional environments are included in the site descriptions that follow. In the following list of sites, arranged from east to west, (O) indicates that the site belongs to the Oxfordian GCR Block and (K) to the Kimmeridgian GCR Block. The location of sites is shown in Figure 5.1.

Balintore (O)
Brora (O)
Helmsdale (K)
Staffin (O)
Kildorais (K)
North Elgol Coast (O)

BALINTORE (NH 854 734 AND NH 851 727)

POTENTIAL GCR SITE

J.K. Wright

Introduction

The Balintore GCR site comprises two shore exposures of Oxfordian rocks that can be seen only at low water; these are at Port-an-Righ (NH 854 734) and adjacent Cadh'-an-Righ (NH 851 727), 3.2 km south of Balintore (Figure 5.3). At Cadh'-an-Righ there is a complete section from the Bathonian Great Estuarine Series to the Middle Oxfordian dipping east at 70°. At Port-an-Righ, approximately 500 m further north, a more gently dipping section shows Lower and Middle Oxfordian rocks. The exposures abut immediately onto the south-eastern side of the Great Glen Fault. This is clearly visible in the foreshore approximately 2.5 km south-west of the village of Balintore and brings Callovian and

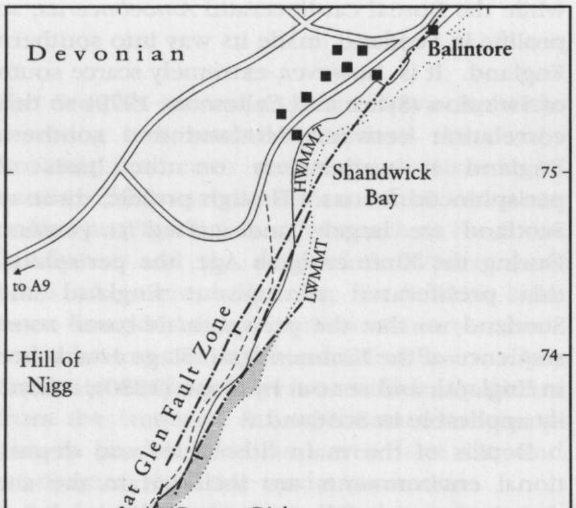

Figure 5.3 Locality map of the Balintore GCR site. Geological information from BGS Sheet 94 (Cromarty) (1973).

Oxfordian strata into contact with the Devonian Old Red Sandstone.

It was Sir Roderick Murchison (1829b) who first described the site. He noted that the ledges eroding from the alternating harder and softer bands gave the appearance of seats at an ancient theatre. The foundation for modern work was laid by Judd (1873), and the area was subsequently studied by the Geological Survey (Lee, 1925). Buckman (1923–1925, p.47) and Arkell (1933) commented on the ammonite fauna. Sykes' (1975) revision of Oxfordian stratigraphy in Scotland emphasized the full significance of this site. Sykes and Callomon (1979) further revised the zonal stratigraphy of the Balintore section, and defined the base of the Middle Oxfordian Maltonense Subzone at this site.

Description

Balintore exposes a fine section through 53 m of Lower and Middle Oxfordian rocks that range from the basal Mariae to middle Tenuiserratum zones. The following section is revised from Sykes (1975) taking into account information from Sykes and Callomon (1979).

Thickness (m)

Balintore Formation

Port-an-Righ Siltstone Member, Tenuiserratum Subzone

6. Fine-grained, argillaceous sandstone forming a prominent feature at low water mark — seen to 5.7
5. Coarse, dark, bituminous siltstone, rhythmically bedded in 0.1–1.8 m units, each coarsening upwards from silt to fine, argillaceous sandstone. An abundant, limited bivalve fauna of *Cucullaea* sp. and *Oxytoma* sp. is present at certain horizons. Ammonites are rare, including *Perisphinctes* spp., *Cardioceras (Maltoniceras) highworthensis* Arkell, *C. (Subvertebriceras) zenaidae* Ilovaisky and *C. (Miticardioceras) tenuiserratum* (Oppel) — 16.0

Port-an-Righ Ironstone Member, Maltonense Subzone

4b. Sandy clay with a prominent, red-weathering, nodular ironstone at the top containing *C. (Maltoniceras) schellwieni* Boden, *C. (M.) maltonense* (Young and Bird), *C. (M.) vagum* Ilovaisky, *C. (Cawtoniceras) cawtonense* (Blake and Hudleston), *C. (Subvertebriceras) zenaidae* Ilovaisky, *Perisphinctes (Dichotomosphinctes)* cf. *antecedens* Salfeld and *P. (Arisphinctes) vorda* Arkell 0.50

Vertebrale Subzone

4a. Sandy clays with several bands of red-weathering, nodular, chamosite–siderite ironstone nodules. *Cucullaea* sp. is common, with *Modiolus* sp. and *Gryphaea dilatata* J. Sowerby. Ammonites are common, including *Perisphinctes (Arisphinctes) helenae* de Riaz, *C. (Scoticardioceras) excavatum* (J. Sowerby), *C. (Subvertebriceras) densiplicatum* Boden, *C. (S.) zenaidae* and *Goliathiceras (Goliathites) capax* (Young and Bird) 1.7

Brora Arenaceous Formation

Shandwick Siltstone Member*, *Cordatum Subzone

3b. Alternations of more and less calcareous siltstones with *Cardioceras* spp. 2.4

Costicardia Subzone

3a. Alternations of more and less calcareous siltstones with a basal sandy siltstone. *Pinna* sp. and *Pleuromya* sp. are the most common bivalves, with *Cardioceras* sp. 9.7

Brora Argillaceous Formation

Shandwick Clay Member (pars)*, *Costicardia Subzone

2b. Bioturbated sandy silts with *Cardioceras (Cardioceras) costicardia* S. Buckman, *C. (Vertebriceras) quadrarium* S. Buckman and *C. (V.)* cf. *altumeratum* Arkell 1.5

Bukowskii Subzone

2a. Bioturbated sandy silts with *Cardioceras* spp. 2.6

1b. Grey-green clay with bands of carbonaceous debris and *C. (Scarburgiceras) bukowskii* Maire approx. 8.0

Mariae Zone

1a. Grey-green clays with pyritic burrow infillings and bands of carbonaceous debris. The bivalves are represented only by *Nuculoma* sp., but ammonites are sporadic, including *Cardioceras (Scarburgiceras) scarburgense* (Young and Bird) approx. 5.0

(continuation of Callovian Shandwick Clay)

The Port-an-Righ section is the type section for each of the four members listed above (Sykes, 1975). Ammonites and bivalves make up the bulk of the fauna at Balintore. Of the seven subzones represented here, three subzonal index ammonites have been recorded by Sykes. A stratigraphical log of the section is given in Figure 5.4.

Interpretation

The base of the Oxfordian sequence at Balintore lies within the Shandwick Clay, whose grey-green clays and bioturbated silts with carbonaceous horizons contrast strongly with the equivalent sandier accumulations at Brora (see GCR site report for Brora, this volume). The striking chamositic sands with bands of red-weathering chamosite–siderite nodules of the Port-an-Righ Ironstone represent a lithofacies unique to eastern Scotland. They have their closest comparisons in the diminutive outcrop of Oxfordian strata adjacent to the Great Glen Fault at nearby Bow Buoy Skerry, Eathie, where there occurs a condensed facies with *Rhaxella* spicules (Phemister, 1936). The nodular texture is possibly due to the diagenesis of *Thalassinoides* burrows (Sykes, 1975).

The Port-an-Righ Ironstone and the overlying Port-an-Righ Siltstone were deposited during a marine transgression in the Inner Moray Firth Basin. This transgression was contemporaneous with a regression and the deposition of quartz sand in the Hebrides Basin (Sykes, 1975). The

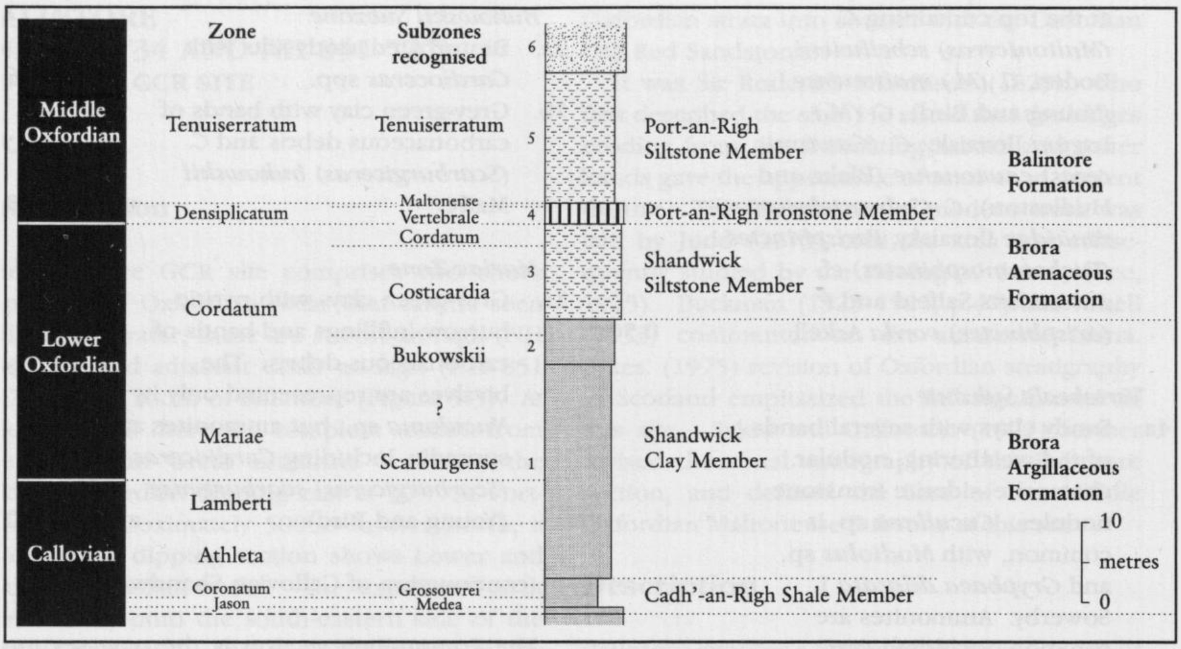

Figure 5.4 Stratigraphical log of the Balintore section (after Sykes, 1975, fig. 4).

tectonic settings that controlled sedimentation in the two basins were thus quite different. A further stratigraphical interest of the Oxfordian sequence at Balintore lies in a comparison with the equivalent succession to the north-east at Brora, which displays coarser-grained rocks (Figure 5.2). The relationship of the Balintore and Brora localities to the Great Glen Fault is also of interest (see site report for Brora, this volume).

One of the most important aspects of the palaeontology is the well-preserved ammonite fauna of the Port-an-Righ Ironstone. Bed 4a yields a good Vertebrale Subzone fauna; a typical *Cardioceras* is illustrated in Figure 5.5. The occurrence of several species of *Maltoniceras* in Bed 4b indicates the Maltonense Subzone. However, this subzone is only thinly developed, the appearance of *Cardioceras (M.) tenuiserratum* (Tenuiserratum Subzone) in the overlying Port-an-Righ Siltstone demonstrating the condensed nature of the Port-an-Righ Ironstone. Its 2.2 m thickness includes both the Vertebrale Subzone and the Maltonense Subzone. This is the only known locality in the United Kingdom where the transition from the Vertebrale Subzone into the Maltonense Subzone can be seen in a continuously fossiliferous succession. Sykes and Callomon (1979) therefore defined the base of the Maltonense Subzone at this locality beneath Bed 4b. The substantial perisphinctid fauna of the Port-an-Righ Ironstone and of the overlying Siltstone is one of the northernmost appearances of such Tethyan ammonites and enables correlation of the Boreal and Sub-Boreal zonal schemes. Ammonites in the Shandwick Clay Member indicate the Scarburgense, ?Praecordatum, Bukowskii and Costicardia subzones of the Mariae and Cordatum Zones.

Upper Oxfordian beds are not known *in situ* at Balintore, but must be present just offshore (Sykes, 1975). Limestone nodules found on the beach here yield *Perisphinctes (Dichotomoceras) dichotomus* S. Buckman and *Amoeboceras* aff. *serratum* (J. Sowerby), of Serratum Zone age. This suggests that the Upper Oxfordian is present in an argillaceous facies with limestone nodules very similar in facies to that of the equivalent Flodigarry Shales at Staffin (see site report for Staffin, this volume).

The bivalves occurring in these silts and clays provide an excellent example of soft sediment infauna with the individuals often found in life position. *Pinna* and *Pleuromya* occur thus in the Shandwick Siltstone, while surface-dwelling forms dominate in the Port-an-Righ Ironstone and Siltstone members. In the clays, faunal

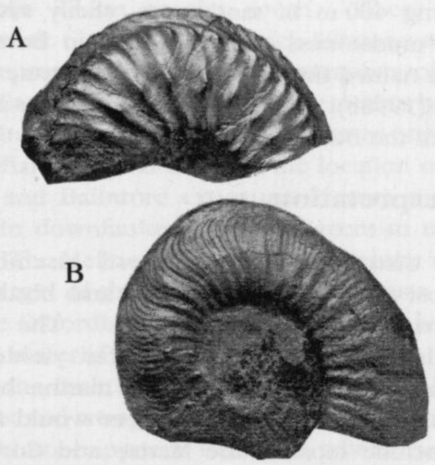

Figure 5.5 Ammonites from the Balintore Formation of eastern Scotland. (A) *Cardioceras (Subvertebriceras) densiplicatum* Boden. Bed 4, Port-an-Righ Ironstone Member, Balintore, ES3, ×1. (B) *C. (Plasmatoceras) tenuicostatum* Nikitin. Ardassie Limestone, Brora, ES2, ×1. (Photos: K. D'Souza. Specimens in the J.K. Wright Collection.)

diversity is low, and only *Nuculoma* and *Pleuromya* are at all common.

Conclusions

These two separate foreshore outcrops constitute the most important locality in eastern Scotland for correlation of Oxfordian strata. They contain the stratotype locality for four members of the Moray Firth Oxfordian sequence, and the type section of the base of the Boreal Middle Oxfordian Maltonense Subzone. They contain the only exposures in eastern Scotland yielding good ammonite faunas in offshore marine facies (see Figure 5.8). This is a key exposure for understanding sedimentation in the Late Jurassic Epoch in the Moray Firth Basin.

BRORA (NC 914 040)

J.K. Wright

Introduction

The site comprises gently dipping foreshore exposures of Middle Oxfordian strata that form Ardassie Point, east of Brora (Figure 5.6), and which constitute part of the most northerly onshore outcrop of Oxfordian strata in north-west Europe. In addition, outcrops of Lower and Middle Oxfordian sandstones and siltstones on both sides of the River Brora lie only a few hundred metres to the east of the Helmsdale Fault system, and some 500 m east of the centre of Brora itself.

In 1826, Murchison (1829b) visited and briefly described the area, although the foundations for modern geological work were laid by Judd (1873). The Middle and Upper Jurassic rocks of the Brora district were later studied by the Geological Survey (Lee, 1925), with detailed comments on the ammonite fauna by Buckman (1923–1925, pp. 48–50) and Arkell (1933). Sykes (1975) undertook a detailed description of the section during his revision of Oxfordian stratigraphy in northern Scotland.

Description

The following is taken from Sykes' (1975) description of the exposures seen in the banks of the River Brora west of the A9 road bridge and at Ardassie Point:

Balintore Formation
Ardassie Limestone Member,
Vertebrale Subzone

2. Fossiliferous, muddy, carbonaceous sandstone alternating with

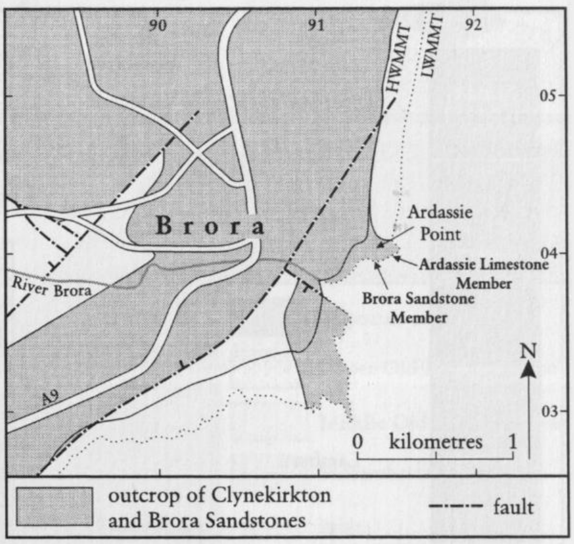

Figure 5.6 Locality map of the Brora GCR site. Geological information from BGS Sheet 103E (Helmsdale) (1998).

carbonate-rich beds 0.3–1.1 m thick — seen to 12 m

Brora Arenaceous Formation
Brora Sandstone Member,
?Mariae and Cordatum Zones

1. Fine-grained, friable sandstone with occasional lenticular quartz conglomerates. Large-scale cross-bedding and trough cross-bedding is present. The fauna is poor; only *Gryphaea dilatata* J. Sowerby is recorded — greater than 30 m

The major part of the Brora Sandstone is exposed in the banks of the River Brora. The member can be followed continuously from its base 540 m west of the bridge to a fault 140 m east of the bridge (Sykes, 1975). There is then an unknown stratigraphical gap before the highest beds are seen south of Ardassie Point. This locality contains the type section of the overlying Ardassie Limestone Member. The 12 m section of these beds is visible as several ledges running out to sea at low tide. The limestones are more accurately described as slightly sandy *Rhaxella* spiculites with the opaline sponge spicules replaced by calcite (Sykes, 1975). A stratigraphical log of the section is given in Figure 5.7. Higher, Middle and Upper Oxfordian beds, comprising 400 m of sandstones, shelly siltstones and mudstones, and seen only in boreholes, were named the Clynekirkton Sandstone by the BGS (1998b). This unit is treated here as a member of the Balintore Formation.

Interpretation

The distribution of the fossil assemblages, almost exclusively ammonites and bivalves, is overridingly facies-controlled. The Brora Sandstone Member has so far yielded no ammonites, although casts of marine bivalves occur throughout. The member would appear to include most of the Mariae and Cordatum Zones. By contrast with this sparse fauna, a rich ammonite and bivalve fauna is found in the Ardassie Limestone. The bivalves are dominated by *Cucullaea* sp. accompanied by large *Gryphaea dilatata* and *Pinna lanceolata* J. Sowerby in life position. The ammonite fauna includes *Cardioceras (Subvertebriceras) densiplicatum* Boden, *C. (S.) sowerbyi* Arkell, *C. (Scoticardioceras) excavatum* (J. Sowerby), *C. (Plasmatoceras) tenuicostatum* Nikitin (illustrated in Figure 5.5) and *Perisphinctes* sp., a fauna indicating the Vertebrale subzone (tenuistriatum horizon of Sykes and Callomon, 1979) (Densiplicatum Zone).

Lithologically, these deposits contrast with the clays and siltstones of similar age found at

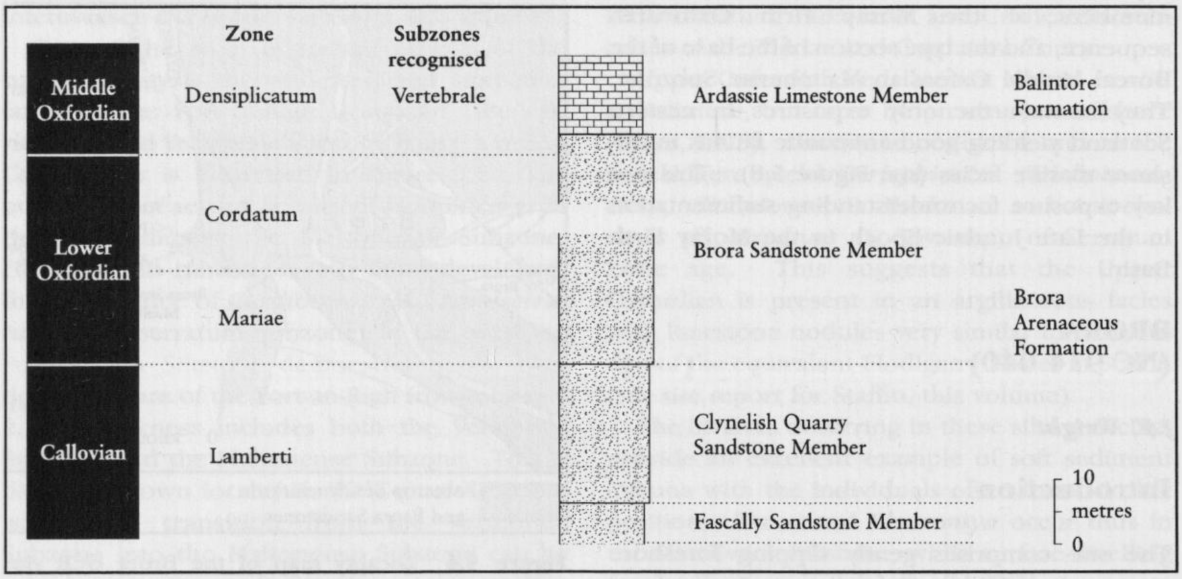

Figure 5.7 Stratigraphical log of the Brora section (after Sykes, 1975, fig. 3).

Balintore 28 km to the south. There, the Shandwick Clay and Shandwick Siltstone members represent the lateral counterparts of the Brora Sandstone at Brora, and were clearly laid down in a more offshore, deeper-water environment than that at Brora. Yet the location of the Brora and Balintore exposures is very similar, being in downfaulted blocks adjacent to major faults. The Helmsdale Fault controlled the western margin of the Inner Moray Firth Basin during the Oxfordian Age (Figure 5.1), with coarse clastic material being brought from the west across the fault and deposited at Brora in large foresets and troughs at the margin of the basin. This did not happen at Balintore, where the sediments adjacent to the Great Glen Fault typify those laid down in an area well removed from clastic input. Holgate (1969) proposed a solution to this dilemma involving 29 km of post-Jurassic dextral strike-slip movement on the Great Glen Fault. By this means, the Balintore Section was situated some 15 km offshore from Brora in the Oxfordian, well out into the Inner Moray Firth Basin (Figure 5.8). The post-Jurassic movements then brought the Balintore section close to the high ground of the Hill of Nigg.

The possibility of such strike-slip movement along the Great Glen Fault has been investigated by a number of authors in recent years, and the maximum amount of movement that seems possible is 8 km. The evidence is summarized by McQuillan *et al.* (1982). It is more likely, according to these authors, that during the Jurassic extension that produced the Moray Firth basins, and which was permitted by 8 km of dextral strike-slip movement along the Great Glen Fault, the western margin of the Moray Firth Basin moved westwards to the Helmsdale Fault. During the Oxfordian Age, deeper-water sediments were laid down on both sides of the Great Glen Fault in the area now occupied by Balintore, and the present pattern of a hilly area adjacent to the fine-grained Oxfordian sediments was produced by normal faulting in late Tertiary times. Such considerations apply only for the Lower Oxfordian, for coarse-grained clastic sediments are absent from both Brora and Balintore in the Middle Oxfordian, with the

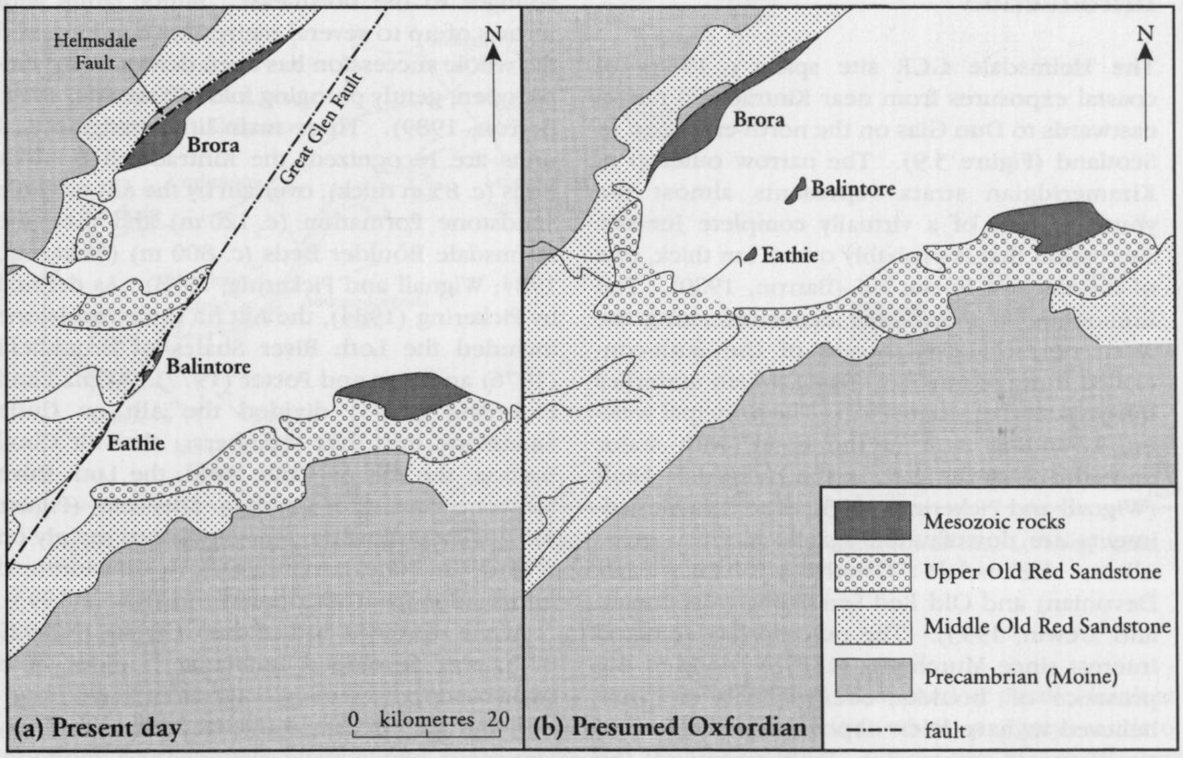

Figure 5.8 Diagram showing possible post-Jurassic movement on the Great Glen Fault (after Sykes, 1975, fig. 2).

Ardassie Limestone being the approximate equivalent of the Port-an-Righ Ironstone.

Conclusions

This is a key locality for studies of the biostratigraphy and palaeogeography of the region adjacent to the Scottish landmass and on the edge of the Inner Moray Firth Basin. The site exposes one of the type sections of the Brora Sandstone Member (Mariae and Cordatum Zones), and the type section of the Ardassie Limestone Member (Vertebrale Subzone), a carbonate facies unique to this part of Scotland. The ammonite assemblage is confined to the Ardassie Limestone and includes Boreal cardioceratids and one of the most northerly occurrences of Tethyan perisphinctids.

HELMSDALE (NC 929 077, NC 937 089–NC 948 095, NC 952 099–NC 973 103, NC 982 114–ND 023 147, ND 031 152–ND 058 172)

B.M. Cox

Introduction

The Helmsdale GCR site spans *c.* 17 km of coastal exposures from near Kintradwell north-eastwards to Dun Glas on the north-east coast of Scotland (Figure 5.9). The narrow outcrop of Kimmeridgian strata represents almost the youngest part of a virtually complete Jurassic succession that is probably over 2 km thick, one of the thickest in the UK (Barron, 1989). The Kimmeridgian strata were deposited along the westernmost active margin of the fault-controlled Inner Moray Firth Basin, which underlies the present-day Moray Firth. The principal western bounding fault of the basin, with major downthrow to the east, is the Helmsdale Fault (Wignall and Pickering, 1993). The Jurassic sediments are downfaulted against Moinian granulites, Helmsdale Granite (Silurian–Early Devonian) and Old Red Sandstone (Macdonald and Trewin, 1993). The outcrop has attracted interest since Murchison (1829b) reported the presence of 'boulder beds', which are now believed to have been deposited at the foot of the Jurassic submarine fault scarp of the Helmsdale Fault. Other early investigators include Cunningham (1841), Miller (1854), Ramsay (1865), Judd (1873) and, later, Blake (1902b), Seward (1911), Seward and Bancroft (1913), Woodward (in Seward, 1911), MacGregor (1916), Norton (1917), Lee (in Read *et al.*, 1925), Bailey *et al.* (1928) and Bailey and Weir (1932). Discovery of oil in the North Sea Basin, where many of the oilfields occur in similar structural settings, and, in particular, the proximity of the Beatrice Oilfield, led to a resurgence of interest in the Helmsdale outcrop, and during the past 25 years there has been a further spate of publications, including a review by Neves and Selley (1975), and papers by Brookfield (1976), Lam and Porter (1977), Riley (1980), Pickering (1984), van der Burgh and van Konijnenburg-van Cittert (1984), Hurst (1985), van de Burgh (1987), Barron (1989), Roberts (1989), Tyson (1989), Trewin (1990), Wignall and Pickering (1993), and a field guide by Macdonald and Trewin (1993).

Description

The Kimmeridgian outcrop, up to a kilometre wide, displays a complex array of boulder beds interdigitating with dark mudstones, siltstones and sandstones, which generally become younger to the north-east. Minor faults with throws of up to several metres are common and the whole succession has been deformed by simple open, gently plunging folds (Pickering, 1984; Barron, 1989). Three main lithostratigraphical units are recognized, the Kintradwell Boulder Beds (*c.* 85 m thick), overlain by the Allt na Cuile Sandstone Formation (*c.* 120 m) and then the Helmsdale Boulder Beds (*c.* 800 m) (Pickering, 1984; Wignall and Pickering, 1993). As defined by Pickering (1984), the Allt na Cuile Sandstone included the Loth River Shales of Brookfield (1976) and Lam and Porter (1977). Wignall and Pickering (1993) divided the Allt na Cuile Sandstone into four members: the Allt Choll Breccia, the Allt na Cuile Sand, the Loth Burn Siltstone and the Lothbeg Siltstone (Figure 5.10). The following notes are based mainly on Wignall and Pickering (1993), with additional information from Macdonald and Trewin (1993).

At the southern end of the GCR site (NC 929 077), well-developed lenticular boulder beds (matrix-supported conglomerate) of the Kintradwell Boulder Beds are interbedded with finely laminated, highly fissile siltstones and thin sandstones. Many compaction features occur around the large boulders (Figure 5.11) and synsedi-

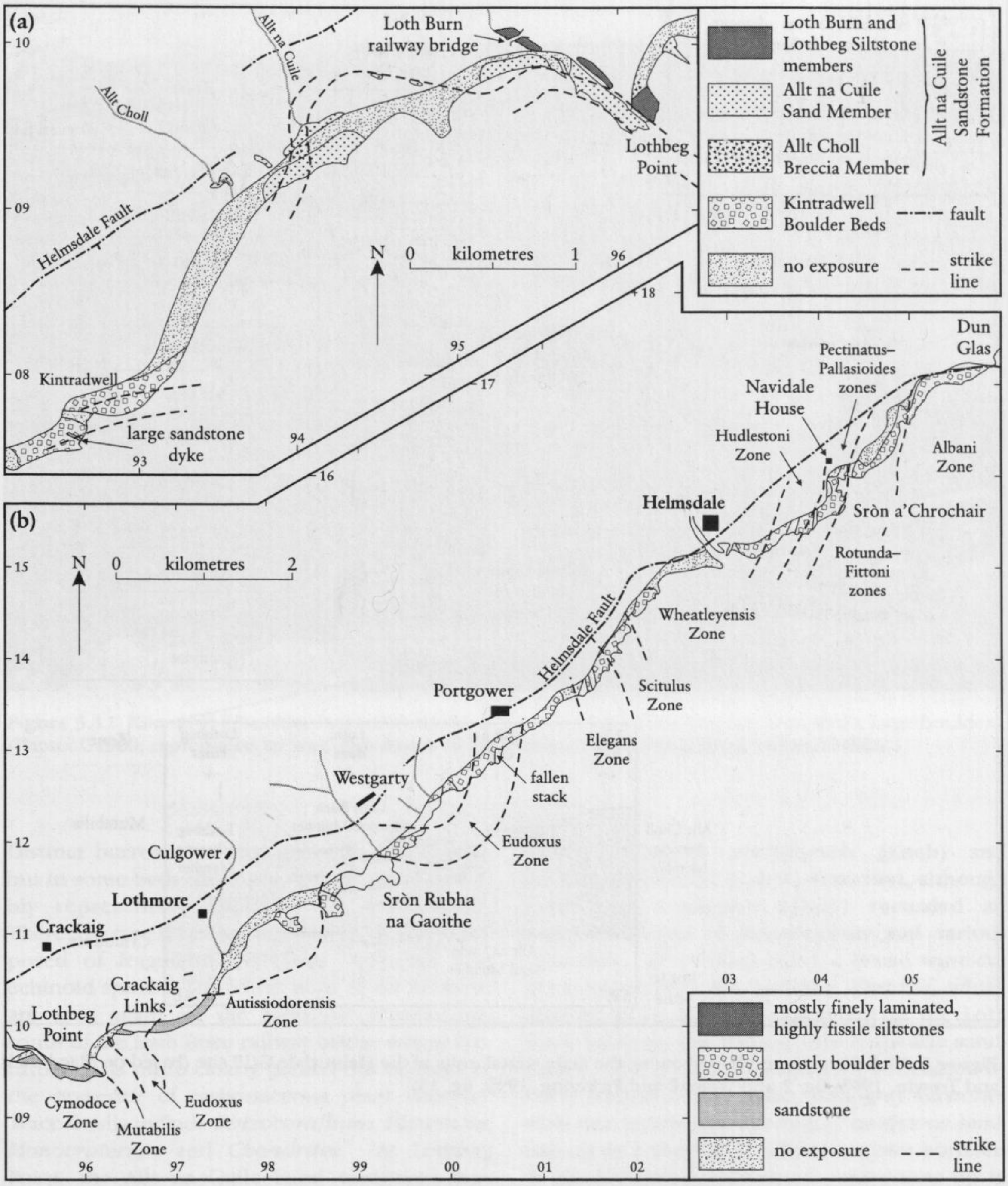

Figure 5.9 Sketch map of the mainly Kimmeridgian outcrop between (a) Kintradwell and Lothbeg Point, and (b) Lothbeg Point and Dun Glas (after Wignall and Pickering, 1993, figs 10 and 17).

mentary deformation features are common in the interbedded strata, notably abundant small-scale, closely spaced faults, low-angle or bedding-parallel shears, clastic dykes, sediment slides and slide folds. The boulders are angular to rounded and composed of parallel laminated and cross-bedded white or grey sandstone (quartz arenite). A large (up to 7 m diameter) boulder of bedded sandstone is prominent on the shore. Wignall and Pickering (1993) report-

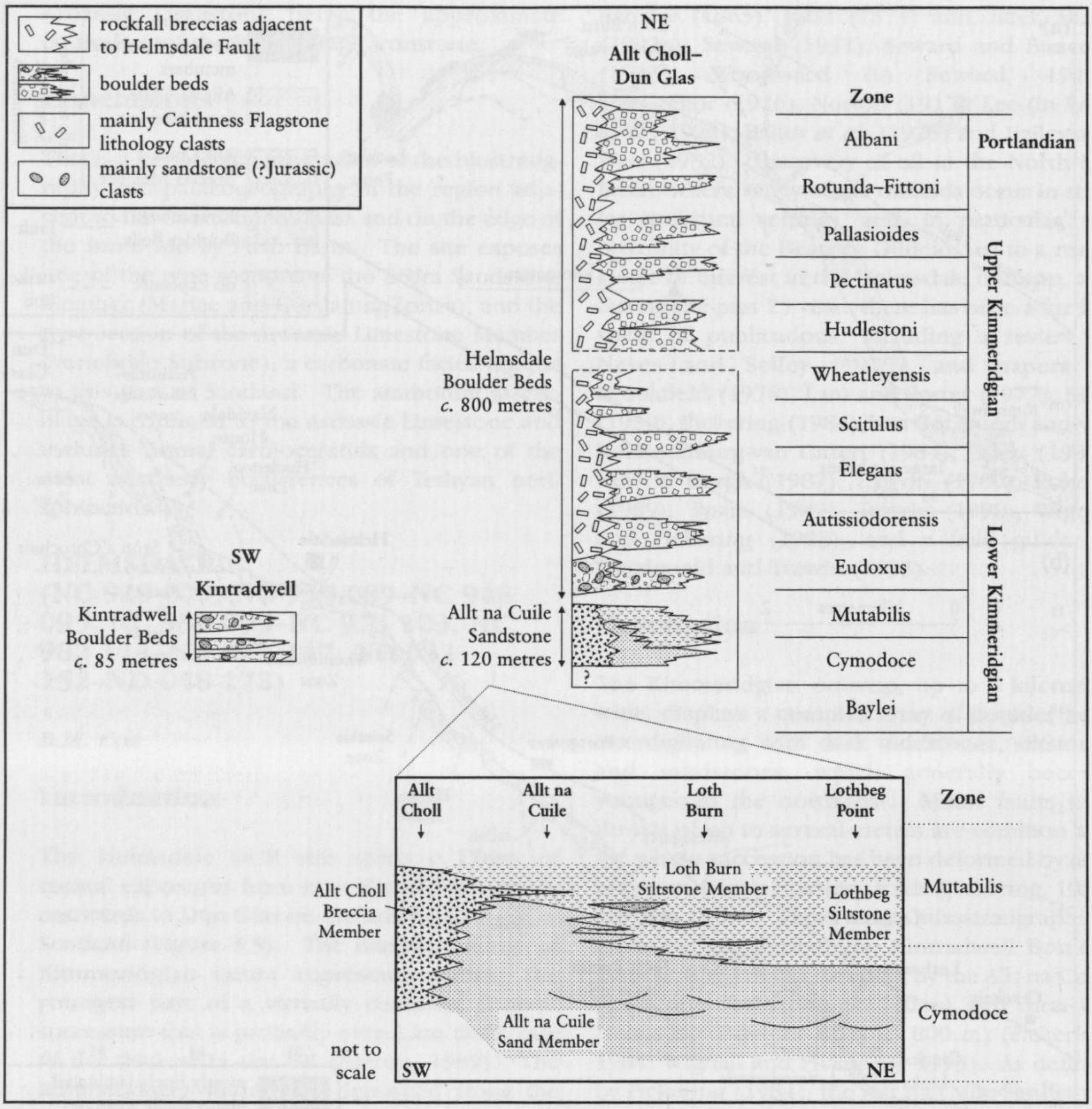

Figure 5.10 Schematic sections showing the main stratal units of the Helmsdale GCR site (based on Macdonald and Trewin, 1993, fig. 2 and Wignall and Pickering, 1993, fig. 15).

ed the ammonite *Amoeboceras subkitchini* Spath common in the siltstones and, at the southern end of the section, *Rasenia evoluta* Spath and *Amoeboceras kitchini* Salfeld.

Between the southern end of the GCR site and Lothbeg Point (NC 960 096), there is a series of disconnected foreshore exposures including the type and only section of the Allt na Cuile Sandstone Formation. At Allt Choll, the Allt Choll Breccia Member comprises 25 m of very coarse breccia in an unconsolidated, fine-grained quartz sand matrix. The clasts range up to several metres in diameter and consist of poorly lithified quartz arenites. Locally, the breccia is interbedded on a *c*. 3 m scale with sandstones of the Allt na Cuile Sand Member, and it dies out eastwards over a distance of *c*. 500 m. Foreshore exposures of the Allt na Cuile Sand at Allt na Cuile show planar-laminated sands alternating with intensely burrowed horizons.

Figure 5.11 Kintradwell Boulder Beds at Kintradwell showing compaction features around the large boulders. (Photo: C1980, reproduced by kind permission of the Director, British Geological Survey ©NERC.)

Distinct burrows are not generally discernable but in some beds there is a vertical fabric probably representing *Skolithos* or *Arenicolites*. There are rare discrete shelly beds, mostly composed of fragmented bivalves, serpulids and echinoid spines. The lower beds of the member are seen again on the foreshore immediately south of the Loth Burn railway bridge where bioturbation is more clearly picked out because of the presence of carbonaceous plant material. Trace fossils include *Rhizocorallium*, *Planolites*, *Monocraterion* and *Chondrites*. At Lothbeg Point, the Allt na Cuile Sand comprises burrowed, clean sandstones with rare, thin, dark siltstones. These pass upwards into more structureless, thick-bedded sandstones with erosional-based sands and sand packets. The overlying Loth Burn Siltstone, comprising a series of lenticular sandstones less than 2 m thick interbedded with finely laminated, highly fissile siltstones, is seen in the banks of the Loth Burn on either side of the railway bridge. The fauna is mainly restricted to isolated nests of the bivalves *Liostrea multiformis* (Koch) and *Buchia concentrica* (J. de C. Sowerby), although Arkell and Callomon (1963) recorded an ammonite fauna of *Amoeboceras* and various 'raseniids'. At Lothbeg Point, a broad wave-cut platform exposes the Lothbeg Siltstone, which appears to be a lateral equivalent of the Loth Burn Siltstone but without the lenticular sandstones. The 30 m thick section is dominated by finely laminated and fissile, dark-grey siltstones with rare interbedded pale-grey mudstone laminae up to 2 mm thick. There are two horizons of giant carbonate-cemented concretions up to 0.4 m thick and 2 m in diameter, and a 3 m thick interval of sand and silt interbedded on a centimetre to millimetre scale (the 'tiger-stripe' facies), which shows wet-sediment deformation structures such as slump folds and small-scale synsedimentary faults. The ammonites *Amoeboceras kitchini* and *Rasenia lepidula* (Oppel) occur throughout much of the section, with *Rasenia evoluta* in the basal metre. The basal two metres of the Lothbeg Siltstone contain the bivalves *Buchia concentrica*, *Liostrea multiformis* and *Parainoceramus*. Plant fragments, dominated by ferns, cycads and conifer needles, are abundant in the siltstones.

There is a short gap in exposure north-east of Lothbeg Point but between Crackaig and Dun Glas (ND 058 172), the Helmsdale Boulder Beds are exposed almost continuously. Bed thicknesses are generally between 0.5 and 1 m but may range from a few centimetres up to tens of metres. Most of the boulder beds contain giant, subangular to subrounded clasts, mainly of Devonian Caithness Flagstone lithologies, and Jurassic material including silicified wood and coral fragments in a heterogeneous fine-grained matrix. The largest clast is the famous 'fallen stack' of Bailey and Weir (1932) near Portgower; it has dimensions of at least *c*. 45 m by 27 m (Figure 5.12). In places, the boulders appear to have sunk up to some tens of centimetres into the underlying fine-grained lithologies, which comprise interbedded sandstones and siltstones but no true mudstones or black shales. The sandstones vary from a centimetre to more than a metre in thickness, and range from quartz arenites to greywackes. Some are rich in shell detritus, others in plant material. Unlike the uncemented sands of the Allt na Cuile Sandstone Formation, the sandstones are tightly cemented by coarsely crystalline calcite. The siltstones are planar interlaminated with fine sand on a 1–5 mm scale; where they are interbedded with somewhat thicker sandstones (up to 3 cm), the so-called 'tiger-stripe' facies is again developed. Wet-sediment deformation features are common throughout the formation, including synsedimentary normal and reverse faults on various scales, slide folds, slumps, clastic dykes as both mud and sand injections, convolute bedding, and dish and pillar structures. A diverse, calcareous fauna, dominated by thick-shelled bivalves, is present in the matrix of the boulder beds throughout the formation. The bivalves include oysters (*Liostrea*, *Nanogyra* and rarer *Lopha*), pectinids (*Chlamys* and *Radulopecten*), very thick-shelled *Isognomon* riddled with lithophagid borings, large trigoniids and small astartids. Gastropods, belemnites, serpulids, echinoids, crinoids and brachiopods are also present as well as rare blocks of the coral

Figure 5.12 The 'fallen stack' in the Helmsdale Boulder Beds near Portgower. (Photo: C1975, reproduced by kind permission of the Director, British Geological Survey ©NERC.)

Isastrea. In the interbedded laminated siltstones, there is a well-preserved but more limited fauna of *Liostrea multiformis*, rare nests of *Buchia concentrica*, and rare *Plagiostoma*. Rare and poorly preserved ammonites from the formation include *Amoeboceras (Euprionoceras) kochi* Spath, *Pectinatites (Arkellites)*, and *Pavlovia concinna* (Neaverson).

Near Dun Glas, the Helmsdale Fault itself is exposed on the foreshore near the mouth of Allt Briste. The rocks in the fault zone are intensely fractured, sheared and veined such that the original lithologies are hard to recognize.

Interpretation

According to Pickering (1984), the boulders in the Kintradwell Boulder Beds are probably derived from older Jurassic formations, such as the Callovian–Oxfordian Brora Arenaceous Formation, which were reworked in the littoral zone. The beds show abundant evidence of synsedimentary deformation and, according to Wignall and Pickering (1993), the Helmsdale Fault was active during their deposition although the rarity of older Jurassic clasts suggests that only a small part of the Jurassic succession was exposed on the fault scarp, and/or the earlier Jurassic sediments were not then lithified. A low-diversity bivalve fauna of *Buchia concentrica* and *Liostrea multiformis* in the siltstone matrix indicates oxygen-restricted conditions of deposition but where these taxa occur in a more diverse assemblage, including the bivalves *Nicaniella* cf. *eathiensis* (Waterston), *Palaeonucula*, *Parainoceramus* and *Solemya* cf. *woodwardiana* Leckenby, and the gastropod *Semisolarium*, almost normal bottom-water oxygen levels can be inferred. The presence of this latter assemblage in laminated sediments, which are typically associated with very low oxygen levels, suggests very high sediment accumulation rates. Rapid sedimentation is also indicated by the presence of small escape structures, probably of bivalves, at the lower contact between sandstone and siltstone beds (Wignall and Pickering, 1993).

Pickering's (1984) interpretation of the Allt na Cuile Sandstone Formation as having accumulated in a large submarine canyon–channel incised into the slope associated with the Helmsdale Fault scarp has been accepted by all subsequent authors. Of these, Trewin (1990) suggested that the Allt Choll Breccia probably formed as a rockfall breccia at the base of the steep-walled proximal canyon. Wignall and Pickering (1993) agreed, in essence, with these ideas but suggested that the area between Allt Choll and Allt na Cuile, where the otherwise straight outcrop of the Helmsdale Fault is displaced by about 500 m to the south-east, may have been preferentially exploited as a conduit for the transport of sandy shelf sediments to the downfaulted basin. The accumulation of sediment, comprising amalgamated channel sand bodies that became gradually smaller down-dip, built out to the east for a distance of at least 2 km but Wignall and Pickering (1993) noted that there is no evidence to suggest a radially distributed and well-organized set of submarine fan environments that would warrant the use of the term 'fan'. The diverse trace-fossil suite in the lower beds indicates that bottom-water oxygen levels were initially normal but the rapid fining-upwards shown by the higher beds, associated with a drastic decline in oxygen values (inferred from the lack of benthos), probably indicates a deepening of the sea.

In the Helmsdale Boulder Beds, the boulder beds themselves show classic features of submarine debris-flow and rockfall–slide processes. According to Wignall and Pickering (1993), the 'fallen stack' at Portgower is most likely to have been emplaced by rockfall and downslope sliding only a few hundred metres from the submarine cliff. They interpreted those isolated boulders that did not sink into the finer-grained beds below them, as the product of non-depositing debris flows or as ejected 'out-runner' blocks at the snouts or lateral margins of debris flows. Sedimentary structures suggest that the sandstones of the Helmsdale Boulder Beds were deposited from turbidity currents, but the finely laminated siltstones represent sedimentation by several different processes, the main one being deposition from dilute, muddy, turbidity currents, with hemipelagic and pelagic background sedimentation. According to Wignall and Pickering (1993), the 'tiger-stripe' facies likewise results from episodic deposition from thin, probably dilute, sandy turbidity currents and muddy turbidity currents, with hemipelagic–pelagic background sedimentation. The fauna in the matrix of the boulder beds is considered to be allochthonous and indicates a shallow, fully oxygenated shelf environment west of the Helmsdale Fault; the presence of corals suggests warmth. The corals occur as isolated colonies, with no indication of the presence of reefs on the upthrown side of the fault. The dominance of sessile epifauna rather than vagile infauna suggests sediment-starved, stable substrate conditions where the influx of sand was fairly infrequent (Wignall and Pickering, 1993). On the other hand, the fauna of the laminated siltstones is considered to be autochthonous. Wignall and Pickering (1993) suspected that the main ways by which the usually anoxic bottom-waters became briefly sufficiently oxygenated to support an impoverished fauna was from occasional turbidity currents carrying warmer and more oxygen-rich water with the sediment from the shelf into deep water.

The ammonite faunas have never been comprehensively reported but the records, recently assessed by Wignall and Pickering (1993), are sufficient to establish a nearly complete Kimmeridgian zonal sequence, from the Lower Kimmeridgian Cymodoce Zone through to the oldest (Albani) zone of the Portlandian (Figure 5.10). These authors concurred with the assessment of the zonal succession made by Barron (1989) on the basis of dinoflagellate cysts. Based largely on the unpublished ammonite data in Linsley (1972), with later refinement by Macdonald (1985) and Barron (1989), an approximate outcrop map of the zones was presented by Barron (1989) and Wignall and Pickering (1993) (Figure 5.9). The ammonite faunas reported from the Kintradwell Boulder Beds are indicative of the Cymodoce Zone. Neves and Selley (1975) thought that these beds were younger than the Allt na Cuile Sandstone but most subsequent authors have suggested that they are slightly older (Roberts, 1989; Tyson, 1989); Wignall and Pickering (1993) showed that they are equivalent in age to most of the Allt na Cuile Sand Member (Figure 5.10). The relationship one to another of the various members of the Allt na Cuile Sandstone Formation, which have mainly discontinuous outcrops, was not clearly demonstrated until the latter authors' work. Brookfield (1976) and Gregory (1989) both reckoned that the Allt na Cuile Sand Member was overlain by the Lothbeg Siltstone Member, which is clearly demonstrated at Lothbeg Point, but Wignall and Pickering (1993) showed that the latter member also grades laterally into the sandstones to the west via the Loth Burn Siltstone (Figure 5.10). The ammonites recorded from the Lothbeg Siltstone indicated to Wignall and Pickering (1993) that it represents the youngest part of the Cymodoce Zone and the Mutabilis Zone (Brookfield, 1976; Gregory, 1989). Arkell and Callomon (1963) recorded an ammonite fauna from the Loth Burn Siltstone indicative of the oldest part of the latter zone, and a fauna of similar age has been collected from loose blocks, probably from the top of the Allt na Cuile Sand Member, at Allt na Cuile (Brookfield, 1976; Wignall and Pickering, 1993). The Helmsdale Boulder Beds range from the Mutabilis Zone to the top of the Albani Zone of the lowest Portlandian but the ammonite faunas are not well known (Spath, 1935; Birkelund and Callomon, 1985). Wignall and Pickering (1993) reckoned that they had substantiated the presence of the Eudoxus, Elegans, Hudlestoni and Rotunda–Fittoni zones. Linsley (1972) and Lam and Porter (1977) had suggested that the Scitulus Zone was faulted out at Gartymore and that the Hudlestoni Zone, although present in the Helmsdale area, was not exposed (Barron, 1989). However, from structural and sedimentological data, MacDonald (in Barron, 1989) reported that the section was assumed to be continuous with only part of the Wheatleyensis Zone unexposed at Helmsdale and no evidence of faulting at Gartymore, although angular disconformities were present on the Helmsdale to Navidale and Gartymore foreshores.

Within the framework of the ammonite zonation, Wignall and Pickering (1993) presented a depositional history of the Kimmeridgian succession that started with deposition of the oldest Kimmeridgian strata (Kintradwell Boulder Beds and Allt na Cuile Sandstone) on the downthrown side of an already active Helmsdale Fault (Figure 5.13). At this time, the water depth in the downfaulted area was probably not very great, and the submarine fault scarp was probably only a few (?ten) metres high. Subsidence on the Helmsdale Fault probably accelerated towards the end of Cymodoce Zone times leading to rapid deepening, and headward erosion and steepening of the Allt na Cuile channel–canyon complex. Late in Mutabilis and Eudoxus Zone times, further rapid deepening led to permanent anoxia. By this time, much of the older Jurassic succession had probably been stripped off the footwall to reveal Middle Old Red Sandstone lacustrine facies (Caithness Flagstone), which constitutes most of the clasts in the Helmsdale Boulder Beds. The height of the scarp must have been greater than 50 m and water depths at the foot of the fault scarp-slope must have exceeded 200 m by mid Eudoxus

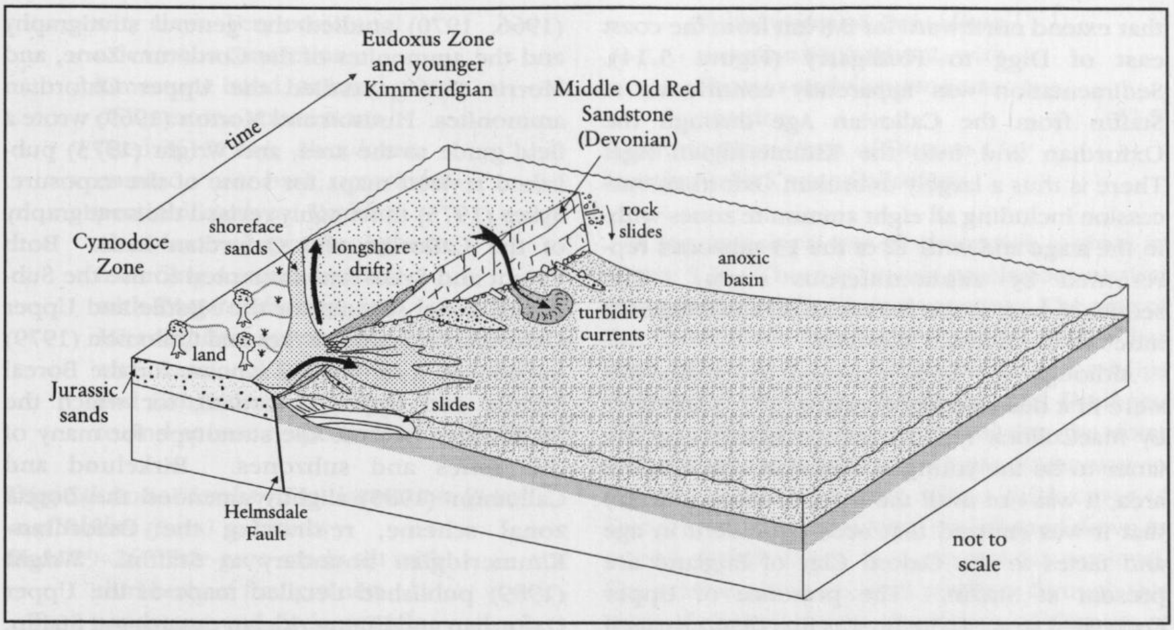

Figure 5.13 Simplified reconstruction of depositional conditions adjacent to the Helmsdale Fault during the Kimmeridgian (after Wignall and Pickering, 1993, fig. 21).

Zone times when a broad shallow shelf had developed on the upthrown side of the fault. From then onwards, sediment reached the foot of the fault scarp-slope as a series of sediment slides, debris flows, avalanches and turbidites that alternated with quieter water hemipelagic–pelagic sedimentation. The substantial reduction in plant detritus in the youngest beds led Wignall and Pickering (1993) to speculate that in Rotunda Zone times, the climate, which earlier in the Kimmeridgian had been humid and supported a rich and varied terrestrial flora (Seward, 1911; Seward and Bancroft, 1913; van de Burgh and van Konijnenburg-van Cittert, 1984; van de Burgh, 1987), had become more arid.

Conclusions

The narrow outcrop of Kimmeridgian strata on the coast of north-east Scotland, which comprises the GCR site known as 'Helmsdale', is the most extensive Kimmeridgian outcrop in Britain apart from that on the Dorset coast (see Chapter 2). It shows a virtually complete Kimmeridgian zonal succession, including the youngest zones and the basal zone of the overlying Portlandian strata, which are otherwise known only in Dorset. It also provides one of the best examples of fault-controlled sedimentation in the British Mesozoic record. The Kimmeridgian beds were deposited at the western active margin of a major half-graben controlled by downthrow on the Helmsdale Fault. The succession provides good sedimentological analogues for several North Sea oilfields. Boulder beds and the millimetre- to centimetre-scale interbedded sandstones and siltstones known as 'tiger stripe' facies, comparable to those that characterize the coastal outcrop, are also known from boreholes in the Moray Firth, Witch Ground Graben and Viking Graben. The site is thus a most important one for sedimentological and stratigraphical studies, offering a 'window' on the economically important subsurface geology of the North Sea.

STAFFIN (NG 473 692–NG 468 717)

J.K. Wright

Introduction

Staffin Bay contains some of the most important exposures of Oxfordian strata in Britain. The sections lie on the east coast of the Trotternish Peninsula near the northern extremity of Skye and comprise low cliff and foreshore exposures that extend northward for 2.8 km from the coast east of Digg to Flodigarry (Figure 5.14). Sedimentation was apparently continuous at Staffin from the Callovian Age through the Oxfordian and into the Kimmeridgian Age. There is thus a largely unbroken Oxfordian succession including all eight ammonite zones within the stage and with 12 of the 13 subzones represented by ammonitiferous strata. The sequence here is the international stratotype for much of the Boreal Oxfordian.

Although the beds exposed in Staffin Bay were first described by Pennant (1774) and later by MacCulloch (1819), and considered by the latter to be the youngest Mesozoic strata in the area, it was not until the work of Forbes (1851) that it was realized that beds equivalent in age and facies to the Oxford Clay of England are present at Staffin. The presence of Upper Oxfordian strata at Staffin was first demonstrated by MacGregor (1934). The area was later studied by Anderson and Dunham for the Geological Survey (field work undertaken and written up in 1936–1937, memoir published in 1966). Turner

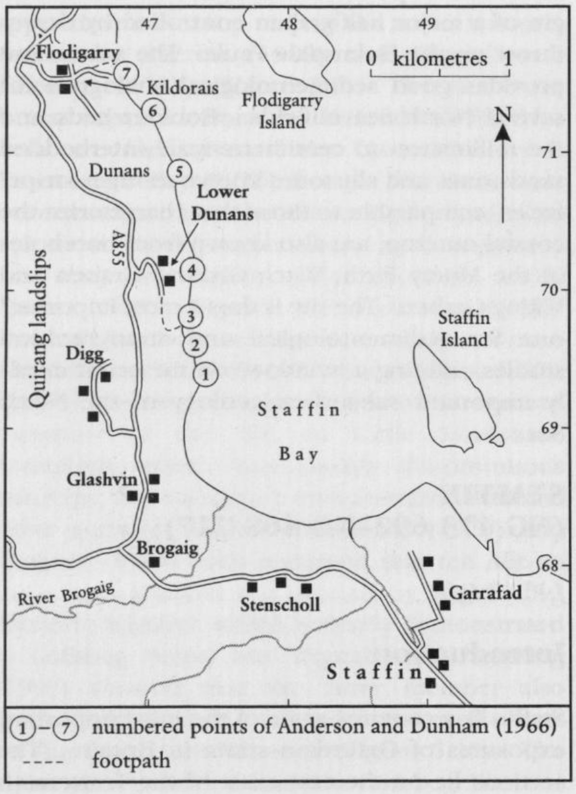

Figure 5.14 Locality map of the Staffin and Kildorais GCR sites (after Cox and Sumbler, in press).

(1966, 1970) studied the general stratigraphy and the ammonites of the Cordatum Zone, and Morris (1968) studied the Upper Oxfordian ammonites. Hudson and Morton (1969) wrote a field guide to the area, and Wright (1973) published revised maps for some of the exposure. Sykes (1975) thoroughly revised the stratigraphy of the Callovian and Oxfordian beds. Both Wright and Sykes had attempted to use the Sub-Boreal zonal scheme for the Middle and Upper Oxfordian at Staffin. Sykes and Callomon (1979) introduced a new zonal scheme for the Boreal Middle and Upper Oxfordian, for which the Staffin area became the stratotype for many of the zones and subzones. Birkelund and Callomon (1985) slightly amended the Boreal zonal scheme, re-drawing the Oxfordian–Kimmeridgian boundary at Staffin. Wright (1989) published detailed maps of the Upper Oxfordian and Kimmeridgian outcrops at Staffin, and Morton and Hudson (1995) produced a detailed field guide to the outcrops, with revised maps.

Description

The Staffin site exposes 104.5 m of Oxfordian strata comprising richly fossiliferous shales, silts and subordinate sandstones. These make up part of the Callovian to Kimmeridgian Staffin Shale Formation (Turner, 1966), and cover the complete Oxfordian zonal range from the Mariae Zone at the base to the Rosenkrantzi Zone at the top with the omission solely of the Maltonense Subzone, which is not exposed. A detailed measured section of the Staffin Shale has been published by Sykes and Callomon (1979), and this was amended slightly by Wright (1989) and Morton and Hudson (1995), while retaining Sykes and Callomon's bed numbers. The main features of the Oxfordian succession are illustrated by the section below and Figure 5.16, summarized from Sykes and Callomon (1979). A complete ammonite faunal list is given below.

Thickness (m)

Staffin Shale Formation
Flodigarry Shale Member (pars),
Blakei (pars), Ilovaiskii, Glosense,
Koldeweyense and Serratum subzones,
Regulare and Rosenkrantzi zones

Beds 36–30. Dark-grey, bituminous, shaley clays alternating with silty clays. Very occasional calcareous concretions. Limestone band, or band of limestone concretions (Bed 36) at top. *Nuculoma* common near base; occasional pectinid bivalves. Prolific *Amoeboceras* spp. throughout, including *A. rosenkrantzi*, with *Ringsteadia* spp. and *Microbiplices* sp. near top and occasional *Decipia* sp. and *Cardioceras* spp. near to and at base respectively. about 40

Digg Siltstone Member, Tenuiserratum (pars) and Blakei (pars) subzones

Beds 29–26. Pale-grey, sandy silt with thin beds of fine-grained sandstone and dark-grey silt. *Perisphinctes* spp. and *Cardioceras* spp. abundant; bivalves dominated by *Cucullaea* sp. 25+

Glashvin Silt Member, Cordatum (pars), Vertebrale, ?Maltonense and Tenuiserratum (pars) subzones

Beds 25–21. Dark-grey, carbonaceous silts, with beds of green clay, and woody bands associated with thin, sharp-based sandy beds up to 5 cm thick. *Cardioceras* spp. and *Perisphinctes* spp. abundant; in silts, rich faunas of bivalves (*Pinna, Cucullaea, Pleuromya* and *Pholadomya*) often preserved in life position 20.5

Dunans Clay Member, Scarburgense, Praecordatum, Bukowskii, Costicardia and Cordatum (pars) subzones

Beds 6–21. Pale, grey-green clays with several horizons of red-weathering, nodular sideritic limestone. Repeated occurrences of thin bands of dark-grey silt full of woody debris. *Cardioceras* spp., *Goliathiceras* spp., *Peltoceras* spp. common, with rare *Longaeviceras*. *Oxytoma*, *Nuculoma* and *Dentalium* common throughout, with *Thracia* and *Camptonectes* near top 31.5

(Continuation down of Dunans Clay Member into Upper Callovian)

A stratigraphical log of the section is given in Figure 5.15. There is no one continuous section through the Staffin Shale Formation. The area of the Trotternish Peninsula north of Staffin has been affected by a substantial series of landslips during the Holocene (Anderson and Dunham, 1966). Numerous blocks containing the complete succession from the Upper Bathonian to the Lower Kimmeridgian, with a thick cover of Tertiary basalt, have rotated and slipped down to a level slightly lower than present-day sea level. The sea has now cut a rock platform through this mass of slipped blocks, the degree of slipping of each block resulting in different levels of exposure of the strata from one block to the next. In the extreme, the red and green mottled mudstones of the Skudiburgh Formation (Bathonian) are faulted against the Flodigarry Shale (Upper Oxfordian). Westerly dips vary from only a few degrees to almost vertical (Wright, 1989, fig. 6). In most blocks, dips are steep. Baking of the shales has taken place close to Tertiary dykes and sills. The sections of Sykes and Callomon (1979) and Morton and Hudson (1995) were compiled by correlation of the disjointed successions in the various slipped blocks. Some parts of the succession are not exposed; other parts are exposed at several localities. In general, Lower and Middle Oxfordian strata are exposed in the centre of the coastal strip, and Upper Oxfordian at the north and south ends where pressure from the Quirang landslip has brought slices of sheared, sometimes rotated, Flodigarry Shale down to sea level.

A lack of local names for the various minor headlands between Staffin and Flodigarry led Anderson and Dunham (1966) to number the headlands Point 1 to Point 7, and this has been followed by subsequent authors. Wright (1973, 1989) gave the more important slipped blocks identification letters, D1 to D5 for those in the south near Digg, and F1 to F8 for those in the north near Flodigarry. A general map of the coastline is given in Figure 5.14, and more detailed maps and logs in Figures 5.16 and 5.17. The description is given from south to north, although the principal southern access route

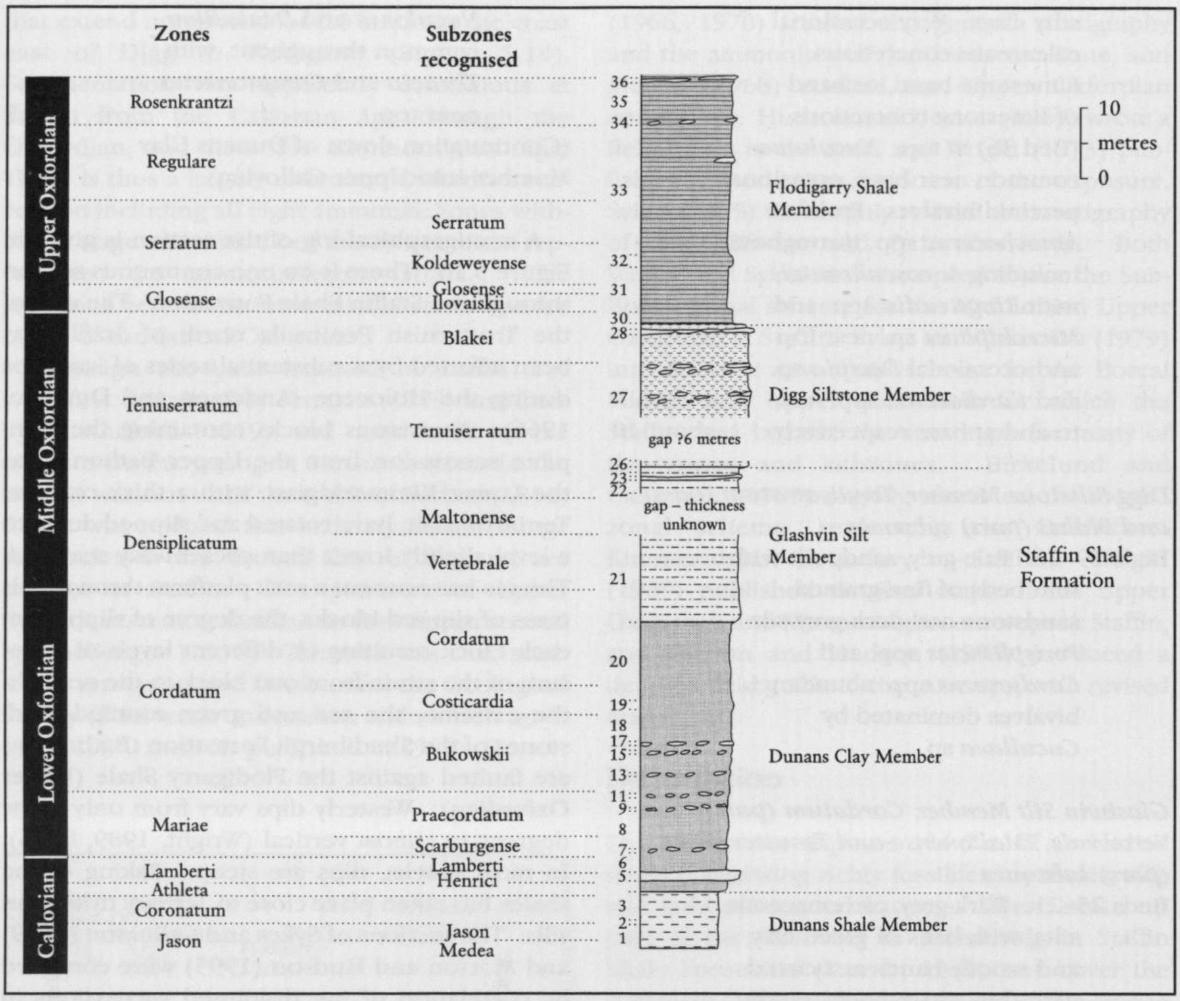

Figure 5.15 General log of the Staffin Shale succession (after Morton and Hudson, 1995, table 4).

given by Morton and Hudson (1995) leads to the shore north of Point 3.

A large boulder on the shore 275 m south of Point 1 is a convenient marker for the southern limit of the Oxfordian beds. Just to the south-east of it, red and green mottled mudstones of the Skudiburgh Formation are exposed. There are poor exposures of the Digg Siltstone dipping at 60° to the north-west, 50 m north of the boulder (Exposure D2, Figure 5.16). Northwards across a small fault, vertically dipping exposures of the Flodigarry Shale yield good *Amoeboceras glosense* (Bigot and Brasil) and *Perisphinctes* (cf. *Dichotomoceras*) sp..

In the small bay between Point 1 and Point 2 (Figure 5.16), a prominent 0.35 m thick limestone (Bed 40 of Wright, 1989) can be located in the mid beach at exposure D5A. It is not persistent and can be traced only 20 m north-westwards before dying out. Below it are 5 m of shale containing the early Kimmeridgian *Amoeboceras bauhini* (Oppel), resting on a persistent, 0.2 m thick, limestone (Bed 36 of Sykes and Callomon, 1979). This limestone and the shales below it yield *Ringsteadia* spp. and *Amoeboceras rosenkrantzi* Spath of the uppermost Oxfordian. Beneath are good exposures of Flodigarry Shale yielding *Amoeboceras regulare* Spath (Regulare Zone), and then to the north in exposure D5B, good exposures of shale yielding *Amoeboceras serratum* (J. Sowerby) and *A. koldeweyense* Sykes and Callomon (Serratum Zone).

On the north side of the bay between Points 2

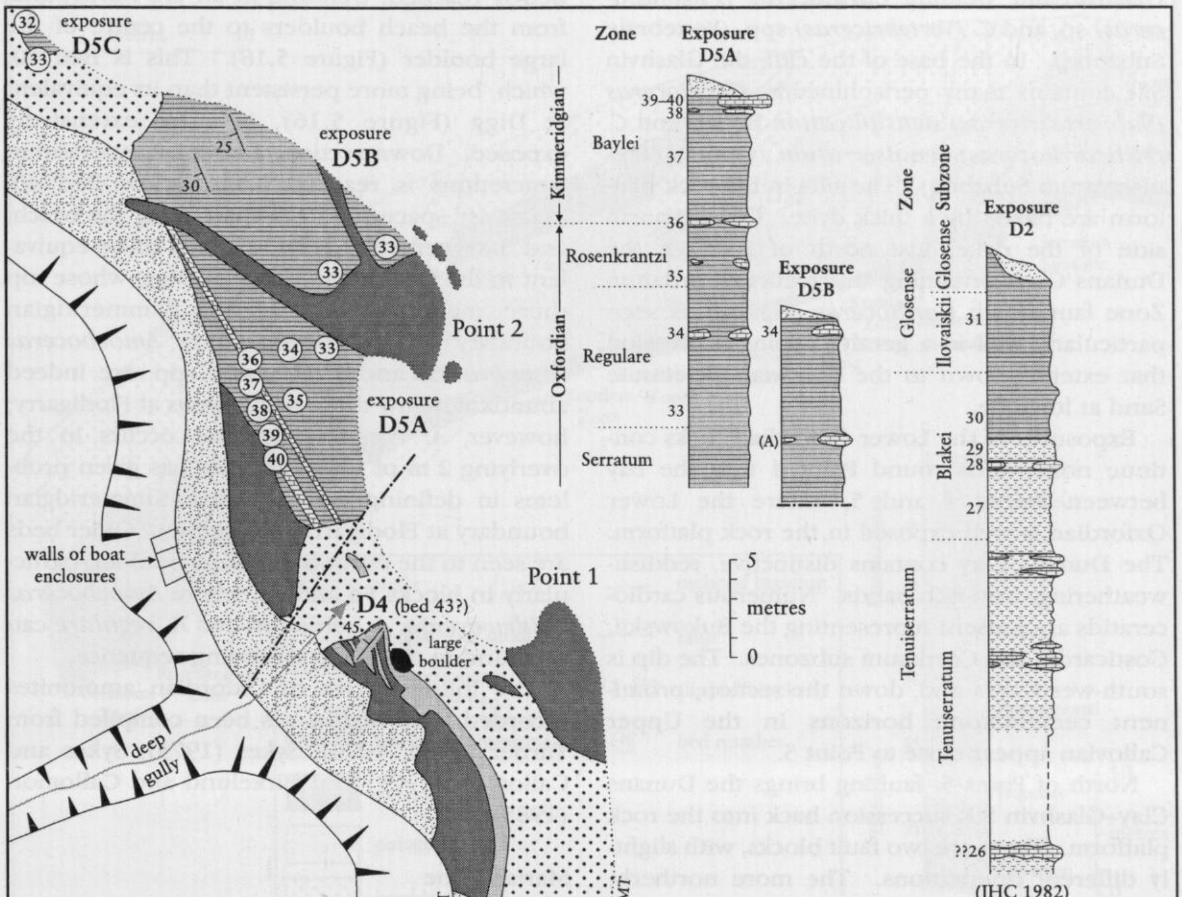

Figure 5.16 Map of the foreshore at Digg, with detailed logs (after Morton and Hudson, 1995, figs 39, 40).

and 3, there is a steeply dipping exposure of Glashvin Silt yielding *Cardioceras (Plasmatoceras)* sp. and *C. (Vertebriceras)* spp. (Vertebrale Subzone). In the base of the cliff, the Glashvin Silt contains many perisphinctids, *Cardioceras (Subvertebriceras) densiplicatum* Boden and *C. (Miticardioceras) tenuiserratum* (Oppel) (Tenuiserratum Subzone). The silts in the rock platform are baked by a thick dyke. On the north side of the dyke, just north of Point 3, the Dunans Clay containing an excellent Cordatum Zone fauna with *Cardioceras (C.)* spp. is seen particularly well in a gently dipping succession that extends down to the Callovian Belemnite Sand at low tide.

Exposures of the Lower Oxfordian rocks continue northwards round Point 4 into the bay between Points 4 and 5, where the Lower Oxfordian is well exposed in the rock platform. The Dunans Clay contains distinctive, reddish-weathering, iron-rich bands. Numerous cardioceratids are present representing the Bukowskii, Costicardia and Cordatum subzones. The dip is south-westwards and, down the section, prominent cementstone horizons in the Upper Callovian appear close to Point 5.

North of Point 5, faulting brings the Dunans Clay–Glashvin Silt succession back into the rock platform. There are two fault blocks, with slightly different orientations. The more northerly, with beds dipping vertically and striking almost due north, shows a succession from the Dunans Clay, with *Cardioceras bukowskii* Maire and *Rursiceras* sp. (Bukowskii Subzone), well into the Glashvin Silt of the Vertebrale Subzone. The dark, silty shales of the latter, with their numerous paler, silty bands, contain exceptionally well-preserved ammonites seen in cross-section in the rock platform. The beds are crowded with *Cardioceras, Vertebriceras* and *Perisphinctes,* both macroconchs and microconchs, all complete, with the body chambers partly filled with micrite, and the inner whorls crushed.

Between Points 5 and 6, the red and green mottled silts of the Skudiburgh Formation are prominently seen in the rock platform, with, at mid-tide level, a faulted slice of Flodigarry Shale containing *Amoeboceras* sp.. North of Point 6, the extensive exposures of Flodigarry Shale in Flodigarry Bay are encountered. The succession is best examined in Block F6 (Figure 5.17), where there is almost continuous exposure for 50–100 m south of the large boulder in the centre of the bay. Immediately seawards of the beach boulders, a prominent 0.35 m limestone bed is reached, trending in an arc northwards from the beach boulders to the centre of the large boulder (Figure 5.18). This is Bed 40, which, being more persistent than its equivalent at Digg (Figure 5.16), is more extensively exposed. Down section, a layer of impersistent concretions is reached 6.5 m below Bed 40. These are spaced 5–10 m apart along the beach, and have generally been assumed to be equivalent to the Bed 36 limestone at Digg, whose top there marked the Oxfordian–Kimmeridgian boundary. The Oxfordian taxa *Amoeboceras rosenkrantzi* and *Ringsteadia* spp. are indeed abundant below these concretions at Flodigarry; however, *A. rosenkrantzi* also occurs in the overlying 2 m of shale, and this has given problems in defining the Oxfordian–Kimmeridgian boundary at Flodigarry (see below). Older beds are seen to the north of the large boulder, particularly in blocks F4 and F2, where *Amoeboceras koldeweyense, A. serratum* and *A. regulare* can be found in the usual ascending sequence.

The following list of Oxfordian ammonites recorded from Staffin has been compiled from Turner (1966, 1970), Sykes (1975), Sykes and Callomon (1979) and Birkelund and Callomon (1985).

Mariae Zone
Scarburgense Subzone (Bed 6 (pars), Bed 7 and Bed 8 (pars)):
Cardioceras (Scarburgiceras) scarburgense (Young and Bird) (rare), *Goliathiceras* sp., *Quenstedtoceras* sp. and *Longaeviceras staffinense* Sykes
Praecordatum Subzone (Bed 8 (pars) to Bed 12 (pars)):
Cardioceras (Scarburgiceras) praecordatum Douvillé, *C. (S.) alphacordatum* Spath, *Euaspidoceras* sp. and *Peltoceras* sp.

Cordatum Zone
Bukowskii Subzone (Bed 12 (pars) to Bed 18):
Cardioceras (Scarburgiceras) bukowskii, C. (S.) alphacordatum, C. (S.) cf. *excavatoides* Maire, *C. (S.) reesidei* Maire, *Goliathiceras (Korythoceras) korys* (S. Buckman), *Euaspidoceras* sp., *Peltoceras (Parawedekindia) arduennense* (d'Orbigny), *P. gerberi* (Prieser) and *P. (Peltomorphites) hoplophorous* (Buckman)
Costicardia Subzone (Bed 19 and Bed 20 (pars)):

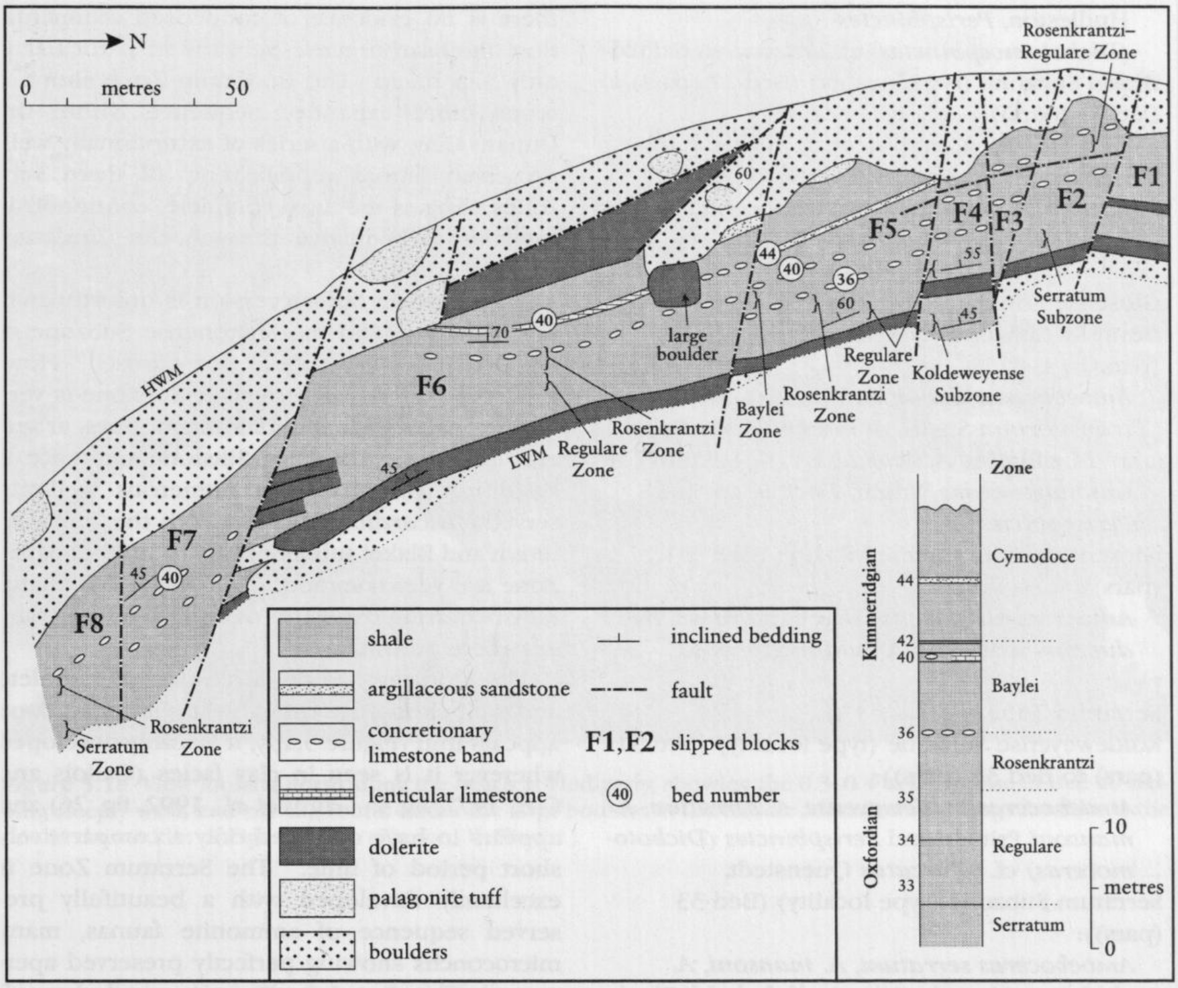

Figure 5.17 Map of the foreshore at Flodigarry, with detailed log (after Morton and Hudson, 1995, fig. 42).

Cardioceras (Cardioceras) costicardia Buckman, *C. (Subvertebriceras) costellatum* Buckman, *Peltoceras (Parawedekindia) arduennense*, *P. (Peltoceratoides) williamsoni* (Phillips) and *Mirosphinctes* sp.

Cordatum Subzone Bed 20 (pars) and Bed 21 (pars):

Cardioceras (Cardioceras) cf. *cordatum* (J. Sowerby), *C.* spp. and *Goliathiceras (Pachycardioceras) repletum* (Maire)

Densiplicatum Zone

Vertebrale Subzone (type locality) (Bed 21 (pars)):

three horizons are present,:

(a) with *Cardioceras (Plasmatoceras) popilaniense* Boden,

(b) with *C. (Scoticardioceras) excavatum* (J. Sowerby), *C. (Subvertebriceras) densiplicatum*, *C. (S.) zenaidae* Ilovaisky and *C. (S.) sowerbyi* Arkell,

(c) with *C. (P.) tenuistriatum* Borissjak and *C. (P.) tenuicostatum* Nikitin. *Perisphinctes (Dichotomosphinctes) rotoides* Ronchadzé and *P. (Arisphinctes)* sp. also occur

Maltonense Subzone: not exposed

Tenuiserratum Zone

Tenuiserratum Subzone (type locality) (Bed 26 and Bed 27 (pars)):

Cardioceras (Miticardioceras) tenuiserratum, *C. (M.) mite* Buckman, *C. (Maltoniceras) schellwieni* Boden, *C. (Cawtoniceras) cawtonense* Blake and

Hudleston, *Perisphinctes (Dichotomosphinctes)* cf. *antecedens* Salfeld

Blakei Subzone (type locality) (Bed 27 (pars) to Bed 31 (pars)):

Cardioceras (Cawtoniceras) blakei, C. (C.) ogivale (S. Buckman), *C. (Maltoniceras) vagum* Ilovaisky, *C. (Miticardioceras) tenuiserratum, Perisphinctes* spp.

Glosense Zone

Ilovaiskii Subzone (type locality) (Bed 31 (pars)):

Amoeboceras ilovaiskii (M. Sokolov), *A. transitorium* Spath, *A. newbridgense* Sykes and Callomon, *A. shuravskii* (D. Sokolov), *A. nunningtonense* Wright, *Decipia* sp. and *Perisphinctes* sp.

Glosense Subzone (type locality) (Bed 31 (pars)):

Amoeboceras glosense Bigot and Brasil, *A. damoni* Spath and *A. nunningtonense*

Serratum Zone

Koldeweyense Subzone (type locality) (Bed 31 (pars) to Bed 33 (pars)):

Amoeboceras koldeweyense, A. serratum, A. mansoni Pringle and *Perisphinctes (Dichotomoceras)* cf. *bifurcatus* Quenstedt.

Serratum Subzone (type locality) (Bed 33 (pars)):

Amoeboceras serratum, A. mansoni, A. shulginae Mesezhnikov, *A.* cf. *freboldi* Spath, *A. regulare, A. leucum* Spath, *Perisphinctes* sp. and *Euaspidoceras* sp.

Regulare Zone (type locality) (Bed 33 (pars) and Bed 34):

Amoeboceras regulare, A. freboldi, A. leucum, A. schulginae and *Ringsteadia caledonica* Sykes and Callomon

Rosenkranktzi Zone (type locality) (Bed 35 and Bed 36):

Amoeboceras marstonense Spath, *A. rosenkrantzi, Ringsteadia caledonica* and *R. pseudocordata* Blake and Hudleston

Interpretation

The Oxfordian sequence at Staffin is remarkable for its completeness (Figure 5.15) and for the often exceptional preservation of its ammonites. Within the Dunans Clay, the initial Mariae Zone is to some extent thinly developed. Though there is no evidence of condensed sedimentation, the Scarburgense Subzone in particular is only 3 m thick. The Cordatum Zone shows a much more expanded sequence within the Dunans Clay, with a series of exceptionally well-preserved faunas representing all three subzones. This is the most complete, continuously fossiliferous sequence through the Cordatum Zone in Britain.

The Glashvin Silt succession is unfortunately not complete, and the Maltonense Subzone of the Densiplicatum Zone is not exposed. However, the underlying Vertebrale Subzone is very well exposed, with abundant ammonites, at several localities. The Digg Siltstone sequence is again not complete, but numerous well-preserved *Miticardioceras* from both the Tenuiserratum and Blakei subzones of the Tenuiserratum Zone are very common. This is the only naturally occurring exposure of the Blakei Subzone anywhere in Britain.

The Flodigarry Shale succession is complete and well exposed. Though the Glosense Zone appears thin (Figure 5.15), it is thinly developed wherever it is seen in clay facies (Gallois and Cox, 1977, fig. 2; Gaunt *et al.*, 1992, fig. 26) and appears to have occupied only a comparatively short period of time. The Serratum Zone is excellently developed with a beautifully preserved sequence of ammonite faunas, many microconchs showing perfectly preserved apertures. The Regulare Zone is similarly well exposed and fossiliferous, this being the only permanent section in Britain where Regulare Zone sediments are visible.

Amoeboceras rosenkrantzi (Rosenkrantzi Zone) occurs up to and within the marker bed 36 at Digg, the top of this being taken as the Oxfordian–Kimmeridgian boundary (Morton and Hudson, 1995). However, as was pointed out by Wierzbowski and Matyja (pers. comm., 1998), at Flodigarry, it is not so easy to distinguish the Oxfordian–Kimmeridgian boundary. *Amoeboceras rosenkrantzi* occurs in the 2 m of shale above a concretion band, which had been regarded as being the equivalent at Flodigarry of the marker Bed 36 of Digg. One view would be that the Oxfordian–Kimmeridgian boundary at Flodigarry is not marked by this concretion band but instead lies within shale some 2 m higher than the Flodigarry concretion band, which would not be the equivalent of Bed 36.

However, as well as *A. rosenkrantzi*, this 2 m of shale also contains *A. bauhini*. This associa-

Figure 5.18 View looking north along the beach at Flodigarry, showing the 0.3–0.4 m limestone of Bed 40 dipping steeply west, and curving round under the large boulder in the middle distance. The large boulder is the one in the middle of Figure 5.17. (Photo: J.K. Wright.)

tion was regarded by Sykes and Callomon (1979) as forming a Bauhini Subzone of the Rosenkrantzi Zone. Later, it was realized that *A. bauhini* is an indicator of the Early Kimmeridgian Baylei Zone, occurring along with the Kimmeridgian species *Pictonia densicostata* S. Buckman at South Ferriby Pit (Birkelund and Callomon, 1985; see site report for South Ferriby, this volume). It was then realized that the perisphinctid that occurs along with *A. rosenkrantzi* and *A. bauhini* in this 2 m of shale at Flodigarry was not *Ringsteadia* cf. *pseudocordata* Blake and Hudleston as recorded by Sykes and Callomon (1979), but *Pictonia densicostata* (Morton and Hudson, 1995). The result of this reasoning would be to say that concretion marker Bed 36 is recognizable at Flodigarry, that the 2 m of shale above it that contains *A. rosenkrantzi* is Kimmeridgian, and that *A. rosenkrantzi* carries on across the Oxfordian–Kimmeridgian boundary.

The succession at Staffin is comparable with that of the East Midlands of England in showing an almost entirely argillaceous succession from the Middle Callovian into the Lower Kimmeridgian strata, there being no marked changes in lithology at either the lower or the upper boundaries of the Oxfordian Stage. This argillaceous succession is considered to have been laid down during a major inundation of the Hebridean shelf area commencing with the transgression that occurred during the preceding Callovian. Subsequent to the deposition of the Dunans Clay during the Early Oxfordian, a regressive episode continued through the Mid Oxfordian with the deposition of sandy silts and thin sandstones (Glashvin Silt and Digg Siltstone). These correspond to the Tobar Ceann Siltstone and Scaladal Sandstone of Strathaird on south Skye. At the beginning of the Late Oxfordian, a second phase of deepening occurred in this basin marked by the deposition of the bituminous Flodigarry Shale. Only in latest Oxfordian times did argillaceous facies reach Strathaird (Camasunary Siltstone).

The abundance of well-preserved ammonites in the Staffin succession indicates the prevalence of an undisturbed, low-energy depositional regime. Though ammonites are sometimes preserved in three dimensions, particularly in the Cordatum Zone, they are normally found as flattened impressions. Despite this, the original nacreous aragonite shell is often present, and the preservation can be excellent, particularly in the Flodigarry Shale, with the finest details of the ribbing and aperture preserved. Nowhere else does such a rich, complete and significant sequence of Oxfordian faunas occur. The closest approach to such completeness outside this part of Scotland occurs in north Cambridgeshire and Humberside where ten index assemblages occur, but where the exposures are not as good, and are not permanent.

Bivalves are associated with the ammonites and are usually confined to discrete horizons. They indicate quiet-water depositional conditions, the associations being dominated by infaunal species such as *Nuculana, Grammatodon, Trautscholdia, Pinna* and *Pleuromya.* Conditions must frequently have been anoxic, particularly during deposition of the bituminous Flodigarry Shale, with a lack of benthic fossils. The absence of scavengers in these conditions resulted in the most perfect preservation of ammonites occurring in this member.

Conclusions

Staffin is one of Britain's most important Jurassic sites, being a primary reference standard of global significance for the Oxfordian Stage. The Oxfordian faunal sequence here has produced 14 zonal or subzonal ammonite faunas. There are rich assemblages of both Boreal and Tethyan affinities, of which the Boreal cardioceratid faunas are the most significant. The Tenuiserratum Zone with its prolific faunas of diminutive cardioceratids was first recognized at Staffin by Sykes and Callomon (1979). This zone is now recognized in Greenland, Russia and Poland. The *Amoeboceras* faunas of the Flodigarry Shale are of great importance, the detailed revision of the *Amoeboceras* zonation of the Boreal Upper Oxfordian succession by Sykes and Callomon (1979) having been based in large part on evidence obtained from Staffin. The site provides the best available section through the Upper Oxfordian strata anywhere in the Boreal Province and is of essential international significance for the study of the Upper Jurassic Series.

KILDORAIS (NG 468 714)

B.M. Cox

Introduction

The youngest Jurassic strata to crop out on the Isle of Skye are of Kimmeridgian age. They form the uppermost part of a *c.* 130 m thick, argillaceous unit (of Callovian to Kimmeridgian age) known as the Staffin Shale Formation (Turner, 1966). The Kimmeridgian beds are best exposed in scattered outcrops between low and high water marks on the east coast of the Trotternish peninsula on the northern arm of Staffin Bay beside the stretch of sea known as 'Poldorais'. They are much disturbed by faulting, landslip and igneous intrusions. The strata are steeply dipping, and the outcrops are, at the time of writing, much obscured by basalt boulders and seaweed. Detailed mapping and careful correlation of thin impersistent concretionary limestone bands between faulted blocks is necessary in order to piece together the succession. Nevertheless, because the beds yield zonally diagnostic ammonite faunas from the Oxfordian–Kimmeridgian boundary succession, they have been considered as a candidate for the basal Kimmeridgian GSSP (Page and Cox, 1995). The presence of Middle–Upper Jurassic shales on this stretch of coast was reported by MacCulloch (1819), Murchison (1829a), Forbes (1851) and Judd (1878), and later by Lee and Pringle (1932) and MacGregor (1934). Detailed geological mapping undertaken in the 1930s (Anderson and Dunham, 1966) has formed a basis for subsequent work. The Kimmeridgian GCR site known as 'Kildorais', which coincides with the northernmost part of the Oxfordian GCR site known as 'Staffin' (this volume) (Figure 5.14), is the foreshore shown by Anderson and Dunham (1966, fig. 11) and Wright (1973, fig. 3; 1989, fig. 5).

Description

The following composite section (Figure 5.19) is based on that recorded by Wright (1989) and by Morton and Hudson (1995) with some additional ammonite records from Wierzbowski and Matyja (pers. comm.) and J.K. Wright (pers. comm.). It is best seen in Exposures F5 and F6 of Wright (1973, 1989), north of the large

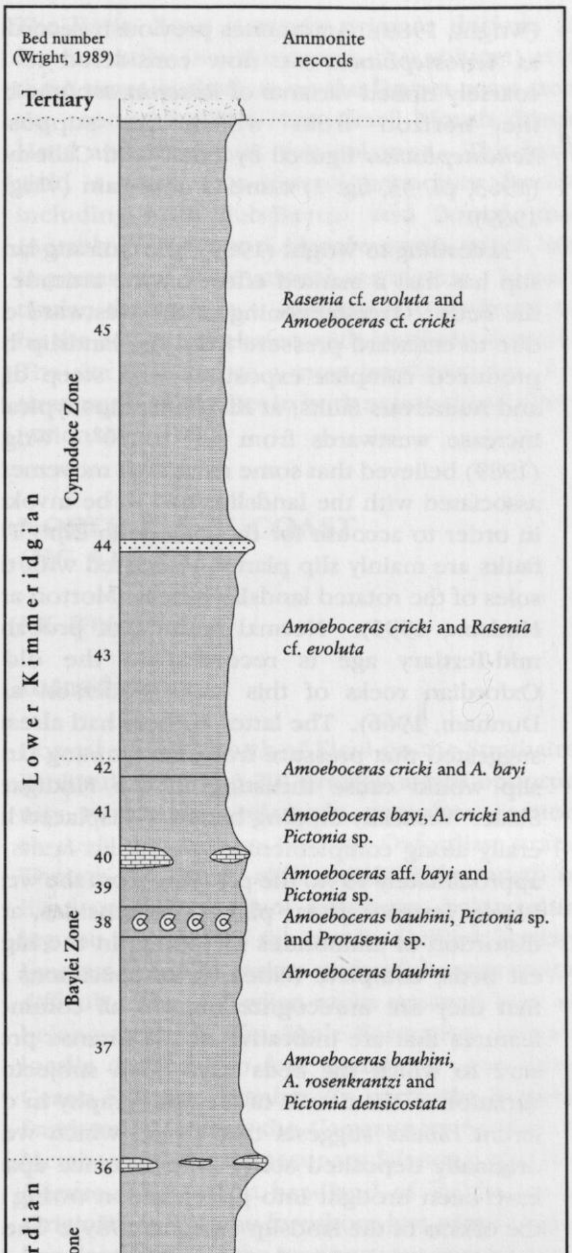

Figure 5.19 Graphic section of the Kimmeridgian and uppermost Oxfordian parts of the Staffin Shale Formation, Flodigarry Shale Member, at Kildorais.

boulder (see Figures 5.17 and 5.18). Bed numbers are those of Wright (1989) and are an upward continuation of those given for the Oxfordian and basal Kimmeridgian beds by Sykes and Callomon (1979). The subdivision of the Staffin Shale Formation into members follows Sykes (1975).

		Thickness (m)
	Staffin Shale Formation	
	Flodigarry Shale Member	
45.	Clay, dark grey, poorly fossiliferous; *Rasenia* cf. *evoluta* Spath and *Amoeboceras* cf. *cricki* (Salfeld)	seen 9.0
44.	Sandstone, argillaceous, tough, forming distinct ridge running across rock platform	0.15
43.	Clay, pale grey, poorly fossiliferous; occasional *A. cricki* and *R.* cf. *evoluta*	4.5
42.	Clay, darker than beds 41 and 43, silty; numerous *A. cricki* together with *Amoeboceras bayi* Birkelund and Callomon preserved in iridescent calcite	0.4
41.	Clay, pale grey, silty; crushed *A. bayi*, *A. cricki* and *Pictonia* sp.	1.5
40.	Limestone; continuous bed, locally as nodules	0.15–0.45
39.	Clay, grey, silty; *A.* aff. *bayi* and *Pictonia* sp.	0.85
38.	Clay, black, shaly; abundant white, crushed ammonites including *Amoeboceras bauhini* (Oppel), *Pictonia* sp. and *Prorasenia* sp.	0.65
37.	Clay, grey, silty; blocky fracture and abundant *A. bauhini* in highest 0.3 m; *A. bauhini* and *Pictonia densicostata* (Salfeld) in lowest 4.2 m with *A. rosenkrantzi* Spath in lowest 2.0 m	4.7
36.	Limestone nodules/concretions	0.07–0.25
35.	Clay, medium to dark grey, silty, slightly bituminous; abundant *Amoeboceras marstonense* Spath, *A. rosenkrantzi*, *Ringsteadia frequens* Salfeld and *Ringsteadia evoluta* Salfeld in highest 1–2 m	6.0

For lower beds, see site report for Staffin (this volume).

The main markers are the variably persistent limestones (Bed 36 and Bed 40), and the distinctive black clay with white 'chalky' ammonites (Bed 38) (Figure 5.19). Small faults running predominantly NW–SE, but also NE–SW, dissect the outcrops. All authors have concentrated on the ammonite faunas, and there are few records of other fossils. In his unpublished thesis, Morris (1968) reported the bivalves *Neocrassina ovata* (Wm Smith) and *Nuculana*, gastropods (*Dicroloma* and *Procerithium*) and belemnites (abundant in the highest part of Bed 43 and the lowest part of Bed 45). Callomon (pers. comm., 1982) recorded belemnites in beds 37–43. The marine palynomorph floras have been investigated by Riding and Thomas (1997).

Interpretation

The bio- and chronostratigraphical classification and correlation of these steeply dipping and variably exposed beds has been difficult, although the fact that they included an ammonitiferous succession across the Oxfordian–Kimmeridgian stage boundary has long been recognized. Sykes and Callomon (1979) based their ammonite zonation of the Boreal Oxfordian nearby at Digg (see site report for Staffin, this volume) and placed its upper boundary at the base of Bed 39. Subsequently, in the spring of 1982, the beds at Digg were unusually well exposed, which enabled their classification to be reassessed. As a result, the Oxfordian–Kimmeridgian stage boundary was lowered to the base of Bed 37 (Birkelund and Callomon, 1985). The key ammonite for marking the basal Kimmeridgian (Baylei Zone) in the section is *Pictonia densicostata*; its occurrence with *Amoeboceras bauhini*, previously thought to belong to the youngest Oxfordian, led to the removal of the Bauhini Subzone from the Upper Oxfordian Rosenkrantzi Zone, which consequently, at present, has no subzones. Although small in size (25 mm maximum), Birkelund and Callomon (1985) regarded it as a macroconch with the even smaller *A. cricki* as the associated microconch. The base of the Cymodoce Zone, the youngest zone proven here, is taken at the base of Bed 43. Although poorly fossiliferous, the presence therein of occasional well-preserved *Rasenia* is indicative of the zone. Contrary to the earlier views of Wright (1973), there is no substantive evidence of the Mutabilis Zone, and certainly none for the Eudoxus Zone (Wright, 1989). Ammonites previously recorded as *Xenostephanus* are now considered to be coarsely ribbed variants of *Rasenia evoluta* but the horizon from which the supposed *Xenostephanus* figured by Arkell and Callomon (1963, pl. 33, fig. 1) came is uncertain (Wright, 1989).

According to Wright (1989), the Quirang landslip has had a marked effect on the attitude of the beds. Oversteepening of the westward dip due to eastward pressure from the landslip has produced complex exposures with steep dips and numerous faults; at Kildorais, dips typically increase westwards from 45° to 90°. Wright (1989) believed that some rotational movement, associated with the landslip, had to be invoked in order to account for the change in dip. The faults are mainly slip planes associated with the soles of the rotated landslip blocks (Morton and Hudson, 1995). Normal faulting of probable mid-Tertiary age is recorded in the older Oxfordian rocks of this area (Anderson and Dunham, 1966). The latter authors had already suggested that pressure from the Quirang landslip would cause thrusting in the Flodigarry Shale. Vertically dipping beds are displaced laterally along complementary strike-slip faults at approximately 45° to the pressure from the west. Blocky fracture, shear planes, slickensides, and distortion of ammonites including, in the highest beds, complete flattening of specimens so that they are unrecognizable, are all common features that are indicative of the intense pressure to which the beds have been subjected. Variation in the details of the stratigraphy in different blocks suggests that strata, which were originally deposited some little distance apart, have been brought into juxtaposition owing to the effects of the landslip (Wright, 1989). These are also responsible for slight thickness variations in the different fault blocks.

Conclusions

The foreshore at Kildorais offers natural exposures through the basal part of the Kimmeridgian Stage and its boundary with the underlying Oxfordian Stage. Although the beds are steeply dipping and often partially obscured by boulders and seaweed, and are affected by landslip and related faults that have led to misclassification in the past, the sections provide a fuller succession through the basal Kimmeridgian boundary beds than anywhere else in Britain.

The Baylei Zone is nearly twice as thick as at South Ferriby (see site report, this volume) and three times as thick as on the Dorset coast (see site reports for East Fleet–Small Mouth, Black Head and Ringstead, this volume). The beds yield a good sequence of ammonite faunas including both Sub-Boreal and Boreal taxa (notably *Pictonia* and *Amoeboceras*), which are important for international correlation. In particular, the species *A. bauhini* is considered to be the key to correlation with southern Europe. The site is therefore a most important one for stratigraphical studies in both national and international spheres.

NORTH ELGOL COAST (NG 516 172)

J.K. Wright

Introduction

Coastal sections north of Elgol on the Strathaird Peninsula (Figure 5.20) provide a rare opportunity to study a relatively complete section through the western Scottish Oxfordian strata. Though the beach, cliffs and hillsides north of Elgol provide excellent exposures, baking during the intrusion of the nearby Cuillins Tertiary Igneous Complex makes study of the succession difficult. The Oxfordian rocks exposed here all belong to the Staffin Shale Formation and are locally divided into four members: the Tobar Ceann Siltstone Member (in part), the Scaladal Sandstone Member, the Camasunary Sandstone Member and the Camasunary Siltstone Member (Figure 5.21). The headland of Rubha na h-Airigh Bàine and the foreshore just north of this headland provide the type sections for the latter three members.

The site has figured in accounts of the Scottish Jurassic deposits since this part of Skye was mapped by the Geological Survey in the early 1900s (Wedd, 1910). Though Arkell (1933) made only brief reference to this locality, the work of subsequent authors has shown it to be of considerable importance in elucidating the Oxfordian stratigraphy of the Hebrides Basin. Both Hudson and Morton (1969) and Turner (1966, 1970) made valuable contributions to understanding the Oxfordian geology of this area. However, it was Sykes' revision of the stratigraphy (Sykes, 1975) and the later studies

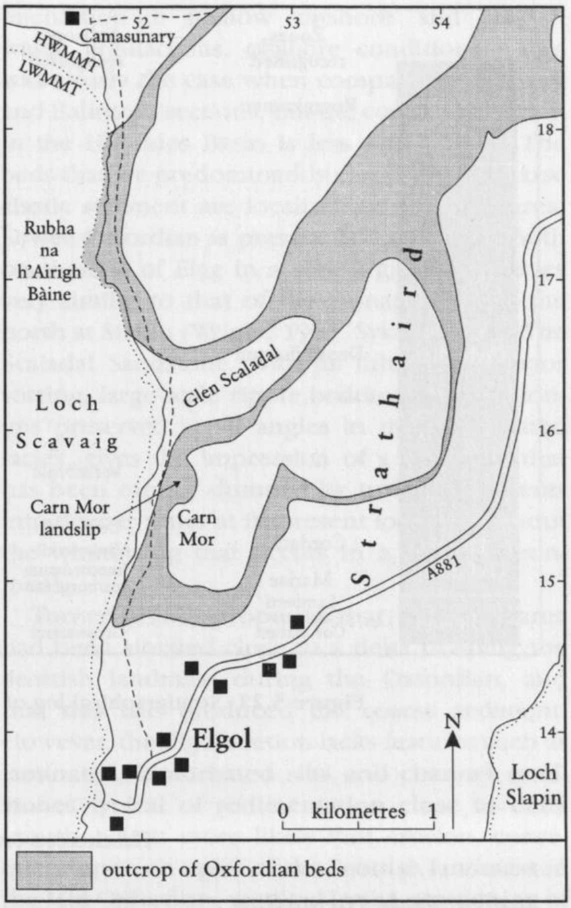

Figure 5.20 Locality map of the North Elgol Coast GCR site. Outcrop of the Oxfordian beds from BGS Sheet 71W (Broadford) (1976).

of Sykes and Surlyk (1976) and Sykes and Callomon (1979) that have provided a firm basis for modern research.

Description

The sequence at Elgol is exposed in a synclinal structure, the core of which lies at NG 517 176. Of the four major sections through the Oxfordian in Scotland, this, though incomplete, is the thickest. The stage is represented by 145.5 m of siltstones and sandstones. The sequence at Elgol shows important thickness and facies changes when contrasted with the type sequence of the Staffin Shale 55 km to the north at Staffin Bay (Turner, 1966; Sykes, 1975). The sequence on the coast from 2.7 km to 3.6 km north of Elgol may be summarized as follows, based on Sykes (1975).

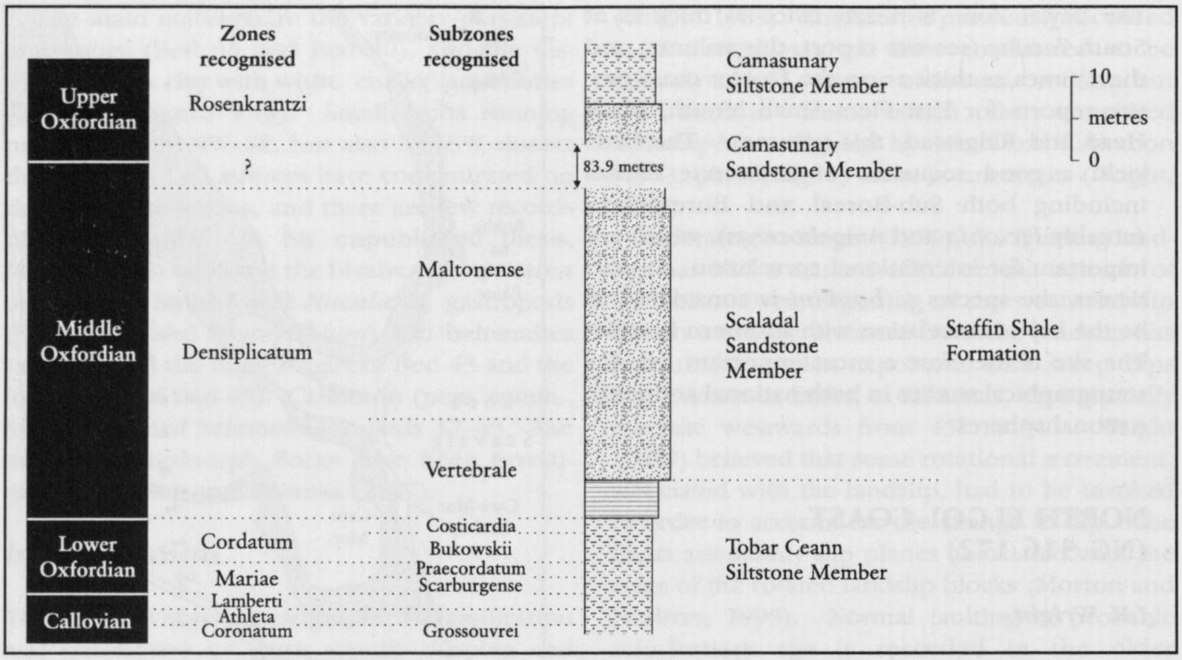

Figure 5.21 Stratigraphical log of the Elgol section (after Sykes, 1975, fig. 6).

	Thickness (m)
Staffin Shale Formation	
Camasunary Siltstone Member	
4. Blue siltstones with indeterminate bivalves and *Amoeboceras* aff. *marstonense* Spath, *Ringsteadia marstonense* Salfeld and *R.* cf. *frequens* Salfeld	seen to 7.5
Camasunary Sandstone Member	
3. Fine-grained, unfossiliferous, bioturbated sandstones with blue silty intercalations becoming more abundant towards the top. Ammonites are very scarce, with *Perisphinctes (Liosphinctes) apolipon* (Buckman) near the base and *?Amoeboceras* sp. about the middle	91.4
Scaladal Sandstone Member	
2. Series of bioturbated and ripple drift bedded, coarse-grained sandstones, baked hard by the nearby intrusion. Ammonites and bivalves are quite common: *Cardioceras (Scoticardioceras) excavatum* (J. Sowerby), *C. (Subvertebriceras) densiplicatum* Boden, *Perisphinctes* spp. and *Euaspidoceras* sp., with *Camptonectes* sp., *Pleuromya* sp. and *Oxytoma* sp.	32.6
Tobar Ceann Siltstone Member	
1b. Sandy silts with *Cucullaea* sp. and *Pinna* sp. and ammonites	4.0
1a. Silty clays and muddy sandstone with a poor fauna. Turner (1966) recorded *Cardioceras (Scarburgiceras) scarburgense* (Young and Bird) and *C. (S.) praecordatum* Douvillé. Sykes (1975) recorded *C. (S.) excavatoides* Maire	9.0
(continuation down of Tobar Ceann Siltstone into the Lamberti zone of the Callovian)	

The type section of the Tobar Ceann Siltstone is in a gully just below the lava plateau at Tobar Ceann (NG 565 196). Much of the section consists of badly weathered silty clay; however, the highest 4 m of sandy silt have yielded an abundant bivalve and ammonite fauna (Sykes, 1975).

The type section of the Scaladal Sandstone is in low cliffs at Rubha na h-Airigh Bàine (NG 517 172). Bedding structures are well displayed in the cliff, consisting of regular alternations of 0.2–0.4 m bands of coarse-grained sandstone displaying large-scale ripples, 0.5 m from crest to crest, separated by laminated, bioturbated, ill-sorted sandstone containing macroconch *Perisphinctes* sp.. The clasts range up to 4 mm in diameter, making the coarsest beds technically granule conglomerates. Numerous sedimentary clasts are present, and the rock is best classed a subgreywacke.

The type section of the Camasunary Sandstone is in low cliffs and the rock platform 100 m to the north (NG 517 173). It comprises a succession of thick-bedded, fine-grained, laminated, bioturbated quartz sandstones with erosive bases, separated by shaley, sandy partings.

The type section of the Camasunary Siltstone is in the rock platform at NG 517 178. It comprises laminated silty sandstones and siltstones, passing up into heavily baked silty shale with well-preserved *Ringsteadia*.

The Scaladal Sandstone is also exposed in the cliff at the southern end of the Carn Mor landslip (Hudson and Morton, 1969). The junction of Scaladal Sandstone resting on Tobar Ceann Siltstone is seen just above the path. The basal sandstone is a poorly sorted calcareous sandstone containing quartz grains and clasts of mudstone exceeding 2 mm diameter. Abundant ammonites infilled with mudstone rest at all angles in the sediment.

Interpretation

The basic stratigraphy of the Elgol section is, in part, similar to that at Staffin, some 55 km to the north. There is the same passage from fine-grained sediment of Mid Callovian to Early Oxfordian age into Mid Oxfordian arenaceous sediments, the Scaladal Sandstone being the equivalent of the Glashvin and Digg silts at Staffin (Figure 5.2). However, the Upper Oxfordian succession is very different, for whereas at Staffin fine, silty, micaceous clays (Flodigarry Shale) were deposited throughout the Late Oxfordian, at Elgol there was a thick incursion of fine sand, the Camasunary Sandstone, followed only in the latest Oxfordian by the silts of the Camasunary Siltstone.

Sykes (1975) discussed the contrast between the Elgol and Staffin successions in terms of sedimentation in shallow 'onshore' and deeper-water, argillaceous, offshore conditions. This was clearly the case when comparing the Brora and Balintore sections, but the comparison within the Hebrides Basin is less satisfactory. The beds that are predominantly composed of coarse clastic sediment are localized in the Elgol area. Lower Oxfordian is present 30 km to the south on the Isle of Eigg in a silty, argillaceous facies very similar to that of the Dunans Clay to the north at Staffin (Wright, 1964; Sykes, 1975). The Scaladal Sandstone, with its lithic clasts, poor sorting, large-scale ripple bedding and ammonites preserved at all angles in the bioturbated facies, gives the impression of a sediment that has been rapidly dumped by turbidity currents into deeper water at its present location without the winnowing that occurs in a shelf environment.

Turner (1966) proposed that the Elgol area had been situated close to a delta draining the Scottish landmass during the Oxfordian, and that this had produced the coarse sediment. However, the Elgol section lacks features such as laminated, bioturbated silts and channel sandstones typical of sedimentation close to delta mouths. It is more likely that erosion, consequent upon an uplift of the Scottish landmass in the Mid Oxfordian, resulted in the positioning of the Elgol area proximal to a submarine fan dumping large quantities of shelf sediments into the deeper waters of the Hebrides Basin. This feature persisted through Late Oxfordian times.

Zonally, the Tobar Ceann Siltstone has yielded ammonites belonging to both subzones of the Mariae Zone. The overlying Cordatum Zone is poorly represented. Sykes (1975) recorded one ammonite typical of the Bukowskii Subzone. The Cordatum Subzone may be absent due to erosion beneath sandy silts near the top of the Tobar Ceann Siltstone (Sykes, 1975). This concept of intraformational erosion is supported by the presence of eroded mudstone clasts in the basal Scaladal Sandstone at Carn Mor. The Vertebrale Subzone is well represented in the Scaladal Sandstone, with a varied and distinctive fauna. Antecedens Subzone *Perisphinctes* are known from the higher Scaladal Sandstone and the lower Camasunary Sandstone, but the drawing of precise zonal boundaries, particularly in the Camasunary Sandstone, is very difficult. However, the *Amoeboceras* and *Ringsteadia* of the Camasunary Siltstone allow precise attribution to the Rosenkrantzi Zone.

Conclusions

Despite the fact that the Elgol sequence is one of the most difficult of the major Oxfordian successions to study because of the baking of the sediments during the intrusion of the Cuillins Tertiary Igneous Complex, the section has considerable palaeontological and sedimentological interest. The site contains the type sections of the Scaladal Sandstone, Camasunary Sandstone and Camasunary Siltstone members of the Staffin Shale Formation. The sequence contains an important assemblage of ammonites including two zonal and five subzonal faunas with characteristics of both the Boreal and Sub-Boreal zonal schemes. The site is of importance in elucidating not only the stratigraphy of the Boreal Oxfordian but also the regional palaeogeography, as the lithologies found here comprise atypical clastic-dominated facies in a Hebrides Basin where sedimentation was predominantly of deeper-water argillaceous facies.