British Lower Jurassic Stratigraphy

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Chapter 7

The Moray Firth Basin

INTRODUCTION

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Like the Cleveland Basin to the south, the Dunrobin Coast Section represents the landward extension of a largely offshore basin intimately linked in its genesis with the extensional rift basins of the North Sea. The onshore Jurassic successions are far from continuous but include some classic sites such as the coal-bearing Middle Jurassic strata around Brora (see *British Middle Jurassic Stratigraphy* for the Brora GCR site report, Cox and Sumbler, 2002) and the Upper Jurassic 'boulder beds' at Helmsdale (Cope *et al*., 1980a; Wignall and Pickering, 1993; see also *British Upper Jurassic Stratigraphy* for the Helmsdale GCR site report, Wright and Cox, 2001). Lower Jurassic rocks are known only from the western part of the Moray Firth Basin.

Trewin (1991) summarized the Mesozoic history of the Inner Moray Firth Basin. The basin was defined and controlled by a series of major NE–SW- to ENE–WSW-trending faults, most notably the Great Glen and Helmsdale faults in the west and the Wick and Banff fault systems to the north and south respectively, with several kilometres of extension during the Mesozoic Era (McQuillin *et al*., 1982). Of these, the Helmsdale Fault was the main controlling influence on Mesozoic sedimentation, with some evidence for movement during earliest Jurassic times (Batten *et al*., 1986) and, spectacularly demonstrated at Helmsdale itself, in the late Jurassic 'boulder beds'. The Helmsdale Fault is thought to be a re-activated Caledonian structure, with rocks on the upthrow side comprising Moinian metasediments intruded by the Late Caledonian Helmsdale Granite and overlain unconformably by Lower Old Red Sandstone. Throughout much of Mesozoic times this fault would have marked the westward limit of the basin and of marine deposition.

The stratigraphical nomenclature of the Lower Jurassic succession was formalized by Batten *et al*. (1986) and revised by Richards *et al*. (1993) (Figure 7.1). The latter elevated the Dunrobin Bay Formation of Batten *et al*. (1986) to the status of a group, with the constituent subdivisions elevated to the ranks of formation. Since the Lower Jurassic Series throughout the rest of Britain is contained within the Lias Group there seems little justification for raising to such elevated rank these relatively minor stratigraphical units within the local Lower Jurassic succession. Accordingly the stratigraphical nomenclature of Batten *et al*. (1986) is followed here.

DUNROBIN COAST SECTION, HIGHLAND (ND 854 007–ND 860 009)

N.H. Trewin

Introduction

The Dunrobin Coast Section GCR site is the only exposed onshore section in the Lower Jurassic rocks of the Moray Firth Basin on the western margin of the North Sea. Besides its significance for correlation with offshore sequences, the section is unique in Britain in showing clear evidence for a freshwater to marginal marine succession. The higher part of the succession can be correlated directly with the Pabba Shales of the Hebrides Basin. It is an important site for basinal and palaeogeographical reconstructions for the Early Jurassic Epoch in Britain.

The Lower Jurassic succession at Dunrobin crops out on the shore, mainly in the intertidal zone, between ND 854 007 and ND 860 009, near Dunrobin Castle, Golspie, Sutherland. This outcrop area includes the most extensive onshore development of non-marine Lower Lias in Britain, showing an upward transition from freshwater to lagoonal and marine strata. Exposures along about 0.9 km of shore show parts of a Hettangian to Pliensbachian succession at the margin of the Inner Moray Firth Basin.

The Dunrobin section was first described by Judd (1873). Lee (1925) gave a detailed account of the section with bed-by-bed descriptions of the fauna in the upper part of the exposed succession, and further details were supplied by Sellwood (1972). The vagaries of drifting beach sand and seaweed cover seldom allow detailed examination of this section. Cored boreholes have provided information on unexposed parts of the succession (Neves and Selley, 1975). The destruction of Dunrobin Pier by storm action resulted in new exposures of the basal part of the Jurassic sequence, which were described by Batten *et al*. (1986).

Description

The rocks are intermittently exposed between ND 854 007, as intertidal reefs within the small bay west of the former position of Dunrobin Pier, and ND 860 009 where marine shales are

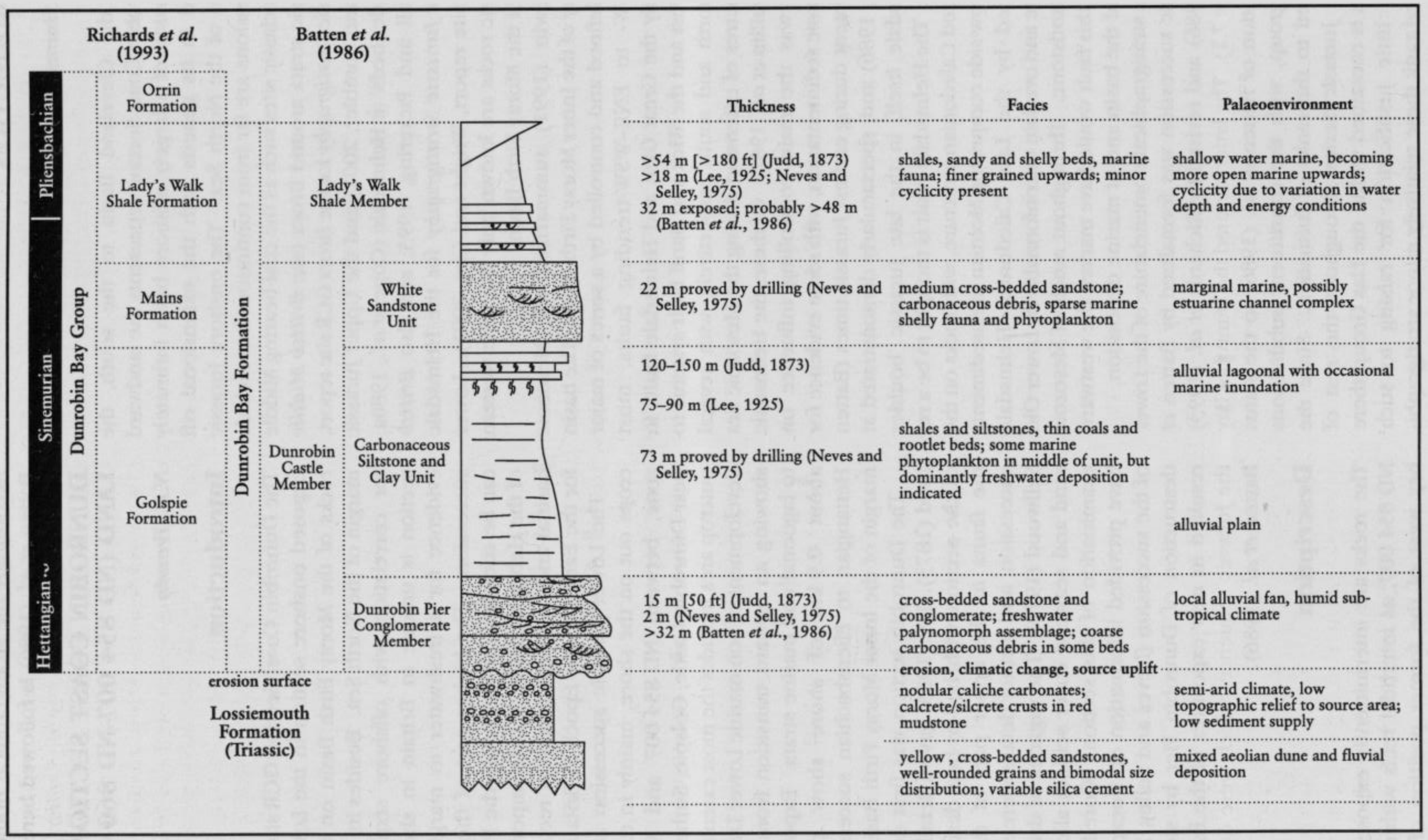

Figure 7.1 Summary stratigraphy and interpretation of the succession at Dunrobin. After Batten *et al.* (1986).

exposed on the foreshore and in a low cliff. The difficulty in measuring the section has resulted in varying estimates of the thicknesses of the units present. The stratigraphy followed here has been summarized by Batten *et al.* (1986) and is presented in Figure 7.1 with details of the various thickness estimates, major features of the succession and an interpretation of the palaeoenvironments represented.

The Dunrobin Bay Formation is divided into three members, the Dunrobin Pier Conglomerate Member, the Dunrobin Castle Member and the Lady's Walk Shale Member. The Dunrobin Pier Conglomerate Member rests on an erosion surface on the underlying clays and calcretes that mark the top of the Triassic succession in the Moray Firth, and contains reworked clasts of Triassic calcrete, silcrete and sandstone. The member is at least 32 m thick (Batten *et al.*, 1986), and includes conglomeratic sandstones, sandstones with trough and planar cross-bedding, and shaly, carbonaceous sandstones. Cross-bedding directions indicate transport to the north-east, parallel to the line of the Helmsdale Fault. The cleaner cross-bedded sandstones, cemented by poikilotopic calcite, occur as channel fills with basal erosion surfaces and stand out as reefs on the shore. The shaly, carbonaceous sandstones are seldom exposed but contain fragments of carbonized woody debris up to 20 cm long and a rich terrestrial palynological assemblage.

The succeeding Dunrobin Castle Member is divisible into two distinct units. Detail of the lower of these, the 'Carbonaceous Siltstone and Clay Unit', is known mainly from drilling (Neves and Selley, 1975). The basal 28 m comprises green-grey clays and siltstones, with red-brown shale interbeds near the base. These strata are overlain by some 45 m of rhythmic grey clays, and thin, fine-grained, buff sandstones. Carbonaceous layers, approaching coal in places, and rootlet beds are present. The microflora (Lam and Porter, 1977) is dominated by bisaccate pollen, small deltoid spores and *Cerebropollenites*. *Classopolis* is locally common and *Botryococcus* is present in some beds, while the dinoflagellates *Micrhystridium* and *Tasmanites* also occur, sometimes in flood abundances. Correlative units in the offshore Beatrice Oilfield include shales with euestheriids as well as ostracods and abundant rootlets. The White Sandstone Unit above is about 22 m thick, medium- to coarse-grained, quartzose and cross-bedded. Carbonaceous debris is common in thin shaly partings or as carbonaceous drapes on the toe-sets of cross-bedded units. Neves and Selley (1975) recorded *Micrhystridium*, *Baltisphaeridium* and *Dapcodinium* from the shale partings within the sandstone, while Lee (1925) recorded marine bivalves, including *Grammatodon*, from a mudstone unit (his Bed 2) about 2 m below the top of the sandstone.

The Lady's Walk Shale Member is the highest of the three members but exposure is poor. Lee (1925) provided a numbered bed sequence for the member, reproduced in emended form here, although some of the units he recorded are now difficult to recognize due to the poor exposure.

		Thickness (m)
Lady's Walk Shale Member		
20:	Sands, muddy, soft, poorly sorted, containing broadly oblate calcareous nodules that pass laterally into an irregularly bedded, yellow-weathering, impersistent limestone.	1.55 (5 ft)
19:	Clay, blue, with a band of limestone nodules 1 ft (0.3 m) from the base (?beds 19–21 of Lee, 1925).	1.85 (6 ft)
18:	Limestone, irregularly bedded.	0.3 (1 ft)
17:	Clay or shale, blue. *Apoderoceras* cf. *sociale*, *A.* aff. *aculeatum* and *Tragophylloceras* sp..	2.15 (7 ft)
16:	Sandstone, coarse, dark, carbonaceous, forming a reef on the foreshore.	0.28 (11 in.)
15:	Shale, sandy, with calcareous *Gleviceras* cf. *victoris*.	0.6 (2 ft)
14:	Sandstone, dark, calcareous, forming reef on foreshore.	0.15 (6 in.)
13:	Shale, sandy, micaceous.	0.15 (6 in.)
12:	Sandstone, shaly, calcareous, bluish, forming reef on foreshore.	0.15 (6 in.)
11:	Shale, sandy, hard, concretionary.	0.9 (3 ft)
10:	Shale, sandy, strongly bioturbated, micaceous; blue and less sandy in lowest 1 m.	5.5 (18 ft)
GAP		0.6 (2 ft)
9:	Shelly band, dark, passing into shelly limestone. Abundant juvenile *Gryphaea* and disarticulated *Pseudolimea*. *Paltechioceras*.	0.15 (6 in.)
8:	Mudstone, dark, with abundant *Gryphaea*, together with *Astarte*, *Cardinia*, *Pleuromya*, *Pseudolimea*, disarticulated pectinids, *Paltechioceras* and fish debris. Forms prominent reef on foreshore.	0.6 (2 ft)
7:	Shale, sandy, dark, passing into limestone.	0.3 (1 ft)
6:	Sandstone, soft, shaly, obscure.	0.05 (0–2 in.)
GAP		0.9 (3 ft)
5:	Sandstone, greenish, micaceous.	0.45 (1 ft 6 in.)
4:	Shale, sandy, micaceous and ferruginous, weathering red and brown.	0.3 (1 ft)
GAP		0.9 (3 ft)
Top of White Sandstone Unit, Dunrobin Castle Member		

Lee's quoted thickness of 18 m seems too low and at least 32 m is present (Batten *et al.*, 1986). Exposed reefs of harder rock include calcareous and muddy sandstones that are interbedded with soft shales containing calcareous concretions. Sellwood (1972) observed several coarsening-upward cycles (Type 1 cycles of Sellwood, 1970) within this part of the succession. Although traces of ripple lamination remain in some beds and a few are capped by coarse sand with scattered pebbles, the sandy tops of these cycles are generally bioturbated, with *Rhizocorallium*, *Spongeliomorpha*, *Siphonites* and *Chondrites* observed. The fauna is otherwise generally sparse, with *Astarte*, *Myoconcha*, *Modiolus* and *Gryphaea* in the sandier units, and *Mactromya* and other lucinoids also present in the mudstones (Sellwood, 1972). Two shale beds (beds 8 and 9 of Lee, 1925) are highly fossiliferous. Both contain abundant juvenile *Gryphaea* but, whereas Bed 8 is otherwise dominated by *Pseudolimea*, with original colour-banding preserved, Bed 9 contains a more diverse assemblage. *Thalassinoides* burrows in both units commonly are filled with minute bivalve-juvenile debris. Rhynchonellid brachiopods are also present and include *Tetrarhynchia dunrobinensis*, for which this is the type locality (Ager, 1956–1967). Copestake and Johnson (1989) noted that the foraminifera are abundant in the fully marine clays of the Raricostatum Zone, represented by beds 8 and 9. The top part of the succession consists of blue-grey shales, much less micaceous and with a much higher proportion of illite than the lower part of the member. Fossil preservation is poor but includes common *Pseudopecten*, *Pseudolimea* and *Cardinia*, together with *Gryphaea*, *Chlamys*, *Parainoceramus*, *Astarte*, *Grammatodon* and *Protocardia*. Calcareous concretions and several impersistent cemented sandstone beds up to 0.4 m thick are present at this level. The latter have basal erosion surfaces and contain rounded pebbles, belemnites, bivalves and woody debris. Lam and Porter (1977) recorded a rich microflora from the shales, dominated by disaccate pollen and *Micrhystridium*, with local abundance of *Classopolis* and *Cerebropollenites*.

Ammonites occur only rarely in the Lady's Walk Shale Member. Lee (1925) cited various taxa which were re-identified by Donovan (in Berridge and Ivimey-Cook, 1967). Beds 7–15 of Lee (1925) yielded *Eoderoceras miles*, *Gleviceras guibalianum*, *Gleviceras* cf. *victoris*, *Paltechioceras* sp. cf. *favrei* and *P. rothpletzi*, while Bed 17 contains *Apoderoceras* cf. *sociale*, *Apoderoceras* aff. *aculeatum* and *Tragophylloceras*. No ammonites are known from the highest part of the succession now exposed.

Interpretation

Although poorly exposed, this section is the only onshore section of the Lias succession characterizing the Moray Firth Basin. The obviously non-marine nature of the lower part of the sequence means that its age has been ascertained only on the basis of palynological assemblages and hence the position of the Triassic–Jurassic boundary cannot be identified with any certainty. Nonetheless, most, if not all, of the succession can be attributed to the Lower Jurassic Series. Palynomorphs recovered from carbonaceous sandstones within the Dunrobin Pier Conglomerate Member were considered by Batten *et al.* (1986) to be probably of Hettangian age, although a latest Rhaetian (Upper Triassic) age could not be discounted. The age of the Dunrobin Castle Member is poorly constrained but presumably falls largely, if not entirely, within the Sinemurian Stage. Only part of the Lady's Walk Shale Member has been dated with any degree of precision, due to the presence of ammonites at several levels. Lee (1925) suggested an age range encompassing the Raricostatum to Davoei zones, but this was based on the mis-identification of some of the ammonites by S.S. Buckman. It is now clear that they indicate only a narrow age range for this part of the succession; specifically a Raricostatum Zone, Aplanatum Subzone (uppermost Sinemurian) age for beds 7–15 of Lee (1925), and a Jamesoni Zone, Taylori Subzone (lowermost Lower Pliensbachian) age for Bed 17. It is possible that higher zones are present but no information is available from the youngest strata now exposed.

The base of the succession here probably is on an erosion surface on the underlying Triassic sediments, as indicated by the abundance of derived clasts of Triassic calcrete, silcrete and sandstone in the conglomerates of the Dunrobin Pier Conglomerate Member. The Dunrobin Pier Conglomerate Member is absent from correlative sections offshore, where there is a transition between presumed Triassic red-beds and Liassic shales. This localized reworking of Triassic clasts and the alignment of cross-bed flow directions parallel to the Helmsdale Fault may indicate the first evidence of Mesozoic movement on this major structure (Batten *et al.*, 1986). The sequence above represents a transition from the fluvial environment of the Dunrobin Pier Conglomerate Member to an alluvial coastal plain setting in the basal unit of the Dunrobin Castle Member. A major climatic change from the late Triassic semi-arid conditions to a more humid climate, in which a well-vegetated landmass supplied abundant carbonaceous debris, is recorded at the base of the section.

In the Dunrobin Castle Member, the Carbonaceous Siltstone and Clay Unit is dominated by freshwater palynomorphs, indicating a low-lying alluvial coastal plain: the occasional floods of dinocysts indicate intermittent marine influence (Lam and Porter, 1977). The White Sandstone Unit also contains increasing evidence of marine influence, in the form of marine microplankton and, towards the top, marine bivalves. Current exposure precludes detailed analysis but it is apparent that the sandstone represents a marine-marginal facies separating the marine facies of the Lady's Walk Shale Member above from the predominantly non-marine strata of the lower part of the Dunrobin Castle Member below. A similar sandstone is also present in the offshore Beatrice Oilfield (Stevens, 1991) and a sheet-like morphology is indicated for sandstone units at this stratigraphical level. Neves and Selley (1975) suggested deposition in an estuarine channel environment, while Stephen *et al.* (1993) envisaged a laterally migrating, sandy, estuarine or tidal-channel environment. Trewin (1993) proposed a sandy barrier bar as a possible environment, separating marine and dominantly non-marine environments. Breaching of such a barrier by the sea might account for the weak marine influence in the underlying unit.

The Lady's Walk Shale Member contains a varied, shallow marine, shelly fauna with rare belemnites and ammonites. The shales and thin sandy beds represent changing water depths, with coarse sand, pebble beds and the size-sorted nature of some shell beds indicating winnowing in a near-shore environment. The rich microflora recorded by Lam and Porter (1977) from the shales is also typical of a shallow inshore environment. Sellwood (1972) considered that benthic diversity was inhibited by high sedimentation rates rather than salinity, and that the shell beds of beds 8 and 9 (of Lee, 1925) reflect reduced sedimentation rates and substrate stabilization, perhaps associated with a transgression. However, the scarcity of cephalopods in the marine part of the sequence may indicate a restricted connection between the Inner Moray Firth Basin and fully open marine conditions in early Jurassic times.

The abundance of kaolinite in many of the shales has been considered to indicate near-shore conditions (Sellwood, 1972). The high kaolinite content might be taken to indicate a humid tropical weathering environment, but Hurst (1985) argued for a subtropical, humid Jurassic climate, and considered the abundant kaolinite to be derived from reworking of regoliths developed under humid tropical conditions in Carboniferous, rather than Jurassic times. Abundant carbonaceous debris from the adjacent Scottish landmass was available throughout deposition of the sequence. The overall upward decrease in sand, mica and kaolinite content in the Lady's Walk Shale Member is consistent with the general reduction of sandy facies associated with sea-level rise at the Sinemurian–Pliensbachian boundary in Britain as noted by Sellwood (1972). The erosive-based sandstones near the top of the Lady's Walk Shale Member may represent tempestites, analogous to those recorded by Greensmith *et al.* (1980) from the Pliensbachian of the Cleveland Basin, and indicate deposition above storm wave-base.

The succession exposed at Dunrobin bears close similarities to the sequence in the Lossiemouth Borehole (NJ 2158 6986), 50 km south-east of Dunrobin, described by Berridge and Ivimey-Cook (1967), and to correlative sections in the Inner Moray Firth Basin (Underhill, 1991; Stephen *et al.*, 1993), particularly that of the nearby Beatrice Oilfield (Linsley *et al.*, 1980; Stevens, 1991). Comparisons with the Lower Jurassic strata of Scandinavia were first made by Judd (1873), while Norling (1972) noted the similarity with the Helsingborg Formation of southern Sweden. The section contrasts markedly in lithologies, palaeontology and palaeoenvironments with Lower Jurassic sections in the west of Scotland (Hesselbo *et al.*, 1998; Morton, 1999a) which display greater open marine influence and a variety of shallow-water marine carbonates.

Conclusions

The Dunrobin Coast Section displays a transition from deposition of red mudstones and caliche soil profiles in a Late Triassic semi-arid climate, to fluvial and floodplain deposits in a wetter Early Jurassic climate. Marine conditions became established in Sinemurian times, and a shelly fauna invaded the shallow near-shore environment. Deepening marine conditions in Pliensbachian times resulted in a reduction in sandy detritus, but the area remained in a near-shore position. Although similar successions are known from offshore oilwells, and the Lossiemouth Borehole, this is the only exposed onshore sequence of the Lower Jurassic part of the Inner Moray Firth Basin succession. With its unique mix of marine and non-marine facies, the Dunrobin Coast Section represents a key point in British Liassic palaeogeography.