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NATURAL ENVIRONMENT RESEARCH COUNCIL

Stratigraphical framework for the Middle Jurassic strata of Great Britain and the adjoining continental shelf

Geology and Landscape Programme

Research Report RR/11/06



BRITISH GEOLOGICAL SURVEY

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Stratigraphical framework for the Middle Jurassic strata of Great Britain and the adjoining continental shelf

A J M Barron, G K Lott, J B Riding

Front cover

Hilltop Quarry, Leckhampton
Hill, Cheltenham, Glos.: the
Birdlip Limestone Formation
overlain by the Aston Limestone
Formation. (P775213, A J M
Barron)

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British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgs_london@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk

Shop online at www.geologyshop.com

Foreword

This report is the published product of a study by the British Geological Survey (BGS) Stratigraphical Framework Committee (SFC) for the Middle Jurassic strata of Great Britain. The report provides a summary of the lithostratigraphical scheme proposed by the SFC that aims to rationalise group and formation nomenclature for the Middle Jurassic of the entire onshore and the adjoining offshore areas of Great Britain.

This framework report provides detailed descriptions of group and formation nomenclature, specifically for the onshore area of Great Britain covering southern England, the Cleveland Basin, the Moray Firth Basin (onshore) and the Hebrides Basin. It also gives outline lithostratigraphical information regarding the offshore areas of the English Channel, Western Approaches and St George's Channel–Cardigan Bay, and the UK area of the North Sea. The report provides criteria for rationalisation of existing nomenclature where necessary. Existing names are used wherever appropriate, although where formation names have not previously existed or are unsatisfactory, the report proposes and rationalises a new nomenclature and provides a full description.

Acknowledgements

The authors would like to thank many current and former BGS colleagues for helpful discussion and suggestions, in particular M G Sumbler, B M Cox, J H Powell, D Stephenson and I J Andrews who advised on parts of this document and who created many of the lexicon entries on which this document draws. Outside BGS, the late Professor J H Callomon, Dr J K Wright and R B Chandler are acknowledged for helpful comments and discussions and the provision of documentation, some unpublished.

Thanks are also due to the Geological Society Stratigraphy Commission and their reviewers for comment and suggestions incorporated in this document.

This report has been compiled on behalf of the BGS Stratigraphy Committee, and inevitably reflects a large degree of pragmatism and compromise. The final form of the formational framework is not necessarily the preferred version of all the authors but, nevertheless, it provides a workable scheme within which any new data and subdivision can be accommodated.

If users of this document discover inconsistencies or factual errors in the specifications given for the various lithostratigraphical units, they are encouraged to notify A J M Barron, British Geological Survey, Keyworth, Nottingham, NG12 5GG (email ajmb@bgs.ac.uk).

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Summary

The Stratigraphy Committee of the British Geological Survey (BGS) is undertaking a review of stratigraphical classification for all parts of Great Britain. Several Stratigraphical Framework Committees (SFC) have been established to review problematical issues for various parts of the stratigraphical column. Each SFC has the following terms of reference:

- To review the lithostratigraphical nomenclature of designated stratigraphical intervals for a given region, identifying problems in classification and correlation.
- To propose a lithostratigraphical framework down to formation level that can be used as a central reference by geologists working in the region concerned.
- To organise peer review of the scheme.
- To present the results in a document suitable for publication.
- To ensure that full definitions of the lithostratigraphical units are held in the web-accessible BGS Lexicon of Named Rock Units for the areas of responsibility covered by the SFC.

The process of erecting a framework requires decisions to be taken about correlations and equivalences leading to a simplified nomenclature. Inevitably, many names will be rendered obsolete. The frameworks are lithostratigraphical and though each is set against a chronostratigraphical reference column, the finer points of the chronostratigraphy of the succession are not the prime concern.

The predominantly Middle Jurassic rocks discussed in this report have been considered by the Jurassic Stratigraphical Framework Committee under the leadership initially of M G Sumbler (who compiled an initial draft in 2003) and, after 2001, A J M Barron. The report introduces a lithostratigraphical framework to formation level for the Middle Jurassic succession of Britain and adjoining offshore areas. It applies to the main outcrops and subcrops (where the strata are present at depth), and the offshore occurrences. It follows on, with an extended geographical brief, from the stratigraphical framework report for the Lower Jurassic of England and Wales (Cox et al., 1999).

The onshore distribution has been divided into six depositional areas; the Wessex–Weald Basin, the Cotswolds, the East Midlands Shelf, the Cleveland Basin, the Moray Firth and the Hebrides, although for practical reasons the essentially arbitrary lateral limits of the first three may differ for various stratigraphical levels.

The economic importance and availability of natural and man-made exposures of Middle Jurassic strata has resulted in well over 200 years of research attempting to classify them. Much of this work occurred long before guidance was available for best practice in naming lithostratigraphical units, and there has been a haphazard approach to the establishment of the hierarchy of units. From an early, relatively simple framework, subsequent publications have greatly added to the complexity of the nomenclature. Often this reflected the localised nature of research with different names being applied to essentially the same unit in different areas. Also, previously laterally contiguous deposits have been separated, eroded or concealed by post-Jurassic tectonic, igneous or sedimentary events and processes.

Chapter 1 of this report is an introduction to the Middle Jurassic Series and the included proposals. It indicates the principles for the development of the new lithostratigraphical scheme and sets out the key publications used for reference.

Chapter 2 summarises the structural and palaeogeographical setting of Great Britain through the Middle Jurassic and sets out the definitions, history and development of the basins.

Chapter 3 briefly describes the key techniques (principally biostratigraphy) for correlation of successions, and sets out the basis for the establishment of the chronostratigraphical framework.

Chapter 4 outlines the development of the lithostratigraphical framework.

The fifth (Chapters 5 to 8) and largest part of the report provides a fuller description of the stratigraphical framework for each of the six onshore groups – the Inferior Oolite, Great Oolite, Ravenscar and Ancholme groups in England, and the Great Estuarine and Sutherland groups in Scotland, subdivided as appropriate into regions and/or palaeogeographical provinces. Each entry includes a description of the origin and history of the nomenclature, rank and subdivisions, principal lithologies, type area and reference sections, geographical extent, lower and upper boundary, thickness, age range, environment of deposition and key references.

Chapter 9 gives a concise account of the framework for the offshore regions, related to the onshore sequences. Definitions of the offshore Fladen, West Sole, Brent and Humber groups and their component formations are not given as the full schemes are formally and satisfactorily published elsewhere (Lott and Knox, 1994; Richards et al., 1993; Ritchie et al., 1996).

1 Introduction

Jurassic strata are widespread through Great Britain and the adjacent continental shelf (Figure 1). This report outlines a proposed lithostratigraphical framework and nomenclature down to formation level for the rocks of Mid Jurassic age of Great Britain and the adjacent continental shelf. Table 1 sets out the relevant and adjacent geological time terms (epochs) and chronostratigraphical ('time-rock') terms (series and stages).

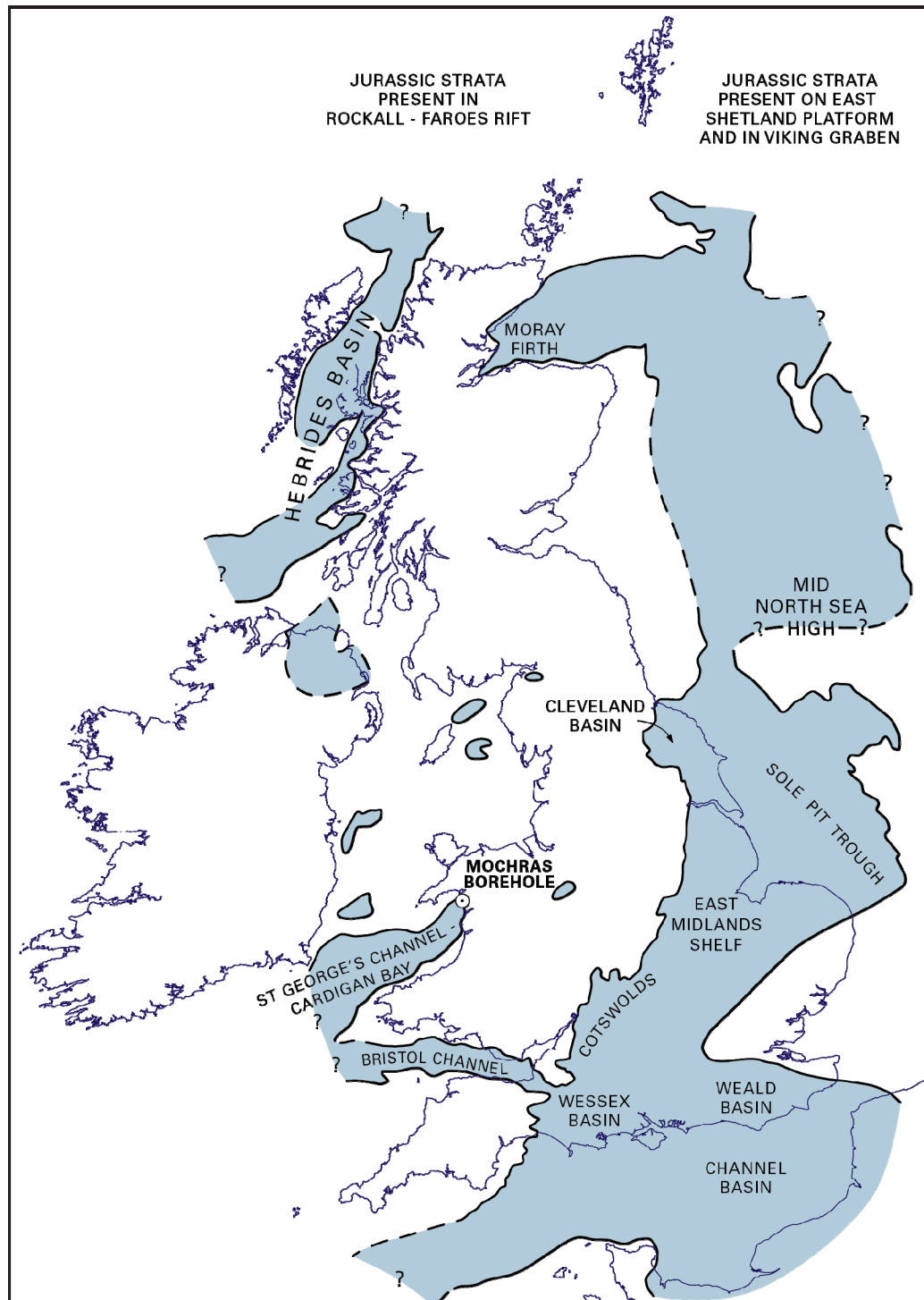


Figure 1 Distribution of Jurassic strata in Great Britain, Northern Ireland and the adjacent continental shelf.

Major depositional areas shown.

The stratigraphical levels of both the base and the top of the Middle Jurassic were formerly a matter of debate (see Torrens, p 2 in Cope, 1980; Cox and Sumblar, 2002, pp. 3-4), with the positions of the Aalenian and Callovian being contentious, but there is now considerable international consensus, set out by Ogg et al. (2008), whose scheme is followed here. The base of the Middle Jurassic Series is taken at the base of the Aalenian, which, as internationally recognised and defined, lies in the Fuentelsaz section in northern Spain (Cresta et al., 2001), and the top of the Series (\equiv base of Upper Jurassic Series) is defined as the Callovian–Oxfordian stage boundary, although the reference section for the boundary is yet to be internationally ratified. Thus the series spans the Aalenian, Bajocian, Bathonian and Callovian stages (Table 1), and the bases of the Bajocian and Bathonian stages are ratified (Ogg et al., 2008).

EPOCH	SERIES	AGE/STAGE	AGE OF BASE OF STAGE (Ma)
Late Jurassic (part)	Upper Jurassic (part)	Oxfordian	161.2
Mid Jurassic	Middle Jurassic	Callovian	164.7
		Bathonian	167.7
		Bajocian	171.6
		Aalenian	175.6
Early Jurassic (part)	Lower Jurassic (part)	Toarcian	183

Table 1 Middle Jurassic geochronological and chronostratigraphical terms.

Ages from Ogg et al. (2008).

The Middle Jurassic strata present onshore include the 'traditional' Inferior Oolite and Great Oolite groups, and the relatively more recently defined Ravenscar and Ancholme groups in England, and the Great Estuarine Group and newly proposed Sutherland Group in Scotland, together with the formations as yet unassigned to groups in some regions. Offshore Middle Jurassic strata are assigned to the Fladen, West Sole, Brent and Humber groups in the North Sea, and elsewhere tentatively to onshore units.

The strata are up to about 1300 m in thickness onshore and up to 1000 to 1200 m offshore (excluding the volcanic rocks interleaved in the offshore sedimentary successions), and represent about 14 million years of Earth history. In southern England the predominant lithologies are marine mudstones and carbonates, but in the East Midlands, Yorkshire, Scotland and the North Sea, sediment types are more diverse, with major intercalations of mainly arenaceous fluvial, deltaic and paralic strata.

The included definitions of the Inferior Oolite Group, Great Oolite Group, Ravenscar Group, Great Estuarine Group and Sutherland Group and of the component and 'standalone' formations form the basis for the entries in the British Geological Survey Lexicon of Named Rock Units which, when complete, will provide definitions for all the lithostratigraphical terms found on current, published BGS maps. The BGS Lexicon can be searched via the BGS internet pages (<http://www.bgs.ac.uk/Lexicon/home.cfm>).

A 'bottom up' approach has been adopted, confirming and/or refining the definitions of generally well recognised formations or, to a lesser degree, proposing new. Where appropriate, these have then been assembled into formal groups, most of which are also traditional or well established. The names of any newly defined units follow the recommendation of Rawson et al. (2002, p. 6) to avoid duplication of use of a geographical epithet. However, in the interests of stability of nomenclature, there are no proposals to eliminate duplication by arbitrary changes to the names of well-established units (e.g. Staffin Bay Formation and Staffin Shale Formation).

The literature on the geology and stratigraphy of the Jurassic of Great Britain stretches back well over 200 years and is very extensive, although in some cases obscure. Readily available publications of particular value to stratigraphical and palaeogeographical studies (mainly from the last 30 years) are as follows:

- Arkell, W J. 1933. *The Jurassic System in Great Britain*. (Oxford: Clarendon Press.) – an extraordinarily thorough and perceptive account of the Jurassic strata found in Great Britain, published when the (sole) author was 29 years old.
- Donovan, D T, and Hemingway, J E. 1963. *Europe; Fasc.3a England, Wales and Scotland; Pt.3a X Jurassic*. Lexique stratigraphique international. No. 1. (Paris, France: Centre national de la recherche scientifique.) – a valuable listing of British Jurassic units with learned bibliographical information.
- Cope, J C W, (editor) 1980. *A correlation of the Jurassic rocks of the British Isles. Part Two: Middle and Upper Jurassic*. Geological Society of London Special Report. No. 15. – a systematic review of the correlation of Middle and Upper Jurassic strata, with much detail on derivation of terms and full references. Some citations below refer to sections within this volume. A new edition of this publication is currently in preparation (see below).
- Chapters by Mudge, Callomon and Cope, and Morton and Hudson in Taylor, P D, (editor) 1995. *Field geology of the British Jurassic*. (London: Geological Society.) – a collection of descriptions of the exposed Jurassic strata of some regions by their foremost experts.
- Bradshaw, M J, Cope, J C W, Cripps, D W, Donovan, D T, Howarth, M K, Rawson, P F, West, I M, and Wimbledon, W A. 1992. Jurassic. 107–129 in *Atlas of palaeogeography and lithofacies. Geological Society Memoir No. 13*. Cope, J C W, Ingham, J K, and Rawson, P F (editors). (London: Geological Society of London.) – a series of palaeogeographical maps of the wider British Isles and adjoining seas, with thorough supporting text describing changing environments and facies but with limited stratigraphical information.
- Cox, B M, and Sumblar, M G. 2002. *British Middle Jurassic Stratigraphy*. Geological Conservation Review Series. No. 26. (Peterborough: Joint Nature Conservation Committee/Chapman and Hall.) – a valuable account of important exposures in Middle Jurassic strata, divided into the same regions as herein, together with much stratigraphical rationale. Some citations below refer to chapters within this volume.
- Cope, J C W. 2006. Jurassic: the returning seas. in *The geology of England and Wales*. Brenchley, P J, and Rawson, P F (editors). (London: Geological Society.)
- In the 1990s, the UK Offshore Operators Association sponsored BGS to compile a series of volumes setting out a comprehensive lithostratigraphical scheme with full definitions for the UK continental shelf areas, and those that describe Middle Jurassic units are: Lott, G K, and Knox, R W O B. 1994. Post-Triassic of the Southern North Sea. in *Lithostratigraphical nomenclature of the UK North Sea*. Knox, R W O B, and Cordey, W G (editors). (Nottingham: British Geological Survey.); Richards, P C, Lott, G K, Johnson, H, Knox, R W O B, and Riding, J B. 1993. 3. Jurassic of the Central and Northern North Sea. in *Lithostratigraphical nomenclature of the UK North Sea*. Knox, R W O B, and Cordey, W G (editors). (Nottingham: British Geological Survey.); Ritchie, J D, Gatliff, R W, and Riding, J B. 1996. 1. Pre-Tertiary stratigraphy. in *Lithostratigraphical nomenclature of the UK north west margin*. (Nottingham: British Geological Survey.). The included definitions closely follow the structure of the BGS Lexicon of Named Rock Units, and it was judged unnecessary to reproduce them here.

The authors have also benefited from consulting Cox, B M, and Sumbler, M G. in prep. Bathonian–Callovian Correlation Chart. In *A correlation of Jurassic rocks in the British Isles: Middle and Upper Jurassic*. Cope, J C W (editor). *Special report of the Geological Society of London*. This will form part of a new comprehensive reference work replacing the 1980 edition.

The succession has been studied by many people over the years, and now includes numerous named units. Recently, many of these units have been given formal status as members, formations etc. but in many cases little systematic consideration has been given to their explicit definition or boundaries, or to their lateral continuity and relationship to correlative units. Full, and in parts revised, lithostratigraphies with properly defined formations have been proposed for all the regions/basins, with remaining problems highlighted. These are as follows: the Inferior Oolite Group, Great Oolite Group and Ancholme Group of southern England (see sections 5.1, 5.2 and 5.3), the Ravenscar Group and Dogger, Cayton Clay and Osgodby formations of the Cleveland Basin of Yorkshire (see Chapter 6), and the Great Estuarine Group, Bearreraig Sandstone, Staffin Bay and Staffin Shale formations of the Hebrides (see Chapter 8). A substantially new scheme has been devised for the Sutherland Group (Middle Jurassic portion) of the Moray Firth (see Chapter 7).

In the text and definitions below, National Grid References are given in square brackets, onshore boreholes are identified by the BGS Registration Number in the form SP57SW9 where the first six characters indicate the 1:10 000 National Grid sheet. BGS 1:50 000 (or 1:63 360) scale sheet numbers are given in parentheses after the sheet name in the form Cirencester (E&W 235) or Broadford (S 71W) indicating England & Wales or Scotland sheets, respectively.

2 Palaeogeography and basin definitions

During the Jurassic Period, Britain lay about 20° latitude further south than now (i.e. approximately between 30 and 40 °N). The climate was warm and humid, with high rainfall and high carbon dioxide levels (Cope, 2006; Morgans et al., 1999), leading to intense weathering and erosion in the emergent areas and substantial runoff carrying suspended sediment and dissolved compounds into the surrounding seas. The warm climate and high levels of atmospheric CO₂ encouraged both chemical and biogenic marine carbonate deposition particularly where conditions were favourable.

The end-Triassic break-up of the Pangaea supercontinent formed extensional rifted basins in the region of north-west Europe, anticipating the early stages of the opening of the Atlantic. The British Isles was situated towards the southern end of a roughly north–south seaway between the continents of Laurentia (including Greenland) and Fennoscandia (Scandinavia) in an area of islands separated by shallow (less than 100 m deep) seas (Figure 2). This archipelago tended to inhibit free exchange or mixing of warmer Tethyan water from the south and colder Boreal water from the north, and in general the northern depositional areas are characterised by terrigenous clastic, marginal marine and nonmarine sedimentation typified by the sediments of the Ravenscar, Great Estuarine, Brent, Pentland and West Sole groups. In the south, the marine carbonate-dominated successions of the Inferior and Great Oolite groups were deposited under warm-water Tethyan influences (Figure 2).

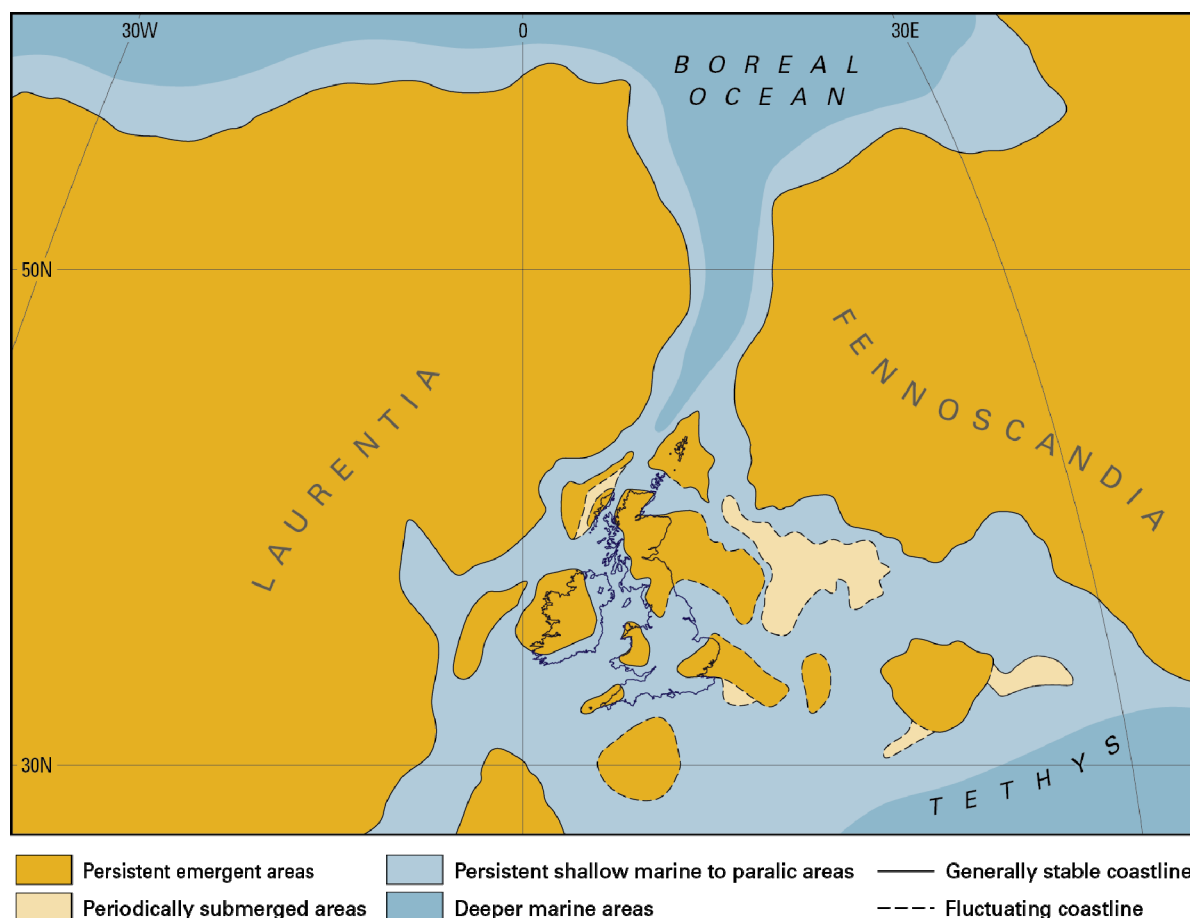









Figure 2 Generalised Mid Jurassic subglobal palaeogeography.

(after Ziegler, 1990, encls 24 to 26, and Bradshaw et al., 1992, figs J4a to J8, and with acknowledgments to Ron Blakey, Northern Arizona University Geology)

The principal rifted basins were in the North Sea, Bristol Channel, St George's Channel–Cardigan Bay and English Channel and around the Hebrides (Figure 3). In the British Isles region, through the Jurassic, the intervening structural highs included the generally long-lived Cornubian, Welsh, Anglo-Brabant, Scottish, Shetland, Hebrides, Irish and Armorican platforms, which through subsidence/uplift and/or relative sea-level change, periodically fluctuated in size and relief, coalesced or submerged, although some remained partly emergent throughout the period. Relief of some of these (including the Scottish and Scandinavian landmasses) may have attained 500 m, with high ground of resistant igneous and metamorphic rocks, providing substantial volumes of relatively coarse sediment to the basins at times. Others such as the Anglo-Brabant and possibly the Welsh landmasses had generally more subdued relief of highly weathered sedimentary rock with possibly intermittent runoff generating smaller amounts of finer sediment, permitting deposition of autochthonous carbonate sediments in the surrounding shallow shelf seas through much of the period. Subsidiary or more transient emergent areas which are important in the Mid Jurassic include the Pennine High, Mid North Sea High and London Platform. Intervening depositional areas include various basins and shelves (Figure 3) that are described below.

The Early Jurassic was generally a period of global sea level rise, with a time of maximum transgression in the mid Toarcian (Bradshaw et al., 1992). In late Toarcian times widespread regression affected most if not all of the British Isles, probably caused by crustal upwarping with associated vulcanicity in the southern North Sea. Following this, most of the Mid Jurassic (Aalenian to Bathonian) is characterised by relatively modest changes in sea level (both eustatic and related to regional uplift/subsidence) and moderate subsidence of the shelf areas. Nevertheless, as a result of the gently shelving margins of some of the land areas, these caused major changes in shoreline positions and configurations, and depositional environments. Consequently, many of the formations are relatively thin and laterally variable and impersistent, facies belts migrate laterally through time and there are many minor and more major non-sequences and instances of overlap. An exception is the Cleveland Basin–Sole Pit Trough depocentre which underwent rapid subsidence during the Bajocian to Bathonian. Through the Callovian and into the late Jurassic, there is a pattern of general, largely eustatic sea level rise, leading to contraction of land areas and deposition of fine-grained siliciclastic sediments throughout Britain.



- | | |
|---|--|
|  | Persistent emergent areas |
|  | Periodically submerged areas, paralic to shallow marine deposition |
|  | Generally persistent depositional areas, shallow marine to paralic |
|  | Lava plateau |
|  | Fault, tick indicates downthrow side |
|  | Generally stable coastline |
|  | Fluctuating coastline |

Abbreviations:

- | | |
|-----|-----------------------|
| PT | Peak Trough |
| MWH | Market Weighton High |
| MH | Mendip High |
| SDH | South Dorset High |
| VMA | Vale of Moreton Axis |
| HDH | Hampshire-Dieppe High |
| WSB | West Shetland Basin |

Figure 3 Generalised Mid Jurassic palaeogeography of the British Isles.
(after Bradshaw et al., 1992, figs J4a to J8 and Ziegler, 1990, encls 24 to 26)

2.1 SOUTHERN BRITAIN (COTSWOLD, WESSEX, WEALD, CHANNEL, WESTERN APPROACHES, BRISTOL CHANNEL AND ST GEORGE'S CHANNEL–CARDIGAN BAY BASINS)

In late Early Jurassic times (Toarcian) at the time of maximum transgression, land areas around southern Britain (south of the English Midlands) were probably restricted to Armorica in the extreme south, Cornubia, and a reduced area of low-lying and gently shelving land (Anglo–Brabant Landmass) extending east from the centre of the London Platform (Figure 3) (Bradshaw et al., 1992). The eastern coastline of Cornubia was probably relatively steep such that it was fairly stable in position and configuration. Wales was formerly thought to be a Jurassic land area but the thick marine Lower Jurassic sequence proved in the Mochras Borehole (Figure 1) (Woodland, 1971) throws some doubt on this, and although its extent through the Mid Jurassic is conjectural (Bradshaw et al., 1992; Cope, 2006), it almost certainly included land in Snowdonia, Mid Wales and at times the Malverns district. During the end-Toarcian regression and following uplift in the North Sea, existing coastlines generally advanced basinward, notably around the Anglo–Brabant Landmass, the Welsh landmass emerged or expanded (possibly joining with the Pennine Landmass to the north-east), and the intervening sea areas shallowed. Palaeozoic to Triassic sedimentary rocks were widely exposed on these areas, plus lesser expanses of granite in Cornubia and older rocks around Wales, providing sources of predominantly siliciclastic sediments.

Many of the depositional areas around southern Britain were controlled or strongly influenced by rift faulting, trending predominantly east–west in the Wessex and Channel basins, east–west and north–west–south–east in the Bristol Channel and east–north–east–west–south–west in the Western Approaches and St George's Channel–Cardigan Bay, to the extent that thicknesses are very variable, and continued tectonic activity had a major effect on the preservation and present distribution of the strata (Figure 3; Figure 4). In the Worcester Basin (Severn Basin of Bradshaw et al., 1992), major pulsed subsidence within a complex north–south graben structure had abated, having generated a very thick Permian to Early Jurassic sediment pile. Its western edge was probably the Malverns, but no Jurassic strata are preserved here to provide evidence. However, in the east, its margin is formed by the Vale of Moreton (or Moreton) Axis (Figure 3), which acted rather like a hinge, with strata thinning and/or changing in facies eastwards across it (Barron et al., 2002; Sumblar et al., 2000). Here and in the adjoining and similarly less tectonically active northern margin of the Weald Basin (the Cotswold–Weald Shelf) more gradual basin floor subsidence, at least partly due to sediment compaction, took place through the Mid Jurassic, and as subsidence kept pace with deposition, shallow marine conditions persisted in which carbonate sediment deposition (ooids, peloids and bioclasts) dominated with only brief interludes of fine terrigenous sand deposition (Inferior Oolite and Great Oolite groups). However, for much of the Aalenian to Bathonian, at least in the Worcester Basin, the water was so shallow and remote from the open sea that ammonites infrequently reached here and are rare in the rocks, although a shelly benthic fauna and infauna is abundant. From time to time, cessation or reduced carbonate sedimentation led to 'hardground' formation, some very widespread and an aid to correlation, others more localised.

At the southern end of the Worcester Basin the east–west Mendip High (Figure 3) was a long-lived and significant influence on sediment deposition and preservation, from the late Carboniferous into the Bathonian. Aalenian to lower Bajocian strata are absent adjacent to the Mendip High but are seen to the south in the Wessex Basin (Somerset and Dorset), where a complex succession is preserved (Inferior Oolite Group), which records a pattern of deposition in a shallow shelf sea connected to the Tethys Ocean (Figure 2) but in which (amongst other factors) the presence of intrabasinal high areas (e.g. the South Dorset High; Figure 2) and faults subject to synsedimentary movement led to periods of widespread sediment starvation and erosion, and rapid lateral changes in deposition and preservation. A decrease in the effects of the South Dorset and Mendip highs and subsidence of the wider Wessex, Weald and Channel basins and the Cotswold–Weald Shelf permitted the onset of predominantly land-derived silicate mud

deposition in the Bathonian, which extended as far as the Vale of Moreton Axis (Fuller's Earth Formation). In Wessex, mudstone (including lime-mudstone) deposition continued up to the late Bathonian (Frome Clay and Forest Marble formations) but the zone of carbonate sediment accumulation that became established in early mid Bathonian on the shelves to the north and east (Cotswold–Weald Shelf and later the East Midlands Shelf) prograded south-west as far as Bath, the Isle of Wight and the Sussex coast. In the late Bathonian, further relative sea level rise extended marine mud deposition even further north-east (Forest Marble Formation). Brief regression across most, if not all, of southern Britain was followed by the very widespread end-Bathonian transgression which deposited marine limestone (Cornbrash Formation, lower part). Although followed by a short further regression, eustatic sea level rise continued during the Callovian, at first depositing the upper (limestone) part of the Cornbrash, then as water deepened and coastlines retreated the area of marine deposition across southern Britain was enlarged, with reduced land areas in Anglo–Brabant, the Pennines, Cornubia and Ireland, and possibly Wales. Terrigenous silicate mud deposition dominated (Kellaways Clay Member and Oxford Clay Formation), although early on, a sheet of fine sand was widely deposited (Kellaways Sand Member).

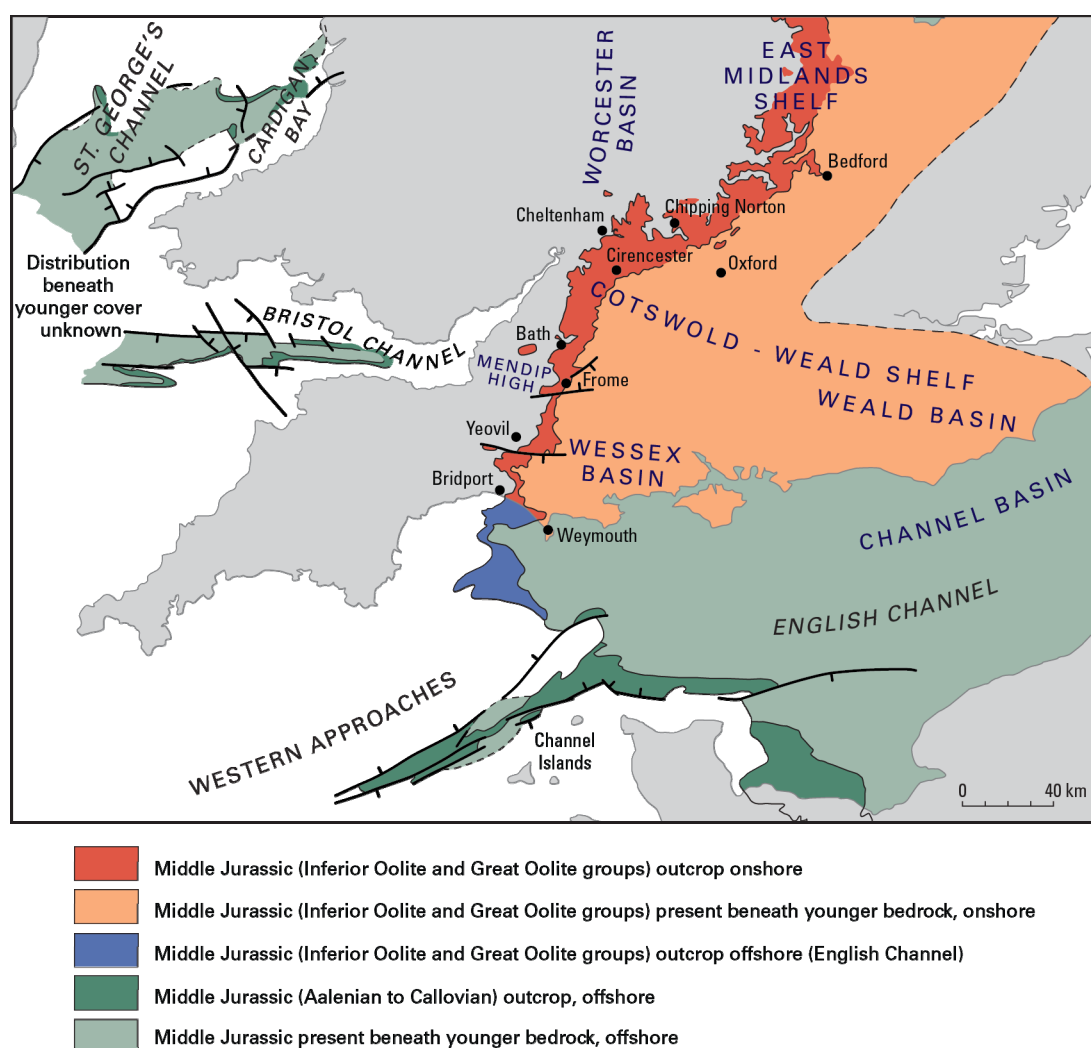


Figure 4 Distribution of Middle Jurassic strata of southern Britain including adjacent offshore areas.

(Onshore and Cardigan Bay–St. George's Channel based on BGS mapping; offshore based on Hamblin et al. 1992, fig. 2, Tappin et al. 1994, fig. 2)

2.2 SOUTHERN BRITAIN (EAST MIDLANDS SHELF, CLEVELAND BASIN AND SOUTHERN NORTH SEA)

The emergence of the Mid North Sea High (Figure 3) in latest Early Jurassic to Aalenian times had a profound influence on deposition in the Cleveland Basin, East Midlands Shelf and southern North Sea area throughout Mid Jurassic times. There was a change from generally low energy and relatively deep marine mudstone deposition (Lias Group) to paralic and higher energy shallow marine conditions with considerable terrigenous sediment input. As well as the Mid North Sea High shedding sand largely derived from Triassic rocks, the conjoined and enlarged Pennine Landmass was generating fine- to coarse-grained siliciclastic sediment from Carboniferous and Permo-Triassic rocks, and predominantly fine-grained sediment was eroding from Lower Palaeozoic to Jurassic rocks on the separate, fairly low-lying Anglo-Brabant Landmass to the south. In addition, at least in Aalenian times, weathering and erosion on these land areas was also producing dissolved ions, notably iron.

A major influence on the intervening basins throughout the Mid Jurassic was the formation and continued development of extensional rifts and half-grabens in the Cleveland Basin and North Sea, notably the Peak Trough and Sole Pit Trough (Figure 3). The East Midlands Shelf also underwent long episodes of modest subsidence. Coupled with relatively minor eustatic sea level changes during the Aalenian to Bathonian, this led to considerable changes in the palaeogeography.

The development of major fluvial systems in the hinterlands of the Pennines and Mid North Sea High led to the construction of extensive floodplains and deltas extending into the Cleveland Basin and adjacent North Sea. These coalesced into a large coastal alluvial floodplain, albeit with very variable sediment input from several sources. Subordinate marine units at some levels in the Ravenscar Group and West Sole Group indicate intermittent marine incursions such as the Eller Beck Formation, the Lebberton Member of the Cloughton Formation and the Leckenby Formation. However, not all have proved to be correlatable between the onshore and offshore sequences (see section 9.1). This may indicate that subsidence took place at different times across the area, and marine incursions progressed from different directions, possibly in part due to movements on the major fault systems.

Subsidence and sediment accumulation on the relatively unfaulted and stable East Midlands Shelf was discontinuous because of periodic shoaling and local emergence. Generally lower energy siliciclastic and carbonate sediment buildup took place here (Inferior Oolite and Great Oolite groups), in conditions ranging from fully marine (Lincolnshire Limestone Formation, Oxford Clay Formation) to nonmarine (parts of the Grantham and Rutland formations).

Intermittent transgressions over low-lying deltaic and land areas in this region caused major fluctuations in coastlines, followed by sea-level fall or uplift leading to erosion. Thus there is a complex pattern of interdigitating facies and breaks in deposition, non-sequences or disconformities. There were no protracted periods of continuous marine deposition until the major sea level rise of the Callovian, and consequently faunas seen in much of the Aalenian to Bathonian successions are largely brackish to semi-marine and biostratigraphically indicative ammonites are generally rare. Callovian and upper Jurassic strata in the region are composed overwhelmingly of marine mudstone (Ancholme Group), hundreds of metres thick, and overlying and overlapping the Bathonian succession, such that Middle Jurassic strata are very widely preserved across the region (Figure 5).

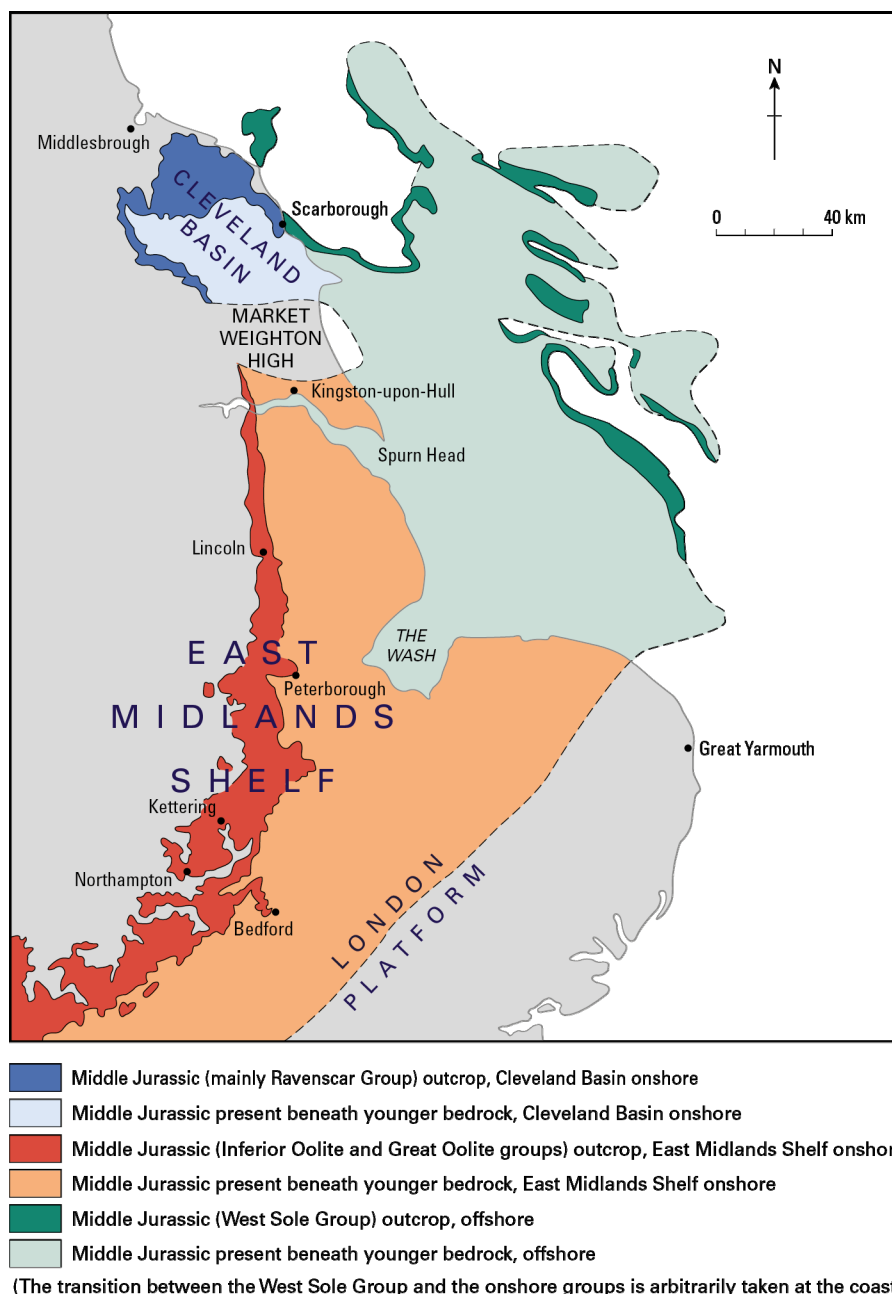


Figure 5 Distribution of Middle Jurassic strata of the Cleveland Basin, East Midlands Shelf and adjacent North Sea.

(Onshore based on BGS mapping; offshore distribution after Cameron et al. (1992, fig. 2), and Lott and Knox (1994, fig. 6))

2.3 MORAY FIRTH BASIN

The Moray Firth Basin was a region of substantial siliciclastic sediment deposition in the Jurassic, fringed by long-lived emergent areas that in part roughly coincide with modern land (Figure 3). Marginal and intrabasinal faulting (Figure 6) was influential, and included features with substantial strike-slip sense (Andrews, I J et al., 1990, pp. 8-13), for example it is thought that there was about 8 km of transcurrent movement on the Great Glen Fault between the Permian and the Cretaceous (McQuillan et al., 1982).

Through most of the Early Jurassic the Moray Firth Basin formed part of the larger depositional area of the North Sea. However, from the late Toarcian through the Aalenian, Bajocian and early Bathonian, thermal uplift associated with volcanicity formed a large plateau – the Mid North Sea

High (Figure 3), severing the north–south marine connection. Aalenian to earliest Bathonian strata are unproven both on- and offshore in the basin. This apparent absence may simply be a result of non-exposure onshore, but offshore in the Inner Moray Firth an unconformity has been inferred, although in places there is evidence of continuous deposition from the Toarcian to late Bathonian (Richards et al., 1993, p. 78).

Although the date of commencement is uncertain, subsequent deposition throughout the Moray Firth Basin was more-or-less continuous, dominated at first by fluvial and paralic processes up to the late Bathonian. Deltas may have prograded as far as the Orkney Islands, although the presence of shelly macrofauna and microfauna at some levels indicate brief marine incursions into coastal lagoons and swamps (Brora Coal Formation). The sea level rise commencing in the early Callovian brought prolonged marine deposition to the basin (StrathSteven Mudstone, Clynekirkton Sandstone, Balintore, Beatrice and Heather formations), initially to the western (including onshore) area, but then progressed eastwards. Full reconnection of the North Sea depositional areas may not have occurred until Late Jurassic (Oxfordian) times, with continued sea level rise and gradual subsidence of the Mid North Sea High.

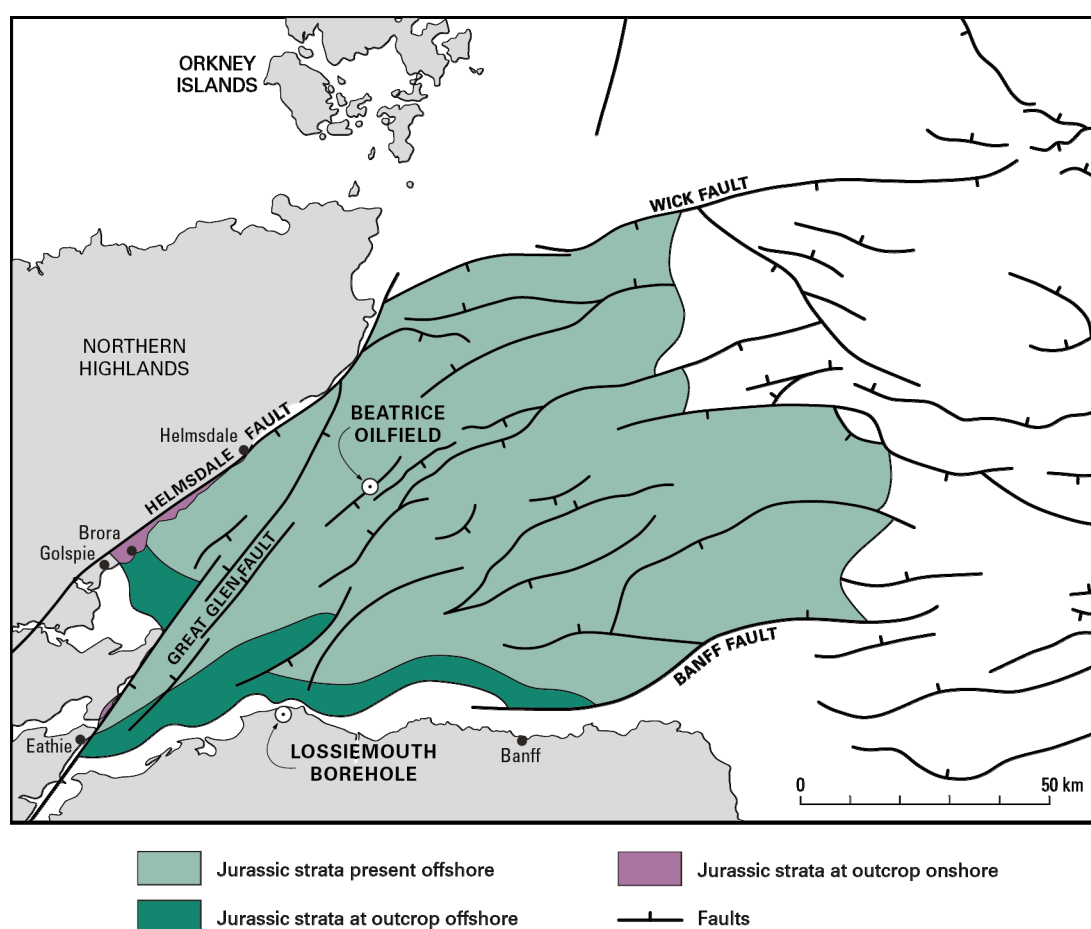


Figure 6 Structural features and distribution of Jurassic strata (Hettangian to mid Oxfordian) of the Moray Firth Basin.

(Based on Andrews, I J et al., 1990, fig. 30)

2.4 HEBRIDES BASIN

Throughout the Jurassic, a region of substantial sediment deposition lay between the long-lived emergent Scottish Landmass and the Hebrides Platform (Figure 3). This is referred to herein as the Hebrides Basin (Bradshaw et al., 1992; Hudson and Trewin, 2002; Morton and Hudson, 1995), and synonymous with the Minch Basin of Hudson (1964, p. 521). It was, in part, fault-bounded (Figure 7), and may be described as a half-graben (Morton and Hudson, 1995, p. 209,

Based on the facies, the distinction was greatest during the Mid Jurassic (Fyfe et al., 1993) and can be demonstrated most clearly for the deltaic sandstone-dominated formations (Elgol and Valtos formations) (Harris, 1989, 1992), although the similarities in facies and successions in the finer-grained units (particularly the Lealt Shale, Duntulm, Kilmaluag and Skudiburgh formations) (Harris and Hudson, 1980) strongly indicate long periods of depositional continuity across the region. Thus despite the difficulties in correlation of the succession across the basin stemming from the separation and concealment of the outcrops by the Tertiary igneous rocks and the sea (Figure 7), generally many of the formations and members are recognised basinwide.

The Hebrides Basin lies between the Minch Fault, which skirts the eastern coast of the Outer Hebrides and may approximate to a western shoreline in the Jurassic, and an eastern, largely unfaulted margin probably close to the modern west coast of the mainland, but less well-defined and subject to fluctuation (Hudson and Trewin, 2002). Although generally narrowing northwards, and subject to periodic shoaling, the Basin was probably connected to the sea at both ends through most of the period.

The Hebrides Platform probably formed a more extensive land area of exposed Lewisian rocks with higher relief than now. However, it is thought to have been a less significant source of sediment to the basin than the Scottish Landmass, where a regolith derived from Devonian Old Red Sandstone overlay metamorphic and sedimentary Neoproterozoic Moine, Dalradian and Torridonian rocks, and Cambrian sedimentary rocks (Hudson, 1964). The Scottish Landmass also suffered recurrent uplift further rejuvenating sediment supply.

The most influential and persistent intrabasinal structure is a postulated high, running south-south-west from Applecross through south-west Skye and Rum, that is bounded to the east by the Camasunary Fault (Figure 7). Various known as the Central Skye Palaeohigh and the Mid-Skye Palaeohigh (Harris, 1989, figs 1, 15) it is termed here the Mid-Skye High following Bradshaw et al. (1992) who note it as 'shallow bank' or 'locally emergent' on palaeogeographical maps.

Following the sea-level fall in late Toarcian times and consequent disconformity, marine deposition was re-established (Bearreraig Sandstone Formation). Further fluctuations in sea level (see above) and basin floor subsidence throughout the Mid Jurassic gave rise to a complex succession of paralic sedimentary strata, ranging from alluvial to lagoonal and littoral with only transient marine influence (Great Estuarine Group), but with remarkable lateral continuity of some beds and formations (Hudson and Trewin, 2002, pp 337-338). The early Callovian marine transgression, seen throughout northern Europe, progressively inundated the basin area, with marine deposition re-established at different times (Staffin Bay Formation) (Hudson and Trewin, 2002, pp 348-349). Fully marine conditions followed, generating the ammonite-bearing Staffin Shale Formation.

2.5 ROCKALL–FAROES RIFT

Continued extensional rifting in the central Atlantic formed the Rockall–Faroës Rift north and west of the Hebrides Platform – a major north-east–south-west-trending complex rifted basin, with a number of parallel intrabasinal faults and highs. Nonmarine to paralic sedimentation is likely to have been widespread, albeit intermittent here, sourced from the Hebridean and Hatton–Rockall highs (De Jager, 2007).

3 Biostratigraphical and chronostratigraphical framework

The following borrows heavily from Cox and Sumblar (2002, chap. 1).

Traditionally, the principal fossils utilised for subdividing the Jurassic System into its chronostratigraphical stages are ammonites, a subclass (Ammonoidea) of free-swimming cephalopods that were numerous in the Jurassic seas, and whose shells may be preserved in abundance, and show evidence of their rapid evolution. These characteristics not only make ammonites ideal fossil zonal indicators, but have ensured that they have been collected, catalogued and studied intensively by many geologists, such that many museum collections exist, including at BGS, and highly detailed schemes of zones have been erected.

In some parts of the Middle Jurassic succession in Britain (e.g. Kellaways and Oxford Clay formations) ammonites are abundant, but in much of the succession the protected marine or paralic depositional environments were unfavourable to ammonite colonisation, and they are consequently rare. However, the succession of ammonite faunas (as found in the wider British region) still provides the basis for the chronostratigraphical subdivisions of the stages (Table 2) but the standard ammonite-based zones may have to be determined indirectly using other fossil or microfossil groups, such as palynomorphs, or by correlating other recognisable basinwide events). Following standard practice, the chronozones and subzones are written in Roman font with initial capitals (e.g. Discus Zone).

Stage	Zone	Subzone
AALENIAN	Concavum	Formosum
		Concavum
	Bradfordensis	Gigantea
		Bradfordensis
	Murchisonae	Murchisonae
		Obtusiformis
		Haugi
	Scissum	
	Opalinum	

Stage	Substage	Zone	Subzone
BAJOCIAN	Upper	Parkinsoni	Bomfordi
			Truellei
		Garantiana	Acris
			Tetragona
			Dichotoma
	Subfurcatum	Baculata	
		Polygyralis	
		Banksi	
	Lower	Humphriesianum	Blagdeni
			Humphriesianum
			Romani
		Sauzei	
		Laeviuscula	Laeviuscula
			Trigonalis
			Sayni
	Ovalis		
	Discites		

Stage	Substage	Zone	Subzone	
BATHONIAN	Upper	Discus	Discus	
			Hollandi	
		Retrocostatum	Hannoveranus	
			Blanazense	
			Quercinus	
	Middle	Bremeri	Fortescostatum	
			Bullatimorphus	
		Morrisi		
		Subcontractus		
		Progracilis	Progracilis	
			Orbigny	
		Lower	Tenuiplicatus	
			Zigzag	Yeovilensis
Macrescens				
Convergens				

Stage	Substage	Zone	Subzone
CALLOVIAN	Upper	Lamberti	Lamberti
			Henrici
		Athleta	Spinosum
			Proniae
			Phaeinum
	Middle	Coronatum	Grossouvrei
			Obductum
		Jason	Jason
			Medea
	Lower	Calloviense	Enodatum
			Calloviense
		Koenigi	Galilaei
			Curtilobus
			Gowerianus
		Herveyi	Kamptus
Terebratus			
Keppleri			

Table 2 Chronostratigraphical subdivisions of the Middle Jurassic Series.

(from Cox and Sumblar, 2002, fig. 1.3)

Although ammonites found many Mid Jurassic environments in the British Isles region unsuitable for colonisation, many other plant and animal groups prospered, and other shelly remains of macrofossils are particularly abundant in many strata. Notable amongst these are bivalves, gastropods and brachiopods, all of which have been studied and classified in detail. Though each of these is to a greater or lesser degree facies-controlled, and some species/genera are very long ranging, many have been utilised as biostratigraphical indicators, but generally of restricted application. For instance, certain gastropods of the genus *Aphanoptyx* have been found to form an evolutionary series and have assisted in correlation of horizons in the White Limestone Formation (Great Oolite Group) of the Cotswolds (Sumbler, 1984). S S Buckman, as well as undertaking much of the foundation work on ammonite biostratigraphy (e.g. Buckman, S S, 1905a), expended much effort in erecting stratigraphies based on brachiopods. That for the Cornbrash (Buckman, S S, 1927), was soon modified by Douglas and Arkell (1928, 1932), and has subsequently been related to the ammonite zonation and proved to have stratigraphical value (see for instance Callomon and Cope, 1995, pp. 76-77).

Both calcareous and organic microfossils also have great relevance to the biostratigraphy of the Middle Jurassic. The principal calcareous microfossil groups comprise calcareous nannofossils, foraminifera and ostracods. Palynomorphs (organic-walled microfossils) include indigenous marine and terrestrially derived forms. Examples of the former are dinoflagellate cysts, and the latter are pollen and spores. All these groups of microfossils are present throughout the Middle Jurassic. Many studies have been undertaken on the distribution of these groups in important reference successions which are calibrated by ammonites. This approach has allowed parallel biozonations to be constructed which allow microfossils to be used as primary biostratigraphical indicators.

4 Lithostratigraphical framework: group level

Southern England

In the onshore Wessex and Weald basins (and extending offshore into the Channel Basin; see p. 155 below) and across England as far as Market Weighton in Yorkshire, the Lower Jurassic Lias Group is overlain in turn by the **Inferior Oolite** and **Great Oolite** groups of Aalenian to earliest Callovian age. The Great Oolite Group is in turn overlain by formations of Middle to Upper Jurassic age, which from Oxford northwards are combined in the **Ancholme Group** (Table 3).

STAGE	WESSEX	MENDIP HIGH	COTSWOLDS- OXFORDSHIRE	EAST MIDLANDS TO NORTH HUMBERSIDE	MARKET WEIGHTON AXIS	YORKSHIRE	MORAY FIRTH	HEBRIDES	
CALLOVIAN	Oxford Clay (part)		Oxford Clay (part)	ANCHOLME (part)		Osgodby	SUTHERLAND (part)	Staffin Shale (part)	
	Kellaways		Kellaways			Cayton Clay Cornbrash		Staffin Bay	
BATHONIAN	GREAT OOLITE		GREAT OOLITE	GREAT OOLITE		RAVENSCAR		SUTHERLAND (part)	GREAT ESTUARINE
BAJOCIAN	INFERIOR OOLITE		INFERIOR OOLITE	INFERIOR OOLITE					Dogger
AALENIAN									

Table 3 Middle Jurassic groups of onshore Great Britain.

The terms Inferior Oolite and Great Oolite originally referred to limestone dominated 'formations' in the Bath area, coined at the turn of the 18th and 19th centuries, and later gave their names to 'series', i.e. the groups of modern usage. In fact, there is very little lithological or palaeo-environmental distinction between the two, and in many places, little or no stratigraphical break. It could be argued that they should be combined into a single group or, alternatively, that the thick mudstone formations which occur in the lower part of the Great Oolite in the south-west Cotswolds and Wessex Basin, and dominate the succession on the Dorset coast, should be excluded and combined in a new group. Arkell (1933, p. 231) believed that the most significant break lay within the Inferior Oolite, and that the overlying 'Upper Inferior Oolite' beds would be better linked with the basal formations of the Great Oolite. However, in the interests of nomenclature stability, continuity with the earliest days of English stratigraphical studies, and the wider public understanding of geology, we recommend that the group terms, and their broad definitions be retained.

In Dorset and south-east Somerset, the Inferior Oolite has of late been treated by BGS as a formal formation on the grounds (amongst others) that it cannot be subdivided for geological mapping

purposes. The late Professor John Callomon (University College London; email communication to AJMB 13/10/04) favoured the use of a single formation in this region, which he regarded as divisible into members (without suggesting any viable units or names), although he also suggested extending the Inferior Oolite Formation [sic] to the Vale of Moreton Axis, with the Group subdivided into several formations only to the east of here. This treatment is not adopted (see also Chapter 5), and it is proposed here to confirm the status of the Inferior Oolite as a group throughout the UK and that in south-west England (south from near Bath) the succession is not formally divided below group level (see Section 5.1 below; Table 4; Figure 8). This does not preclude such subdivision at a later date, given sufficient data. Where the group is most thickly developed in the mid and north Cotswolds (Figure 8), the three formations of Barron et al. (1997) are confirmed, having proved entirely recognisable and able to be subdivided into formal members.

In north Lincolnshire in the Kingston-upon-Hull and Brigg districts (British Geological Survey, 1982a, 1983; Gaunt et al., 1992), the term 'Redbourne Group' was coined by the BGS for the combined Inferior Oolite and Great Oolite, on the imprecise grounds that the succession there is thin (24 to 70 m) relative to that elsewhere and that it contains a proportion of nonmarine units. Neither of these arguments is valid; the succession is comparable in thickness and facies with other areas on the East Midlands Shelf, where Inferior Oolite and Great Oolite have traditionally been applied; indeed the Inferior Oolite and Great Oolite are more readily separated than in the Cotswolds type area, as the marine Lincolnshire Limestone Formation (of similar facies to the type Inferior Oolite) is overlain by 'estuarine' sands, with a major erosive nonsequence between the two. Therefore it is recommended that the terms Inferior Oolite Group and Great Oolite Group should be applied throughout southern England (i.e. south of the Market Weighton High).

Throughout southern England, the Great Oolite Group is overlain by a thick succession dominated by marine mudstone. North of Oxford, this is divided in ascending order the Kellaways, Oxford Clay, West Walton, Ampthill Clay and Kimmeridge Clay formations, which are assembled into the Middle to Upper Jurassic (Callovian to Kimmeridgian) **Ancholme Group**; a term of considerable utility, especially in the subsurface (away from the outcrop), where the formations commonly cannot be differentiated. South-west of Oxford, the Upper Jurassic (Oxfordian) Corallian Group lies approximately at the level of the West Walton Formation, separating the remaining Ancholme Group formations above and below. Thus the Corallian and Ancholme groups are mutually exclusive in geographical range. The Ampthill Clay and Kimmeridge Clay are beyond the scope of this report, but a case could be made for combining the underlying Kellaways and Oxford Clay (Middle to Upper Jurassic) into a new group, although this is not favoured here.

The Great Oolite Group is divided into a large number of formations; an indication of this is given in Table 5 (p. 46). Many of these formations extend across regions, but some are of very local extent, and only one (the Cornbrash) extends across the whole country. To a large extent, this is a correct reflection of the geology; considerable vertical and lateral facies changes characterise the succession. Nevertheless, some rationalisation of nomenclature may be possible in the long term, as indicated below. Some 'formations', of particularly limited distribution might better be regarded as members, although in other cases the converse may be true. In addition, there are almost certainly a number of redundant names listed below (see *Informal subdivisions* or *Other subdivisions*), although there are still sufficient uncertainties in correlation to warrant great caution in trying to eradicate them. In some cases, long accepted correlations are based on dubious grounds and may prove false, so that additional names may yet have to be introduced. There is still a lot to be learnt, and premature establishment of a rigid nomenclature could constrain future work.

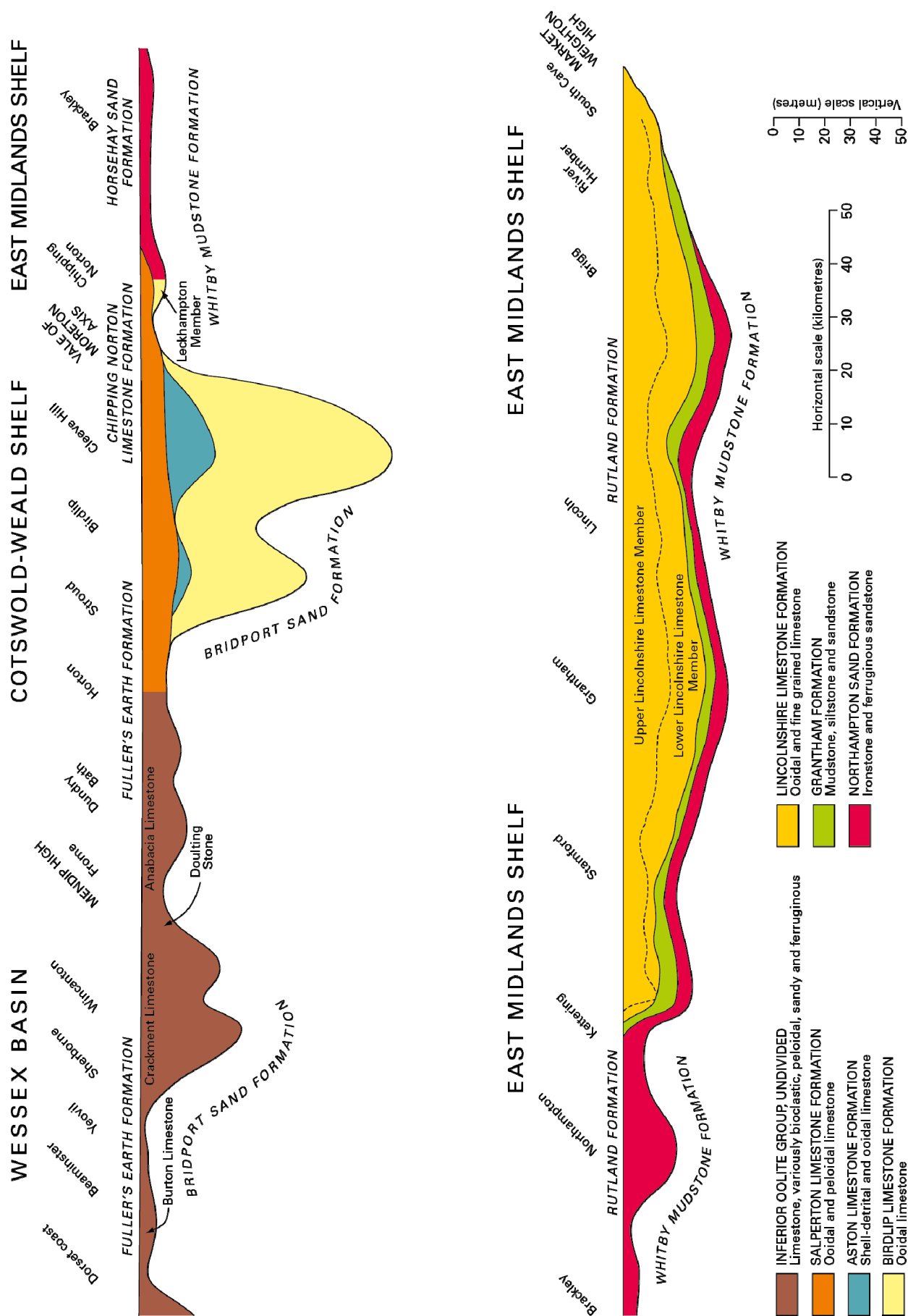


Figure 8 Schematic section along the outcrop of the Inferior Oolite Group from the Dorset coast to Market Weighton.

Cleveland Basin

For a brief account of the history of research and the formation level nomenclature see Section 6.

In the Cleveland Basin, strata are present ranging in age throughout Mid Jurassic times, and the lithostratigraphical nomenclature is unique to the region. The strata equivalent in age to the Inferior Oolite and Great Oolite (Aalenian to Bathonian) are dominated by paralic and fluvial facies with thin fully marine units, and the majority of this succession was formerly termed the (Great?) Estuarine Series (Phillips, 1875). This term was considered inappropriate by Hemingway (1949, see also Hudson, 1962, pp. 163-164) who renamed it the 'Deltaic Series' (also 'Yorkshire Deltaic Series'). Hemingway and Knox (1973) later assigned the strata to the **Ravenscar Group** (Table 3), fully subdivided into formations (Section 6), in keeping with modern stratigraphical practice. From early on, the thin Dogger Formation at the base of the succession was excluded, and resides on its own between the Lias and Ravenscar groups because it is essentially a marine sediment, although similar marine intercalations occur within the Ravenscar Group (notably the Eller Beck and Scarborough formations). Similarly, the thin Cornbrash Formation, lying above, is excluded from the group; elsewhere in England, this unit, persistent from Dorset to Yorkshire is the topmost formation of the Great Oolite Group. As much of the Jurassic succession has been removed by Cretaceous erosion across the Market Weighton High, the Ravenscar Group is isolated within the Cleveland Basin, and we do not, therefore, have the problem of defining its southern limit onshore. Its general lack of age-diagnostic fossils renders close correlation with other sequences problematical. However, a broad correlation with the Grantham Formation (Inferior Oolite Group) to Rutland Formation (Great Oolite Group) succession of the East Midlands Shelf may be inferred from the presence of sparse ammonites in the Scarborough Formation (Parsons, 1980a), certain ostracod evidence (Bate, 1965, 1967a) and determinations of marine palynomorphs from the Scalby Formation (Riding and Wright, 1989). Offshore the Ravenscar Group can be correlated with strata forming the median part of the West Sole Group (Section 9.1).

The remaining Middle Jurassic formations (Dogger, Cornbrash, Cayton Clay and Osgodby) in the Cleveland Basin are not assigned to groups and no change is proposed. The Oxford Clay Formation is represented here only by the uppermost part (Weymouth Member), which is entirely Upper Jurassic (Oxfordian).

Moray Firth

For a brief account of the history of research and the formation level nomenclature see Section 7.

In formalising the onshore Moray Firth Middle Jurassic succession (see Section 7 below) neither Sykes (1975) nor Hurst (1981) assigned their formations to any group. Simms et al. (2004, p. 310) implicitly included the Lower Jurassic Dunrobin Bay Formation in the Lias Group of England. A considerably revised scheme of formations within a formal group structure (see Section 7 below) is proposed here. R A Smith of BGS erected a 'Sutherland Group' (Table 3) for BGS digital map data in 2000 which included the entire Jurassic succession, ranging down possibly into the latest Triassic, but a definition remained unpublished. The group appeared on the BGS Stratigraphical Chart for northern Britain (Waters et al., 2007) despite Simms' usage of Lias in this region. R A Smith's definition with revisions is confirmed herein, to encompass the succession from the onshore Dunrobin Bay Formation (probably Hettangian to Pliensbachian) to the Helmsdale Boulder Beds Formation (Kimmeridgian to Tithonian). Despite the succession's conspicuous heterolithic nature, with substantial unknown sections (notably the entire Toarcian to Bajocian), it possesses considerable unity and deposition is inferred to have been more-or-less continuous in an overwhelmingly clastic paralic or nearshore environment.

Hebrides Basin

The presence of sedimentary rocks with ammonites on the islands of the Inner Hebrides has been known since the late eighteenth century (see Anderson and Dunham, 1966, p.7), and descriptive accounts including correct identification of Middle Jurassic rocks date from almost 200 years ago, including the introduction of the term 'Loch Staffin Beds' for the strata exposed in north-

east Skye (see also Hudson, 1962b; Murchison, 1829b). A thorough account of the history of research is given by Cox and Sumbler (2002, pp.365-366) also briefly set out below and in Section 8.

The terrain and geology impose considerable difficulties for recording and collecting from the strata, not least the high and steep sea cliffs, and the presence of Palaeogene volcanic rocks, the effects of which include thermal alteration, pervasive bed-parallel and cross-cutting minor intrusions, separation of outcrops by major intrusions and blanketing by lava flows.

Early descriptions of the Jurassic succession generally used terms referring to inferred correlations with units in England, fossil content, relative position in the sequence or readily visible physical characteristics (see Section 8). However, a major grouping of presumed genetically related beds was named by Judd (1878, p.722) the 'Great Estuarine Series', to exclude the underlying and overlying marine 'Inferior Oolite' and 'Oxford Clay' (see Hudson, 1962b, pp. 141-142). This was adopted by the Geological Survey when mapping commenced in the 1890s (Cox and Sumbler, 2002, p. 366), and proved to be of great utility, including, locally, as a mappable unit (British Geological Survey, 2002a), where subdivision was impracticable. Nonetheless, the Great Estuarine Series was divided and detailed stratigraphical schemes were erected for the various districts (see Section 8). Hudson (1962b, pp. 144-146) revised the definition of the 'series', excluding some marine beds at the top, and expressed some reservations about the appropriateness of the term 'Estuarine', pointing out that many of the environments were lagoonal or nearshore (1962b, pp. 163-164). Later, with Harris, he proposed the '**Great Estuarine Group**' (Harris and Hudson, 1980; Hudson and Harris, 1979) (Table 3; Table 9). This term has achieved universal currency in the literature, and for reasons of familiarity and stability of nomenclature it is retained herein.

The exclusion of the marine Middle Jurassic strata as stand-alone formations underlying (Section 8.1) and overlying (Section 8.3) the group is also fully accepted in the literature and herein.

North Sea Basin

In the UK sector of the North Sea, the Middle Jurassic depositional basin formed the western part of a shallow epicontinental basin that extended eastwards through the Netherlands into Poland, and from southern Germany to Norway in the north. Connections through the North Sea linking a northern Boreal Sea, via the Central and Viking Graben systems, to a Tethyan Ocean to the south were maintained for much of the Middle Jurassic period (Figure 2). Throughout the Middle Jurassic the eastern limit of the northern North Sea Basin was marked by nonmarine, clastic sedimentation along the Fennoscandian High, while to the west a similar pattern of sedimentation developed along the rifted margins of the Shetland Platform and Mid North Sea High.

Locally, however, subsidence patterns in the North Sea basin were disrupted, most notably by the developing thermal uplift of the Mid North Sea area, beginning in the late Toarcian–Aalenian and continuing into the mid Oxfordian, before collapse and renewed subsidence and transgression occurred (Callomon, 2003; Underhill and Partington, 1993).

The palaeogeographical position of the North Sea area in subtropical latitudes throughout the Mid Jurassic also meant that sedimentation in UK basins are characterised by both warm-water Tethyan influences from the south, and cold-water Boreal influxes from the north. In general in the Aalenian to Bathonian, the northern depositional areas are therefore characterised by siliciclastic, marginal marine and nonmarine sedimentation seen in the offshore **Fladen** (Section 9.2) and **Brent** (Section 9.3) groups, and the northern portion of the **West Sole Group** (Section 9.1), and their onshore correlatives (Ravenscar and Great Estuarine groups). Further south a gradual transition is evident in the West Sole Group to more marine carbonate-dominated successions of the equivalent formations of the onshore Inferior and Great Oolite groups. In the central and northern North Sea, the Fladen and Brent groups are overlain by the Callovian–Oxfordian **Humber Group** (Section 9.4).

English Channel Basin

In the English Channel Basin the succession is closely comparable with that of the contiguous onshore basin areas of southern England and the Inferior and Great Oolite groups, Kellaways and Oxford Clay formations are present (see Chapter 9, *English Channel*).

Western Approaches Basin

Based largely on seismic reflection evidence, Middle Jurassic sediments are inferred to be preserved only as isolated fault-bounded remnants in the Western Approaches Basin (Figure 4) and little is known of their facies and stratigraphy (see Chapter 9, *Western Approaches*).

Bristol Channel and St George's Channel–Cardigan Bay basins

A succession equivalent in age to the Inferior and Great Oolite groups and Kellaways and Oxford Clay formations is preserved in fault-bounded basins in the Bristol Channel and St George's Channel–Cardigan Bay (Figure 4). Although the strata present are somewhat different in lithofacies, with significant siliciclastic intercalations, the use of the southern Britain onshore terms is extended into the area (Tappin et al., 1994): see formation entries below and Chapter 9, *Bristol Channel and St George's Channel–Cardigan Bay*.

Hebrides Basin (offshore)

Middle Jurassic strata are present in several largely contiguous fault-bounded offshore basins in both the Inner and Outer Hebrides area (Figure 7) (Buckman, S S, 1923; Fyfe et al., 1993; Stoker et al., 1993). The succession can be referred to the Bearreraig Sandstone Formation (Section 8.1.1), overlain by the Great Estuarine Group (Section 8.2), followed by the Staffin Bay and Staffin Shale formations – probable Humber Group equivalents (sections 8.3.1 and 8.3.2). Stoker et al. (1993, p.54) observe that Jurassic strata are widely present in the West Orkney–Hebrides Shelf but extension of the onshore Hebrides stratigraphical scheme into this area is poorly constrained. Where recorded the succession rests conformably on marine Lower Jurassic strata.

West Shetland and Faroe–Shetland basins

Through the Jurassic a series of localised nonmarine to marine depositional settings developed in the Rockall–Faroes Basin, but west of the Shetland Platform proven Middle Jurassic strata beneath the Upper Jurassic Kimmeridge Clay Formation are relatively limited occurrences of the Rona Formation and the Heather Formation, both of marine origin. All three formations are assigned to the Humber Group (Ritchie et al., 1996).

5 Southern and eastern England

5.1 INFERIOR OOLITE GROUP (INO)

The Inferior Oolite Group is present throughout southern and eastern England south of the Market Weighton High, extending offshore into the English Channel (Figure 4 and Figure 5) and ranges from Early Aalenian to earliest Bathonian in age (Table 4). Apart from in the Wessex Basin (south Cotswolds to Dorset), the group is fully divided into formations (Table 4 and Figure 8). For the purposes of description the account below is divided into three depositional areas: the Wessex Basin, the Cotswolds–Weald Shelf and the East Midlands Shelf, all of which extend offshore. The extension of the Wessex Basin south into the English Channel lies to the south of an important west-north-west-trending structural high – the South Dorset High (Green, 1992, fig. 27). To the east (though offset by faulting) is the similar trending, partly offshore Hampshire–Dieppe High (Hamblin et al., 1992, figs 20 and 30). The Hampshire–Dieppe High divides the offshore Wessex Basin from the Weald Basin to the north, where more Cotswold-like facies and thicknesses are preserved.

Wessex Basin

For the purposes of description of the Inferior Oolite Group, the Wessex Basin onshore can be regarded as the geographical region that extends from the Dorset coast near Bridport, through Dorset into east Somerset and to the southern end of the Cotswolds near Bath (Figure 4). The northern part of the basin deepened east into the Weald. In this region the Inferior Oolite has been accorded formation status (Bristow et al., 1999; Cope, 2006, p 341; Cox and Sumblér, 2002) – the ‘Inferior Oolite Formation’. For geological mapping purposes this would seem appropriate as subdivision into recognisable and regionally persistent units (i.e. formations) proved impossible (see also Bristow et al., 1995). However, for the purposes of the formal stratigraphical framework the succession is regarded herein as the indivisible Inferior Oolite Group.

As outlined in 2.1 above, the condensed succession of thin beds of highly bioturbated, ammonite-bearing limestone, capped by hardgrounds forming sharp bed boundaries records a pattern of deposition in a shallow but well connected shelf sea (Figure 3), generally rather starved of sediment, and subject to repeated synsedimentary movement on a number of intrabasinal faults. This led to differential subsidence, with concomitant lateral facies and thickness changes and local erosion, such that a highly condensed succession was generated ranging from less than two to over forty metres thick (Figure 8), and its preservation at any one place is very unpredictable, and correlation across the basin is problematical (Callomon and Cope, 1995).

The availability of coastal sections and numerous quarries and the rich fossil content in the Inferior Oolite sequence led to a long history of study and collecting from the early days of English geology, and a brief account is given by Cox and Sumblér (2002, pp. 16–17). The chronostratigraphical ‘Lower’, ‘Middle’ and ‘Upper Inferior Oolite’ terms have been applied to the succession, based on the presence of perceived widespread unconformities and biostratigraphical determinations (Callomon and Cope, 1995). The plethora of local bed and unit names (some unique to one locality) that resulted from this research is exemplified by Parsons (1980a, columns AB1 to AB17) and many are rather archaic or unhelpful. Cox and Sumblér (2002, fig. 2.3) set out a somewhat simplified listing, but also recognised the difficulties of establishing a formal lithostratigraphical scheme. However, they accepted five units in the Shaftesbury district (Bristow et al., 1995) as formal members (Corton Denham, Miller’s Hill, Sherborne Building Stone, Rubbly and Crackment Limestone) even though none are claimed to continue south-west to the classic south Dorset sections; nor could all be recognised in the

neighbouring Wincanton district by the same authors (Bristow et al., 1999) and none can be mapped out, even at 1:10 000 scale. Thus, no strong case has yet been made for any laterally persistent formal members. Those of Bristow et al. (1995) and other named but informal units of some lateral persistence are listed below. Further study and consultation is required to progress this exercise, including the possibility of assembling these into viable formations.

Offshore from the Dorset coast (Lyme Bay), the Inferior Oolite succession thickens to 20 m in similar facies, but east on the Hampshire–Dieppe High is highly condensed – represented by a metre of limestone (Hamblin et al., 1992, p 46).

Cotswold–Weald Shelf

The Inferior Oolite succession's passage northwards into the three Cotswold formations (Birdlip Limestone, Aston Limestone and Salperton Limestone) is regarded here as occurring in the area north of Bath (see paragraphs below). These formations satisfy standard stratigraphical requirements, including being separated by regionally persistent breaks, and being consistently recognised in borehole cores and in the field. Each can be divided into distinct formal members, themselves composed of distinct beds, but many of these are of more limited geographical extent and ease of recognition.

Farther south, in the centre of the Weald Basin, the Aalenian to Bajocian sequence that accumulated shows many lithological similarities to that of the Cotswolds, attaining up to 170 m in thickness and differentiated into 'Lower Inferior Oolite', 'Middle Inferior Oolite' and 'Upper Inferior Oolite' (Gallois and Worssam, 1993). However, further study is required to determine whether these might be assigned the Cotswold formational names.

The approximate location of the northward passage into the formation(s) of the Cotswold succession is uncertain. The natural area would seem to be around the Mendip High, which was generally a profound influence on deposition, but the picture is not clear cut as peloid/ooid-dominated limestones, indicating extension of Cotswold-shelf type depositional conditions, are seen further south. Most of the south Dorset units are sparsely or non- (calcareous) ooidal, but there is a gradual increase in ooid content northwards, although this is not at all levels nor is it progressive, so it is not thought to be a strong criterion for drawing a distinction. The succession on Dundry Hill, over 20 km to the north of the Mendips, was divided by Parsons (1979) into five named members unique to the location, none conspicuously ooidal. The lower part bears a much stronger resemblance to that of Dorset–Somerset (Green, 1992), whilst Parsons claims the upper is more comparable with the nearby Cotswolds, and correlates them with that succession.

From south of Bath to near Horton, Gloucestershire the Aalenian to Lower Bajocian units of the Inferior Oolite – the Birdlip Limestone and Aston Limestone formations of the north Cotswolds, and the dissimilar 'Lower' and 'Middle Inferior Oolite' of Dundry Hill and Wessex are absent, and the Upper Bajocian rests unconformably on the Lias Group, so the change between is not seen. On the main escarpment, the gradual change in lithology northwards into peloidal and pisoidal limestone of the Upper Bajocian to Bathonian Clypeus Grit Member (the majority of the Salperton Limestone Formation of the Cotswolds) was thought by Green (1992) to take place south of the Horton, Gloucestershire area [ST 76 84] on the Malmesbury (E&W 251) sheet (British Geological Survey, 1970) with a lateral passage from ooid limestones he assigned to the Doultong Stone/Anabacia Limestone, and which are identified as far south as Doultong in Somerset (Bristow et al., 1999). Recent observations by one of the authors (AJMB) in the Bath district have generally confirmed the dissimilarity of the Upper Bajocian sequence there with that of the north Cotswolds, although locally Clypeus Grit-like lithologies were recorded. For the above reasons, we propose to draw the southern limit of the named Inferior Oolite formations for pragmatic purposes at the boundary between the BGS sheets Malmesbury (E&W 251) (British Geological Survey, 1970) and Bath (E&W 265) (British Geological Survey, 2011) [grid line northing 816], until further work is done to clarify any necessity to subdivide or further classify the succession in Wessex.

East Midlands Shelf

Continuity between the Cotswolds–Oxfordshire sequence and that of the East Midlands is provided by a single formal unit – the Leckhampton Member, which passes east into the Northampton Sand Formation near Chipping Norton, north-west Oxfordshire. The Northampton Sand is the sole representative formation of the Inferior Oolite through north-east Oxfordshire and south Northamptonshire to Kettering, where the Grantham Formation and Lincolnshire Limestone Formation appear above it. This tripartite division holds good northwards through the north-east Midlands and Lincolnshire almost to the Humber, where the Northampton Sand Formation fails (overstepped by the Grantham Formation; Gaunt et al., 1992), the Grantham Formation persisting a few kilometres further before itself being (probably) overstepped by the Lincolnshire Limestone approximately at the Humber. North of the river, the Lincolnshire Limestone Formation continues to Market Weighton, where it is overstepped by Cretaceous strata. This constitutes the northern limit of the Inferior Oolite Group.

The Group includes a number of unconformities and non-sequences – of which some are substantial and cross-cutting. These involve uplift, erosion, marine transgression and deposition. Two non-sequences that are widespread – seen from Dorset to Oxfordshire, were identified by S S Buckman (1887, 1897), and Arkell (1933, pp. 90–91). For the purposes of this report, they are termed the ‘Bajocian Unconformity’ and ‘Vesulian Unconformity’ (see Callomon and Cope, 1995).

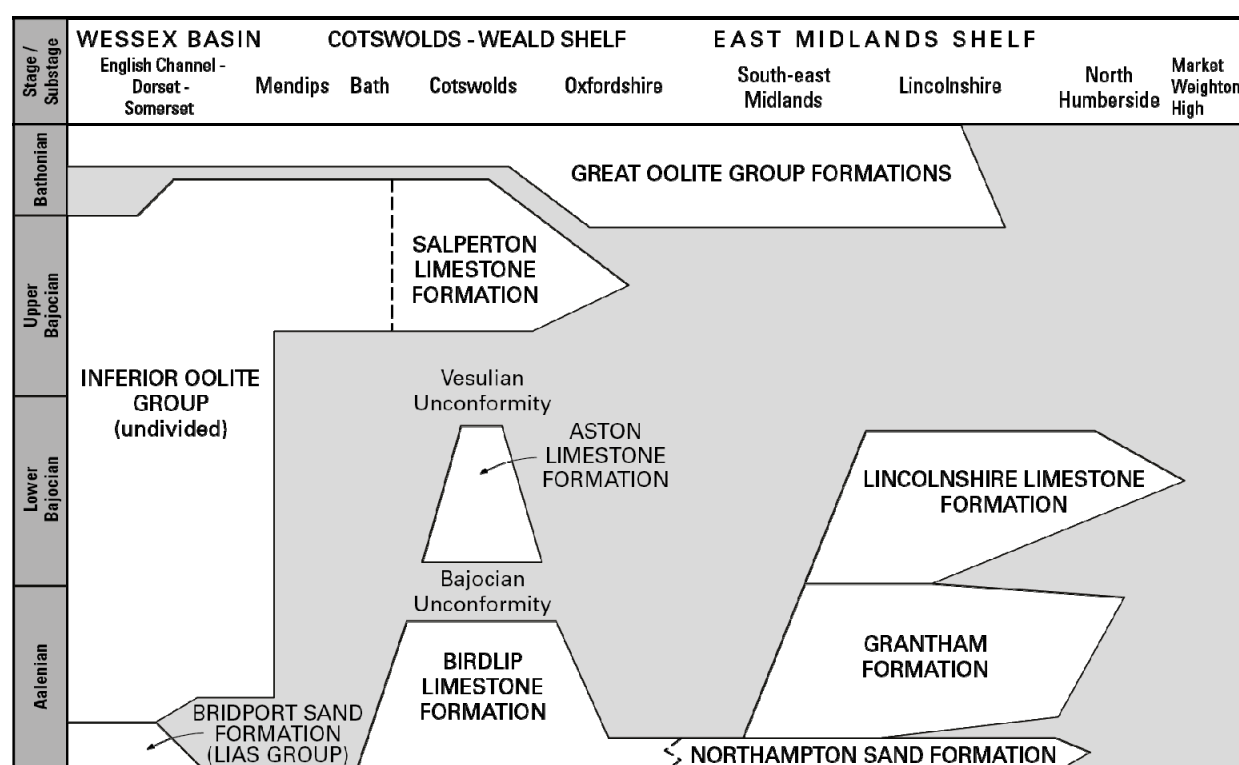


Table 4 Lithostratigraphy of the Inferior Oolite Group to formation level.

Name

In the earliest days of British stratigraphy, when the order of superposition of even the largest units was still uncertain, unpublished or disputed, units were generally given names that included a lithological or genetic term, but many also included a word indicating relative position (Lower, Middle, Upper) or perceived importance or economic value (Great, Superior) (see for instance Phillips, 1844, pp. 146-148; Smith, W, 1817). Thus the ‘freestone’ or ‘oolite’ interval between the ‘marls’ and ‘sands’ of the Lias and the clay/mudstone of the Fuller’s Earth was variously known as the Under Oolite or Oolyte by William Smith (probably circulated in manuscript but

not published until 1815) but early on termed Inferior Oolite (Townsend, 1813). The latter term achieved wide currency in the later 19th century (see Worssam and Donovan, pp. 174-176 in Donovan and Hemingway, 1963), including within the Geological Survey. Woodward (1887) employed it as 'Inferior Oolite Series' to encompass the sand beds below (now Bridport Sand Formation of the Lias Group), the Northampton Sand to Lincolnshire Limestone succession of the East Midlands Shelf and the Dogger to Scarborough Limestone succession of north Yorkshire, as well as the 'traditional' oolites of south-west England. Strata of inferred similar age were also referred to as 'Inferior Oolite' in Scotland (Anderson and Dunham, 1966; Arkell, 1933; see for instance Lee, 1920). Further refinements were made to the definition (see Worssam, pp. 176-177 in Donovan and Hemingway, 1963), until the probable first published use of 'Inferior Oolite Group' by Parsons (1980a, p. 4). Parsons includes only the limestone-dominated Aalenian to earliest Bathonian strata, as herein, but recommends restricting its use to 'the western periphery of the Hampshire-Weald basin', which is not accepted here as the term has proved of value in grouping the Northampton Sand to Lincolnshire Limestone formations succession of the East Midlands Shelf (see discussion of Redbourne Group above).

Type area

Cotswold Hills: Bath to Moreton-in-Marsh

Reference section(s)

Quarries at Cleeve Common SSSI [SO 98 25 – SO 98 26], Cleeve Hill, Gloucestershire, together display near complete succession (albeit disjointed) of Birdlip Limestone, Aston Limestone and Salperton Limestone formations in typical, fullest and thickest development (Barron, 1999a; Buckman, S S, 1897; Mudge, 1978a, b; Richardson, 1929)

British Geological Survey Stowell Park Borehole (SP01SE1) [SP 0835 1176], Gloucestershire, 160' 10" (49.02 m depth) to 401' 2" (122.28 m), all three of the Cotswold formations (Birdlip Limestone, Aston Limestone and Salperton Limestone) were proved in generally typical development, although the upper, Notgrove and Rolling Bank, members of the Aston Limestone are absent beneath the Vesulian unconformity (Green and Melville, 1956; Sumbler and Barron, 1995; Sumbler et al., 2000).

Purse Caundle Borehole (ST71NW7) [ST 7012 1826], Dorset, 89.99 m to about 134.19 m depth, proves all five named informal subdivisions of the group of the Shaftesbury district (Barton et al., 1993; Bristow et al., 1995).

Nettleton Bottom Borehole (TF19NW54) [TF 1249 9820], Lincolnshire, c.346 m to c.392 m depth, proves full thicknesses of all three formations (Lincolnshire Limestone, Grantham and Northampton Sand) in the region (Gaunt et al., 1992).

Burton Cliff, Bridport, Dorset [SY 481 893]. Permanently but inaccessibly exposes the full sequence of the group between the sand of the Bridport Sand Formation below and calcareous mudstone of the Fuller's Earth Formation above. Lithologies and rich fauna including ammonites can be studied in fallen blocks. Callomon and Cope (1995, pp. 64–67) record a succession of 18 thin limestone beds 4.1 m thick, some subdivided and many with local names, grouped into 'Lower Inferior Oolite', 'Middle Inferior Oolite' and 'Upper Inferior Oolite'. Cox and Sumbler (2002, pp. 34-41) revise the base upwards by 0.5 m and avoid the above chronostratigraphical terms.

Horn Park Quarry, Dorset, [ST 458 022], exposes the full sequence of the group between the sand of the Bridport Sand Formation below and calcareous mudstone of the Fuller's Earth Formation above. The site is famous for its rich fauna of ammonites. Callomon and Cope (1995, pp. 67–69) record a succession of 11 thin limestone beds 4.8 m thick, some subdivided and many with local names, then grouped into 'Lower Inferior Oolite', 'Middle Inferior Oolite' and 'Upper Inferior Oolite'. Cox and Sumbler (2002, pp. 47-52) also feature the section but avoid the above chronostratigraphical terms. See also Chandler (1997).

Formal subdivisions

Listed in descending stratigraphical order with citation of source of definition. For origin of formation terms and listing of their informal including obsolete units see individual entries (sections 5.1.1 to 5.1.6).

Cotswolds
Salperton Limestone Formation (SALS) (Barron et al., 1997)
Aston Limestone Formation (ASLS) (Barron et al., 1997)
Birdlip Limestone Formation (BLPL) (Barron et al., 1997)

East Midlands Shelf
Lincolnshire Limestone Formation (LL) (Ashton, 1980)
Grantham Formation (GRF) (Kent, 1975)
Northampton Sand Formation (NS) (Hollingworth and Taylor, 1951)

Informal subdivisions of the Wessex Basin that are laterally persistent

Listed in approximate descending stratigraphical order with citation of source of definition.

Crackment Limestone (Bristow et al., 1995; White, 1923)*
Burton Limestone (Parsons, 1975)**
Anabacia Limestone (Richardson, 1907)**
Doultong Stone (DOB) (Woodward, 1894)**
Rubbly Beds (Bristow et al., 1995; Buckman, S S, 1893)*
Sherborne Building Stone (Bristow et al., 1995; Richardson, 1932)*
Miller's Hill Beds (Bristow et al., 1995)*
Corton Denham Beds (Bristow et al., 1995; Richardson, 1916)*

* Units accorded formal member status by Cox and Sumbler (2002, pp. 47-52).

** Other units of some lateral persistence which may merit member status.

Lithology

Dorset–Somerset (Wessex Basin): Varied succession of bioclastic, peloidal, sandy, ferruginous, argillaceous, bioturbated limestones, with subordinate ooidal limestone, sandstone, limestone conglomerate, lime-mudstone and mudstone beds. Thinly and rubbly bedded with many non-sequences, commonly marked by well-developed hardgrounds, many probably representing considerable breaks. Abundant shelly fauna including ammonites at many levels. A general, but not progressive, increase in ooid content is seen northwards across the region.

Cotswolds–Weald: varied succession of ooidal, peloidal, sandy, ferruginous and shelly limestones, with subordinate sandstone, lime-mudstone and mudstone beds (Birdlip Limestone, Aston Limestone and Salperton Limestone formations).

South and east Midlands to east Yorkshire: ironstone, ferruginous limestone and sandstone (Northampton Sand Formation), overlain by mudstone, sandy mudstone and siltstone–sandstone (Grantham Formation), and shell-detrital and ooidal limestone (Lincolnshire Limestone Formation).

Lithogenetic description

Predominantly shallow marine carbonate shelf well connected to larger sea areas (Inferior Oolite Group in Wessex, Lincolnshire Limestone Formation), or with restricted marine water circulation (Worcester Basin: Birdlip Limestone, Aston Limestone, Salperton Limestone formations) generally precluding ammonite penetration. Also shallow marine clastic and iron-rich sediment deposition (Northampton Sand Formation) and predominantly fluvial/lagoonal (Grantham Formation).

Landform description

Dorset to Cotswolds, Northamptonshire to Lincolnshire: lying between softer mudstone and sand formations the group forms a prominent escarpment even where thin.

Definition of upper boundary

In Dorset–Somerset, change from ooidal limestones upward into Fuller's Earth Formation mudstone with beds of finer-grained limestone. In Cotswolds, change from predominantly ooidal limestone (Salperton Limestone Formation) into mudstone (Fuller's Earth Formation) or into sandy fine-grained ooidal limestone (Chipping Norton Limestone Formation) where present, of the Great Oolite Group. In both cases the contact is generally transitional, but locally an erosive non-sequence marked by a hardground is evident.

In North Oxfordshire to Lincolnshire, sharp upward change (unconformity) from ironstone (Northampton Sand Formation), fine-grained sandstone (Grantham Formation; where present) or ooidal limestone (Lincolnshire Limestone Formation; where present) into mudstone, siltstone, limestone and sandstone succession of the Great Oolite Group (Rutland Formation).

Definition of lower boundary

Worcester Basin–East Midlands Shelf: a disconformity with a change upwards from Lias Group (mudstone with or without sand or sandstone, ferru-ooidal mudstone and limestone beds) into predominantly limestone succession as described in the lithology section. Wessex Basin: passage or sharp change upwards from fine-grained sand and sandstone (Bridport Sand Formation) into limestone succession, by decrease in sand and increase in carbonate cement. Locally (in Mendips area and at depth on the London Platform) unconformably overlies older beds including lower Lias Group, Triassic, Carboniferous and Devonian strata.

Thickness

0 to 106 m at outcrop. Generally 4 to 20 m in south Dorset and close offshore, locally thinner or thicker. Thickens north to around 40 m in north Dorset and Somerset (Penn, 1982). 20 to 25 m thick in Wiltshire. South Cotswolds: 10 to 20 m. Thickens east and present at depth in Wessex–Weald Basin (Green, 1992) where up to 120 m thick (Kingsclere No. 1 Borehole, SU45NE1 [SU 4984 5820]). North Cotswolds: 20 to 106 m. Oxfordshire–Northamptonshire: up to 30 m. Lincolnshire: up to 50 m. Offshore: up to 70 m thick in English Channel (Hamblin et al., 1992), up to 257 m thick in St. George's Channel–Cardigan Bay (Tappin et al., 1994).

Distribution

Outcrop: Dorset, Somerset, Gloucestershire, Oxfordshire, Northamptonshire, Lincolnshire and Yorkshire (south of Market Weighton High). Subcrop: southern England, apart from interior of London Platform (Parsons, 1980a; Sumbler, 1996). Offshore English Channel, Bristol Channel, St. George's Channel–Cardigan Bay.

Previous names

Inferior Oolite (Townsend, 1813).

Under Oolite or Oolyte (Smith, W, 1815).

Inferior Oolite Series (Woodward, 1887).

Redbourne Group. The lower part of this now obsolete unit (Gaunt et al., 1992) comprised rocks that are better considered as components of the Inferior Oolite Group.

Parent

None

Age

Aalenian to Bathonian, Opalinum Zone to Zigzag Zone

References

Principal reference (Parsons, 1980a).

Cotswolds and Oxfordshire formations

This region extends through the Cotswold Hills from the southern end near Bath [ST 76 area] to Chipping Norton, north-west Oxfordshire [SP 35 30] (Figure 4; Figure 8). The lithostratigraphy of the Inferior Oolite Group of most of this region was revised by Barron et al. (1997) and Sumbler et al. (2000) who subdivided the succession into three formations, the Birdlip Limestone, Aston Limestone and Salperton Limestone in ascending order. These units are separated by the ‘Bajocian Unconformity’ and ‘Vesulian Unconformity’ (see below), and correspond respectively with the quasi-chronostratigraphical Lower, Middle and Upper Inferior Oolite of the north and mid Cotswolds of authors such as Buckman, Richardson and Arkell (Barron et al., 1997, table 1). They are lithologically distinct, recognisable throughout the region, and are mapped with confidence at 1:10 000-scale. In the south Cotswolds, strata belonging to all three ‘Lower’, ‘Middle’ and ‘Upper Inferior Oolite’ are locally present (Parsons, 1980a), see Section 5.1 above.

The Cotswolds lie at the southern end of the north–south trending partly fault-bounded Worcester Basin (Figure 3) a centre of enhanced deposition through the early Mesozoic, and by the Mid Jurassic, an area of shallow marine carbonate deposition (the Cotswold Shelf, or Cotswold–Weald Shelf) became established in this region. Arkell (1933) termed the locus of thickest succession the ‘Cotswold Basin’, but the modest scale of accumulation hardly justifies this term. The area of greatest carbonate accumulation may have coincided approximately with the Worcester Basin; its western margin probably in the area of the ‘Malvern Swell’ of Mudge (1978a), although evidence for this such as thinning and detrital mineral content (Mudge, 1978a) is restricted to rocks of Aalenian age. The northern limit is entirely unknown.

The location and development of the Cotswold Shelf was undoubtedly influenced by the presence of the thick subsiding and compacting basin infill. There is no clear evidence that movement on intrabasinal faults was substantially influential in the early Middle Jurassic (but see 5.1.2). Hull (1855) inferred the presence of fold axes in the Cotswolds from the topography, and Buckman (1901) considered that the development of the overstep relationships beneath the ‘unconformities’ was due to local uplift, forming (amongst others) a north-west-trending anticline (‘Birdlip Anticline’), flanked by synclines (‘Painswick Syncline’ to the south-west, ‘Cleeve Hill Syncline’ to the north-east (Arkell, 1933, pp. 197-199)). However, considering the modest scale of these structures, with dips of a small fraction of a degree on the ‘limbs’, they are more likely a result of differential compaction and erosion during lower sea-level times than uplift.

Towards the east of the region lies the ‘Vale of Moreton Axis’ (or ‘Moreton Axis’ of some authors), a structural feature which marks the eastern edge here of the Worcester Basin, and overlies an array of major faults, most of which do not reach the surface. Rather than being a zone of uplift the Axis is more appropriately viewed as acting like a hinge: stable to the east, subsidence occurring on the west side, thus it is the locus of eastward thinning of the Jurassic cover (as a result of either reduced or nondeposition or erosion), to the extent that only one of the

eleven members of the three Inferior Oolite formations continues across it to die out some 30 km to the east (Figure 8). In addition, a further unit reappears to the east of the Axis and some 9 km on passes laterally into the basal formation of the East Midlands succession.

5.1.1 Birdlip Limestone Formation (BLPL)

Name

Named after Birdlip village [SO 925 143] on the Cotswold escarpment overlooking Crickley Hill, Gloucestershire (Barron et al., 1997).

Type section

Limekiln and Devil's Chimney quarries at Leckhampton Hill SSSI, Cheltenham, Gloucestershire. [SO 9490 1854, 9470 1835 to 9474 1842] (Mudge, 1978b, pp. 7-11, beds 1-60). (See also Ager, 1969; Brodie, 1850, 1851; Cox and Sumblar, 2002; Mudge, 1995; Murray, 1968; Richardson, 1904, 1906; Sumblar and Barron, 1996a; Woodward, 1894; Wright, T, 1860)

Type area

Cotswold Hills, Gloucestershire.

Reference section(s)

Disused quarries on face of Cleeve Cloud [SO 9838 2574 to 9840 2549], Cleeve Hill, Gloucestershire. (Barron, 1999a; Mudge, 1978a, b).

For further reference sections see Barron et al. (1997).

Formal subdivisions

Harford Member (HFD) (Barron et al., 1997)
Scottsquar Member (SQAR) (Barron et al., 1997)
Cleeve Cloud Member (CLCL) (Barron et al., 1997)
Crickley Member (CRKY) (Barron et al., 1997)
Leckhampton Member (LECK) (Barron et al., 1997)

Informal subdivisions

Tilestone (Buckman, S S, 1901), part of Harford Member
Snowhill Clay (SNC) (Buckman, S S, 1897), part of Harford Member
Harford Sands (HDS) (Buckman, S S, 1887), part of Harford Member
Naunton Clay (Richardson, 1929), part of Harford Member
Upper Freestone (UFR) (Hull, 1857), part of Scottsquar Member
Oolite Marl (OOM) (Buckman, J, 1842), part of Scottsquar Member
White Guiting Stone (Richardson, 1929), part of Cleeve Cloud Member
Yellow Guiting Stone (Richardson, 1929), part of Cleeve Cloud Member
Lower Freestone (LFR) (Hull, 1857), part of Cleeve Cloud Member
Pea Grit (Murchison, 1834), part of Crickley Member
Pea Grit Series (Arkell, 1933), part of Crickley Member
Lower Limestone (LLST) (Witchell, 1882), part of Crickley Member

Other subdivisions of uncertain status

Frocester Hill Oolite Member (Mudge, 1978a)
Selsley Hill Oolite Member (Mudge, 1978a)

Lithology

Predominantly white, pale grey and yellow ooidal limestone lithologies of varying types; ferruginous and sandy (Leckhampton Member), pisoidal and shelly (Crickley Member) at the base, unfossiliferous and cross bedded in the middle (Cleeve Cloud Member), shelly and carbonate-muddy in the upper part (Scottsquar Member), uppermost beds include sand and clay (Harford Member).

Lithogenetic description

Shallow marine carbonate shelf, remote from open sea areas. Mainly low energy conditions with carbonate mud deposition and very little terrigenous sediment influx, and a profuse shelly epifaunal biota. Higher energy conditions at times depositing coarser carbonate grains (ooids and bioclasts).

Landform description

The formation forms the prominent escarpment of the north Cotswolds, and caps several outlying hills. Soil developed is commonly rich in ooid-limestone fragments.

Definition of upper boundary

Disconformity, generally a hardground: ooidal limestone, sand or clay overlain by shelly, ooidal, sandy, shell-detrital and bioturbated limestone of the Aston Limestone Formation where present; or members of the Salperton Limestone Formation, i.e. very shelly and coarsely shell-detrital ooidal grainstone and packstone (Upper Trigonina Grit Member, where present) or rubbly, fine- to coarse-grained ooidal, peloidal and finely shell-detrital packstone to grainstone (Clypeus Grit Member). The capping hardground is not well developed where the uppermost beds are the weak mudstones or sandstones of the Harford Member.

Definition of lower boundary

Disconformity: upward change into predominantly ooidal limestone sequence as in Lithology above from noncalcareous mudstone in the north-east of its range (Whitby Mudstone Formation) and sandstone, in the centre and south (Bridport Sand Formation). Locally, bioclastic, ferru-ooidal calcareous mudstone and muddy limestone (the Cotswold Cephalopod Bed Member of the Bridport Sand Formation, (Simms et al., 2004)) underlies the formation. .

Thickness

Typically 40 to 46 m; type section c. 45 m, maximum c. 74 m (Cleeve Hill area).

Distribution

North and mid Cotswold Hills from north Oxfordshire (near Chipping Norton) to north-east South Gloucestershire District. Only its lowest (Leckhampton) member is present to the east of the Vale of Moreton Axis, passing east into the Northampton Sand Formation near Chipping Norton. Absent due to overstep by the Salperton Limestone Formation in the south Cotswolds near Old Sodbury, and in the Vale of Moreton area (see Barron et al., 1997, fig. 4).

Supplementary information

The scheme of eleven formal members proposed by Mudge (1978a) of his Lower Inferior Oolite Formation, some of very local extent, was tested during systematic geological mapping in the mid

and north Cotswolds, and as a result was reduced to five members (Barron et al., 1997) (although this may change, pending further studies in the south Cotswolds, where the status of the Frocester Hill Oolite and Selsley Hill Oolite members will be assessed). Three members (Leckhampton, Scottsquar and Harford) coincide precisely in definition and extent with those of Mudge, with minor modifications and abridgement of names. The other two members (Cleeve Cloud and Crickley) combine two or more of Mudge's members. The members are recognisable and laterally persistent across the region and under ideal conditions can be traced at outcrop and recognised in borehole cores, to the extent that they have been widely mapped (British Geological Survey, 1998a, 2000a). Minor, noncalcareous, lithologies (silicate mudstone and sandstone) are restricted to the upper part and together with a limestone bed are assembled into the Harford Member. This might warrant formational status (named the Stanway Hill Formation by Parsons (1980b)), but in the context of the basin, is felt here to merit the lower rank.

In addition to Mudge's (1978a) formal terms, there is a multitude of informal and local terms, dating from the early days of geological studies in the region, for single beds and groups of beds within the succession (see for example Barron et al., 1997, table 1), some of which undoubtedly have descriptive merit, but many of which are poorly defined or of very restricted or unknown extent.

South of Cheltenham the formation's younger beds are progressively overstepped (Bajocian Unconformity) by the Aston Limestone Formation, which is then itself overstepped by the Salperton Formation (Bajocian plus Vesulian unconformities), such that the latter rests on the lower beds of the Birdlip Limestone Formation in the mid-Cotswolds south of Stroud (Barron et al., 1997, fig. 5). In the north Cotswolds, the eastwards overstep of the Aston Limestone is less radical, with the upper members of the older Birdlip Limestone Formation extending further east than it, and both then overstepped by the younger Salperton Limestone Formation.

Previous names

Lower Inferior Oolite (Buckman, S S, 1901, 1905b)

Lower Inferior Oolite Formation (Mudge, 1978a)

Combined Cheltenham and Stanway Hill formations (Parsons, 1980b)

Parent

Inferior Oolite Group

Age

Aalenian, Opalinum Zone to Bradfordensis Zone (and probably Concavum Zone?)

References

Principal reference (Barron et al., 1997)

5.1.2 Aston Limestone Formation (ASLS)

Name

Named after the village of Cold Aston (also known as Aston Blank) [SP 128 198] in the Cotswold Hills near Bourton-on-the-Water, Gloucestershire (Barron et al., 1997)

Type section

Harford railway cutting SSSI, [SP 1360 2184 to 1404 2166] (Buckman, S S, 1887, sections 3 and 4; Cox and Sumblar, 2002, pp. 191-194; Parsons, 1976; Richardson, 1929).

Type area

Cleeve Hill, Gloucestershire, [SO 98 25 to 98 26] (Barron, 1999a; Buckman, S S, 1897; Richardson, 1929).

Reference section(s)

‘Tumulus’ railway cutting, Chedworth Woods, Glos. [SP 0507 1392 to SP 0500 1404] (Buckman, S S, 1895; Richardson, 1933; Sumblar and Barron, 1995, appendix 1, locality A)

For further reference sections see Barron et al. (1997)

Formal subdivisions

Rolling Bank Member (ROBA) (Barron et al., 1997)
Notgrove Member (NGRV) (Barron et al., 1997)
Gryphite Grit Member (GRGR) (Barron et al., 1997)
Lower Trigonía Grit Member (LTG) (Barron et al., 1997)

Informal subdivisions

Phillipsiana Beds (Buckman, S S, 1897), part of Rolling Bank Member
Bourguetia Beds (Buckman, S S, 1897), part of Rolling Bank Member
Witchellia Grit (Buckman, S S, 1897), part of Rolling Bank Member
Buckmani Grit (Buckman, S S, 1895), part of Gryphite Grit Member

Lithology

Grey and brown variously shelly, ooidal, sandy, shell-detrital and bioturbated limestones; rubbly in parts, with a median peloidal ooid-grainstone unit (Notgrove Member) well developed in places, and minor sandy and shell-detrital calcareous mudstone beds. The formation includes a bored hardground on top of the Notgrove Member.

Lithogenetic description

Shallow marine carbonate shelf. Mainly low energy conditions with carbonate mud deposition and terrigenous sediment influx, and a profuse shelly epifaunal biota. Higher energy conditions at times depositing coarser carbonate grains (ooids).

Landform description

Caps plateau behind the north Cotswold escarpment. May form minor scarp above mudstone and sand beds of the uppermost Birdlip Limestone Formation.

Definition of upper boundary

Disconformity, generally a hardground: grey and brown variously shelly, ooidal, sandy, shell-detrital and bioturbated limestones overlain by members of the Salperton Limestone Formation, i.e. very shelly and coarsely shell-detrital ooidal grainstone and packstone (Upper Trigonía Grit Member, where present) or rubbly, fine- to coarse-grained ooidal, peloidal and finely shell-detrital packstone to grainstone (Clypeus Grit Member) – the Vesulian Unconformity.

Definition of lower boundary

Disconformity: upward change from ooidal and peloidal limestone (Scottsquar Member: Birdlip Limestone Formation) or sand, mudstone and sandy limestone (Harford Member: Birdlip Limestone Formation) – the Bajocian Unconformity, into grey and brown variously shelly, ooidal, sandy, shell-detrital and bioturbated limestones. The basal beds commonly contain pebbles derived from the underlying rocks. Generally a hardground.

Thickness

Type section up to about 6.45 m. Maximum c. 22 m (Cleeve Hill area).

Distribution

North and mid Cotswolds: the area west of Northleach, Cold Aston, Blockley and Chipping Campden and north-east of Stroud. Present locally outside this area to the south of Cold Aston, and absent between Birdlip and Cirencester ('Birdlip Anticline') due to overstepping relationships resulting from differential subsidence (Barron et al., 1997, fig. 4; Sumbler et al., 2000).

Supplementary information

Where present in full, the Aston Limestone Formation comprises four members, two of which (Lower Trigonina Grit Member, Notgrove Member) correspond to traditional units whose names are formalised, one (Gryphite Grit Member) combines two traditional rather similar units, utilising the name of the most easily recognised, and the last (Rolling Bank Member) groups three traditional units of very restricted extent with a new name. Local variations and absence reveal rare evidence of faulting in Mid Jurassic times (Sumbler et al., 2000, fig. 14).

Previous names

Middle Inferior Oolite (Buckman, S S, 1901, 1905b)

Hartley Hill Formation (Parsons, 1980b)

Parent

Inferior Oolite Group

Age

Bajocian, Discites Zone to Sauzei Zone

References

Principal reference (Barron et al., 1997)

5.1.3 Salperton Limestone Formation (SALS)

Name

Named after Salperton village [SP 077 204] in the north Cotswolds, near the type section (Barron et al., 1997).

Type section

Notgrove railway cutting SSSI [SP 0847 2091 to SP 0866 2099], 1 km east-north-east of Salperton, Gloucestershire. (Beds 1 to 5 of Buckman, S S, 1887, section 6 (first cutting west of Notgrove Station)) (Barron, 1998; Cox and Sumbler, 2002; see also Woodward, 1894).

Type area

North Cotswold Hills, Gloucestershire.

Reference section(s)

Harford railway cutting SSSI [SP 1360 2184 to SP 1404 2166] (Barron, 1999b; Buckman, S S, 1887, sections 3 and 4; Cox and Sumbler, 2002; Parsons, 1976; Richardson, 1929)

For further reference sections see Barron et al. (1997).

Formal subdivisions

Clypeus Grit Member (CG) (Barron et al., 1997)
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Lithology

Pale grey to brown rubbly, fine- to coarse-grained ooidal, peloidal and finely shell-detrital packstone to grainstone (Clypeus Grit Member), generally with very shelly and coarsely shell-detrital ooidal grainstone and packstone (Upper Trigonía Grit Member) at base.

Lithogenetic description

Shallow marine carbonate shelf. Mainly low energy conditions with carbonate mud deposition and terrigenous sediment influx, and a profuse shelly epifaunal biota. Higher energy conditions at times depositing coarser carbonate grains (ooids).

Landform description

In the north Cotswolds caps the plateau behind the escarpment. In the south Cotswolds forms the crest of the escarpment. Develops a very stony soil, with peloidal and shelly limestone fragments and common fossil shells of brachiopods and the echinoid *Clypeus* (Clypeus Grit Member), or large bivalves (Upper Trigonía Grit Member).

Definition of upper boundary

Upward change from ooidal, peloidal and finely shell-detrital limestone to mudstone (Fuller's Earth Formation) in south-west or into fine- to medium-grained ooidal grainstone (Chipping Norton Limestone Formation) in north-east. Generally transitional, but locally marked by a hardground (Sumbler et al., 2000).

Definition of lower boundary

Disconformity: hardground capping various limestone members of Aston Limestone or Birdlip Limestone formations, or correlative disconformity on mudstone or sandstone formations of Lias Group.

Thickness

Typically 10 to 15 m. Type section 13 m. Maximum c.20 m (Colesbourne area).

Distribution

From south of Horton, Gloucestershire where it passes south into the ooid limestones of the Douling Stone/Anabacia Limestone of the undivided Inferior Oolite Group (Green, 1992; see also Barron, et al. 1997, p 281, fig. 4 and Section 5.1), north through the Gloucestershire Cotswolds to north Oxfordshire west of a line from Hook Norton to Tackley where overlapped by the Great Oolite Group (Horton et al., 1987, fig. 26), although it may be present (Clypeus Grit Member) at depth further to the east (Horton et al., 1995, p. 10).

Previous names

Upper Ragstones (Buckman, S S, 1905b).

Stroud Formation (Parsons, 1980b).

Upper Inferior Oolite (Arkell, 1933; Buckman, S S, 1901).

Parent

Inferior Oolite Group

Age

Bajocian to Bathonian, Garantiana Zone to Zigzag Zone

References

Principal reference (Barron et al., 1997)

East Midlands formations

North-east from Chipping Norton as far as Kettering, the Inferior Oolite Group is represented solely by the Northampton Sand Formation (Figure 8) and even this formation fails south-eastwards. This zone of disappearance was termed the ‘Scissum Line’ by Arkell (1933, fig. 38), although the Northampton Sand persists further south down the Cherwell Valley than he shows (British Geological Survey, 1968), and there are indications that correlatives may reach south Oxfordshire (Horton et al., 1995, p. 10). Nonetheless, this district was regarded as a shallow marine area marginal to the London Platform (Figure 5) with reduced or nondeposition in Aalenian–Bajocian times, and called the ‘Oxfordshire Shallows’ by Arkell (1933, p 176) and Sylvester-Bradley and Ford (1968, pp. 211-214). Alternatively or additionally, the reduction of the Northampton Sand and absence of any overlying formations of this age may indicate erosion prior to deposition of the Great Oolite Group, as is inferred to have taken place further to the north-east in Northamptonshire. Here, the Great Oolite Group progressively oversteps southward towards the margin of the London Platform across the tripartite Inferior Oolite Group succession of Northampton Sand, Grantham and Lincolnshire Limestone formations (present in full in Lincolnshire and Leicestershire), to rest on the Lias Group in north Bedfordshire.

5.1.4 Northampton Sand Formation (NS)

Name

Named after the town of Northampton [SP 76 61] as Northampton Sand (Aveline and Trench, 1860; Sharp, 1870).

Type section

Duston Top Pit [SP 714 627] (Sharp, 1870; Thompson, 1921); also known as 'Old Duston Stone Pit' according to Richardson (1926) and formerly exposed about 2.9 m of 'Northampton Ironstone' (base not seen), overlain by about 8.7 m of 'Variable Beds', total about 11.6 m of Northampton Sand Formation, overlain by 'Lower Estuarine White Sands' (Stamford Member, Rutland Formation). There may be an extant face here.

Type area

Northampton area

Formal subdivisions

None

Informal subdivisions

Upper Chamosite-Kaolinite Group (Hollingworth and Taylor, 1946)
Upper Siderite Mudstone-Limestone Group (Hollingworth and Taylor, 1946)
Lower Chamosite-Kaolinite Group (Hollingworth and Taylor, 1946)
Main Oolitic Ironstone Group (Hollingworth and Taylor, 1946)
Lower Siderite Mudstone-Limestone Group (Hollingworth and Taylor, 1946)

Other subdivisions of uncertain status

Duston Member

Variable Beds (Sharp, 1870)
Corby Ironstone Member
Northampton Ironstone (Lamplugh et al., 1920)

Lithology

Sandy, berthierine-ooidal and sideritic ironstone, greenish grey where fresh, weathering to brown limonitic sandstone, typically displaying a box-stone structure. The basal part is commonly muddy and less ferruginous. The uppermost beds are generally more-or-less ferruginous sandstone. The unit includes lenses of mudstone and limestone in places, and contains a fairly abundant marine fauna of bivalves, brachiopods and ammonites, which are not generally evident in weathered sections.

Lithogenetic description

Deposited in a narrow and shallow seaway between the Anglo–Brabant and Pennine landmasses, in which terrigenous iron was incorporated in ooids and carbonate minerals. Indications present of intermittent emergence and erosion, and locally areas of mud or sand deposition, or development of shelly marine faunas.

Landform description

Forms the crest of a deeply incised escarpment and caps many flat-topped spurs and outlying hills through the East Midlands. Distinctive orange-brown soil developed, with abundant ironstone fragments.

Definition of upper boundary

Generally a sharp erosional, or in some places apparently transitional boundary, from sandy, berthierine-ooidal and sideritic ironstone with, to the north of the Kettering–Peterborough area, a generally less ferruginous sandstone, siltstone or mudstone of the Grantham Formation, which in some places contains pebbles of reworked Northampton Sand, or to the south of Kettering–Peterborough, a sharp erosional contact with essentially nonferruginous interpreted nonmarine sandstone, siltstone or mudstone of the Stamford Member of the Rutland Formation, or in the Brackley district the equivalent Horsehay Sand Formation.

Definition of lower boundary

A sharp, unconformable contact of sandy, berthierine-ooidal and sideritic ironstone overlying mudstones of the Whitby Mudstone Formation (Lias Group). The boundary is commonly marked by a pebble bed containing phosphatic nodules and derived fossils from the underlying Whitby Mudstone.

Thickness

Up to about 21 m thick (Hollingworth and Taylor, 1951; Thompson, 1921), typically in the range from 4 to 8 m.

Distribution

North Lincolnshire from just south of Humber, where the unit is apparently overstepped by the Grantham Formation (Gaunt et al., 1992), to the Chipping Norton area, where it passes laterally into the ‘Scissum Beds’ of Horton (1987), now known as the Leckhampton Member of the Birdlip Limestone Formation. East and south-eastwards from the outcrop, the Northampton Sand is overstepped by the Grantham Formation in the north (e.g. west of Peterborough [TL09]), and the Rutland Formation in the south (e.g. east of Northampton [SP 85 60]).

Supplementary information

As originally conceived by Sharp (1870) the Northampton Sand encompassed all the strata from the top of the Lias up to the top of the ‘White Sands’ (now Stamford Member of Rutland Formation), but Judd (1875) restricted it to the beds below the White Sands (which he called the Lower Estuarine Series). The original usage was perpetuated by Thompson (1921, 1928) and Arkell (1933, pp. 207–208), leading to confusion in the literature (partly tied up with the ‘White Sands problem’; see Section 5.2 *East Midlands Shelf* below), but Judd’s practise was followed by the Geological Survey (Woodward, 1894, pp. 165-227), and remains the basis of the Northampton Sand Formation here.

Hollingworth and Taylor (1951) undertook a detailed study of the Northampton Sand Formation, and recognised five subdivisions defined petrographically, but their classification is of dubious stratigraphical utility as the lateral relationships of the various units are uncertain. Commonly, however, there would appear to be two principal facies developed in the Northampton Sand, firstly a widespread ironstone unit, essentially the Lower Siderite Mudstone-Limestone Group and Main Oolitic Ironstone Group of Hollingworth and Taylor (1951) and secondly, less ferruginous sandy beds. Generally, the latter, when present, overlie the former, often non-sequentially as in the Northampton area itself, where the upper portion of the Northampton Sand has been termed the Variable Beds (Sharp, 1870). Further work may show this to be the basis of two members (the Corby Ironstone Member below and Duston Member above), although the lateral continuity of the Duston Member is uncertain as at many localities there appears to be a lateral passage into the sandy facies.

Previous names

Dogger [north Lincolnshire] (Kent, 1968).

Northampton Sand (Aveline and Trench, 1860; Sharp, 1870).

Northampton Beds (lower part) (Woodward, 1894, pp. 165-169)

Northampton Sand Ironstone (Hollingworth and Taylor, 1946)

[Northampton] Ironstone Series/Beds (or Ironstone) plus Variable Beds of Northampton Sand (Arkell, 1933, pp. 207–208).

Parent

Inferior Oolite Group

Age

Aalenian, ?Opalinum Zone to Murchisonae Zone

References

Principal reference: (Hollingworth and Taylor, 1951)

5.1.5 Grantham Formation (GRF)

Name

Named after the town of Grantham, Lincolnshire by Kent (1975). See also *Supplementary information* below.

Type section

Colsterworth No. 2 Mine [SK 914 233 to 915 232], a quarry, now obscured, near Bourne, Lincolnshire, but the formation was formerly fully exposed, 3.59 m thick, including the Stainby Member, resting on the Northampton Sand Formation, and overlain by the Lincolnshire Limestone Formation (Kent, 1975).

Type area

The Grantham area of south Lincolnshire, north Leicestershire and Rutland: Market Overton to Leadenham, [SK 91 76].

Reference section(s)

Sproxton Quarry [SK 864 253], Leicestershire, formerly exposed the full thickness of the formation, 3.8 m thick, including the Stainby Member, resting on the Northampton Sand Formation, and overlain by the Lincolnshire Limestone Formation, but now probably obscured (Cox and Sumbler, 2002, pp. 286-289).

Graded face adjoining A43 Weldon bypass, Northants (?former quarry face of Barn Close Quarry No. 1) [SP 915 885] exposes the full thickness of the formation, about 6 m thick, resting on the Northampton Sand Formation, and overlain by the Lincolnshire Limestone Formation (Herbert et al., 2005, p. 11).

Formal subdivisions

Stainby Member (STAI) (Kent, 1975) (yet to be fully defined)
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Lithology

Mudstone, sandy mudstone and argillaceous siltstone-sandstone, which are commonly ferruginous, and containing generally abundant plant debris and rootlets, arranged in several rhythms. The formation is typically a tripartite succession comprising: a generally pale, locally carbonate cemented and commonly ferruginous more or less argillaceous sand or sandstone at the base, which may have a seatearth with rootlets at the top, overlain in the type area at least, by a median unit of marine fissile sandy mudstone with carbonaceous rootlets designated the Stainby Member, overlain by an upper, possibly rhythmic succession of alternating sand or sandstone with mudstone or sandy mudstone that may be rootlet-bearing in parts. Further to the south around Corby a dark carbonaceous fissile mudstone, named the 'Coaly Bed' (Richardson and Kent, 1938; Taylor, 1963) may be the Stainby Member equivalent.

Lithogenetic description

Interpreted as both nonmarine and shallow marine facies, comprising several shallowing-upwards, delta-type rhythms.

Landform description

The pale grey sandstone and dark grey mudstone strata of the Grantham Formation contrast strongly in lithology with the underlying ironstone-dominated and overlying limestone-dominated formations. This distinction renders the formation eminently mappable in broad outcrops.

Definition of upper boundary

A sharp or apparently transitional and somewhat arbitrary boundary between grey to white mudstone, sandy mudstone and argillaceous siltstone-sandstone of the Grantham Formation, and limestone of the Lincolnshire Limestone Formation, which may be very sandy at the base, distinguished from the Grantham Formation by the presence of shell debris and peloids.

Definition of lower boundary

Generally a sharp erosional, or in some places apparently transitional boundary, with ferruginous sandstone or ironstone of the Northampton Sand Formation, the top of which may be rootlet-bearing, or where the latter is absent, grey mudstone of the Whitby Mudstone Formation, overlain by generally less ferruginous grey to white mudstones, sandy mudstones and argillaceous siltstone-sandstone with locally a conglomeratic bed of reworked Northampton Sand pebbles at the base.

Thickness

Typically from 2 to 5 m in the type area, and extremely variable, locally ranging up to 15 m in channels, for example, 13.6 m measured in the Copper Hill Borehole (SK94SE56) [SK 9787 4265] near Ancaster.

Distribution

From approximately the line of the River Humber, where the unit may be overstepped by the Lincolnshire Limestone Formation, southwards to the Kettering–Peterborough area, just beyond the southern limit of the Lincolnshire Limestone, where it is believed to be overstepped by the Rutland Formation (see Bradshaw, 1978; Herbert et al., 2005). Beds between the Humber and Market Weighton, formerly classified as the ‘Lower Estuarine Series’ of de Boer et al. (1958) are now included in the Lincolnshire Limestone (Gaunt et al., 1992, p. 45).

Supplementary information

Since the nineteenth century, the Lower Estuarine Series (Judd, 1875) was, considered to be present from Yorkshire to Oxfordshire. This presumption has never been researched thoroughly and has been the subject of some confusion. For example Arkell (1933, p. 207) apparently included it in (or equated it with) the Variable Beds of the Northampton Sand Formation. In the northern area, where the Lincolnshire Limestone is developed, it forms a more or less continuous unit between the Northampton Sand below and Lincolnshire Limestone above, comprising a few metres of sand/sandstone and mudstone of dominantly nonmarine facies. Kent (1975), examined its development in the area of the town of Grantham (south Lincolnshire); his section records show that the formation comprised at least two shallowing-upward cycles of deltaic type (c.f. Rutland Formation), although the basal part of the lower cycle is the Northampton Sand Formation, and the lower marine shaly part of the upper being named the Stainby (Shale) Member (Kent, 1975). However, this member is a unit mapped nowhere by BGS, and is yet to be formally defined.

Because of the assumed continuation of the ‘Ironstone Junction Bed’ which occurs at the top of the Lincolnshire Limestone, where present, the Grantham Formation (‘Lower Estuarine Series’) was formerly thought to extend into the area south of Kettering–Peterborough where the Lincolnshire Limestone pinches out, being overlain directly by the Rutland Formation (‘Upper Estuarine Series’) there (Taylor, 1963). This presumption is now thought to be invalid – with iron-rich horizons developed at other levels (Aslin in Sylvester-Bradley and Ford, 1968), and these beds are now known to represent the much younger, late Bajocian–Bathonian Stamford Member of the Rutland Formation (Section 5.2.16), or in the Brackley district, the equivalent Horsehay Sand Formation (Section 5.2.11).

Previous names

Lower Estuarine Series (Judd, 1875).

Lower Estuarine Beds

Parent

Inferior Oolite Group

Age

Aalenian, inferred within Murchisonae Zone to Concavum Zone range.

References

Principal reference (Kent, 1975)

5.1.6 Lincolnshire Limestone Formation (LL)

The Lincolnshire Limestone is a long-recognised formation (Judd, 1875), formalised by Kent (1966), the definition and status of which is generally uncontroversial, being represented by a limestone-dominated unit that is overlain and underlain by siliciclastic units. However, Bradshaw and Penney (1982) correlated parts of the sequence in north Lincolnshire, which display terrigenous influence, with units of the clastic-dominated Cleveland Basin succession. In addition, the upper part of the formation becomes increasingly arenaceous northwards (Gaunt et al., 1992, p. 52), apparently passing into the overlying Thorncroft Sand Member (Rutland Formation, Great Oolite Group).

The southern limit of the Lincolnshire Limestone Formation is its pinch-out in the south along a line through Maidwell (Northamptonshire), Kettering and Peterborough. In the onshore subcrop it extends east through Wisbech to the Wash, and its original depositional limit probably lay parallel and some distance to the south-east of this. North of the Humber, the Lincolnshire Limestone probably extends further towards Market Weighton than any other Middle Jurassic formation (Figure 8), overstepping the Grantham Formation, before itself being overstepped by Cretaceous strata. A similar pattern is believed to take place in the onshore subcrop east of Hull.

Since the nineteenth century or earlier, study of the Lincolnshire Limestone has generated a multitude of terms for beds or groups of beds of local and wider usage. As is the case for most formations that have been worked for stone, many of the names are probably quarrymen's terms and are of dubious stratigraphical value and regional applicability, and lack the consistency of usage for formal definition. Nonetheless, some of the building stones from the Lincolnshire Limestone are well known (e.g. Barnack, Ancaster, Clipsham, Weldon and Ketton stones/freestones, and Collyweston Slate). In addition, geologists have coined names derived from included fossils and although some of these, together with the building stone names, merit retention for descriptive purposes and continuity they are not listed below.

A number of attempts have been made to erect systematic schemes to subdivide the formation fully into formal or informal divisions, of local or universal applicability. Hollingworth and Taylor (1946, 1951) recognised an upper and lower division in the Kettering district, later extended throughout the Northampton ironstone field, through Leicestershire and south Lincolnshire, at least as far as Lincoln. Although this distinction was made largely on lithological grounds, and the highly erosive relationship between the divisions was well known (Taylor, 1946) it also relied in part (in south Lincolnshire) on the identification of a supposed single unit (the 'Crossi Bed/Beds') bearing the distinctive brachiopod *Acanthothiris crossi* (Walker), which was inferred to intervene. However, *A. crossi* is known to occur at several levels (Kent, 1966) and other objections have been raised against its reliability and correlation value (Sylvester-Bradley and Ford, 1968, p. 221) (Ashton, 1979). Further studies have shown that erosive non-sequences, probably less significant regionally, occur at other levels (Ashton, 1980).

Kent (1966) reviewed the history of terminology and correlations for the subdivisions throughout the formation's outcrop, evidently favouring the wide usage of Lower Lincolnshire Limestone and Upper Lincolnshire Limestone, whilst recognising the difficulties in definition and the reliance on recognition of the Crossi Bed/Beds.

Ashton (1980) erected nine formal members, distributing them between three informal divisions: the 'lower', 'middle' and 'upper' Lincolnshire Limestone, based on detailed studies of sections between Stamford and Lincoln, and made a tentative attempt to correlate this succession with that of north Lincolnshire. In addition, he describes two informal units within his Lincoln Member. His members are well defined, but have not generally been found to be mappable, and only of value for descriptions of sections and borehole core. Strangely, Ashton did not suggest a type section for the formation, but Ketton is an obvious key reference section being the only place where the whole formation is visible from top to bottom (dependent on transient excavations in quarry floor).

Only Hollingworth and Taylor's (1946, 1951) scheme of a Lower Lincolnshire Limestone (Member) and Upper Lincolnshire Limestone (Member) is regarded as passing the test of mappability throughout the formation's range (Figure 8), having been applied from Kettering to Lincoln, and following the guidance in the definition below is thought to be applicable to the mapped units in north Lincolnshire and east Yorkshire on the Brigg (E&W 89) and Kingston-upon-Hull (E&W 80) sheets (British Geological Survey, 1982b, 1983). It therefore seems reasonable to expect it to be workable in the intervening ground – the Market Rasen (E&W102) sheet (British Geological Survey, 1999).

Name

Named after the county of Lincolnshire, and defined by Ashton (1980) as modified herein.

Type section

None designated.

Partial type sections

Leadenham Quarry [SK 962 523] exposes part of the Upper Lincolnshire Limestone and most of the Lower Lincolnshire Limestone, including the base (Sumbler et al., 1990).

Copper Hill Quarry, Ancaster [SK 978 426], exposes parts of the Upper Lincolnshire Limestone, and Lower Lincolnshire Limestone, totalling about 20 m thick (Cox and Sumbler, 2002, pp. 289-292; Sumbler et al., 1990).

Metheringham Quarry [TF 053 616], Lincolnshire, exposes parts of the Upper Lincolnshire Limestone, and Lower Lincolnshire Limestone, totalling about 20 m thick (Ashton, 1980; Cox and Sumbler, 2002, pp. 292-294).

Type area

South Lincolnshire, Leicestershire and Rutland (Grantham to Stamford area)

Reference section(s)

Ketton Quarry [SK 970 060], Rutland, fully exposed: up to 17.3 m of beds of the Upper Lincolnshire Limestone and Lower Lincolnshire Limestone members (Hudson and Clements, 2007).

See also Cox and Sumbler (2002, pp. 286-289)

Formal subdivisions

(Cox and Sumbler, 2002, but M G Sumbler has recently (2005) compiled formal definitions for these members; see Hollingworth and Taylor, 1951; Kent, 1966)

Upper Lincolnshire Limestone Member (ULL) includes beds mapped as the obsolete Hibaldstow Limestones and Cave Oolite members (Gaunt et al., 1992) of north Lincolnshire, and the Sleaford and Clipsham members of south Lincolnshire (Ashton, 1980).
--

Lower Lincolnshire Limestone Member (LLL) includes: informal Cleatham Limestone, Raventhorpe Beds, Ellerker Limestone, Santon Oolite, Kirton Cementstone Beds, Scawby Limestone of north Lincolnshire, and Sproxton to Blankney members of south Lincolnshire (Ashton, 1980).

Informal subdivisions

North Lincolnshire–east Yorkshire
--

(shown on BGS 1:50 000 sheets E&W 80 and 89)
--

Kirton Cementstone Beds (KCM, KCMK) (Gaunt et al., 1992), part of Lower

Lincolnshire Limestone Member
Scawby Limestone (SYL) (Gaunt et al., 1992), part of Lower Lincolnshire Limestone Member
Santon Oolite (SNO) (Gaunt et al., 1992; Kent, 1966), part of Lower Lincolnshire Limestone Member
Raventhorpe Beds (RVB) (Gaunt et al., 1992), part of Lower Lincolnshire Limestone Member
Ellerker Limestone (ELL) (Gaunt et al., 1992), part of Lower Lincolnshire Limestone Member
Cleatham Limestone (CML) (Gaunt et al., 1992), part of Lower Lincolnshire Limestone Member

South Lincolnshire–Leicestershire (none appear on BGS maps)
Clipsham Member (Ashton, 1980), part of Upper Lincolnshire Limestone Member
Sleaford Member (Ashton, 1980), part of Upper Lincolnshire Limestone Member
Blankney Member (Ashton, 1980), part of Lower Lincolnshire Limestone Member
Metheringham Member (Ashton, 1980), part of Lower Lincolnshire Limestone Member
Kirton Shale Member (Ashton, 1980), part of Lower Lincolnshire Limestone Member
Lincoln Member (Ashton, 1980), part of Lower Lincolnshire Limestone Member
Leadenham Member (Ashton, 1980), part of Lower Lincolnshire Limestone Member
Greetwell Member (Ashton, 1980), part of Lower Lincolnshire Limestone Member
Sproxton Member (Ashton, 1980), part of Lower Lincolnshire Limestone Member

Other subdivisions

(possibly to be made obsolete)

Hibaldstow Limestones Member (HIL) (Gaunt et al., 1992), part of Upper Lincolnshire Limestone Member

Cave Oolite Member (CVO) (Gaunt et al., 1992), part of Upper Lincolnshire Limestone Member

Lithology

Limestone, typically calcilutite, and peloidal wackestone and packstone beds in lower part (Lower Lincolnshire Limestone Member) and high energy medium- to very coarse-grained ooidal and shell fragmental grainstone in upper part (Upper Lincolnshire Limestone Member). Commonly includes sandy limestone in basal part and may contain substantial units of mudstone, particularly from the Lincoln area northwards.

Lithogenetic description

Deposited in a shallow or very shallow fully marine carbonate shelf environment, for the most part with little terrigenous sediment influx. The lower part is dominated by low to moderate

energy facies, the upper shows indications of high energy conditions including erosion of submarine channels.

Landform description

Forms escarpment and plateau along 'Lincoln Edge'.

Definition of upper boundary

Disconformable, often markedly eroded and karstic top surface of limestone of Lincolnshire Limestone Formation, overlain by noncalcareous, nonmarine sandstone, siltstone and mudstone of overlying Rutland Formation. Near northern limit only (near Market Weighton), disconformable contact between limestone of the Lincolnshire Limestone Formation and ferruginous sandy calcareous sediments of Hunstanton Formation above (Cretaceous).

Definition of lower boundary

Conformable or more or less disconformable contact between sandstone and mudstone of underlying Grantham Formation or, where the latter is absent (mainly in north) ferruginous sandstone of Northampton Sand Formation, or mudstone of Lias Group, overlain by limestone or sandy limestone of Lincolnshire Limestone Formation.

Thickness

Typically 25 to 33 m (Lincolnshire) (Ashton, 1980). Up to 15 m in Northamptonshire and north of the Humber.

Distribution

Market Weighton area, where it is overstepped by Cretaceous, Hunstanton Formation, to Kettering–Peterborough area, where overstepped by Rutland Formation. In the subcrop, it is restricted essentially to onshore areas of the northern part of the East Midlands Shelf. Offshore, it passes eastwards into noncarbonate Strangways Formation of the West Sole Group (see Section 9.1).

Previous names

Lincolnshire Limestone (Judd, 1875)(Kent, 1966)

Parent

Inferior Oolite Group

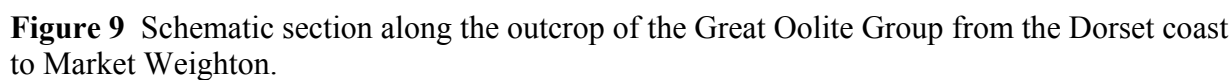
Age

Bajocian, Discites Zone to ?Sauzei Zone

References

Principal reference (Ashton, 1980)

The history of research into the strata of the Great Oolite Group is as long as any in British stratigraphy (see Cox and Sumbler, 2002 for brief account), and the succession has long been known to present major stratigraphical and correlation problems due to its complex lateral changes and vertical repetition of sedimentary facies (Figure 9), the paucity of the biostratigraphical index fauna (ammonites), uncertainties over lateral persistence of thin strata and ‘marker’ beds, and the common, but sometimes localised occurrence of emergent/erosional events leading to non-sequences or even unconformities.



Cotswold–Weald Shelf, Wessex Basin and Weald Basin

Nowhere are the above problems more apparent than in the succession preserved in the southern part of the Cotswold–Weald Shelf (best seen in the outcrop in the south and mid Cotswolds) and the Wessex and Weald basins. Here the pattern of facies reveals the transition from a shallow marine shelf relatively remote from the open sea and receiving little terrigenous sediment input, but subject to high energy currents mobilising the carbonate sediment (e.g. Taynton Limestone, Athelstan Oolite, Chalfield Oolite formations), to a more open marine basin setting in which silicate and calcareous mud deposition dominated in deeper, quieter water (Fuller's Earth and Frome Clay formations). In progressing up-sequence, this change is seen migrating south and south-east from the Cotswold–Weald Shelf into the Wessex and Weald Basins (Figure 4; Figure 9). However, with variations in basin floor depth and topography, possibly tectonically influenced, and in sediment supply conditions through space and time, this process was neither steady nor continuous and interdigitation of facies is widespread, such that in any section or borehole repetition of facies/lithologies may prevent easy classification of packages of beds. Although its influence was diminished, the Mendip High may still have been a relatively positive area, leading to the deposition of shallow water limestone beds from time to time in this area.

East Midlands Shelf

A transition is also seen from the high or moderate energy marine environment (e.g. Chipping Norton Limestone, Taynton Limestone, White Limestone formations) on the northern Cotswold–Weald Shelf into the more variable marine to paralic conditions on the East Midlands Shelf (e.g. Horsehay Sand, Rutland, Blisworth Limestone and Blisworth Clay formations; Figure 9). Its locus fluctuated through north Oxfordshire in the Bathonian, mainly as a result of minor relative sea level changes and gradual shelf floor subsidence. The lateral facies passages seen are thus more subtle but less prone to interdigitation and thickness variations.

The Group is generally more extensively preserved than the Inferior Oolite Group in the subcrop across the northern margin of the London Platform.

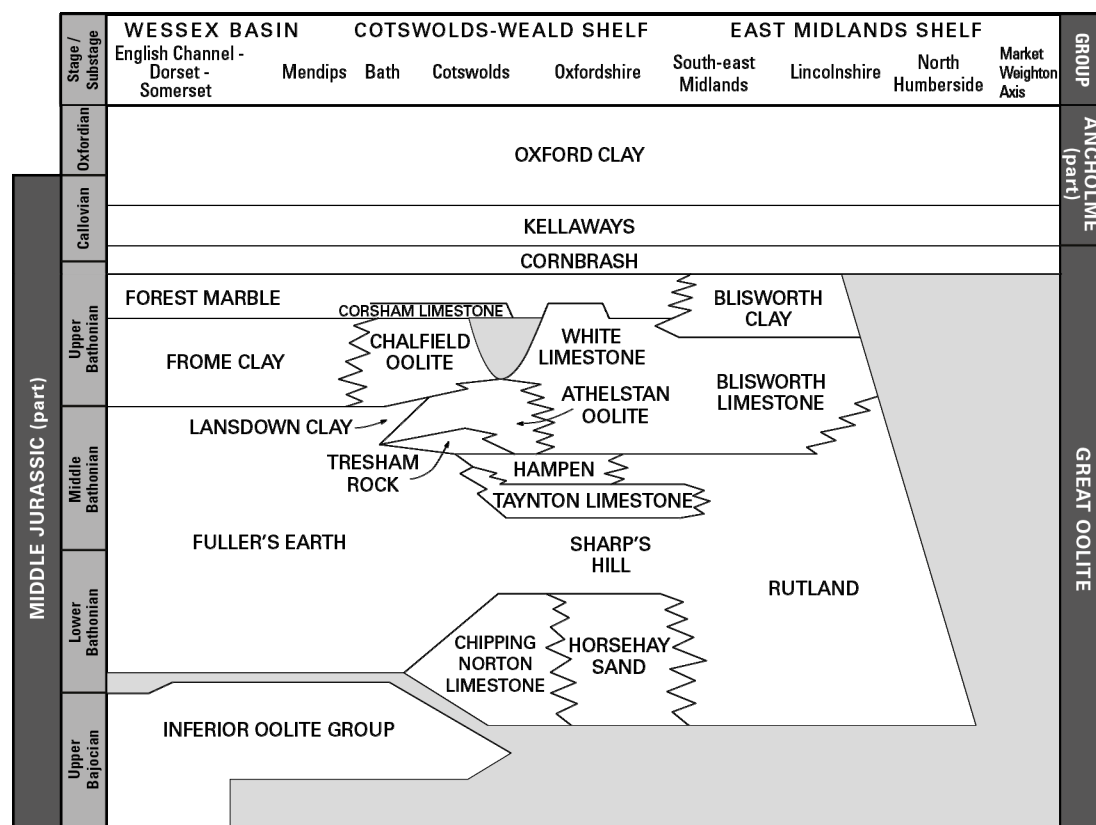


Table 5 Lithostratigraphy of the Great Oolite Group and part of the Ancholme Group to formation level.

In parts of the Midlands where the Lincolnshire Limestone is absent (i.e. Brackley to Peterborough) the Stamford Member (Rutland Formation, Great Oolite Group) and Grantham Formation (Inferior Oolite Group) are potentially in contact. Because each is of similar facies, there are problems dividing the two or deciding whether Rutland Formation, Grantham Formation or both are present.

The north-eastward passage of the marine formations of the Cotswolds into ‘estuarine’ facies of the Rutland Formation is gradational, and interdigitation of facies necessarily creates problems in defining the lateral limits of the Hampen, Taynton Limestone, Sharp’s Hill and Fuller’s Earth formations. In north-east Oxfordshire and Buckinghamshire, beds traditionally assigned to the Hampen (Marly) Formation are of ‘estuarine’ facies and are consequently now termed Rutland Formation in the description of the Buckingham district (Sumbler, 2002). However, the strata are equivalent to only a part of the type Rutland Formation. Lower in the succession, the ‘estuarine’ Sharp’s Hill Formation (a long-established term) could equally validly be classified as Rutland Formation.

Name

Various usages of the name ‘Great Oolite’ have been made over the past 200 years, for strata generally of Bathonian age, with various suffixes applied. This has included the Great Oolite Limestone of the English Midlands (Torrens, 1967), now named the Blisworth Limestone Formation (Section 5.2.17 below) and the Great Oolite [limestone] of the Bath district (Arkell and Donovan, 1952; Green and Donovan, 1969), and now renamed the Chalfield Oolite Formation (Section 5.2.8). These renaming/redefinition decisions have followed the widespread adoption of the ‘Great Oolite Group’ to include all of the mainly Bathonian formations of southern Britain, and to accord with the underlying Inferior Oolite Group (Cope, 2006).

Type section

None designated for entire group. See individual formation entries.

Type area

Bath area, [ST 75 60].

Formal subdivisions

(in approximate descending order, with laterally equivalent southern units first)

Cornbrash Formation (CB) (Page, 1989)
Forest Marble Formation (FMB) (Sumbler, 1984)
Corsham Limestone Formation (CSHF) (Sumbler, 2003) as modified herein
Blisworth Clay Formation (BWC) (Sharp, 1870) as modified herein
Frome Clay Formation (FRC) (Penn et al., 1979)
Chalfield Oolite Formation (CFDO) (Wyatt and Cave, 2002)
Lansdown Clay Formation (LDN) (Arkell and Donovan, 1952) as modified herein
White Limestone Formation (WHL) (Palmer, T J, 1979)
Blisworth Limestone Formation (BWL) (Torrens, 1967) as modified herein.
Athelstan Oolite Formation (AOL) (Cave, 1977)

Tresham Rock Formation (TRR) (Arkell and Donovan, 1952)
Hampen Formation (HMB) (Sumbler and Barron, 1996b)
Taynton Limestone Formation (TY) (McKerrow and Kennedy, 1973)
Fuller's Earth Formation (FE) (Penn et al., 1979)
Sharp's Hill Formation (SHHB) (McKerrow and Kennedy, 1973)
Rutland Formation (RLD) (Bradshaw, 1978)
Chipping Norton Limestone Formation (CNL) (Sellwood and McKerrow, 1974)
Horsehay Sand Formation (HYSA) (Bradshaw, 1978; Cox and Sumbler, in prep)

Lithology

Variety of mudstone-dominated and ooidal, bioclastic and fine-grained limestone formations.

Definition of upper boundary

Base of succeeding Kellaways Formation; comprising mudstone, commonly shelly at base, resting generally sharply and conformably or non-sequentially on bioclastic limestone of the Cornbrash.

Definition of lower boundary

Change up from ooidal and/or pisoidal limestone (Inferior Oolite Formation (Wessex)/Salperton Limestone Formation/Lincolnshire Limestone Formation) or ironstone or ferruginous sandstone (Northampton Sand Formation), all of Inferior Oolite Group; overlain by silicate/calcareous mudstone (Fuller's Earth Formation) or pale sandstone (Horsehay Sand Formation/Stamford Member of Rutland Formation) or sandy, fine-grained ooid limestone (Chipping Norton Limestone Formation). Generally a non-sequence or disconformity.

Thickness

About 20 m through Lincolnshire and the Midlands (East Midlands Shelf), thickening south through the Cotswolds (60 to 90 m) to 100 to 200 m in Somerset and Dorset, and in the Weald subcrop (Green, 1992; Sumbler, 1996). Offshore English Channel up to 224 m (Hamblin et al., 1992).

Distribution

Dorset, Somerset, through the Cotswolds, Oxfordshire, Northamptonshire, Lincolnshire and northwards as far as the Market Weighton High (including the outcrop of the now obsolete 'Redbourne Group'). Also proved in borings in the Weald (Wyatt, 2011), the London area and Norfolk.

Previous names

Great Oolite (Warner, 1811) (Townsend, 1813)

Great Oolite Series (Judd, 1875)

Redbourne Group, the upper part of this now obsolete unit (Gaunt et al., 1992) comprised rocks that are better considered as components of the Great Oolite Group.

Parent

None

Age

Late Bajocian to Early Callovian: Parkinsoni Zone to Herveyi Zone

References

Principal reference: (Woodward, 1894).

Wessex Basin formations

In the context of the Great Oolite Group, the onshore Wessex Basin is considered to extend at outcrop from the Dorset coast to Bath (i.e. including the southern part of the Worcester Basin). Although the Mendip High continued to affect deposition, its influence was far less profound than in Aalenian–Bajocian times, and all the formations continue unbroken across it (Figure 9), albeit with indications of thinning of some portions.

The succession is fully marine and dominated by silicate-mudstone with a rich shelly fossil content including ammonites. However, a few kilometres south of Bath, the succession passes laterally northwards into the complex succession of mainly shallow marine limestone formations of the Cotswolds (see Figure 9 and *Cotswold–Weald Shelf formations* below).

Similarly, east from the Dorset coast, the mudstone-dominated Great Oolite succession persists at depth into south-west Hampshire, but beyond here, in a pattern analogous to the Inferior Oolite Group, it passes into a succession in the Weald Basin that is dominated by carbonate shelf facies (see *Cotswold–Weald Shelf formations* below, and Wyatt, 2011).

5.2.1 Fuller’s Earth Formation (FE)

Name

The name Fuller’s Earth, like many of the terms for Great Oolite units, goes back to the early nineteenth century, but is confused by its usage for the true (commercial) fuller’s earth bed (Warner, 1801) which it hosts but which is thin and of much less areal extent than the formation. Its first usage in the modern stratigraphical sense is probably that of Buckland (1818) in setting out the scheme of William Smith. Its definition was modified to exclude the Frome Clay by Penn and Wyatt (1979).

Type section

BGS Horsecombe Vale No. 15 Borehole (ST76SE24) [ST 7555 6225], near Bath, Somerset, 7.62 to 53.45 m depth. Dominated by mudstone, and includes fuller’s earth bed. Resting on hardground top of Inferior Oolite Group (here the informal Doulling Beds). Sharp top with encrusting oysters overlain by Chalfield Oolite Formation (Penn et al., 1979).

Type area

Bath area, Somerset, [ST 75 64] (William Smith, 1799, unpublished; see Arkell, 1933, p. 263; Penn and Wyatt, 1979).

Reference section(s)

Winterborne Kingston Borehole (SY89NW1) [SY 8470 9796]. 793.00 to 906.06 m depth. Mudstone dominated and includes Fuller’s Earth Rock. Overlies Inferior Oolite Group limestone, and underlies Wattonensis Limestone Member of Frome Clay Formation (Barton et al., 2011; Penn, 1982).

Stowell Park Borehole (SP01SE1) [SP 0835 1176] 32.79 to 49.02 m depth, including Eyford Member 32.79 to 34.62 m. Sharp, irregular base on burrowed top of ooidal limestone of Salperton Limestone Formation (Inferior Oolite Group). Overlain by white ooid-limestone of Taynton Limestone Formation (Green and Melville, 1956; Sumbler et al., 2000).

Purse Caundle Borehole (ST71NW/7) [ST 7012 1826], near Sherborne, Dorset, 12.48 to 89.99 m depth; dominated by mudstone, with subordinate limestone. Subdivided into three members: Lower Fullers Earth, Fullers Earth Rock and Upper Fullers Earth which are further divided into named units. Passes up from silicate-muddy limestone of Inferior Oolite Group (here the informal Crackment Limestones), passes up into calcareous mudstone of Wattonensis Limestone Member (Frome Clay Formation) samples held by BGS (Barton et al., 1993; Bristow et al., 1995).

Formal subdivisions

Eyford Member (EYF) (Ager et al., 1973; Sellwood and McKerrow, 1974) N.B These authors included this member in the Sharp's Hill Formation, whereas Wyatt (1996) included it in his Charlbury Formation (see 5.2.13 below).
Upper Fuller's Earth Member (UFE) (Penn et al., 1979)
Hawkesbury Clay Member (HACL) (Arkell and Donovan, 1952)
Dodington Ash Rock Member (DASHR) (Torrens, 1968b)
Fuller's Earth Rock Member (FER) (Barton et al., 1993; Smith, W, 1819)
Througham Member (TT) (Cave, 1977)
Lower Fuller's Earth Member (LFE) (Penn et al., 1979)

Lithology

Silicate-mudstone, grey, bedded, variably calcareous, grading to lime-mudstone, fossiliferous, with units of thinly interbedded, more or less silici-muddy shell-detrital limestone (including the shelly Fuller's Earth Rock Member, and variably ooidal, fine-grained Dodington Ash Rock Member), and well-bedded sandy limestone and calcareous sandstone (including Eyford Member and Througham Member). Where the Fuller's Earth Rock Member is present, the mudstone beds below and above are termed the Lower Fuller's Earth Member and Upper Fuller's Earth Member respectively, and parts of these may be given local names. The commercial fuller's earth bed occurs in the upper part of the formation in the Bath area. In the English Channel the formation is predominantly mudstone with carbonaceous material at some levels and shell beds. In the St George's Channel it is predominantly mudstone and includes calcareous sandstone beds.

Lithogenetic description

Open marine basin setting in which silicate and carbonate mud deposition dominated in deeper, quieter water, with occasional shallowing and limestone deposition. Progressive encroachment by prograding carbonate shelf deposition from north.

Landform description

Generally forms slopes very liable to instability (landsliding) below escarpments or plateaux formed by more competent strata such as limestone or sandstone.

Definition of upper boundary

Generally sharp commonly non-sequential, junction between variably calcareous silicate-mudstone, and limestones of overlying parts of Great Oolite Group: including from Bath south to Dorset (and in the English Channel) fossiliferous limestones of the Wattonensis Limestone Member of the Frome Clay Formation, and (north-east of Bath) ooidal and shell-fragmental limestones, including of the Chalfield Oolite Formation or Taynton Limestone Formation, or fine-grained limestone of the Tresham Rock Formation.

Definition of lower boundary

In north-east Cotswolds, passage up from fine to medium-grained ooid-grainstone of Chipping Norton Limestone Formation (Great Oolite Group) into silicate-mudstone. In the Cotswolds to English Channel area generally a sharp commonly non-sequential, junction between predominantly coarse-grained peloidal, ooidal and shell-fragmental limestones of the Inferior Oolite Group (or calcareous sandstone in the St George's Channel) overlain by silicate-mudstone of the Fuller's Earth Formation.

Thickness

5 to over 260 m (thickest in Wessex Basin area). Offshore: generally over 100 to 300 m in English Channel (Barton et al., 2011; Hamblin et al., 1992), up to 300 m in Cardigan Bay–St George's Channel (Tappin et al., 1994).

Distribution

Onshore: Dorset coast to Burford area, Oxfordshire. At Dyrham [ST 74 74] near Bath, from where the Tresham Rock Formation is present northwards, the Upper Fuller's Earth Member which overlies it passes north into the Lansdown Clay Formation (see e.g. Wyatt, 1996). In subcrop, widespread in Wessex Basin. Offshore: English Channel, Cardigan Bay -St George's Channel.

Supplementary information

The formation includes a number of significant limestone and minor sandstone units and packages, most with formal names. Passing north from Bath the proportion of these increases as a result of lateral facies migration (Figure 9). The point comes where some of these units merit full formation status (e.g. the Tresham Rock Formation) and in part of their geographical range, their 'feather edge' may lie within the Fuller's Earth Formation. This is unavoidable and is covered as far as possible in the other formations' definitions.

There are also a great number of minor mudstone or limestone beds (Torrens, 1980) named after their distinctive fauna, which may merit formal bed status. However some have a distinctive lithofacies, such as the packages dominated by calcareous fine-grained sandstone of the Eyford Member (Ager et al., 1973; Sellwood and McKerrow, 1974), present west of Stow-on-the-Wold, and the rather similar 'Througham Tilestones' (Cave, 1977) present north of Stroud. The latter is given formation status by Wyatt (2009), with a component 'Daglingworth Member' to resolve the difficulties he perceives in the classification of the Fuller's Earth–Taynton Limestone–Hampden Formation interval north of Cirencester. This solution is rejected here: the original definition of the Hampden Formation at its type section is regarded as satisfactory, given its known lithological variability in the wider area; and it is also reasonable to include the beds of Wyatt's Daglingworth Member seen to the south-west in either the Hampden or Taynton Limestone formations, such that the sandy limestone and sandstone beds seen further south-west which are typical of the Througham Tilestones can be accorded the status of a formal Througham Member of the Fuller's Earth Formation.

Previous names

Fuller's Earth. In Dorset, the Fuller's Earth previously included the unit now separated as Frome Clay Formation (see Penn and Wyatt, 1979)

Parent

Great Oolite Group

Age

Bathonian, Zigzag Zone to Bremeri Zone

References

Principal reference (Penn et al., 1979)

5.2.2 Frome Clay Formation (FRC)

Name

Name first used by Bourne (1846) after the town of Frome in Somerset, but achieved no currency at that time. It was then revived and defined by Penn and Wyatt (1979)

Type section

Frome (Gibbet Hill) Borehole (ST74NE3) [ST 7632 4769], 22.56 to 52.63 m, penetrating full thickness comprising variably calcareous mudstone with minor limestone beds; Wattonensis Limestone Member not developed at base here (Penn and Wyatt, 1979).

Type area

None

Reference section(s)

Baggridge No. 2 Borehole (ST75NW23) [ST 7407 5602], 26.25 to 47.82 m, penetrating full thickness comprising variably calcareous mudstone with minor limestone beds; Wattonensis Limestone Member not developed at base here. North of here, within 1 to 3 kms, the formation passes laterally into the limestone beds of the Chalfield Oolite Formation, and the calcareous nature of some of the beds in the borehole shows this lithological change (Penn and Wyatt, 1979, fig. 2 pp. 75-76).

Purse Caundle Borehole (ST71NW7) [ST 7012 1826], 0 to 12.48 m depth penetrating lower part comprising 2.91 m of interbedded limestone and mudstone of the Wattonensis Limestone Member at base overlain by 9.5 m of olive-grey calcareous mudstone, variably bioclastic with a fauna dominated by bivalves (Barton et al., 1993).

Winterborne Kingston Borehole (SY89NW1) [SY 8470 9796], 732.7 to 793.0 m depth penetrating full thickness comprising 4.4 m of interbedded limestone and mudstone of the Wattonensis Limestone Member at base overlain by 5.4 m of dark grey fissile mudstone, overlain by 50.5 m of grey calcareous mudstone (Penn, 1982).

Formal subdivisions

Wattonensis Limestone Member (WAB) (Kellaway and Wilson, 1941; Wyatt, 2011)

Lithology

Silicate-mudstone, grey, blue grey and olive-grey, calcareous in parts, with minor generally fine-grained limestone units. Highly fossiliferous and/or bioturbated at some levels. A unit of between five and twenty 0.1 m-thick muddy, shelly, bioturbated limestone beds interbedded with 0.3 m-thick mudstone beds is developed at the base and termed the Wattonensis Limestone Member, which is poorly developed around Frome, but thickens south to the Dorset coast and offshore. Above it in Dorset, oyster-rich mudstone beds are developed at two levels.

Lithogenetic description

Open marine basin setting in which silicate and calcareous mud deposition dominated in deeper, quieter water.

Landform description

Generally forms slopes prone to instability (landsliding) below escarpments or plateaux formed by more competent strata (e.g. limestone or sandstone).

Definition of upper boundary

The base of the Boueti Bed (Forest Marble Formation) a thin shell-fragmental muddy limestone with abundant *Goniorhynchia boueti* overlying silicate mudstone of the Frome Clay Formation, which may contain burrows.

Definition of lower boundary

The base of the Wattonensis Limestone Member, a thin unit (3 to 4 m) of interbedded limestone and mudstone, resting on calcareous mudstone of the Fuller's Earth Formation. Base defined by an increase in shell-detritus in the calcareous mudstone.

Thickness

20 to 50 m in Wiltshire and Somerset, 45 to 70 m in Dorset (see Bristow et al., 1995).

Distribution

From Norton St Philip [ST 76 56], near Bath, Somerset where passes north into ooid limestone of Chalfield Oolite Formation, south to Dorset coast, passing east at depth in western Hampshire into limestone (?Chalfield Oolite Formation) of Wessex Basin (Wyatt, 2011). Present in offshore English Channel south of the Hampshire–Dieppe High (Hamblin et al., 1992).

Supplementary information

The well-known oyster-rich beds (lumachelle) overlying the Wattonensis Limestone Member in Dorset were formerly known as the Elongata Beds (e.g. Cox and Sumblar, 2002, pp 22-23). However, the BGS Sea Barn Farm Borehole (SY68SW3) [SY 6263 8054] (Hamblin et al., 1992, fig. 35) and the work of Palmer (2005) show there to be two wide-ranging oyster lumachelles within the Frome Clay Formation, the lower one now known as the Lobata Beds, the upper some 32 m above is the Elongata Beds.

Previous names

Upper Fuller's Earth (e.g. Arkell, 1933)

Fuller's Earth (due to misunderstanding of lateral relationships) See references in Penn and Wyatt (1979).

Parent

Great Oolite Group

Age

Bathonian, Retrocostatum Zone

References

Principal reference: (Penn et al., 1979)

5.2.3 Forest Marble Formation (FMB)

Name

Name originated with William Smith (c. 1812), after the type area, Wychwood Forest in Oxfordshire; first use of 'Forest Marble Formation' by McKerrow and Kennedy (1973), although differing in detail from herein. The stratigraphy in the type area, recognition of base and abandonment of alternative names discussed by Sumblar (1984), although no type section proposed. See also Chalfield Oolite, Corsham Limestone and White Limestone formations entries (sections 5.2.8, 5.2.9 and 5.2.15) for further discussion of base.

Type section

None designated

Type area

Wychwood Forest, Oxfordshire (i.e. the area approx. from Burford, to Bladon, and northwards to the River Evenlode [about SP 25 12 to 35 20 to 43 15] (Smith, 1812, unpublished stratal tables; see Arkell, 1933)

Reference section(s)

Shipton-on-Cherwell Cement Works Quarry [SP 473 177], near Woodstock, Oxfordshire (immediately east of type area), exposes the full thickness of the formation, underlain by the Bladon Member of the White Limestone Formation and overlain in places by the Cornbrash Formation. The Forest Marble comprises between 5 and 8 m of beds clearly displaying the lateral passage between the low energy mudstone facies and the high energy carbonate-sand shoal and channel-fills (Allen and Kaye, 1973; Cox and Sumblar, 2002)

Watton Cliff [SY 451 908], West Bay, Dorset permanently but variably exposes over 25 m of beds, including 0.35 m-thick Boueti Bed at base (overlying the Frome Clay Formation), overlain by mudstone with lenses and beds of limestone: top not seen (Callomon and Cope, 1995)

Formal subdivisions

Boueti Bed (BOU) (Buckman, S S, 1922).
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Informal subdivisions

Acton Turville Beds (AT) (Cave, 1977)

Bradford Clay (BDY) (Woodward, 1894)

Hinton Sand(s) (Arkell, 1933; Warner, 1811)

Lithology

Silicate-mudstone, greenish grey, variably calcareous and in the south notably sandy, with lenticular typically cross-bedded limestone units which form banks and channel-fills especially in lower part. A variety of limestone types occur of which grey weathering brown and flaggy, variably sandy medium to coarsely bioclastic grainstone or less commonly packstone predominates, especially at the base. North from Bath into the north Cotswolds the basal limestone beds become increasingly ooidal. Other types include fissile sandy limestone, grading to calcareous sandstone, and oyster-limestone. South of the Mendips, a silicate-muddy, fossiliferous (notably brachiopod-rich) lime-mudstone (Boueti Bed) lies at the base. Bivalves and brachiopods dominate the fauna in the formation, and lignite debris and fish scales and teeth are common, but infauna and signs of bioturbation are rare. The formation consists of interbedded mudstone and limestone in the Weald and English Channel, but in St George's Channel comprises rhythmically bedded mudstone, siltstone and fine sandstone.

Lithogenetic description

Shallow, generally low energy, marine conditions, with silicate mud deposition, but with highly mobile lime-sand shoals forming channel-fills and banks.

Landform description

Generally forms plateaux behind escarpments formed by basal limestone of the formation or underlying limestone formations.

Definition of upper boundary

Generally mudstone in upper part of Formation, overlain sharply and non-sequentially by rubbly, ooidal shelly wackestone/packstone limestone of the Cornbrash Formation

Definition of lower boundary

South Midlands and Cotswold region: base of greenish grey silicate-mudstone, or, grey to brown variably sandy medium to coarsely bioclastic grainstone or packstone limestone, resting with erosive, commonly channelled disconformity (e.g. in the north Cotswolds) on (from north to south) white to yellow peloidal, lime mud-rich, less silicate-muddy limestone, locally with coralliferous beds, of White Limestone Formation, or on bored and oyster encrusted hardground on ooidal limestone of Athelstan Oolite Formation, or on ooidal limestone of Chalfield Oolite Formation, or on ooidal and shell detrital limestone with coralliferous lenses of Corsham Limestone Formation.

South of Mendips: marked by Boueti Bed, a brachiopod-rich lime-mudstone, resting non-sequentially on olive grey bioturbated mudstone of Frome Clay Formation (formerly Upper Fuller's Earth Clay).

Thickness

Up to 5 m thick in Buckinghamshire, 10 to 30 m in Oxfordshire and Gloucestershire, 30 to about 50 m in north Dorset, 30 to 75 m in south Dorset and English Channel (Barton et al., 2011; Hamblin et al., 1992), St George's Channel 242 m proved (Tappin et al., 1994)

Distribution

Onshore: Weymouth area, Dorset coast to Olney area [SP 88 51], Buckinghamshire, where the formation is either overstepped by the Cornbrash Formation or passes into the Blisworth Clay Formation. Present at depth in Weald (Wyatt, 2011). Offshore: English Channel, Bristol Channel, St George's Channel.

Supplementary information

The basal limestone beds are locally termed the Acton Turville Beds between Biddestone and Didmarton.

Previous names

Bradford Beds: Lower part of formation (but may exclude basal limestone beds), overlain by Wychwood Beds (Arkell, 1947; Donovan and Hemingway, 1963)

Wychwood Beds: Upper part of formation, underlain by Bradford Beds (Arkell, 1947; Donovan and Hemingway, 1963)

Forest Marble: Generally coincides with the usage defined here, but where it includes 'Kemble Beds' may include some underlying strata (Sumbler, 1984)

Kemble Beds. A term coined by Woodward (1894) but so inconsistently applied variously to strata now included in the Forest Marble, White Limestone and Chalfield Oolite formations by him and others (e.g. Arkell, 1933; Richardson, 1933) that it has no value (Sumbler, 1984, 1991).

Parent

Great Oolite Group

Age

Bathonian, Retrocostatum Zone to Discus Zone

References

Principal reference (Sumbler, 1984)

5.2.4 Cornbrash Formation (CB)

Name

In common with several other well-known Jurassic formations, the Cornbrash has been recognised since the earliest days of British stratigraphy. It carries a name derived from a farming term referring to its stony soils suited to cereal growing, and given to the stratum by Wm. Smith (in Townsend, 1813). See also Smith (1817) and Page (1989) modified herein as above.

Page (1989) rejected Wright's (1977) division of the formation in North Yorkshire into a Cornbrash Limestone Member and Shales of the Cornbrash Member, maintaining the former as his Abbotsbury Cornbrash Formation, and dubbing the latter the Cayton Clay Formation. This treatment is adopted here, apart from Page's 'Abbotsbury' prefix which has achieved no currency, and his Berry and Fleet members (see above paragraph).

Type section

Berry Knap (cliff section) [SY 585 830], near Abbotsbury, Dorset: full sequence exposed, 9.35 m thick (Cox and Sumbler, 2002, p. 223; Page, 1989)

Type area

None designated

Reference section(s)

Shipton-on-Cherwell Cement Works Quarry [SP 478 173], near Woodstock, Oxfordshire: complete Lower Cornbrash Member and basal part of Upper Cornbrash Member exposed at top of quarry (Cox and Sumbler, 2002; Sumbler et al., 2002).

Formal subdivisions

Upper Cornbrash Member (UCB) (Douglas and Arkell, 1928, 1932)
Lower Cornbrash Member (LCB) (Douglas and Arkell, 1928, 1932)

Other subdivisions of uncertain status

Fleet Member (Page, 1989): use Upper Cornbrash Member

Middle Cornbrash (Buckman, S S, 1927): part of Upper Cornbrash Member

Berry Member (Page, 1989): use Lower Cornbrash Member

Astarte-Trigonia Bed, locally developed within the upper part of the Berry Member of Page (1989)

Corston Beds, locally developed within Berry Member of Page (1989)

Obovata Biozone limestones and marls, locally developed within Berry Member of Page (1989)

Intermedia Bed, basal part of Berry Member of Page (1989)

Lithology

Limestone, medium- to fine-grained, predominantly bioclastic wackestone and packstone with sporadic peloids; generally and characteristically intensely bioturbated and consequently poorly bedded, although better bedded, commonly somewhat silicate-sandy units occur in places, particularly in the upper part. Generally bluish grey when fresh, but weathers to olive or yellowish brown. Thin silicate-muddy partings or interbeds of calcareous mudstone may occur.

Lithogenetic description

Product of a very widespread marine transgression establishing open marine conditions and depositing mixed carbonate sediment, but with repeated minor regressions causing erosion and non-sequences.

Landform description

Generally lying between mudstone formations, and so forms minor escarpments and plateaux.

Definition of upper boundary

Base of succeeding Kellaways Formation, or Cayton Clay Formation in the Cleveland Basin; comprising mudstone, commonly shelly at base, resting generally sharply and conformably or non-sequentially on bioclastic limestone of the Cornbrash.

Definition of lower boundary

Generally sharp, disconformable non-sequence: bioclastic limestone resting upon mudstone (and bioclastic ooidal limestones, locally) of the Forest Marble Formation (Wessex Basin and south Midlands), or mudstone of the Blisworth Clay Formation (East Midland Shelf east and north) or mudstone with minor sandstone beds of the Scalby Formation (Cleveland Basin).

Thickness

Up to about 10.5 m (Page, 1989); thickest in Wessex Basin but more generally 2 to 4 m from Wiltshire to Yorkshire.

Distribution

Onshore: Dorset coast (Weymouth area) to Yorkshire coast (Scarborough area); absent over Market Weighton High. Present at depth in the Weald Basin (Wyatt, 2011), though absent over interior of London Platform. Offshore: present in the offshore extensions of the Weald and Wessex basins, in the English Channel (Hamblin et al., 1992), and recognised in the Bristol Channel and St. George's Channel basins (Tappin et al., 1994).

Supplementary information

The Cornbrash has the greatest geographical extent of any Middle Jurassic formation, its outcrop extending from Dorset to the Yorkshire coast, interrupted only at Market Weighton, and was formerly recognised on Raasay, Inner Hebrides (Hudson, 1962b, p. 148), the strata here now included in the Duntulm Formation (Section 8.2.5). Despite its limited thickness (generally less than 4 m), its stratigraphical position, between thick and persistent mudstone-dominated units, coupled with its excavatability and suitability for rough building and road-making, has resulted in the Cornbrash being worked in countless small pits in districts where it may be the only local source of stone. Over 150 years, this has facilitated comprehensive collecting and documentation of its prolific, varied and well-preserved shelly fauna, dominated by brachiopods and bivalves, but including (relatively, compared with the underlying units) common ammonites (e.g. Blake, 1905).

In addition, it was recognised at an early stage that the formation included several significant non-sequences. Studies of the fauna and successions have generated a number of stratigraphical and biostratigraphical subdivisions over the years (see especially Douglas and Arkell, 1928, 1932; Wright, J K, 1977), and the terms 'Lower Cornbrash' and 'Upper Cornbrash' have become widely utilised, respectively of Bathonian and Callovian age, commonly separated by a significant non-sequence (Cope, 2006), fig. 14.16. Page (1989) proposed the Berry Member and Fleet Member respectively as formal lithostratigraphical units, but they are not precise synonyms. Although in most areas the Lower and Upper Cornbrash (or Berry and Fleet members) are indistinguishable in lithology, nevertheless, some lithologies are more common in one unit rather than the other (e.g. bedded sandy limestones are more or less restricted to the

‘Upper Cornbrash’). Thus it is proposed here that the Lower Cornbrash and Upper Cornbrash are formal members.

Previous names

Cornbrash (Smith, W, 1817)

Cornbrash Limestone Member (Wright, J K, 1977)

Abbotsbury Cornbrash Formation (Page, 1989)

Parent

Great Oolite Group. None in Cleveland Basin.

Age

Upper Bathonian to Lower Callovian, Discus Zone to Herveyi Zone

References

Principal reference (Page, 1989)

Cotswold–Weald Shelf: south and Mid Cotswolds formations

In the Bathonian, this region was the locus of the general southward dynamic progradation of carbonate facies belts (Figure 9), with styles of deposition ranging from silicate mud in deeper quiet marine conditions, through carbonate mud on the shelf foreslope, carbonate sand (ooids, peloids, bioclasts) on the very shallow marine shelf, in fluctuating high energy conditions, through to mixed carbonate grains (mud to sand-grade) in shallow but protected marine lagoon conditions. Hence the region shows the most stark manifestations of rapid lateral change and interdigitation. This presents the most difficulties in defining viable lithostratigraphical units.

In the lower part of the succession, the mudstone-dominated Fuller’s Earth Formation persists north from the Wessex Basin, and within it a number of distinctive limestone units appear, some of which have been named (Figure 9; Arkell and Donovan, 1952; Torrens, 1968b).

The famous oolite building stones, extracted by quarrying and mining from the hills of the Bath district, which gives its name to their geochronological Age of Bathonian, have been known by a number of names since the days of Wm Smith, many relating to their relative position in the sequence or to their value as stone (e.g. Lonsdale, 1832). In their considered study of the district, following a thorough Geological Survey (BGS) mapping exercise, Green and Donovan (1969) described the succession and gave names (some adopted) to well defined subdivisions – the Combe Down Oolite, Twinhoe Beds, Bath Oolite, Upper Rags – of their Great Oolite (Formation), which lay between the Fuller’s Earth (Formation) and Forest Marble (Formation) (their adoption of ‘Bath Oolite’ for a subdivision of the formation may be regarded as unfortunate). The principal building stones lie within the Bath Oolite and to a lesser extent the Combe Down Oolite. Following wide adoption of the term Great Oolite Group (e.g. Callomon and Cope, 1995) for all the (almost entirely Bathonian) strata in southern England between the Inferior Oolite Group and the Kellaways Formation, the usage of ‘Great Oolite (Formation)’ for a more vertically and laterally restricted ooid-limestone interval became untenable, despite its arguable precedence and greater appropriateness, on the grounds of imprecise earlier usage, and continued potential for confusion. A solution to this was proposed by Wyatt and Cave (2002) with a formal formation – the Chalfield Oolite Formation (Section 5.2.8).

Fuller’s Earth Formation

See 5.2.1 above.

5.2.5 Tresham Rock Formation (TRR)

Name

Named after the village of Tresham [ST 79 91], Gloucestershire by Arkell and Donovan (1952), formalised by Wyatt (1996).

Type section

Foxley No. 1 Borehole (ST98NW14A) [ST 9775 8947], full thickness between 47.80 and 64.50 m depth, dominated by limestone with median mudstone unit, underlain by Dodington Ash Rock Member (Fuller's Earth Formation), overlain by Athelstan Oolite Formation. Samples held by BGS. (Wyatt, 1996, fig. 4).

Type area

Tresham to Kingscote, Gloucestershire, [ST 790 911 to 820 962]

Reference section(s)

Hullavington Borehole, ST88SE16 [ST 8894 8249], full thickness between 34.59 and 48.55 m depth, dominated by fine-grained limestone with median calcareous mudstone unit, underlain by Fuller's Earth Formation (Hawkesbury Clay Member), overlain by typical Athelstan Oolite Formation. Samples held by BGS. (Wyatt, 1996, fig. 4).

Formal subdivisions

None. Dodington Ash Rock Member (Torrens, 1968b) is herein placed in the Fuller's Earth Formation.

Lithology

Limestone, calcilutite, pale grey, bioturbated, silicate-muddy, poorly fossiliferous; passing up into whitish grey, less silicate-muddy calcilutite. Lenses of ooidal limestone occur in places, at the base (Hen's Cliff Oolite of Arkell and Donovan, 1952); and in the upper part. Subordinate calcareous mudstone beds in places. Passes laterally by interdigitation southwards into the predominantly mudstone sequence of the Fuller's Earth Formation, and by increase in ooid content north-eastwards into the Athelstan Oolite Formation.

Lithogenetic description

Carbonate shelf foreslope, carbonate mud accumulation.

Landform description

Generally forms ledges within mudstone slopes, or minor plateaux.

Definition of upper boundary

Rapid passage up from fine-grained limestone with ooidal limestone lenses into massive ooid-limestones of Athelstan Oolite Formation, or locally where that formation is absent, bedded ooid-limestone of the Chalfield Oolite Formation. In south, there is a sharp change up into grey mudstone of the Lansdown Clay Formation, locally (seen in Biddestone borehole) a non-sequence with a hardground.

Definition of lower boundary

Sharp change up from grey mainly calcareous mudstone of Fuller's Earth Formation (locally known as the Hawkesbury Clay Member), or where absent, erosive non-sequence, with sharp change up from shell-detrital limestone of the Dodington Ash Rock Member (Fuller's Earth Formation), into fine-grained limestone of the Tresham Rock Formation.

Thickness

0 to about 17 m.

Distribution

Outcrop: near Dyrham [ST 74 74], Gloucestershire, where the Tresham Rock passes into the Fuller's Earth Formation, to Kingscote [ST 82 96], Gloucestershire, where it passes into Athelstan Oolite Formation. Subcrop: Biddestone to Milbourne (Malmesbury), Wiltshire (Wyatt, 1996), extends east into Hampshire, where it passes into the Athelstan Oolite Formation (Wyatt, 2011).

Previous names

Tresham Rock (Arkell and Donovan, 1952), (see also Cave, 1977)

Parent

Great Oolite Group

Age

Bathonian, Morrisi Zone

References

Principal reference (Arkell and Donovan, 1952)

See also (Cave, 1977; Cox and Sumblar, in prep; Wyatt, 1996)

5.2.6 Lansdown Clay Formation (LDN)

Name

Named after Lansdown Hill [ST 72 68] by Arkell and Donovan (1952), as a name for the Upper Fuller's Earth (Member) from north of Bath to Grickstone Farm [ST 776 829], Little Sodbury; formalised herein.

Type section

Cutting on M4 motorway at Dodington Ash where it is fully exposed, and comprises about 9 m of calcareous mudstone with thin limestone beds (Torrens, 1968b).

Type area

South Cotswolds, Tormarton area [ST 75 78], Gloucestershire.

Reference section(s)

Biddestone Borehole (ST87SE1) [ST 8609 7282], full thickness at 52.19 to 56.05 m depth. Samples held by BGS (Wyatt, 1996).

Formal subdivisions

None.

Lithology

Mudstone, grey, bedded, calcareous, shell-detrital, with subordinate fine-grained, shell-detrital and ooidal limestone beds.

Lithogenetic description

Marine basin setting in which mud deposition dominated, with occasional shallowing and limestone deposition.

Landform description

Forms a slope between more resistant limestone formations

Definition of upper boundary

Sharp change up from mudstone of Lansdown Clay into ooid-limestone or coarse-grained shelly ooidal limestone ('Grickstone Beds'), locally with limestone pebbles, of Chalfield Oolite Formation. May be a non-sequence.

Definition of lower boundary

Sharp change up from fine-grained limestone of the Tresham Rock Formation, locally (seen in Biddestone Borehole) a non-sequence with a hardground, or massive ooid-limestone of the Athelstan Oolite Formation (where present) into mudstone of Lansdown Clay.

Thickness

Up to about 10 m. 3.9 m in Biddestone Borehole (ST87SE1) [ST 8609 7282].

Distribution

South Cotswolds: at outcrop from the southern limit of the underlying Tresham Rock Formation near Dyrham [ST74 74] to the pinch-out/passage of the Lansdown Clay Formation into the Athelstan Oolite Formation at Grickstone Farm [ST 776 829], Little Sodbury. At depth seen from Biddestone Borehole (ST87SE1) [ST 8609 7282], near Corsham to boreholes at Hullavington (ST88SE16) [ST 8894 8249] (Wyatt, 1996) and Sherston (ST88NW1) [ST 8474 8542] (Wyatt and Cave, 2002), near Malmesbury.

Supplementary information

Formation defined as a unit of predominantly mudstone beds lying between Tresham Rock and Chalfield Oolite formations. As defined no longer present at Lansdown Hill.

Previous names

Upper Fuller's Earth (Member) (Arkell and Donovan, 1952).

Parent

Great Oolite Group

Age

Bathonian, Bremeri Zone

References

Principal reference (Wyatt, 1996).

5.2.7 Athelstan Oolite Formation (AOL)

Name

Unit proposed by Cave (1977). The name is alleged to have been taken from that of a local bus company in Malmesbury.

Type section

BGS Charlton (Lower Moor Farm) Borehole (ST98NE2) [ST 9775 8947], full thickness at 37.36 to 58.20 m depth, samples held by BGS (Wyatt, 1996, fig. 4).

Type area

Tresham to Chipping Sodbury, Gloucestershire [ST 800 923 to 776 830]

Reference section(s)

Gate Quarry, Minchinhampton Common [SO 856 017]. About 5 m of ooidal and bioclastic limestone in the lower part of the formation, (Cox and Sumbler, 2002, pp. 151-153).

Formal subdivisions

None

Informal subdivisions

(Crapwell) Coppice Limestone (Cave, 1977)

Lithology

Limestone, white to pale yellow, poorly fossiliferous ooid-grainstone and ooidal limestone; in south-west are generally well sorted medium-grained and massive, rarely cross-bedded; in north-east become more bioclastic, less well-sorted fine- to coarse-grained, commonly cross-bedded. Generally capped by a bored, encrusted hardground that are shown on the Gloucester (E&W 234) sheet (British Geological Survey, 1972a) and Malmesbury (E&W 251) sheet (British Geological Survey, 1970) as 'chinastone' or 'Coppice Limestone' (Cave, 1977). Lateral passage north-east into peloidal packstone and wackestone of the Ardley Member (White Limestone Formation), and lower part passes south-westwards by decrease in ooid content into the Tresham Rock Formation.

Lithogenetic description

High energy shallow carbonate shelf with mobile ooid shoals.

Landform description

Generally forms cap to escarpment above mudstone slopes, or minor plateaux.

Definition of upper boundary

The top of the formation is a bored and oyster encrusted hardground on ooidal limestone, overlain by pale grey, bioclastic ooidal limestones of Chalfield Oolite Formation, or ooidal and shell detrital limestone with coralliferous lenses of Corsham Limestone Formation, or where both are absent brown and grey variably ooidal, sandy or muddy bioclastic lime-grainstone/packstone (Forest Marble Formation). Near the formation's southern limit, grey mudstone of the Lansdown Clay Formation intervenes beneath the Chalfield Oolite.

Definition of lower boundary

South of Horsley [ST 840 975]; rapid passage up from fine-grained slightly argillaceous limestone with ooidal limestone lenses (Tresham Rock Formation), into massive ooid-limestones. Locally a thin grey mudstone bed (a leaf of the Lansdown Clay Formation) may intervene. North of Horsley; sharp change up from grey mainly calcareous mudstone (Fuller's Earth Formation), or where absent, from shell-detrital limestone of the Dodington Ash Rock Member (Fuller's Earth Formation), into massive ooid-limestones.

Thickness

About 3 to 21 m.

Distribution

Outcrop: near Old Sodbury [ST 76 81] to area [SO 90] west of Cirencester, Gloucestershire, where the Athelstan Oolite passes into the White Limestone Formation (boundary is taken arbitrarily at the western and southern edges of the Cirencester (E&W 235) sheet (British Geological Survey, 1998a). Subcrop: Hullavington, Wiltshire to Sandpool Farm (Somerford Keynes), Gloucestershire (Wyatt, 1996). Present at depth in the Weald (Wyatt, 2011).

Previous names

Bath Stone and Lower Rags (Arkell and Donovan, 1952, p. 235, pl. 16)

Parent

Great Oolite Group

Age

Bathonian, Bremeri Zone to Retrocostatum Zone

References

Principal reference (Cave, 1977)

5.2.8 Chalfield Oolite Formation (CFDO)

Wyatt and Cave (2002) contend that the Chalfield Oolite Formation forms a succession of southward-prograded prisms of ooid limestone, overstepped northward by the Forest Marble Formation, such that the lowest prism ('Lower' Combe Down Oolite) extends furthest north. However, at the same time in defining the Chalfield Oolite Formation, Wyatt and Cave (2002) reassigned the Upper Rags (including the 'Reef Bed', or Corsham Coral Bed of Green and Donovan (1969)) as the basal member of the Forest Marble Formation, and drew a correlation with similar strata exposed at Kemble [ST 9748 9757] (Cave, 1977) and coralliferous beds described from the Cirencester district – the Fairford Coral Bed (Sumbler, 1991; Sumbler et al., 2000). This correlation and classification conflicted with that of Green and Donovan (1969), Sumbler (1991) and Sumbler et al. (2000), and closely argued correspondence ensued (Green and Donovan, 2003; Sumbler, 2003; Wyatt and Cave, 2003). This has failed to resolve the dispute (Cox and Sumbler, in prep). However, after separate discussions with Messrs Wyatt and Sumbler and a review of the descriptions of sections (Cave, 1977; Green and Donovan, 1969; Wyatt and Cave, 2002), this author (AJMB) accepts Wyatt and Cave's (2002) Chalfield Oolite Formation definition in the Bath district (i.e. excluding the Upper Rags), and also the definition of the base of the Forest Marble Formation of Green and Donovan (1969) in the Bath district (Barron et al., 2011) and Sumbler (e.g. 1991, 2003) in the wider region, and suggests that the lithofacies of the intervening Upper Rags beds, including the Bradford Coral Bed and Corsham Coral Bed, is sufficiently different to merit a new formation, named here the Corsham Limestone Formation, defined below (Section 5.2.9). In addition, following this review it is concluded that Wyatt and Cave's (2002, fig. 4) classification or reclassification of many of the published sections, including identification of the Upper Rags, and Upper and Lower Combe Down Oolite units, is not supported by the evidence. Together with the ammonite data cited by Sumbler (2003) this suggests that their model of successive dipping carbonate wedges, progressively truncated northwards may not be sustainable.

Name

Named after the hamlet of Great Chalfield, near Bradford on Avon, Wiltshire by Wyatt and Cave (2002), where the type section borehole is located. Formation proposed by Wyatt and Cave (2002) as modified herein, to replace the unsatisfactorily named 'Great Oolite Formation' (see above) of Green and Donovan (1969) in the Bath district.

Type section

Chalfield No. 1A Borehole (ST86SE3) [ST 8523 6333], full thickness at 28.73 to 54.08 m depth. Samples held by BGS (Wyatt and Cave, 2002)

Reference section(s)

Mural exposures at Brown's Folly [ST 795 663 to 794 692], Bathford, about 15 m of strata seen from top, but base not seen (Cox and Sumbler, 2002, pp. 125-127).

Biddestone Borehole (ST87SE1) [ST 8609 7282], full thickness at 21.63 to 52.19 m depth. Samples held by BGS (Wyatt and Cave, 2002)

Formal subdivisions

Bath Oolite Member (BHO) (Green and Donovan, 1969; Lewis, 1990)

Twinhoe Member (TW) (Green and Donovan, 1969; Lewis, 1990)
Combe Down Oolite Member (CODO) (Green and Donovan, 1969; Lewis, 1990)

Lithology

Calc-oolidal grainstone, predominantly light grey and pale yellow to white fine- to coarse-grained, with variable bioclastic content, in medium to thick beds; cross-bedded in parts; burrowed in parts. A median unit of pisoidal, bioclastic limestone (Twinhoe Member) is developed south of Corsham. The generally moderately bioclastic ooid-limestones below (Combe Down Oolite Member) are fine- to coarse-grained, and those above (Bath Oolite Member) are medium to coarse-grained ooid-limestones. Where the Twinhoe Member is not recognisable, the Combe Down and Bath Oolite members may not be distinguishable. Lenses or partings of coral debris are locally seen in the Bath Oolite.

The basal beds from Tormarton north to Hawkesbury Upton comprise a unit of coarse-grained shelly ooidal limestone ('Grickstone Beds'). These resemble the basal limestone of the Forest Marble Formation and north of Little Badminton where the overlying Combe Down Oolite beds are absent they cannot be reliably distinguished.

Lithogenetic description

High energy tidal shallow carbonate shelf with mobile ooid shoals, the whole prograding into deeper water.

Landform description

Generally forms cap to escarpment above mudstone slopes, or significant plateaux.

Definition of upper boundary

A non-sequence, taken above the highest light coloured generally moderately bioclastic ooid-grainstone, either erosive or marked by a bored and/or oyster-encrusted hardground, overlain by grey or brown variably sandy bioclastic limestone, variously ooidal or shelly, with in places one or more lenticular coralliferous beds, termed the 'Upper Rags' by Green and Donovan (1969) or locally by calcareous silicate-mudstone (all of the Forest Marble Formation).

Definition of lower boundary

The base is marked by a sharp change up from grey calcareous silicate mudstone with subordinate argillaceous limestone beds of the Fuller's Earth or Lansdown Clay formations into ooid-limestone (Combe Down Oolite Member) or coarse-grained shelly ooidal limestone ('Grickstone Beds'), locally with limestone pebbles. North of Badminton [ST 78 83] to Didmarton [ST 82 88], the base rests sharply on fine-grained ooid-limestone of the Athelstan Oolite Formation, which is widely surmounted by a hardground mapped on Malmesbury (E&W 251) sheet (British Geological Survey, 1970) as 'chinastone' or 'Coppice Limestone' (Cave, 1977).

Thickness

25 m to perhaps 31 m in type area, thins north to zero. 30.6 m in Biddestone Borehole.

Distribution

Outcrop: Wellow [ST 74 56], 7 km south-west of Bath, where the Chalfield Oolite passes laterally into the Frome Clay, north-east to Didmarton [ST 82 88], Gloucestershire, where it is overstepped by the Forest Marble Formation. The formation thins progressively and substantially north-east of Badminton, mainly due to erosion of the upper beds beneath the Forest Marble Formation, but also possibly through lateral passage into the Athelstan Oolite Formation. Subcrop: present at depth in the Weald (Wyatt, 2011; Wyatt and Cave, 2002).

Previous names

Great Oolite (approximately equivalent to a term used by William Smith in about 1800 and cited in Warner (1811), by Lonsdale (1832), by Woodward (1894) and by Green and Donovan (1969), who coined the subdivisions Combe Down Oolite, Twinhoe Beds and Bath Oolite.)

Great Oolite Limestone; Chalfield Oolite Formation approximately equivalent to term used by Welch (1957), including his (quoting G W Green) lower un-named ‘oolitic freestone’, Twinhoe Ironshot Limestone, Bath Oolite but excluding his Ancliff Oolite, including the Coral Bed).

Great Oolite Formation of Cox and Sumbler (2002, pp. 125–130, fig. 3.4), including their Combe Down Oolite, Twinhoe and Bath Oolite members.

Parent

Great Oolite Group

Age

Bathonian, Retrocostatum Zone

References

Principal reference (Wyatt and Cave, 2002)

Additional references (Arkell and Donovan, 1952; Cox and Sumbler, in prep).

5.2.9 Corsham Limestone Formation (CSHF)

Name

Named after the type section railway cutting in the town of Corsham in Wiltshire [ST 87 70] as Corsham Member by Sumbler (2003). Formalised as a formation herein see also Barron et al. (2011).

Type section

Corsham railway cutting [ST 8581 6942 to 8653 6955], Corsham, Wiltshire, exposing the full thickness of the formation, between 6.2 and 6.7 m thick, overlying the Bath Oolite Member of the Chalfield Oolite Formation, and overlain by the Forest Marble Formation (Barron et al., 2011; Cox and Sumbler, 2002, pp. 128-130; Green and Donovan, 1969, pp.50-52, beds 3 to 6).

Reference section(s)

Chalfield No. 1A Borehole (ST86SE3) [ST 8523 6333], full thickness at 20.60 to 28.73 m depth. Samples held by BGS.

Mural exposures at Brown’s Folly [ST 795 663 to 794 692], Bathford, formation fully exposed showing 6.4 m of strata including the Bradford Coral Bed and Corsham Coral Bed; underlain by Bath Oolite Member of Chalfield Oolite Formation; overlain by Forest Marble Formation (Cox and Sumbler, 2002, pp. 125-127).

Formal subdivisions

None.

Informal subdivisions

Bradford Coral Bed (Green and Donovan, 1969)
Ancliff Oolite (Woodward, 1894, as modified by Green in Welch, 1957)
Corsham Coral Bed (Green and Donovan, 1969)

Lithology

Limestone, white or brown, variably ooidal and shell detrital, grainstone, packstone and wackestone textures, medium- to thick-bedded, cross-bedded or massive, with in places especially around Bath one or more lenticular or mound-shaped. shell-detrital, shelly, rubbly limestone beds with compound coral masses, notably at the base ('Corsham Coral Bed') and at/towards the top ('Bradford Coral Bed'). Where white, cross-bedded ooidal limestone beds are well-developed in the Bath area they have been termed the 'Ancliff Oolite'. The ooidal limestone beds in the lower part in the Sherston area may be sandy. The formation has a rich fauna dominated by brachiopods and bivalves.

Lithogenetic description

Shallow, generally high energy, marine conditions, with mobile lime-sand shoals of bioclasts and ooids forming channel-fills and banks, but with at times local coral mound accumulation, or episodes of low-energy conditions leading to deposition of thin beds of terrigenous mud.

Landform description

Forms part of a thicker succession of resistant limestone formations capping plateaus and escarpments.

Definition of upper boundary

Sharp, disconformable change up from ooidal and shell detrital limestone with coralliferous lenses of Corsham Limestone Formation into grey to brown variably sandy medium to coarsely bioclastic grainstone or packstone limestone of Forest Marble Formation; commonly marked by an oyster-encrusted hardground.

Definition of lower boundary

Sharp non-sequential change up from white, yellow or light grey ooidal grainstone limestone of the Chalfield Oolite or Athelstan Oolite formations, capped with a hardground that is commonly bored, overlain by ooidal and shell detrital limestone with coralliferous lenses of Corsham Limestone Formation.

Thickness

Lenticular. Up to about 9 m. 6.2 to 6.7 m thick in type section, Corsham railway cutting.

Distribution

Mid and south Cotswolds: from the Tetbury area, Gloucestershire [ST 89 93], where the formation pinches out or passes northwards into the Signet Member of the White Limestone Formation, south to Baggridge [ST 74 56] near Norton St Philip, Somerset where it passes south into the basal beds (Boueti Bed) of the Forest Marble Formation.

Previous names

Upper Rags (Lonsdale, 1832).

Great Oolite of Malmesbury district (British Geological Survey, 1970; Cave, 1977)

Upper Rags Member (Wyatt, 1996)

Corsham Member (Sumbler, 2003)

Parent

Great Oolite Group

Age

Bathonian, *Retrocostatum* Zone (by inference)

References

Principal references (Barron et al., 2011; Green and Donovan, 1969).

Forest Marble Formation

See Section 5.2.3 above.

Cornbrash Formation

See Section 5.2.4 above.

Cotswolds–Weald Shelf: North Cotswolds and Oxfordshire formations

In this region during the Bathonian, a pattern of lateral change is seen from the generally persistently marine but relatively protected northern part of the Cotswold–Weald Shelf into the predominantly paralic conditions of the East Midlands Shelf (Figure 9). The proximity of a large, long-lived emergent area on the London Platform to the south-east is significant and fluctuations in the coastline through time are seen in the pattern of facies preserved here. Marine carbonate sand deposition occurred in conditions ranging from high (Taynton Limestone Formation) through moderate (Hampen, Chipping Norton Limestone formations) to low energy (White Limestone Formation); marginal marine to paralic/deltaic deposition is also seen (Horsehay Sand, Sharp’s Hill formations).

5.2.10 Chipping Norton Limestone Formation (CNL)

Name

Named Chipping Norton Limestone by Hudleston (1878) after the town of Chipping Norton in Oxfordshire and formalised as Chipping Norton Formation by Sellwood and McKerrow (1974).

Type section

Oxfordshire County Council Quarry [SP 3184 2748], Chipping Norton exposes about 5.3 m of the formation in typical facies, including layers of pebbles at some levels, but the base and top are not seen (Horton et al., 1987, p. 71)

Reference section(s)

Ditchley Road Quarry [SP 368 198], Charlbury exposes the full thickness of the formation in typical facies, 6.2 m thick, resting on the Salperton Limestone Formation and overlain by the Sharp’s Hill Formation (Cox and Sumbler, 2002, pp. 215-218).

Hornsleasow Quarry [SP 131 322], Bourton-on-the-Hill, exposes at least 12 m of the formation including the top and base, and formerly exposed the vertebrate-bearing ‘Hornsleasow Clay’ (Cox and Sumbler, 2002, pp. 199-202; Cresta et al., 2001).

For other reference sections see Horton et al., (1987)

Formal subdivisions

None.

Informal subdivisions (not adopted as formal here)

Chipping Norton Member (Sellwood and McKerrow, 1974; Torrens, 1980)

Swerford Member (Richardson, 1911; Torrens, 1980)

Hook Norton Member (HNL) (Sellwood and McKerrow, 1974; Torrens, 1980)

Roundhill Clay (RC) (Richardson, 1929)

Lithology

Limestone, off-white to pale brown fine- to medium-grained ooidal and coated peloidal grainstone, with common fine burrows, medium- to coarse-grained shell debris and flakes of greenish grey mud and dark lignite and minor amounts of fine sand. Thick-bedded and cross-bedded or massive, weathering to flaggy or platy. Thin shell-detrital and ooidal marl and mudstone intercalations in places. Passing eastward into very sandy ('Swerford Beds' facies) into Horsehay Sand Formation. Locally a thin olive-grey mudstone bed ('Roundhill Clay' of Richardson, 1929) less than a metre thick occurs at the base.

Lithogenetic description

Moderate to high energy shallow carbonate shelf with mobile ooid and bioclast shoals.

Landform description

Generally forms plateau, or cap to escarpment above mudstone slopes.

Definition of upper boundary

Rapid passage upwards from fine- to medium-grained rather sandy ooidal and peloidal grainstone into mudstone-dominated Fuller's Earth Formation or Sharp's Hill Formation

Definition of lower boundary

Conformable/non-sequential; fine- to medium-grained rather sandy ooidal and peloidal grainstone, with fine burrows and flakes of mud and lignite on generally coarser-grained ooidal and peloidal limestone, locally with ferruginous peloids, of the Clypeus Grit Member, Salperton Limestone Formation. Oversteps north-eastwards to rest non-conformably on sands of the Horsehay Sand Formation, ooidal ironstone of the Northampton Sand Formation (Figure 9) and (locally) mudstone of the Whitby Mudstone Formation.

Thickness

0 to 12 m

Distribution

North Gloucestershire to north Oxfordshire, passing east into Horsehay Sand Formation

Supplementary information

It might be argued that with its dominant lithology The Chipping Norton Limestone Formation would sit comfortably in the underlying group, even given the basal non-sequence. However, priority places it in the Great Oolite Group, and given its eastward passage into the Horsehay Sand Formation (Section 5.2.11; Figure 9), and thence into the basal part of the Rutland Formation (Great Oolite Group), this treatment is supported here.

Previous names

Chipping Norton Limestone (Hudleston, 1878)

Chipping Norton Formation (Sellwood and McKerrow, 1974)

Parent

Great Oolite Group

Age

Bajocian–Bathonian, Parkinsoni Zone to Zigzag Zone (Cox and Sumblar, 2002; Horton et al., 1987).

References

Principal reference (Sellwood and McKerrow, 1974)

5.2.11 Horsehay Sand Formation (HYSA)

Name

Named after the type section, Horsehay Quarry, by Cox and Sumbler (2002, pp 211-214); defined herein. The history and rationale for this proposal is set out in *The 'White Sands Problem'* below.

Type section

Horsehay Quarry [SP 455 272], Duns Tew, Oxfordshire exposes the full thickness of the formation in typical facies, reportedly once seen as 10.8 m thick (Sellwood and McKerrow, 1974), but in 1997 only 2.45 m of beds were observed; resting on the Northampton Sand Formation and overlain by the Sharp's Hill Formation (Cox and Sumbler, 2002; Horton et al., 1987, pp. 57-58)

Reference section(s)

BGS Charlton Borehole (SP53SW9) [SP 5291 3487]. from 7.29 to 9.98 m depth in mudstone, sand and sandstone (Fenton et al., 1994; Horton et al., 1987, p. 58).

Formal subdivisions

None.

Lithology

Sand, pale grey and brown to off-white, medium- to fine-grained, quartzose, unbedded to weakly bedded and cross-bedded, locally cemented into calcareous or weakly ferruginous sandstone; with thin dark grey mudstone and siltstone beds in places. Rootlets and lignitic debris common. Shells and shell debris very rare.

Lithogenetic description

Marginal marine or deltaic conditions depositing mainly sand.

Landform description

Generally forms hollow (with mudstone of overlying Sharp's Hill Formation, where present) between upstanding harder limestone or ironstone units.

Definition of upper boundary

Change up into mudstone, calcareous mudstone and limestone beds of Sharp's Hill Formation, where present, or ooidal and shell detrital limestones of Taynton Limestone Formation. Boundary non-sequential. May be marked by an eroded or leached and rootlet-bearing top.

Definition of lower boundary

Change up from (lithologically similar) sand and sandstone beds with marine shelly fauna, but also including ooidal and shell-detrital limestones of Northampton Sand Formation (Inferior Oolite Group), where present, or mudstone beds of Whitby Mudstone Formation (Lias Group), into barren sand-dominated beds. Boundary on Northampton Sand Formation though non-sequential, is usually apparently conformable or even gradational (probably as a result of weathering effects), but locally may be disconformable or channelled (Horton et al., 1987, p. 56).

Thickness

Up to 7 m.

Distribution

Oxfordshire north-east of Sibford Gower, Hook Norton and Tackley (Horton, 1977, fig. 4), where it passes south-west on the Chipping Norton sheet (E&W 218) (British Geological Survey, 1968) into the Chipping Norton Limestone Formation. North-west Buckinghamshire. Northamptonshire south-west of Eydon and Wappenham on the Towcester sheet (E&W 202) (Hains and Horton, 1969). Here the overlying Taynton Limestone Formation passes north-east by lithological passage into the Wellingborough Member of the Rutland Formation (unpublished BGS data). As a result the mudstone beds and sand beds underlying it are no longer differentiated as the Sharp's Hill Formation and Horsehay Sand Formation respectively but are deemed to pass north-east into parts of the Rutland Formation; the Sharp's Hill Formation into un-named mudstone beds, the Horsehay Sand Formation into the Stamford Member.

Previous names

White Sands (Sharp, 1870).

Swerford Beds (Richardson, 1911)

Swerford Member (Sellwood and McKerrow, 1974)

Indexed in places as Lower Estuarine Series (Inferior Oolite) on the Chipping Norton (British Geological Survey, 1968), Towcester (Hains and Horton, 1969) and Banbury (British Geological Survey, 1982b) sheets (E&W 218, 202 and 201).

Parent

Great Oolite Group

Age

Bajocian to Bathonian, ?Parkinsoni Zone to Zigzag Zone

References

Principal reference (Bradshaw, 1978; Cox and Sumbler, in prep)

Fuller's Earth Formation (FE)

See Section 5.2.1 above.

5.2.12 Sharp's Hill Formation (SHHB)

Name

The term Sharp's Hill Beds was coined by Arkell (1933, pp. 297–301) after the type section quarry, later (Arkell, 1947) extending the definition to include all the mudstone-dominated beds between the Chipping Norton Limestone Formation and the Taynton Limestone Formation, as recognised here. The term was formalised by McKerrow and Kennedy (1973), but its wider relationship was elucidated by Bradshaw (1978) (see *Distribution* below).

Type section

Sharp's (or Sharps) Hill Quarry [SP 338 358], Sibford Ferris, Oxfordshire, exposes 4.6 m of the formation in clay, calcareous clay and fine-grained limestone facies, resting on the Chipping Norton Limestone Formation; the top is not seen (Cox and Sumbler, 2002, pp. 204-208; Horton et al., 1987, p. 79).

Reference section(s)

Horsehay Quarry, Duns Tew, Oxfordshire, [SP 455 272] exposes the full thickness of the formation in clay, sand and ooid-limestone facies, 6.7 m thick, resting on the Horsehay Sand

Formation and overlain by the Taynton Limestone Formation (Cox and Sumblar, 2002; Horton et al., 1987, pp. 57-58)

Formal subdivisions

None.

Lithology

Varied sequence of greenish grey, silty, moderately shelly and calcareous mudstone, pale greenish-grey shelly calcilutite fine-grained shelly limestone and locally bioclastic ooid-limestone. Fauna both marine and freshwater-influenced. Rootlets are common, and some mudstone beds display seatearth textures and more variegated colours, also indicating shallow, proximal conditions. Subordinate siltstone and sandstone beds are present near the base of the formation.

Lithogenetic description

Fluctuating very shallow marine to paralic and emergent conditions, with fine terrigenous sediment input.

Landform description

Generally forms hollow (with sand of underlying Horsehay Sand Formation, where present) between upstanding harder limestone or ironstone formations.

Definition of upper boundary

Conformably overlain by ooidal and shell detrital limestone of the Taynton Limestone Formation. Where this is locally absent, the formation is difficult to distinguish from the lithologically similar Rutland Formation.

Definition of lower boundary

Non-sequential, on Chipping Norton Limestone Formation, where present, or Horsehay Sand Formation. The base is taken at the first mudstone (commonly carbonaceous), calcilutite, sand or fine-grained limestone (commonly richly fossiliferous or pebbly) above the ooidal limestone of the Chipping Norton Limestone Formation (Horton, 1987, p. 74) or the barren sand of the Horsehay Sand Formation. It may be marked by an uneven junction.

Thickness

Up to 5 m

Distribution

North Oxfordshire north-east of Milton-under-Wychwood and Minster Lovell, where it passes south-west the Witney sheet (E&W 236) (British Geological Survey, 1982b) into the marine mudstone of the Fuller's Earth Formation. North-west Buckinghamshire. Northamptonshire south-west of Eydon and Wappenham on the Towcester sheet (E&W 202) (Hains and Horton, 1969). Here the overlying Taynton Limestone Formation passes north-east into the Wellingborough Member of the Rutland Formation (unpublished BGS data). As a result the beds underlying it are no longer differentiated as the Sharp's Hill Formation and are deemed to pass north-east into lithologically similar un-named mudstone beds of the Rutland Formation.

Previous names

Neaeran Beds (Walford, 1906)

Sharp's Hill Beds (Arkell, 1933, pp. 297–301)

Parent

Great Oolite Group

Age

Bathonian

References

Principal reference (McKerrow and Kennedy, 1973)

5.2.13 Taynton Limestone Formation (TY)

Name

Name introduced (as Taynton Stone) by Woodward (1894) for a ‘freestone’ within the Great Oolite sequence, and worked in quarries on Taynton Down, near Burford. Formalised as Taynton Limestone Formation by McKerrow and Kennedy (1973).

Type section

Lee’s Quarry [SP 236 152], Taynton Down, Oxfordshire, exposes over 7 m of the formation in typical cross-bedded bioclast- and ooid-grainstone facies in thick sets separated by thin calcareous mudstone beds, overlain by the Hampen Formation; the base is not exposed (Sumbler and Williamson, 1998).

Type area

Burford, Oxfordshire area.

Reference section(s)

Hampen Railway Cutting [SP 062 205] exposes the full thickness of the formation in typical facies, plus the ‘Rhynchonella Bed’, ‘Ostrea Acuminata Limestones’ and ‘Sevenhampton Marl’ of Richardson (1929), in total 4.08 m thick, resting on the Fuller’s Earth Formation and overlain by the Hampen Formation (Barron, 1998).

Farmington Quarry, Gloucestershire [SP 130 169] in three disconnected sections exposes up to 7 m of the formation in typical cross-bedded bioclast- and ooid-grainstone facies; top overlain by the Hampen Formation seen; the base is not exposed (Sumbler, 1995).

Formal subdivisions

Minchinhampton Limestone Member (MHPL) (Sumbler, 1999) as modified herein
Charlbury (Limestone) Member (CHAR) (Cox and Sumbler, in prep)

Lithology

White to pale brown, typically well-sorted medium- to coarse-grained, moderately to highly shell-detrital ooidal grainstone, locally fine- to very coarse-grained; medium to thickly well-bedded and cross-bedded, with thin shell-detrital calcilutite beds and locally calcareous sandstone beds.

Lithogenetic description

Generally high energy, shallow sea, mobile ooid shoal. Also some quieter water carbonate and terrigenous sediment deposition.

Landform description

Forms ledges on valley sides and minor plateaux. It is generally easily distinguished within an otherwise rather moderate energy mudstone and fine-grained limestone succession although lenses of coarse white ooid limestone also occur locally within the overlying Hampen Formation.

Definition of upper boundary

The top of the formation is placed within a passage upwards from medium- to coarse-grained, bioclastic ooidal grainstone into fine-grained ooidal limestone and calcilutite of Hampen Formation or mudstone, siltstone and limestone of the Rutland Formation.

Definition of lower boundary

The base of the formation is placed at the top of the highest significant mudstone in the Fuller's Earth Formation or Sharp's Hill Formation, or passage from finer grained limestone of the Eyford Member, where present, into medium- to coarse-grained, bioclastic ooidal grainstone.

Thickness

Up to 11 m, locally possibly up to 15 m, type area 6 to 8 m

Distribution

From Stroud, Gloucestershire, where the formation passes westwards into finer grained limestones of the Througham Member (Fuller's Earth Formation) and succeeding Hampen Formation (Sumbler et al., 2000), to Brackley, Northants where the formation passes north-east into the Wellingborough Limestone Member (formerly Upper Estuarine Limestone) of the Rutland Formation (Horton et al., 1987). Present at depth in the Weald (Wyatt, 2011).

Supplementary information

A succession of mainly ooidal limestone beds underlie/are equivalent to parts of the Tresham Rock Formation/Athelstan Oolite Formation in a relatively restricted area centred on Minchinhampton Common in the Gloucestershire Cotswolds. Each bed/unit has a local quarryman's name (e.g. 'Weatherstone', 'Oven-stone', 'Shelly Beds', 'Scroff', and 'Planking'). The beds have attracted much attention as having yielded a relatively rich fauna (for Great Oolite limestone) of ammonites in the mid nineteenth century that include a number of type specimens of zonal indicators. The status of the beds has recently been reassessed by Wyatt (1996), Sumbler (1999) and Cox and Sumbler (2002, p. 152; in prep) and although some can be tentatively attributed to the Dodington Ash Rock Member of the Fuller's Earth Formation, or the Athelstan Oolite, the lower beds (approximately the 'Shelly Beds' and 'Weatherstones') are given herein member status as the Minchinhampton Limestone Member of the Taynton Limestone Formation. They comprise between 5 and 8 m of bedded and cross-bedded shelly and shell-detrital ooidal limestone (Arkell and Donovan, 1952; Woodward, 1894).

A sequence of about 3 m of shelly lime-mudstone and fine-grained limestone at the base of the Taynton Limestone Formation in Ditchley Road Quarry [SP 368 198], Charlbury has been named the Charlbury Formation (Boneham and Wyatt, 1993). Wyatt (1996) claims to have also recognised the unit in a number of boreholes in south-east Gloucestershire and in the Weald (Wyatt, 2011), but it has never been mapped at outcrop, and its geographical range is uncertain. It is included as the Charlbury Limestone Member here in the Taynton Limestone Formation.

Occurrences of fissile, calcareous fine-grained sandstone in an area of about 1 km² around the village of Stonesfield [SP 39 17], Oxfordshire, have been mined for tilestone and are known for their fish, reptile and mammal remains. Termed the 'Stonesfield Slate Beds' {Buckland, 1818 #6}, the beds are now known to lie at three levels within the ooidal limestone beds of the Taynton Limestone Formation, necessitating their continued informal status (Boneham and Wyatt, 1993).

Previous names

Taynton Stone (Woodward, 1894, p. 306).

Parent

Great Oolite Group

Age

Bathonian, Progracilis Zone to ?Subcontractus Zone

References

Principal reference (McKerrow and Kennedy, 1973).

5.2.14 Hampen Formation (HMB)

The Hampen Formation displays an eastward transition between fully marine facies in the north Cotswolds (type area) to strata including facies more typical of its correlative on the East Midlands Shelf, the Rutland Formation (Figure 9), and the boundary between the formations was considered by Horton et al. (1995, fig 4) who, pragmatically, took it approximately along the line of the Cherwell Valley or the boundary between the Chipping Norton (E&W 218) (British Geological Survey, 1968) and Buckingham sheets (E&W 219) (British Geological Survey, 2002b), although if the development of the micro-oolites which characterise the type section of the Hampen Formation are taken as the principal criterion of classification, the boundary should be taken substantially farther west, in the Burford area, at the boundaries of the Cirencester (E&W 235) (British Geological Survey, 1998a) and Witney (E&W 236) (British Geological Survey, 1982b) sheets, and Moreton-in-Marsh (E&W 217) (British Geological Survey, 2000a) and Chipping Norton (E&W 218) (British Geological Survey, 1968) sheets.

The western limit of the formation and its definition in the type area is the subject of recent controversy. Wyatt (2009) casts doubt on the inclusion of certain lower beds at its type section and introduced a new Daglingworth Member of his Throughtam Formation here and in the adjacent area. This solution is rejected here: the original definition of the Hampen Formation at its type section is regarded as satisfactory, given its known lithological variability in the wider area; and it is also reasonable to include Wyatt's Daglingworth Member beds seen to the south-west in either the Hampen or Taynton Limestone formations. See also Section 5.2.1.

Name

This succession of fine-grained variable limestone beds between the pale ooid limestone and peloidal limestone of the Taynton Limestone and White Limestone formations was identified and named as 'Marly Beds' by Woodward (1894), and Arkell (1933) added the geographical epithet after the railway cutting near the hamlet of Hampen that is now the type section. Formalised by McKerrow and Kennedy (1973), the misleading and archaic lithological epithet 'Marly' was later dropped (Sumbler and Barron, 1996b).

Type section

Hampen [Railway] Cutting SSSI [SP 062 205], near Salperton, Gloucestershire, about 11 km west of Bourton-on-the-Water; exposes the full thickness of the formation comprising interbedded calcareous mudstone and fine-grained ooid-grainstone, the former dominating the upper part, the latter the lower, total 8.96 m thick, resting on the Taynton Limestone Formation and overlain by the White Limestone Formation (Sumbler and Barron, 1996b).

Type area

North Cotswolds

Reference section(s)

Daglingworth Quarry [SP 001 061] exposes about 8 m of the upper part of the formation, (Sumbler et al., 2000).

Chedworth Station Railway Cutting, formerly exposed at least 9.1 m of the formation, overlain by the White Limestone Formation; the base not seen [SP 055 115] (Sumbler and Barron, 1995).

Formal subdivisions

None.

Lithology

Limestone with subordinate interbedded calcareous mudstone ('marl'); limestone characteristically grey to brown, thinly bedded, fine- to very fine-grained, well-sorted, ooidal grainstone to packstone, commonly slightly sandy or silty, with small-scale cross-bedding.

Lithogenetic description

Fully marine carbonate facies with moderate siliciclastic input in the north Cotswolds (type area) passing eastward into very shallow marine to paralic near its inferred limit (see above).

Landform description

Tends to form a slight hollow between the harder upstanding limestone formations above and below (White Limestone Formation; Taynton Limestone Formation).

Definition of upper boundary

More or less sharp boundary between interbedded fine-grained limestone and calcareous mudstone, and off-white or yellowish peloidal packstone, wackestone or grainstone of the overlying White Limestone Formation.

Definition of lower boundary

Well bedded, fine-grained limestone and calcareous mudstone, resting sharply on cross-bedded coarse-grained ooidal grainstone of the Taynton Limestone Formation or on mudstone/sandy limestone of the Fuller's Earth Formation.

Thickness

About 4 to 11 m; 8.96 m at type locality.

Distribution

Frome Valley, west of Cirencester (where it passes into limestone beds in the upper part of the Fuller's Earth Formation) eastwards to Oxford–Brackley area (where it passes into the Rutland Formation).

Previous names

Marly Beds (Woodward, 1894).

Hampen Marly Beds (Arkell, 1933).

Hampen Marly Formation (McKerrow and Kennedy, 1973).

Parent

Great Oolite Group

Age

Bathonian, mainly Subcontractus Zone

References

Principal reference (Sumbler and Barron, 1996b).

5.2.15 White Limestone Formation (WHL)

Name

Name White Limestone first used for a defined interval by Woodward (1894), but was formally defined and subdivided by Palmer (1979); see also Sumbler (1984) and Sumbler et al. (2000) and this document for amendments.

Type section

Shipton-on-Cherwell Quarry [SP 473 177], formerly exposed up to 16 m of the upper part of the formation, including the entire Bladon and Ardley members and part of the Shipton Member; lower beds now obscured by backfill; overlain by Forest Marble Formation (Arkell, 1931; Cox and Sumbler, 2002; Palmer, T J, 1979; Sumbler, 1984).

Type area

Woodstock to Ardley [SP 43 16 to 53 27], Cherwell Valley, north of Oxford (Palmer, T J, 1979)

Reference section(s)

Ardley Railway Cuttings, Ardley Fields Farm Quarry and Ardley Wood Quarry [approximately SP 521 285 to 552 257] together expose the full thickness of the formation, over 13 m thick, near to the eastern edge of its range, showing terrigenous influence at some levels; it is divided here into three members: Shipton, Ardley and Bladon (Arkell, 1933; Cox and Sumbler, 2002). See Sumbler (1984) for additional reference sections

Formal subdivisions

Bladon Member (BLAD) (Palmer, T J, 1979)
Signet Member (SI) (Sumbler, 1991; Sumbler et al., 2000)
Ardley Member (ARDY) (Palmer, T J, 1979)
Shipton Member (SHIP) (Palmer, T J, 1979)

Lithology

Pale grey to off-white or yellowish limestone, as peloidal wackestone and packstone with subordinate ooidal and shell fragmental grainstone; with recrystallised limestone and/or hardgrounds at some levels; rarer sandy limestone, muddy limestone, calcareous mudstone and silicate mudstone/clay. Coralliferous units (including Fairford Coral Bed) occur at or close to the top.

Lithogenetic description

Shallow and protected marine carbonate facies with periods of reduced sedimentation leading to hardground formation. Higher energy conditions indicated by cross-bedded ooid limestones at some levels in part of the range.

Landform description

Caps escarpments and valley slopes, and forms broad plateaux throughout the north Cotswolds. Much limestone debris in soil.

Definition of upper boundary

Generally sharp, erosive boundary with cross-bedded shell-fragmental ooidal limestone of Forest Marble Formation, or mudstone of Forest Marble Formation or Blisworth Clay Formation.

Definition of lower boundary

Base of peloidal wackestone/packstone/grainstone, overlying calcareous mudstone/fine grained ooidal grainstone of Hampen Formation or calcareous mudstone of Rutland Formation.

Thickness

Up to about 30 m; typically 20 m in type area.

Distribution

Stroud–Cirencester area of Gloucestershire (where the formation passes south-westwards through passage into the high energy ooid limestone of the Athelstan Oolite Formation), north-eastward through Oxon and Bucks to the south Northamptonshire area, where it passes through gradual facies change into limestone with greater terrigenous influence of the Blisworth Limestone Formation. In the subcrop, passes south-east in Berkshire into the Athelstan Oolite and Chalfield Oolite formations of the Weald (Wyatt, 2011).

Previous names

White Limestone (including Kemble Beds of some workers- see Sumbler, 1984, table 2)

Blisworth Limestone (in Buckinghamshire)

Part of Great Oolite Limestone of some authors

Parent

Great Oolite Group

Age

Middle–Upper Bathonian, Subcontractus Zone to Retrocostatum Zone

References

Principal reference (Palmer, T J, 1979).

Additional references (Sumbler, 1991).

Forest Marble Formation

See Section 5.2.3 above.

Cornbrash Formation

See Section 5.2.4 above.

East Midlands Shelf formations

The lithostratigraphical framework for the Great Oolite Group of this area was established by Sharp (1870, 1873) and Judd (1875), the latter subdividing the group into Upper Estuarine Series, Great Oolite Limestone, Great Oolite Clay and Cornbrash, in ascending order. The Cornbrash Formation is present in marine limestone facies from Dorset to Yorkshire (Section 5.2.4). The other units, however, exhibit substantial facies variation with the development of non-marine facies in the East Midlands. These changes take place through interdigitation over considerable distances and so lateral boundaries between units are inevitably somewhat arbitrary, and most of the problems in nomenclature stem from this. A further problem stems from the similarity of facies of the ‘Lower Estuarine Series’ (= Grantham Formation, Inferior Oolite Group) and ‘Upper Estuarine Series’.

The eastern England Bathonian succession was reviewed in an impressive thesis by Bradshaw (1978), in which the ‘Upper Estuarine Series’ succession in the East Midlands was described in

terms of six or seven shallowing-upwards, essentially deltaic, progradational rhythms, with lacustrine sands and silt (Stamford Member) at the base. This unit he termed the Rutland Formation, a term adopted by BGS in the early 1990s. Bradshaw (1978) showed that the equivalent of the Rutland Formation in Oxfordshire and the Cotswolds comprised the Chipping Norton Limestone, Sharp's Hill, Taynton Limestone and Hampen formations (see Sumbler, 1996, fig. 13 and table 4). Two contentious issues remain however; firstly, the extent to which the Grantham Formation and equivalents is present in the area to the south and south-west of Kettering (the 'White Sands problem') and secondly the location of the south-westward boundary of the Rutland Formation. Regarding the latter, Bradshaw (1978), recognising that the boundary between the Cotswold formational scheme and the East Midlands scheme is essentially arbitrary, took it at the Oxfordshire–Northamptonshire border, though considered in detail it may be more logical to take the boundary at different geographical points depending on the stratigraphical level in question (see Figure 9).

The 'White Sands Problem'

The following borrows heavily from the account of Bradshaw (1978).

The Grantham Formation (Lower Estuarine Series) and Rutland Formation (Upper Estuarine Series) are of essentially similar facies, each comprising quasi- and nonmarine sands and clays with rootlets etc. North of Kettering, these two units are separated by the Lincolnshire Limestone, 30 m or more in thickness in places. However, in the Kettering–Peterborough area, the Lincolnshire Limestone dies out, being overstepped by the Rutland Formation. Commencing with Morris (1853), the strata (Lower Estuarine Series) beneath the Lincolnshire Limestone were equated with similar beds in the Northampton area, their position, each resting directly on the Northampton Sand Formation, and containing plant-rich beds (Sharp, 1873) tending to support this correlation. Judd (1875) identified locally developed ironstone nodule beds in this area as the equivalent of the Ironstone Junction Bed (as secondary development of limonitic ironstone commonly found at the base of the Rutland Formation where it overlies the Lincolnshire Limestone), and used it to define the junction between the Lower and Upper Estuarine Series there. The correlation was further substantiated when doggers of calcareous sandstone east of Kettering were identified as remnants of Lincolnshire Limestone (Hollingworth and Taylor, 1951; Richardson and Kent, 1938; Thompson, 1930). In reality, there are no markers which confirm the persistence of the Grantham Formation far from the southern limit of the Lincolnshire Limestone, but the beds between the Northampton Sand Formation and the oyster-rich strata that have always been accepted as Upper Estuarine Series closely resemble the Stamford Member as developed at the base of the Rutland Formation farther north. The change in lithology between these beds (white sands and silts) and the Grantham Formation farther north (where the beds typically include a median argillaceous and carbonaceous unit – the Stainby Member) which takes place between Kettering and Peterborough, was attributed to facies change (Hains and Horton, 1969; Taylor, 1963).

Bradshaw (1978), however, argued that it is more probable that this change in lithology indicates overstep of the Grantham Formation in this area, as it is adjacent to the southern limit of the Lincolnshire Limestone, and it seems unlikely that erosion sufficient to have removed the Lincolnshire Limestone hereabouts can have failed to have removed the softer sediments of the Grantham Formation when these became exposed. Thus, the area in which the Upper Estuarine Series and Lower Estuarine Series is in contact is likely to be very narrow, and so, on a purely circumstantial basis, Bradshaw (1978) assigned all the supposed Lower Estuarine Series farther south, in the Northampton area, to the Upper Estuarine Series, i.e. Rutland Formation. Similarly, the supposed overstep of the Northampton Sand Formation by the Lower Estuarine Series to the south-east of Northampton (Taylor, 1963), was interpreted as overstep by the Upper Estuarine Series/Rutland Formation.

To the south-west, in the Cherwell valley area of Oxfordshire, beds of sand (the White Sands) have been attributed variously to the Chipping Norton Limestone Formation (essentially the

Swerford Beds/Member (Arkell, 1947; Richardson, 1911; Sellwood and McKerrow, 1974)) or the Lower Estuarine Series (Horton, 1977; Horton et al., 1987). Bradshaw (1978) taking the former view, regarded the Swerford Member as the lateral equivalent of his Stamford Member, the basal unit of the Rutland Formation throughout its outcrop. Fenton, Riding and Wyatt (1994, 1995) attempted to resolve the problem by palynology. At New Duston [SP 715 627], Northampton, a clay at the base of the White Sands (Sharp, 1870) which overlies the Northampton Sand Formation there (? Sharp's Plant Bed) yielded late Bajocian to Bathonian dinoflagellate cysts, of an assemblage similar to that of the Chipping Norton Limestone of Oxfordshire and Rutland Formation of Lincolnshire. From Swalcliffe [SP 3680 3585] west of Banbury, samples from near the base of the White Sands yielded an abundant and well-preserved palynoflora indicating a late Bajocian age (probably Parkinsoni Zone). Samples from near the base of the 'White Sands' at Duns Tew [SP 455 272] to the south of Banbury also yielded a late Bajocian palynoflora, as did the thin White Sands of the Chalgrove Borehole (SU69NE20 [6565 9620]; (Horton et al., 1995)) which there rest on probable 'Scissum Beds'. Rare, poorly preserved Aalenian cysts in the samples from Duns Tew and Chalgrove were deduced to be derived from the subjacent beds.

Fenton et al., (1994, 1995) argued that the data precludes correlation of the 'White Sands' with the Aalenian Grantham Formation, and confirms equivalence with the Stamford and Swerford members, the Bajocian age suggesting that the latter equates with the Chipping Norton Limestone as a whole (including the so-called 'Hook Norton Member'), not just the upper (Bathonian) part as had previously been thought (e.g. Sellwood and McKerrow, 1974; Torrens, 1980). Horton et al. (1995) cast some doubt on their interpretation by implying that their 'White Sands' material from Swalcliffe may in fact be 'Hook Norton Member' partly because a conglomerate was recorded from the base, whereas in exposures in the Chipping Norton area, the contact between the Northampton Sand Formation and any white sands tends to be gradational. This apparently gradational contact is in contrast to the base of the Stamford Member where indisputably present to the north-east, which is a marked unconformity. Horton's observations concur with one of the present author's (MGS) notes of Horsehay Quarry [SP 459 274], Duns Tew, where the base of the White Sands is indefinite but where the top (succeeded by the Sharp's Hill Formation) is leached and rootlet-bearing. It has to be acknowledged, however, that the obscure base of the White Sands is, in many places at least, in part due to secondary development of limonitic ironstone associated with the Northampton Sand Formation. For example, in the Ardley–Fritwell Cutting, where the Northampton Sand Formation is in a less ferruginous and oxidised condition, the base of the White Sands exhibits well defined channels into it (Arkell et al., 1933; Bradshaw, 1978). On the above grounds, their distinct noncalcareous sand facies within a contrasting limestone–mudstone succession, and also their geographical separation from their presumed correlative in the Stamford Member (Rutland Formation), the White Sands of north Oxfordshire have been defined as a new formation – the Horsehay Sand Formation (see Section 5.2.11 above).

5.2.16 Rutland Formation (RLD)

Name

Named after the county of Rutland in the East Midlands (Bradshaw, 1978). See also above.

Type section

Ketton Quarry [SK 970 060], Rutland, exposes the full thickness of the formation in typical facies, 11.7 to 12.8 m thick, including the Stamford Member, and six rhythms above, resting on the Lincolnshire Limestone Formation, and overlain by the Blisworth Limestone Formation (Aslin, 233-237 in Bradshaw, 1978; Cox and Sumbler, 2002; Torrens, 1968a) (Hudson and Clements, 2007)

Type area

East Midlands including Rutland, from Wellingborough to Grantham, [SP 86 to TF 03]

Reference section(s)

Thompson's Quarry [SK 992 409], Wilsford Heath, near Ancaster, (especially upper part of formation) (Richardson, 1939).

Gregory's Quarry [SK 992 410], Wilsford Heath, near Ancaster, (especially the lower part of the formation).

Ardley Railway Cutting, [SP 544 265]. (Arkell et al., 1933; Cox and Sumblar, 2002).

Cranford St John Quarry [SP 924 764], near Kettering, (Bradshaw, 1978; Cox and Sumblar, 2002).

See (Bradshaw, 1978; Cox and Sumblar, 2002) for additional reference sections.

Formal subdivisions

Castle Member (Hudson and Clements, 2007)
Wellingborough Limestone Member (WBRO) (Bradshaw, 1978)
Thorncroft Sand Member (THS) (Gaunt et al., 1992)
Stamford Member (STAM) (Bradshaw, 1978)

Other subdivisions of uncertain status

Priestland Clay Member (PLC) (Gaunt et al., 1992)

Lithology

Interpreted as a succession of up to seven shallowing-upward, essentially delta type rhythms, comprising ideally of a grey marine mudstone passing up into nonmarine mudstone and siltstone, with a greenish grey rootlet bed at the top. The formation's basal beds comprise mainly fluvial and lacustrine sandstone with subordinate mudstone, designated the Stamford Member in the south, passing north in central Lincolnshire into the Thorncroft Sand Member. Subordinate sandstone beds occur locally higher in the sequence, as well as typically shelly and shell-detrital, marine limestone and calcareous mudstone beds, notably in the mid part, the Wellingborough Limestone Member, in Northamptonshire. The Wellingborough Limestone thins and loses its character northwards such that it is not recognisable in Rutland, where the formation above the Stamford Member is called the Castle Member (Hudson and Clements, 2007). This is approximately equivalent to the 'Priestland Clay Member' (Gaunt et al., 1992) of central Lincolnshire to east Yorkshire.

Lithogenetic description

Fluvial and lacustrine environments, depositing sand, silt and clay (Stamford Member) followed by several cycles comprising marine clay passing up through delta progradation into nonmarine clay and silt with in places fluvial sand bodies. Very shallow delta top conditions with at times emergent phases are indicated by seatearth-type beds and loss of beds by erosion.

Landform description

Typically overlain by more competent limestone-dominated formation, so tends to form a hollow although the Wellingborough Limestone Member may form a weak ledge on slopes. Clayey soil with rare limestone debris.

Definition of upper boundary

A gradational boundary from argillaceous beds of the Rutland Formation into limestone beds of the Blisworth Limestone Formation, or in the south-west, on BGS sheets 218, 219, 236 and 237 into limestone of the White Limestone Formation.

Definition of lower boundary

Generally a sharp unconformable boundary of sandy beds of the Stamford or Thorncroft Sand members overlying: in Lincolnshire, Rutland and north Northants, limestones of the Lincolnshire Limestone Formation, commonly marked by the 'Ironstone Junction Bed'; in mid Northants, north Buckinghamshire and Bedfordshire, ironstone or ferruginous sandstone of the Northampton Sand Formation, or mudstones of the Lias Group; and across the London Platform subcrop by Palaeozoic strata. In the south-west, the lower boundary is an upwards gradation from limestones of the Taynton Limestone Formation to mudstone of the reduced Rutland Formation (see *Distribution* below).

Thickness

Typically from about 8 to 12 m, and up to about 15 m thick, measured as about 12 m at the type section, and, where reduced in the south-west, typically from 2 to 4 m thick.

Distribution

In south-west Northamptonshire and north Oxfordshire, the lower part is replaced by the Horsehay Sand, Chipping Norton Limestone, Sharp's Hill, and Taynton Limestone formations and only the upper part of the formation is represented, by largely argillaceous strata, and passes westward into the Hampen Formation (Horton et al., 1987, fig. 8). The formation's outcrop extends from the Cherwell Valley, around Northbrook [SP 49 22], Oxfordshire, north-east and north, to the Market Weighton High around North Newbald [SE 91 37], where the unit is overstepped by Cretaceous rocks.

Previous names

Upper Estuarine Series (Judd, 1875)

Formerly the Thorncroft Sand and Priestland Clay forming part of the now obsolete Glentham Formation (Gaunt et al., 1992)

Parent

Great Oolite Group

Age

Bajocian to Bathonian, Parkinsoni Zone to Morrisi Zone, possibly Humphriesianum Zone to Retrocostatum Zone

References

Principal reference (Bradshaw, 1978).

5.2.17 Blisworth Limestone Formation (BWL)

The unit traditionally known as the Great Oolite Limestone (Judd, 1875) has in recent years been renamed the 'Blisworth Limestone' (e.g. Hains and Horton, 1969 and many subsequent works). This term was introduced in the Towcester district (E&W 202) (British Geological Survey, 1969) in the 1960s, though never properly defined. It has since been extended northwards from Buckinghamshire (e.g. Horton et al., 1974) to Lincolnshire (e.g. Grantham (E&W 127) sheet (British Geological Survey, 1996a) (Berridge et al., 1999)). In addition to its indefinite geographical limits, it has been argued that use of the term Blisworth Limestone Formation is inappropriate because firstly the Blisworth epithet had already been used for the succeeding

formation (the Blisworth Clay (Sharp, 1870) see below); secondly, in the implied ‘type area’, (Blisworth [SP 72 53] between Towcester and Bicester), most of the succession is of a facies closely similar to the White Limestone as developed in its Oxfordshire type area, and so the earlier term White Limestone Formation (Woodward, 1894) is more appropriate. However, north-eastwards from Blisworth, through Northamptonshire and Lincolnshire, strata which have been assigned to the Blisworth Limestone gradually change in lithological character such that in more northern parts of the outcrop, the unit is radically different from that in Oxfordshire and an alternative name does indeed seem necessary, despite the fact that Cripps (1986) chose to apply the term White Limestone throughout, extending it from the Cotswolds to Humberside.

In the southern part of the East Midlands, the formation is divisible into members correlative with those developed in the White Limestone of Oxfordshire. The basal unit, comprising interbedded limestone, mudstone and sandstone is characterised by the brachiopod *Kallirhynchia sharpi* and is consequently known as the Sharpi (or *Kallirhynchia Sharpi*) Beds e.g. Torrens, 1980). This unit is based on the ‘Rhynchonella Zone’ of Thompson (1924, 1927) as described at Roade Railway Cutting [SP 750 525], where it is about 3 m thick, although its base is no longer visible (Barron and Woods, 2010a). Nonetheless, this may be regarded as the type locality and the Roade Member is proposed as a formal name consistent with modern lithostratigraphical procedure. According to Cripps (1986) it represents a single sedimentary rhythm (‘Rhythm B’), and, with its eponymous brachiopods can be recognised between Pury End [SP 707 459] near Towcester in the south, and Ketton [SK 98 06] near Stamford in the north, although Torrens (1968a) considered that the unit was absent at this latter locality. To the south-west, it passes into the Shipton Member (Palmer, T J, 1979; Sumbler, 1984) whilst south-eastwards it is believed to be overstepped by younger strata (Cripps, 1986) so that it is absent in the Stony Stratford–Bedford area. North of Stamford, it cannot be recognised or separated from succeeding beds.

According to Cripps (1986) it has proved impracticable to separate the Ardley and Bladon Members of the White Limestone east of a line approximately from Roade to Stony Stratford and he introduced the term Irchester Member for the indivisible unit developed between the Sharpi Beds (Roade Member) and Blisworth Clay in the area north from this line to just beyond Kettering, based on Irchester Old Lodge Pit [SP 914 648] where the unit is 6.15 m thick. However, Cripps’ definitions of the Ardley and Bladon Members differed slightly but significantly from that used herein (following Sumbler, 1984), and when this is taken into account it transpires that the Irchester Member represents the Ardley Member only, the Bladon Member being represented in the lower part of the succeeding Blisworth Clay (see below). This interpretation is supported by the presence of *Aphanoptyxis bladonensis* in the topmost bed of the ‘Irchester Member’ at its type locality (Cripps, 1986), as this species elsewhere occurs most abundantly in the Bladonensis Bed (Sumbler, 1984) which marks the top of the Ardley Member in Oxfordshire. Furthermore, the Irchester Member, being characterised by interbedded white lime-mudstone, cross-bedded ooidal shell-fragmental grainstone, fossiliferous, bioturbated ooidal and shell-fragmental packstone and wackestone with thin calcareous mudstone beds (i.e. Cripps’ (1986) ‘Lithofacies Association B’), is lithologically much like the Ardley Member in Oxfordshire. Thus, the term Irchester Member is regarded as redundant and can be replaced by the older term Ardley Member, as described herein.

From north of Cranford to Thrapston, the ‘Irchester Member’ becomes increasingly dominated by oyster-rich carbonate-muddy limestones, and beyond Oundle, northwards to Stamford, Cripps (1986) used the term the Longthorpe Member for these strata, after Longthorpe Road Cutting [TL 156 986], Peterborough. There, the unit comprises over 2 m of argillaceous packstone and wackestone with grainstone intercalations and thin calcareous mudstone beds, with a fauna dominated by *Praeexogyra hebridica*, associated with *Modiolus*, *Placunopsis* etc. In this area, then, the formation comprises the Roade Member and Longthorpe Member.

North of Stamford, because of the failure of the Roade Member, the formation is indivisible but nevertheless retains the lithological and oyster-rich characters of the Longthorpe Member. This

is essentially the lithology of the Snitterby Limestone, a term coined (as a member of their Glenthams Formation) by Gaunt et al. (1992) for a unit of shelly flaggy sandy fossiliferous limestones with *P. hebridica* and *Modiolus* in the Brigg district (E&W 89) of north Lincolnshire (British Geological Survey, 1982a). This was originally defined as a member of their composite Glenthams Formation, but subsequently the term Snitterby Limestone Formation was used on the Market Rasen sheet (E&W 102) (British Geological Survey, 1999).

One way to rationalise ‘Great Oolite Limestone’ nomenclature would be to extend the use of Snitterby Limestone Formation from north Lincolnshire to the whole region north of the Cranford–Thrapston area (approximately the southern margin of the Kettering sheet (E&W 171); (British Geological Survey, 2002d)), where ‘oysters become the dominant element in all Irchester Member faunas’ (Cripps, 1986, Vol. 2, pp 78, 79), but to use the term White Limestone Formation farther south, coincident with the extent of the Ardley Member.

However, in view of the widespread use of the term Blisworth Limestone both in BGS publications and in the wider geological community, it seems pragmatic to retain and formalise it as Blisworth Limestone Formation despite its variability. It is proposed that the southern and western limit of the Blisworth Limestone Formation should be defined by the extent of the Roade Member (see above), thus the term is applicable to the Blisworth area itself, and Roade Railway Cutting (2 km south-east of Blisworth village) is an appropriate type section. There, based on Thompson’s (1924) record, and a recent study by Barron and Woods (2010a), the formation is between 7 and 8 m thick. As applied to BGS maps, the southern boundary of the formation should be taken at the southern margin of the Towcester (E&W 202) and Bedford (E&W 203) sheets (British Geological Survey, 1969, 2010) or (for the constituent 1:10 000 geological sheets) grid line ²40. To the south and west, the term White Limestone should be used. The Blisworth Limestone Formation extends northwards to just south of the Humber where it wedges out (Gaunt et al., 1992; Torrens, 1967), perhaps in part due to overstep by the ‘Great Oolite Clay’ but more probably, judging by the succession in the Nettleton Bottom Borehole, by passage into Rutland Formation by intercalation of mudstone.

Name

Named after the type section in Blisworth village in Northamptonshire (British Geological Survey, 1969). Not previously defined (see above).

Type section

Blisworth Rectory Farm Quarry [SP 716 531], formerly exposed 7.3 m of the formation, but top and base not seen, now very poorly exposed (Cox and Sumblar, 2002, pp. 249-252; Sharp, 1870; Torrens, 1967, but gives incorrect NGR; Woodward, 1894).

Type area

Blisworth area, Northants, between Towcester and Northampton

Reference section(s)

Ketton Quarry [SK 970 060], Rutland, exposes the full thickness of the formation in Longthorpe Member facies, 3.57 m, resting on the Rutland Formation, and overlain by the Blisworth Clay Formation (Cripps, 1986; Hudson and Clements, 2007) (Cox and Sumblar, 2002, pp. 276-282).

Roade Railway Cutting [SP 747 530 to 756 514], near Blisworth, Northamptonshire, exposes 7.2 m of the formation, but top and base no longer seen (Barron and Woods, 2010a, b; Cox and Sumblar, 2002; Thompson, 1924; Torrens, 1967).

Formal subdivisions

Longthorpe Member (LONG) (Cripps, 1986)
Ardley Member (ARDY) (Sumblar, 1984)

Lithology

Pale grey to off-white or yellowish limestones with thin calcareous mudstone or silicate mudstone beds, fossiliferous, bioturbated, peloidal, ooidal and shell-fragmental more-or-less muddy packstone and wackestone, hardgrounds at a few levels, subordinate cross-bedded ooidal shell-fragmental grainstone beds: fauna may include rhynchonellids particularly in the lower part in the south (see Road Member, Section 5.2.17.1), and may be dominated by oysters, notably in the upper part in the north (Longthorpe Member).

Lithogenetic description

Deposited in fully marine conditions on a shallow seafloor. Conditions were predominantly tranquil (low-energy), conducive to the accumulation of fine carbonate mud, and the development of a prolific mollusc-dominated bottom-dwelling fauna. Near continuous influx of fine terrigenous sediment (noncarbonate mud and silt). Occasional periods of nondeposition and sea-floor cementation, and of higher energy conditions.

Landform description

Typically overlain and underlain by softer mudstone-dominated formations, so tends to form a positive feature, locally a minor escarpment. Much limestone debris in soil.

Definition of upper boundary

Generally a sharp boundary of limestone of the Blisworth Limestone Formation, with mudstone (Blisworth Clay Formation), or locally an erosive contact with cross-bedded shell-fragmental ooidal limestone (thin lens at the base of the Blisworth Clay Formation).

Definition of lower boundary

Conformable; the base of the limestone of the Blisworth Limestone Formation overlying mudstone of the Rutland Formation, locally a passage, including possibly a lateral passage of the lowest beds.

Thickness

Typically from 6 to 7 m thick in the type area, up to about 12 m to the south-west, and 4 m thick at Ketton.

Distribution

Towcester district, Northants to Brigg, north Lincolnshire; passes south-west into the White Limestone Formation and to the north by intercalation into the marls and mudstones of the Rutland Formation. As applied to BGS maps, the southern boundary of the formation should be taken at the southern margin of the Towcester (E&W 202) and Bedford (E&W 203) sheets (British Geological Survey, 1969, 2010) or (for the constituent 1:10 000 geological sheets) grid line ²40.

Previous names

White Limestone (Cripps, 1986).

Great Oolite Limestone (Judd, 1875; Torrens, 1967).

Snitterby Limestone Member/Formation (Gaunt et al., 1992).

Parent

Great Oolite Group

Age

Bathonian, Subcontractus Zone to Retrocostatum Zone

References

Principal reference (Torrens, 1967) as modified herein.

5.2.17.1 ROADE MEMBER (ROAD)

Name

Named after the type section, Roade Railway Cutting, in Roade village, Northamptonshire.

Type section

Roade Railway Cutting [SP 747 530 to 756 514], Roade village, near Blisworth, Northamptonshire, exposes 3 m of the member, but base no longer seen (Barron and Woods, 2010a, b; Cox and Sumbler, 2002; Thompson, 1924; Torrens, 1967).

Reference section(s)

Cranford St John Quarry [SP 9210 7677 to 9287 7607] exposes the full thickness of the member, 1.8 m, resting on the Rutland Formation, and overlain by the Ardley Member (Cox and Sumbler, 2002; Torrens, 1967).

Formal subdivisions

None.

Lithology

Pale grey to off-white or brownish, more or less calcareous-muddy or sandy, bioclastic, bioturbated, peloidal wackestone and packstone, characteristically containing *Kallirhynchia sharpi* (Muir-Wood) and other brachiopods, and bivalves such as mussels and oysters with thin calcareous mudstone or silicate mudstone beds.

Lithogenetic description

Deposited in fully marine conditions on a shallow seafloor. Conditions were predominantly tranquil (low-energy), conducive to the accumulation of fine carbonate mud, and the development of a prolific brachiopod- and mollusc-dominated bottom-dwelling fauna. Near continuous influx of fine terrigenous sediment (noncarbonate mud and silt).

Landform description

Text

Definition of upper boundary

Generally a sharp boundary between limestone, calcareous mudstone or silicate mudstone containing *Kallirhynchia sharpi* of the Roade Member with beds of limestone, calcareous mudstone or silicate mudstone lacking *Kallirhynchia sharpi* of the Ardley or Longthorpe members, commonly a calcareous mudstone or silicate mudstone bed at this level which may prove a reliable marker compared to the mudstone at the base of the Ardley Member of the White Limestone in Oxfordshire.

Definition of lower boundary

Conformable; the base of the limestone of the Roade Member overlying mudstone of the Rutland Formation, locally a passage, including possibly a lateral passage of the lowest beds.

Thickness

Typically about 3 m thick.

Distribution

From the Towcester (E&W 202) district (British Geological Survey, 1969), Northants to the Stamford district (Cripps, 1986); passing south-west into the Shipton Member of the White Limestone Formation and north into the undivided Blisworth Limestone Formation, where the member cannot be separated from the Longthorpe Member, notwithstanding the presence of *Kallirhynchia sharpi* in the lower part of the Blisworth Limestone Formation in north Lincolnshire (Cripps, 1986).

Previous names

Sharpi Beds

Rhynchonella Zone (Thompson, 1924, 1927).

Kallirhynchia sharpi Beds (Cripps, 1986; Torrens, 1967).

Parent

Blisworth Limestone Formation

Age

Bathonian, Subcontractus Zone to Morrisi Zone

References

Principal reference (Torrens, 1967, as modified herein).

5.2.18 Blisworth Clay Formation (BWC)

Like the controversy over the White Limestone/Blisworth Limestone below, similar issues of nomenclature arise for the succeeding strata beneath the Cornbrash. The term Forest Marble (Hull, 1857) has tended to be used in Oxfordshire, and Great Oolite Clay (Judd, 1875) or Blisworth Clay (Sharp, 1870) in the Midlands. It is clear that two substantially different facies are developed in these two areas, and separate formational names are appropriate, but the geographical limits of the two formations has never been clearly or consistently established, with different authors choosing different, essentially arbitrary limits. A further complication is that although these units have generally been understood to be equivalent, it has recently been suggested that the Great Oolite Clay/Blisworth Clay may be the lateral equivalent not of the Forest Marble but of the Bladon Member of the Oxfordshire White Limestone Formation, with the Forest Marble being overstepped by the Cornbrash in the Milton Keynes area (Cripps, 1986; Palmer, T J, 1974; Sumbler, 1996), and survey work in the Buckingham (E&W 219) district (British Geological Survey, 2002b) shows that in the adjacent Towcester (E&W 219) district (British Geological Survey, 1969) at least, the strata mapped as Blisworth Clay Formation include representatives of both units (i.e. all or the upper part of the Bladon Member, plus the Forest Marble). Recent work in the Bedford district (Barron et al., 2010) appears to show that the lateral passage is somewhat complex, with Forest Marble facies present further east (the Marston Vale) than previously thought. Despite these niceties of correlation, the continuing uncertainties render it pragmatic to regard the two formations as mutually exclusive, and to accept Cripps' (1986) solution of using the term Forest Marble where the ooidal and shell fragmental grainstone and packstone typical of the Oxfordshire type area occur. Using this definition, the Forest Marble Formation (Section 5.2.3 above) extends more-or-less continuously as far north-eastwards as a quarry at Weston Underwood [SP 861 514] near Olney, Buckinghamshire and possibly a little farther east [?SP 899 516], where Arkell (1933 p. 305) reported several metres of 'massive Forest Marble'. The occurrence of its characteristic facies close to Bedford is noted as a local variant.

North-eastwards from Olney, the succession above the White Limestone is made up very largely of nonmarine, often rootlet-bearing and variegated seatearth-like mudstone. This mudstone

extends northwards to the Humber where, due to the overstep or failure of the ‘Snitterby Limestone’, the unit is in contact with similar beds in the Rutland Formation (Priestland Clay) below (Gaunt et al., 1992), rendering identification difficult, but is probably overstepped by Cornbrash or Kellaways Formation just north of the Humber between Alandale and Brough. The succession is typically developed at Thrapston Quarry [TL 000 776] near Kettering where the succession comprises 3.5 m of green, turquoise and mauve mud between the rootlet-bearing top of the White Limestone and the base of the Cornbrash. Based on this locality, Cripps (1986) suggested the term Thrapston Clay Formation, but the earlier term Blisworth Clay Formation is retained herein because of its widespread use following its adoption by Arkell (1933). Nevertheless, Thrapston is taken as the type locality of the Blisworth Clay Formation; Blisworth is unsuitable because it lies in the transition zone close to the limit of the Blisworth Clay facies and, moreover, Sharp’s (1870) original usage of the term Blisworth Clay (at Blisworth Stone Quarries [SP 739 530]) relates to 0.6 m of variegated, oyster-rich clay of dubious affinity; Cripps (1986) suggested it may belong to the White Limestone Formation.

The south-western limit of the Blisworth Clay Formation is complicated by interdigitation of Blisworth Clay and Forest Marble facies; the latter, tending to predominate in the top of the succession, perhaps representing the Forest Marble Formation of the west which typically rests non-sequentially on underlying beds. For example, at Roade Railway Cutting [SP 751 523], about 1 km south-east of Blisworth Stone Quarries, the succession, some 7 m thick, is predominantly composed of purplish red, yellow and green variegated clay with rootlets and ironstone nodules (typical Blisworth Clay Formation) but with beds rich in marine bivalves (oysters and *Placunopsis*; typical Forest Marble) at the base and top (Thompson, 1924). As mutually exclusive formations, the boundary between the Forest Marble and Blisworth Clay formations is necessarily arbitrary but, considering lithologies recorded in sections in the neighbourhood of Blisworth (Cripps, 1986; Horton et al., 1974), the limit of the Blisworth Clay Formation is herein taken a little to the south of Blisworth, extending eastward to Olney, and then southwards to Newport Pagnell, within the Towcester (E&W 202) and Bedford (E&W 203) sheets (British Geological Survey, 1969, 2010).

In the northern part of the Buckingham district (E&W 219) (British Geological Survey, 2002b), although ‘Blisworth Clay’ was mapped in the 1960s and early 1990s, reconnaissance (by MGS) shows that both clay-rich Bladon Member and limestone-rich Forest Marble strata are present. Nevertheless, for pragmatic reasons, the whole package is depicted as Forest Marble Formation on the map, with the ‘true’ Forest Marble separated as ‘ls’ in those few places where the basal boundary is known.

Name

Named after the type area around Blisworth village in Northamptonshire. See above and Sharp (1870), as modified by Arkell (1933) and herein.

Type section

Thrapston Quarry [TL 000 776], near Kettering, Northants formerly exposed the full thickness of the formation, 2.5 m, in typical facies with basal ironstone nodule bed; resting on the Blisworth Limestone Formation, and overlain by the Cornbrash Formation; but now poorly exposed and base no longer seen (Cox and Sumbler, 2002, p. 264; Cripps, 1986).

Type area

Blisworth, Northants

Reference section(s)

Ketton Quarry [SK 982 073], Rutland, near Stamford, Lincolnshire exposes the full thickness of the formation, 5.07 m; resting on the Blisworth Limestone Formation, and overlain by the Cornbrash Formation (Hudson and Clements, 2007). Hudson and Clements (2007) divide it here into the Ketton Heath, Tinwell Lodge and Grange members.

Formal subdivisions

Ketton Heath Member (Hudson and Clements, 2007)
Tinwell Lodge Member (Hudson and Clements, 2007)
Grange Member (Hudson and Clements, 2007)

Lithology

Silicate mudstone, grey, commonly variegated purplish red, yellow and green, poorly bedded to blocky, commonly containing fossil rootlets and sideritic ironstone nodules, and locally with impersistent beds and lenses of argillaceous limestone including (mainly in the south) shell-fragmental wackestone, packstone and grainstone, and (mainly in the north) sandstone. Mudstone weathers to highly plastic clay.

Lithogenetic description

Nonmarine clay facies with rootlets and other signs of ‘seatearth’ formation. Transient marine influence.

Landform description

Tends to form hollow between adjacent upstanding limestone formations.

Definition of upper boundary

Sharp, generally disconformable contact between variegated mudstone of Blisworth Clay Formation and limestone of succeeding Cornbrash Formation or (very locally near northern limit) silty mudstone and sandstone of Kellaways Formation.

Definition of lower boundary

Sharp but generally more or less conformable contact: limestone of Blisworth Limestone Formation or locally, near northern limit, bluish and greenish grey variably shelly mudstones of Rutland Formation overlain by grey or variegated mudstone of Blisworth Clay Formation.

Thickness

0 to c. 10 m, typically 2 to 4 m throughout most of range

Distribution

East Midlands Shelf, from the Humber area where [probably] overstepped by the Cornbrash Formation, southwards to just north of Milton Keynes, where the formation passes laterally into the Forest Marble Formation. This boundary is necessarily arbitrary but the limit of the Blisworth Clay Formation is herein taken a little to the south of Blisworth, extending eastward to Olney, and then southwards to Newport Pagnell, within the Towcester (E&W 202) and Bedford (E&W 203) sheets (British Geological Survey, 1969, 2010).

Previous names

Great Oolite Clay(s) (Judd, 1875)

Blisworth Clay Member (of obsolete Glenthams Formation) (Gaunt et al., 1992)

Parent

Great Oolite Group

Age

Bathonian, Retrocostatum Zone to Discus Zone

References

Principal reference (Sharp, 1870, as modified herein).

Cornbrash Formation (CB)

See 5.2.4.

5.3 ANCHOLME GROUP (AMG)

As has been stated above (Chapter 4), the formations overlying the Great Oolite Group in southern England have been arranged in a formal group only from Oxford northwards (Table 3). This, the Ancholme Group was defined by Gaunt et al. (1992, as the Ancholme Clay Group), and ranges in age from Callovian to Kimmeridgian; thus spanning parts of both the Mid and Late Jurassic. Its component formations are generally much longer established and more widely cited, the origins of many terms dating from the early 19th century (Buckland, 1818; Smith, W, 1815).

The two Ancholme Group formations that are wholly or partly of Middle Jurassic age (Table 6) and fall within the scope of this report (the Kellaways and Oxford Clay formations) are of much wider onshore geographical range, extending from the Dorset coast into North Yorkshire. South-west from Oxford to Trowbridge (Wiltshire), near Bath, the mudstone-dominated Kellaways and Oxford Clay formations are sandwiched between the limestone-dominated Great Oolite Group and the sandstones and limestones of the Corallian Group. In the Bath area, the Great Oolite Group limestones pass south into a succession of generally calcareous mudstones with subordinate limestones, which persist to the Dorset coast. Through this southern province, the Kellaways and Oxford Clay formations are generally well-defined and mappable, and there is little merit in designating a parent group.

Name

The Ancholme Group is a relatively new term proposed (as Ancholme Clay Group) by Gaunt et al. (1992) for a sequence of mudrock not previously formally assembled. For further rationale see Chapter 4. Named after the Vale of Ancholme in north Lincolnshire.

Type section

None

Type area

Vale of Ancholme, north Lincolnshire; Brigg district (E&W 89) (British Geological Survey, 1982a; Gaunt et al., 1992).

Reference section(s)

Nettleton Bottom Borehole (TF19NW54) [TF 1249 9820], 31.00 to 320.65 m depth, Kimmeridge Clay Formation (upper beds (above Hudlestoni Zone) missing beneath unconformity), complete Amphill Clay, West Walton, Oxford Clay and Kellaways formations (Gaunt et al., 1992, figs 46 and 47).

See also BGS Lexicon entries for component formations (Kellaways (Section 5.3.1), Oxford Clay (Section 5.3.2), West Walton, Amphill Clay and Kimmeridge Clay).

Formal subdivisions

Kimmeridge Clay Formation* (KC) (Webster, 1816)
Amphill Clay Formation* (AMC) (Seeley, 1869) (see also Arkell, 1933, pp. 409-411; Cox and Gallois, 1979)
West Walton Formation* (WWB) (Gallois and Cox, 1977)
Oxford Clay Formation (OXC) (Buckland, 1818; as modified in Gallois and Cox, 1977)
Kellaways Formation (KLB) (Judd, 1875)

* entirely Upper Jurassic; not covered in this report

Lithology

Predominantly grey, marine mudstone and silty mudstone; beds of argillaceous limestone nodules (or more or less persistent beds) at some levels; units of siltstone and sandstone at some levels, widespread near base (in Kellaways Formation), in middle part (West Walton Formation) and more locally at other levels (notably Kimmeridge Clay Formation of Oxfordshire/Buckinghamshire); shelly marl, limestone and sandy limestone developed locally (notably in the West Walton Formation).

Lithogenetic description

Relatively deep marine environment depositing silicate mud and lesser amounts of calcareous mud. Generally quiet conditions with restricted bottom water circulation leading to anoxic conditions at times, promoting preservation of organic-rich mud.

Landform description

Underlies many low-lying 'clay vales' of central England, from the Humber through the East Midlands and South Midlands.

Definition of upper boundary

Unconformable junction of mudstones with uppermost Jurassic/Lower Cretaceous limestones and sandstones; in the south-west (Oxfordshire/Buckinghamshire) Kimmeridge Clay Formation overlain by Portland Formation and in Bedfordshire–Cambridgeshire by the Woburn Sands Formation; farther north, Ancholme Group formations (Kimmeridge Clay to Kellaways) progressively overstepped towards the Market Weighton High by the overlapping Cretaceous Sandringham Sand (Norfolk), Spilsby Sandstone, Carstone and Hunstanton Chalk formations (Lincolnshire to Yorkshire).

Definition of lower boundary

Base of Kellaways Formation, generally sharp, conformable or non-sequential; commonly a shelly mudstone resting on limestone of the Cornbrash Formation.

Thickness

Zero (over Market Weighton High) to about 350 m in central/eastern Lincolnshire, about 150 to 180 m in Buckinghamshire and Oxfordshire.

Distribution

Waddesdon, Buckinghamshire, between Oxford and Aylesbury in the Thame (E&W 237) district (British Geological Survey, 1994b), where Corallian Group wedges out (Horton et al., 1995) to Market Weighton area, Yorkshire in the Beverley (E&W 72) district (British Geological Survey, 1995). Mutually exclusive with the Corallian Formation/Group, thus not used south of Oxford, nor in the Cleveland Basin.

Previous names

Ancholme Clay Group (Gaunt et al., 1992).

Parent

None

Age

Callovian to Kimmeridgian

References

Principal reference (Gaunt et al., 1992)

5.3.1 Kellaways Formation (KLB)

Exposures of sandstone in the banks of the Avon [ST 94 75] near the hamlet of Kellaways (or Kelloway in the earlier part of the 19th century) north-east of Chippenham, Wiltshire were noted by William Smith and others (Townsend, 1813) as displaying strata inferred to lie between the Cornbrash and the Oxford Clay. The 'Kellaways' was applied by authors to name several rock types: Clay, Sand, Rock and Stone; within this interval, and the term 'Kellaways Beds' for all the strata was coined by Judd (1875) and Ussher et al. (1888), recognising correlatives of the Wiltshire sequence in the East Midlands. This usage was affirmed by Woodward (1895), who also divided them into Kellaways Clay below and Kellaways Rock above, and documented their extension more widely through England.

Page's (1989) formalisation of the Kellaways Formation excluded his 'Cayton Clay Formation' at the base, which beds are considered here to be the lower, more phosphatic part of the Kellaways Clay Member throughout its geographical range, and hence part of the Kellaways Formation. Subsequently, Gaunt et al. (1992, p. 60) named the strata between the Cornbrash and the mudstone underlying their 'Brantingham Formation' the 'Kellaways Beds Formation', a form that has achieved no currency and goes against modern practice (Cox and Sumbler, 1998, p. 15).

Onshore the Kellaways Formation has been mapped up to the overstep by Cretaceous strata at North Newbald [SE 90 37] approaching the Market Weighton structure in North Yorkshire. It was also identified in a BGS borehole near Acklam (Brown Moor, SE86SW4 [SE 81266 62043]) (Gaunt et al., 1980), 21 km north of Market Weighton, which is considered to be the most northerly known occurrence. Sandstones mapped as 'Kellaways Rock' in the 19th century to the north (see Arkell, 1933, pp. 360–365) are now attributed to the Osgodby Formation (see Section 6.3.2), and Callovian sandstones attributed to the Kellaways Beds on Skye and Eigg (see Arkell, 1933, pp. 370–372) are now accorded a local Hebridean name – Staffin Bay Formation (see Section 8.3.1).

A bipartite formal division of the formation into Kellaways Clay Member and Kellaways Sand Member has generally proved to be applicable and mappable through most of the outcrop. However, south from Kellaways itself, as the formation thickens, this distinction decreases, and the formation is mapped undivided throughout Dorset. Here the occurrence of sand and sandy mudstone beds has been found to be less systematic, but nonetheless the Kellaways Clay and Sand members have been found to be locally recognisable in sections and boreholes (Bristow et al., 1995; Bristow et al., 1999).

In some regions, some sand beds within the formation, generally at or near the top, are conspicuously well cemented with calcium carbonate. These were formerly called the Kellaways Rock (or less commonly Kellaways Stone). However, the beds are not reliably continuous or demonstrably correlative, and this informal term is retained here for descriptive purposes, notably in Wiltshire where the beds may locally be mappable. In north Lincolnshire and East Yorkshire, a well-cemented sandstone bed at the top of the formation was termed the Cave Rock Member by Page (1989). Gaunt et al. (1992, pp. 61–62, fig. 24) showed it to be continuous and named it the Kellaways Rock Member, but Page's term has precedence.

Name

Named after the hamlet of Kellaways north-east of Chippenham, Wiltshire by Judd (1875) as 'Kellaways beds', based on Smith's (1817) 'Kellaways Stone' (see also Arkell, 1933; Page, 1989).

Type section

BGS Tytherton No. 3 Borehole (ST97SW2) [ST 9440 7445], 2.7 km east-north-east of Chippenham, Wiltshire, 3.35 to 24.27 m depth (top of formation not seen). (Cave and Cox, 1975)

Type area

Kellaways, near Chippenham, Wilts (Cave and Cox, 1975).

Reference section(s)

BGS Walks Farm Borehole (TF14NE18) [TF 1534 4635], 2.5 km north-north-east of Heckington, near Sleaford, Lincolnshire, 91.60 to 98.37 m depth (Berridge et al., 1999).

Other reference sections

'Fault Corner', Grange Top Quarry [SK 981 073], Ketton, Rutland. Fully exposed, 8.50 m thick. (Hudson and Clements, 2007, pp 258-259).

Formal subdivisions

Cave Rock Member (Page, 1989)
Kellaways Sand Member (KLS) (Ussher et al., 1888, as modified herein)
Kellaways Clay Member (KLC) (Woodward, 1895, as modified herein)

Informal subdivisions

Kellaways Rock (Townsend, 1813)

Lithology

Mudstone, grey, commonly silicate-silty or silicate-sandy, with (predominantly in the upper part) beds of generally calcareous silicate-siltstone and silicate-sandstone.

Definition of upper boundary

Generally sharp but conformable junction between sandstone/siltstone in upper part of formation with mudstone of overlying Oxford Clay Formation; in expanded successions (Wessex Basin), arbitrary boundary drawn at the top of highest substantial sandstone or sandy mudstone, above which the succession is predominantly mudstone; in Market Weighton area, sharp disconformable contact with chalky argillaceous sediments of Hunstanton Formation or ferruginous sandstone of Carstone Formation where present (both Lower Cretaceous).

Definition of lower boundary

Generally sharp, conformable or non-sequential junction with bioclastic limestone of underlying Cornbrash Formation, overlain by grey mudstone; commonly a thin unit of shell-fragmental, more or less sandy mudstone occurs at base (where this bed is more strongly cemented it is included in Cornbrash Formation).

Thickness

Up to perhaps 50 m (in south Dorset); typically about 20 m in Wessex Basin, and 5 to 8 m on East Midlands Shelf.

Distribution

Continuous outcrop from the Dorset coast (Weymouth area) to North Newbald [SE 90 37], south of Market Weighton High. Also seen in the Malton area, Yorkshire (just north of Market Weighton High). Extensive in onshore subcrop, though absent over interior of London Platform.

Previous names

Kellaways Beds (Jukes-Brown in Ussher et al., 1888; Woodward, 1895)

Kellaways Formation plus Cayton Clay Formation (areas excluding Cleveland Basin) of Page (1989).

Kellaways Beds Formation (Gaunt et al., 1992)

Kellaways Rock plus Kellaways Clay

Parent

Ancholme Group north-east from Buckinghamshire. None from Oxfordshire south-west, where the Kellaways and Oxford Clay formations are consistently mapped separately.

Age

Lower Callovian, Herveyi Zone to Calloviense Zone

References

Principal reference (Cave and Cox, 1975)

5.3.2 Oxford Clay Formation (OXC)

The name Oxford Clay, for the thick succession of rather monotonous grey mudstones above the Great Oolite limestones, is of similar vintage to Kellaways, appearing in Buckland's (1818) table in 'Order of the superposition of strata'. However, he offers two alternatives; the Fen Clay, which spans the Callovian to Kimmeridgian mudstone formations of eastern England (i.e. is equivalent to the modern Ancholme Group minus the Kellaways Formation), and the Forest Clay which appears to have been intended to include the mudstones between the Great Oolite and Corallian of England south-west from Oxford (also excluding the Kellaways Formation). In addition, Wm. Smith (1817) used the term 'Clunch Clay and Shale' for the interval between the 'Kellaways Stone' and a sand bed at the base of the 'Coral Rag and Pisolite'. None of these names has achieved any currency since the mid 19th century, whereas the term Oxford Clay became universally utilised throughout onshore Britain, being recognised at outcrop in southern England from Dorset to the Humber. Coeval strata were named Oxford Clay in North Yorkshire, on the Scottish east coast and in the Hebrides (see Arkell, 1933 pp. 370-372). Subsequently, separate local lithostratigraphical schemes have been erected for the two Scottish basins (see chapters 7 and 8). However, the formation is now known to extend at depth into the Weald Basin and across much of the London Platform and the name has been adopted for certain offshore areas (see Chapter 9).

The upper boundary of the Oxford Clay in eastern England was redefined by Gallois and Cox (1977) to exclude their West Walton Beds (now Formation). The West Walton Formation is mapped as far south-west as Oxford [SP 51 03], beyond which it has not been distinguished from the Oxford Clay. However, it is 25 m thick in the BGS Henwood Farm (Cumnor) Borehole (SP40SE11 [SP 47835 03370]) (Horton et al., 1995), 4 km to the west, and so is likely to persist some distance further in this direction, such that it must be included in the Oxford Clay outcrops west of Oxford on the Witney sheet (E&W 236) (British Geological Survey, 1982b).

Although the Oxford Clay had been widely treated as a formation for a number of years, some disagreement still attended its status, including within BGS, until the Formation was formalised by Cox et al. in 1992. At the same time, three formal members were proposed; the Peterborough, Stewartby and Weymouth members, corresponding respectively with the Lower, Middle and Upper Oxford Clay of traditional usage, and which are recognisable, at least in boreholes and unweathered sections, through most if not all of the formation's range. In addition, minor units can be recognised locally: the Mohuns Park Mudstone of Wessex (Wincanton (E&W 297) (British Geological Survey, 1996b) and Shaftesbury (E&W 313) sheets (British Geological Survey, 1996b)) was accorded Member status by Bristow et al. (1995) (see also Bristow et al., 1999). However, study of the descriptions indicates that it is a natural part of the Peterborough Member – it contains typical Peterborough lithologies in places and passes into it laterally in a rather indefinite way. It is downgraded to formal Bed status herein.

The formation overlies the Osgodby Formation in North Yorkshire (see Section 6.3.2), where the latter is regarded as ranging in age up to latest Callovian. Thus the Oxford Clay in the Cleveland

Basin is entirely Oxfordian in age, and is attributed to the uppermost unit, the Weymouth Member (Wright, J K, 1983).

Name

Buckland (1818), as modified in Gallois and Cox (1977). Named after the city in southern England.

Type section

None designated

Type area

Oxford area

Reference section(s)

BGS Chalgrove Borehole (SU69NE20) [SU 6565 9620], 2.0 km east-south-east of Chalgrove, near Oxford, 153.88 to 220.94 m depth (Horton et al., 1995, p 23).

Formal subdivisions

Weymouth Member (WEY) (Cox et al., 1992) (Upper Jurassic)
Stewartby Member (SBY) (Cox et al., 1992)
Peterborough Member (PET) (Cox et al., 1992)
Acutistriatum-Comptoni Bed (ACCO) (Hudson and Martill, 1994), part of Peterborough Member
Mohuns Park Mudstone Bed (MPMU) (Bristow et al., 1995; Bristow et al., 1999), part of Peterborough Member

Informal subdivisions

Lamberti Limestone

Lithology

Mudstone, grey, generally smooth to slightly silty, with sporadic beds of secondary muddy, fine-grained limestone nodules. Over most of outcrop (except Cleveland Basin, where only upper part is present) comprises a tripartite succession:

Lower part (Peterborough Member) Silicate-mudstone, mainly brownish-grey, fissile, organic-rich ('bituminous'), with subordinate beds of pale to medium grey, blocky mudstone;

Middle part (Stewartby Member) Silicate-mudstone, mainly pale to medium grey, smooth to slightly silty, blocky, with subordinate beds of silty shell-debris-rich mudstone;

Upper part (Weymouth Member) mudstone, mainly pale grey, calcareous, smooth, blocky with silty limestone beds, especially near the top.

Definition of upper boundary

Upward transition from mudstone to silty mudstone of overlying West Walton Formation (Oxford to Market Weighton) or sandy mudstones and calcareous sediments of Corallian Group (Dorset to Oxford, and Yorkshire, north of Market Weighton); in Market Weighton area, sharp disconformable contact with chalk of Hunstanton Formation; Westbury to Longleat, Wiltshire, sharp disconformable contact with sandy micaceous mudstone (Cretaceous, Gault Fm.).

Definition of lower boundary

Generally a fairly sharp conformable junction with silicate-sandstone or sandy mudstone of underlying Kellaways Formation or, in Cleveland Basin, sandstone of underlying Osgodby

Formation, overlain by mudstone. In thicker, expanded successions (Wessex Basin) an arbitrary boundary is interpreted at the top of highest substantial silicate-sandstone or sandy mudstone above which the succession is predominantly silicate-mudstone.

Thickness

0 to perhaps (in south Dorset) 185 m; typically 50 to 70 m over much of East Midlands Shelf.

Distribution

Dorset coast (Weymouth area) to north Yorkshire coast. Extensive in onshore subcrop including the Weald, though absent over interior of London Platform. Offshore English Channel.

Previous names

Clunch Clay and Shale (Smith, W, 1817)

Forest Clay (Buckland, 1818)

Fen Clay (Buckland, 1818) see Arkell (1933).

N.B. Oxford Clay of many accounts (and all pre-1970s) includes beds now assigned to the West Walton Formation and/or in some cases, Corallian Group.

Parent

Ancholme Group north-east from Buckinghamshire. None in the Cleveland Basin or from Oxfordshire south-west, where the Kellaways and Oxford Clay formations are consistently mapped separately.

Age

Mid to Late Jurassic, Early Callovian to Early Oxfordian, Calloviense Zone to Cordatum Zone (Cox et al., 1992).

References

Principal reference (Cox et al., 1992).

SUBSTAGE	ZONE	Member	FORMATION
EARLY/LOWER OXFORDIAN (part)	CORDATUM (part)	Weymouth	OXFORD CLAY
	MARIAE		
LATE/UPPER CALLOVIAN	LAMBERTI	Stewartby	
	ATHLETA		
MID/MIDDLE CALLOVIAN	CORONATUM	Peterborough	
	JASON		
EARLY/LOWER CALLOVIAN	CALLOVIENSE	Kellaways Sand	KELLAWAYS
	KOENIGI	Kellaways Clay	
		HERVEYI	

Table 6 Chronostratigraphy of the Kellaways and Oxford Clay formations.

6 Cleveland Basin

Middle Jurassic strata of the Cleveland Basin are magnificently exposed in the sea cliffs between Whitby and Filey, a distance of over 35 km. Although in places or at times difficult of access, due to steepness and instability or unfavourable tides, the sections have attracted geologists from the early nineteenth century onwards, and the literature is voluminous.

A thorough account of the history of research is given by Cox and Sumbler (2002, pp. 315-318). However, of especial note is that William Smith was resident in the Scarborough district in later life and published a geological map of Yorkshire in 1821, for which he coined a number of stratigraphical terms, some new or unique to Yorkshire, such as the Hackness Rock.

Geological Survey activity in the Cleveland Basin commenced in about 1845, with Charles Fox-Strangways prominent, culminating in a series of sheet and stratigraphical memoirs (Fox-Strangways, 1880, 1892; Fox-Strangways and Barrow, 1882, 1915; Fox-Strangways et al., 1885) through which a consistent lithostratigraphical scheme was set out. The stratigraphical names in this scheme used a mixture of colour, genetic (e.g. 'Estuarine'), relative position (e.g. 'Lower', 'Middle' etc.), lithological and palaeontological (e.g. 'Millepore') terms. In his original revision of the stratigraphy and redefinition of most of the formational boundaries, John Hemingway (1949) removed reference to 'Estuarine' preferring 'Deltaic' (see Chapter 4). His later almost entirely new scheme proposed with Robert Knox (Hemingway and Knox, 1973) complied with modern stratigraphical practice in proposing a new group and formal formations (many subdivided into formal members) with geographical epithets (Table 7). Their omission of lithological terms in the formal names reflects the heterolithic nature of the strata. However, although Hemingway and Knox (1973) quote maximum thicknesses and assign type sections, no details are given, the descriptions are brief and the lower and upper boundaries are poorly defined. Their scheme is adopted almost in its entirety here (apart from their Blowgill Member, see Section 6.2.2) with comprehensive definitions set out below, and has generally proved useful in geological mapping (British Geological Survey, 1992, 1998c, d, 2000b; Frost, 1998; Powell et al., 1992).

Research interest was boosted by the North Sea hydrocarbons industry from the 1960s onward, as the Middle Jurassic strata were seen as analogues of the reservoir rocks, although their correlatives have not been found to be productive (Cameron et al., 1992). Nonetheless, the relationship between the onshore and offshore lithostratigraphical schemes is well known, although most of the formations do not have direct correlatives (see individual formation entries below).

6.1 STAND-ALONE FORMATIONS BELOW THE RAVENSCAR GROUP

As stated above (Chapter 4), the Dogger Formation is a stand-alone formation at the base of the Middle Jurassic succession, beneath the largely paralic Ravenscar Group. It is essentially a condensed sequence of shallow water sediments that accumulated over a relatively long time in a marine environment into which a variety of sediment and dissolved iron was introduced, although according to Hemingway and Knox (1973), not from the north (Mid North Sea High area), unlike the Ravenscar Group. The formation comprises probably two distinct successions (Knox et al., 1991) separated by at least one important non-sequence, such that the younger beds overstep the older, and may include material eroded from them. It has a relatively rich marine fauna including ammonites.

MIDDLE JURASSIC	Stage / Substage	FORMATION	GROUP
	Lower Oxfordian	OXFORD CLAY	
	Upper Callovian	OSGODBY	
	Middle Callovian		
	Lower Callovian		
		CAYTON CLAY	
		CORNBRASH	
	Upper Bathonian	?	
	Middle Bathonian	SCALBY	
	Lower Bathonian		
	Upper Bajocian		
	Lower Bajocian	SCARBOROUGH	
		CLOUGHTON	
	Aalenian	ELLER BECK	
		SALTWICK	
		DOGGER	

Table 7 Lithostratigraphy of the Middle Jurassic strata of the Cleveland Basin to formation level.

6.1.1 Dogger Formation (DGR)

Name

The term ‘dogger’ probably stems from a miner or quarryman’s term for hard masses of well cemented rock separated by joints or lying within softer material (although it is rather archaic, it is still quite widely used in geological texts particularly for ovoid or irregular sandstone concretions). Fox-Strangways (1892, p 154) suggests that its use in north Yorkshire probably began where the underlying alum-bearing shale beds were extracted. Its first use for this stratigraphical unit is by Young (1817) for ‘a hard compact stone 6 to 12 feet thick’ which divided into large blocks, overlying the ‘aluminous schistus’ (Alum Shale Member of the Whitby Mudstone Formation). Its value as a source of iron ore is recognised in the later name Dogger Ironstone (Rastall, 1905). Hemingway and Knox (1973) declined to rename it and in the interests of nomenclature stability, this decision is confirmed here, especially as it is represented locally by other lithologies.

Type section

Exposure at the base of the cliff, west of Saltwick Bay [NZ 908 113], south-east of Whitby, North Yorkshire. The lithofacies variation of the Dogger Formation makes selection of a type section difficult. However, the best exposed and familiar sections are those in the ferruginous sandstone and ironstone lithofacies located near Whitby on the Yorkshire coast. The type section is located between Whitby East Cliff [NZ 903 114] and Saltwick Bay [NZ 915 110] (Hemingway, 1974; Hemingway and Knox, 1973).

Grey, fissile mudstone of the Alum Shale Member, Whitby Mudstone Formation (Lias Group) is overlain by yellow-brown, bioturbated, ferruginous sandstone with occasional berthierine (chamosite) ooids and phosphatised pebbles that comprise the Dogger Formation (0.75 to 1.5m thick). Clasts in the Dogger Formation include mudstone pebbles, and fragments of ammonites and bivalves derived from the underlying Alum Shale Member. At the lower boundary, sand-filled burrows locally extend downwards from the Dogger Formation to the underlying mudstone. The upper boundary is marked by the sharp change from ferruginous, bioturbated sandstone of the Dogger Formation to grey, fine- to medium-grained, locally cross-bedded sandstone with plant fragments of the overlying Saltwick Formation (Ravenscar Group).

Type area

The Dogger Formation occurs as variable lithofacies across the Cleveland Basin from the Yorkshire Coast, near Whitby [NZ 480 500] to the Hambleton Hills [SE 496 827] and Howardian Hills [SE 600 600].

Reference section

A crag at Yew Grain [NZ 717 018] in Great Fryup Dale, Upper Eskdale, reported in Rastall and Hemingway (1943, p. 219) is typical of the ironstone and sandstone lithofacies.

This section is less accessible than the coastal type section and partly degraded, but it provides an example of the mixed ironstone and sandstone lithofacies typical of the Eskdale area. Grey fine-grained sandstone and, locally, siderite mudstone of the Blea Wyke Sandstone Formation is overlain sharply by a thin phosphatic pebble bed that marks the base of the Dogger Formation. This passes up to blue-grey, bioturbated sandstone (1.07 m), black mudstone (0.61 m) and green siltstone (0.15 m) ('Danby Facies') that are, in turn, overlain by green-grey, fine-grained sandstone (0.91 m) and black to grey chamosite ooidal ironstone (3.96 m), with a siderite matrix ('Ajalon facies'). The base of the overlying Saltwick Formation is marked by black, carbonaceous clay, passing up to yellow sandstone. Rapid local lateral variation is illustrated by the absence of the basal pebble bed and overlying bioturbated sandstone bed at the nearby Yew Grain section [NZ 7172 0185] reported by Young, T P (1994, fig.3).

Other reference sections

See *Supplementary information*.

Formal subdivisions

None.

Lithology

Highly variable and heterolithic with substantial lateral interdigitation and lithofacies changes. In the Whitby area and coastal sections to the south-east, the formation consists mainly of grey, weathering yellow-brown, sideritic sandstone, medium- to coarse-grained, with sporadic phosphatic pebbles; berthierine (chamosite) ooids may be present. In central, north and west Cleveland there is a complex interdigitation between grey, weathering yellow-brown, berthierine (chamosite) ooidal ironstone (with siderite mudstone matrix) and pale grey fine-grained limestone, medium-grained, bioclastic wackestone and packstone with peloids and ooids, generally bioturbated and locally cross-bedded. In addition, partings, lenses and beds of grey,

fossiliferous, fissile mudstone may occur, and south-west of Malton, a distinctive iron-rich pebbly medium-grained sandstone facies is locally developed. The sandstones and ironstones are characteristically highly bioturbated and yield marine fossils including bivalves and scattered ammonites; corals, bryozoans, crinoids and brachiopods are locally present in the limestones.

Lithogenetic description

Shallow marine.

Landform description

Forms a small bench or positive topographical feature above the Whitby Mudstone Formation; less distinctive where it overlies the Blea Wyke Sandstone Formation at Ravenscar, or is overlain by thick sandstone beds of the Saltwick Formation.

Definition of upper boundary

The upper boundary is unconformable or disconformable, sharp, marked by a rapid upward change from ferruginous sandstone, ironstone or limestone at the top of the Dogger Formation to cross-stratified, nonbioturbated sandstone, siltstone and mudstone (commonly with plant fragments) of the overlying Saltwick Formation (Ravenscar Group). Where both formations are dominated by mudstone, the boundary may be somewhat cryptic – that of the Dogger Formation is dark grey, less silty and of a distinctly marine aspect, that of the Saltwick Formation is paler grey, silty and with black plant debris.

Definition of lower boundary

Across most of the Cleveland Basin, the lower boundary is generally sharp, disconformable or unconformable on the gently folded Lower Jurassic Lias Group. Marked by an abrupt change where grey fissile mudstone of the Lower Jurassic Whitby Mudstone Formation is overlain by sandstone, ironstone or limestone of the Dogger Formation. The boundary is less distinctive in the Peak Trough (Knox, 1984) (e.g. at Blea Wyke [NZ 991 015], Ravenscar) where the bioturbated sandstone of the Blea Wyke Sandstone Formation (late Toarcian in age) is overlain by the yellow brown sandstone of the Dogger Formation (Aalenian in age), although at Blea Wyke the basal bed contains phosphate pebbles and casts of brachiopods (the Terebratula Bed) (Cox and Sumbler, 2002, pp. 357-361). In the Rosedale area, the base of the formation is generally marked by an ooidal ironstone with phosphatic pebbles sharply overlying bioturbated sandstone or ooidal ironstone of the Blea Wyke Sandstone Formation (Young, T P, 1994), although in localities where these lithologies repeat, the boundary may be difficult to place.

Thickness

Variable, both locally and regionally; generally about 0.75 to 2 m thick on the Yorkshire Coast and in ferruginous sandstone/ironstone lithofacies; limestone and mudstone lithofacies, up to 12.2 m locally preserved. Thought locally to attain 29 m in the Rosedale area [SE 729 946] (Hemingway, 1974, p. 188), although Young, T P (1994) regards much of this strata as belonging to the underlying Blea Wyke Sandstone Formation in which case the Dogger Formation here is up to about 8 m thick. May be absent, locally, due to erosion prior to deposition of the overlying Saltwick Formation (Ravenscar Group), or at the base of Saltwick Formation channels.

Distribution

Cleveland Basin, North Yorkshire, including the North York Moors, North Yorkshire coast (between Boulby and Gristhorpe Bay) and the Howardian Hills. Offshore, the Dogger Formation is equivalent, in part, to the Wroot Formation (Lott and Knox, 1994) in the southern North Sea and in part to the Drake Formation in the Brent Province (Butler et al., 2005). The formation is locally absent in the Cleveland Basin, especially on parts of the Egton sheet (E&W 43) around Ingleby Greenhow (British Geological Survey, 1992), and Thirsk sheet (E&W 43) in the Hambleton Hills (British Geological Survey, 1972b), where the Dogger Formation has been

removed by penecontemporaneous erosion prior to deposition of the overlying Saltwick Formation (Ravenscar Group).

Supplementary information

Other reference sections include: Kettleness [NZ 834 158] ferruginous sandstone and ironstone lithofacies (Rastall and Hemingway, 1940); Kirby Knowle [SE 478 862] ironstone lithofacies (Powell et al., 1992); Cleaves [SE 496 827] shelly, ooidal limestone lithofacies (Powell et al., 1992); Boulby [NZ 738 203] ironstone lithofacies (Black, 1934); Blea Wyke [NZ 991 014] ferruginous sandstone lithofacies (Knox, 1984); Spy Hill [SE750 646] ferruginous pebbly sandstone lithofacies. In the Rosedale area, the very local development of beds of magnetite and/or ferric cronstedtite spinel-rich ironstone at Hollins Mines (Hemingway, 1974) is now claimed by Young, T P (1994) to belong to the underlying Blea Wyke Sandstone Formation. At Blea Wyke [NZ 990 013], the formation includes a lenticular ooidal ironstone bed with a rich macrofauna of gastropods and bivalves, about 3 m from the top – the Nerinea Bed (Cox and Sumbler, 2002, pp. 357-361).

Previous names

Dogger (Young, G, 1817)

Dogger Ironstone (origin unknown but see Rastall, 1905)

Parent

None

Age

Aalenian, Opalinum Zone to Murchisonae Zone

References

Principal reference (Hemingway and Knox, 1973)

6.2 RAVENSCAR GROUP (RAG)

Name

Named by Hemingway and Knox (1973) after Ravenscar village on the Yorkshire coast between Whitby and Scarborough. It is considerably heterolithic and hence the name does not include a lithological term.

Type section

None.

Type area

The type area is the North Yorkshire coast, specifically the Ravenscar area [NZ 985 020] (Hemingway and Knox, 1973; Versey and Hemingway, 1948) for the lower part of the group, up to the base of the Scarborough Formation. The upper part of the group, represented by the strata including the Scarborough Formation and the overlying Scalby Formation is best exposed from Cloughton Wyke [TA 020 950] to Cornelian Bay [TA 060 860], near Scarborough.

Formal subdivisions

See also Table 7.

Scalby Formation (SCY) (Hemingway and Knox, 1973)
Scarborough Formation (SCR) (Hemingway and Knox, 1973)
Cloughton Formation (CLH) (Hemingway and Knox, 1973)

Eller Beck Formation (EBB) (Hemingway and Knox, 1973)
Saltwick Formation (SWK) (Hemingway and Knox, 1973)

Lithology

Mudstone, siltstone and sandstone, intercalated with relatively thin units of calcareous sandstone, calcareous mudstone, calcareous siltstone, limestone and ironstone. Thin coal seams and seatearth mudstones occur in the paralic lithofacies.

Lithogenetic description

Fluvial, fluviodeltaic and paralic with transient marine influence.

Definition of upper boundary

The upper boundary is taken at the unconformable or disconformable upward passage from sandstone, siltstone and mudstone, commonly with plant fragments, of the Scalby Formation to calcareous, bioturbated mudstone and nodular, shelly limestone of the Cornbrash Formation.

Definition of lower boundary

The lower boundary is taken at the base of the Saltwick Formation where sandstone, siltstone or mudstone, commonly with plant fragments, rest unconformably or disconformably on the heterolithic, marine, Dogger Formation (ferruginous sandstone; ooidal ironstone; limestone; calcareous mudstone) or, where the Dogger Formation is absent, on grey, shelly mudstone or siltstone of the Lias Group.

Thickness

Generally about 240 m thick on the North Yorkshire coast (Ravenscar to Scarborough) thinning westward to 114 m in the Hambleton Hills.

Distribution

The Cleveland Basin, including the North York Moors, Cleveland Hills, Hambleton Hills, Howardian Hills and the North Yorkshire coast. Equivalent strata offshore form all but the lowermost and uppermost parts of the West Sole Group (Lott and Knox, 1994).

Previous names

Estuarine Series (Phillips, 1875)

Middle Jurassic Series (Fox-Strangways, 1892)

(Yorkshire) Deltaic Series (Hemingway, 1949)

Parent

None

Age

Aalenian to Bathonian, Murchisonae Zone to Discus Zone

References

Principal reference (Hemingway and Knox, 1973)

6.2.1 Saltwick Formation (SWK)

Name

Hemingway (1949) redefined the Lower Estuarine Series of Fox-Strangways (1892) excluding all the beds from the Eller Beck Bed of Barrow (1877) upwards, and therefore restricting it to the fluvial to paralic facies and dubbed it the 'Lower Deltaic Series'. At the same time (Sylvester-

Bradley, 1949) named the same interval ‘Hayburn Beds’. As stated above (Section 6) the name Lower Deltaic Series employs unhelpful terms, and it was renamed as a formal formation by Hemingway and Knox (1973), after Saltwick Bay on the North Yorkshire coast. Parsons (1980a) preferred Hayburn Formation after Sylvester-Bradley on the grounds of precedence, but it has achieved little currency and Saltwick Formation is preferred here.

Type section

Cliff section on the North Yorkshire coast at Saltwick Bay [NZ 917 108] south-east of Whitby (Hemingway and Knox, 1973). Grey mudstone and siltstone with plant debris and rootlets (Saltwick Formation) overlie yellow-brown, ferruginous sandstone (Dogger Formation). Also present within the Saltwick Formation are yellow-weathering, cross-bedded, laterally impersistent, channel sandstones and grey mudstones (the latter commonly in abandoned channels). The upper boundary with ferruginous sandstone of the Eller Beck Formation is present in the cliff, but is better exposed farther south near Hayburn Wyke [TA 010 971].

Formal subdivisions

None.

Lithology

Grey mudstone, yellow-grey siltstone and yellow, fine- to coarse-grained sandstone. Sandstones commonly display sharply erosional bases, and channel-fill bed forms. Locally, thin coal seams, seatearth mudstone and nodular sideritic ironstone beds may be present. Plant remains and plant rootlets are common in some beds.

Lithogenetic description

Fluvial, fluviodeltaic and paralic ‘coal measures’ lithofacies

Landform description

Forms steep cliffs on the North Yorkshire coast; generally steep slopes on the escarpments of the North York Moors, and a positive topographical feature in the Hambleton and Howardian Hills, especially where it is sandstone-dominated. Mudstone units generally form topographical hollows.

Definition of upper boundary

The upper boundary is taken at the conformable, abrupt upward change from the plant debris-rich, cross-stratified sandstones, siltstones and mudstones of the Saltwick Formation to the calcareous mudstone, ooidal ironstone or ferruginous sandstone, commonly with shelly fossils, at the base of the Eller Beck Formation.

Definition of lower boundary

The lower boundary is taken at the unconformable or disconformable boundary between the underlying heterolithic, marine Dogger Formation (ferruginous sandstone; ironstone; limestone; or calcareous mudstone) and the sandstone, siltstone or mudstone (with plant fragments) of the Saltwick Formation. Where the Dogger Formation is absent due to penecontemporaneous erosion, the Saltwick Formation rests unconformably on grey, calcareous mudstone or siltstone (commonly shelly) of the marine Lias Group, generally the Whitby Mudstone Formation, or on lower stratigraphical units, such as the Redcar Mudstone Formation, near the Market Weighton High.

Thickness

About 50 m on the North Yorkshire Coast, between Whitby and Scarborough, and inland in the North York Moors and Cleveland Hills; 20 to 25 m in the Hambleton Hills on the western escarpment (Powell, et al., 1992; Frost, 1998), thinning southwards to about 5 to 10 m in the Howardian Hills.

Distribution

North York Moors, Cleveland Hills and Howardian Hills; well exposed in several coastal cliff sections between Whitby [NZ 890 115] and Saltwick Bay [NZ 917 108] and south from Blea Wyke Point [NZ 995 010] to Hayburn Wyke [TA 010 971]. Offshore, the formation is equivalent, in part, to the Wroot Formation of the West Sole Group (Lott and Knox, 1994).

Previous names

Included in the Lower Estuarine Series of Fox-Strangways (1892) which is equivalent to the Saltwick and Eller Beck formations and the lower part of the Cloughton Formation.

Lower Deltaic Series (Hemingway, 1949).

Hayburn Beds (Sylvester-Bradley, 1949).

Parent

Ravenscar Group

Age

Aalenian, Murchisonae Zone to ?Bradfordensis Zone

References

Principal reference (Hemingway and Knox, 1973)

6.2.2 Eller Beck Formation (EBB)

Name

The name 'Eller Beck Bed' was originally used by Barrow (1877) after the locality Eller Beck near Goathland for this intercalation of laterally variable marine strata within the paralic facies-dominated Ravenscar Group. This usage was repeated by Fox-Strangways (1892), who also employed the name 'Hydraulic Limestone' for the fine-grained limestone facies in the south valued for cement-making. Hemingway (1949) used the same name but it was later made a formal formation by Hemingway and Knox (1973). Hemingway and Knox (1973) also recognised an additional marine unit – the 'Blowgill Member' which they placed in the overlying Cloughton Formation. This was later shown to be part of the Eller Beck Formation by Powell and Rathbone (1983). The formation is named after the Eller Beck near Goathland.

Type section

The type section is at Walk Mill Foss [NZ 833 023], Eller Beck, Goathland. The formation was originally recognised here by Barrow (1877) and later adopted by Fox-Strangways (1892, p.197) for the Eller Beck Bed. It was formalised by Hemingway and Knox (1973, p.531). Here, the pale grey, plant-debris rich mudstone of the underlying Saltwick Formation is overlain by a basal transgressive sideritic ironstone, overlain by an upward-coarsening succession of mudstone (with ironstone concretions), siltstone and fine- to medium-grained sandstone. Bivalves, preserved as kaolinitic moulds, are common in the basal ironstone and the ironstone concretions; the sandstone includes sparse bivalve moulds and burrows (including *Diplocraterion* and *Rhizocorallium*) and grazing trails.

Reference section(s)

The reference section for the ironstone, mudstone and limestone succession is at Skipton Hill [SE 498 843] (Powell et al., 1992, pp.41-42). The section is degraded but a trench excavation revealed yellow sandstone and mudstone with plant rootlets of the Saltwick Formation overlain by grey, yellow-weathering ironstone with a siderite matrix and berthierine ooids (Ingleby Ironstone of Knox (1973), which passes up into grey, calcareous mudstone with bivalves and thin beds of grey siderite, overlain by grey calcareous mudstone with irregular beds of fine-grained limestone, yielding bivalves and gastropods (Gormire Limestone of Powell et al., 1992)

and green-brown fine- to medium-grained ripple cross-laminated sandstone. The upper boundary is taken at the sharp boundary with yellow medium-grained, cross-bedded sandstone with plant fragments of the overlying Cloughton Formation. Powell and Rathbone (1983) demonstrated that the supposed Blowgill Member' of the Cloughton Formation (Hemingway and Knox, 1973) is a lateral lithofacies equivalent of the Eller Beck Formation, and not a separate, later marine transgression. The Gormire Limestone was formerly known as the Hydraulic Limestone (Fox-Strangways et al., 1886) on account of its suitability for cement making. The ostracod fauna (Bate, 1967b) suggests a tentative correlation with the lower part of the Lincolnshire Limestone of late Aalenian to early Bajocian age (Cope, 1980).

Formal subdivisions

None.

Some beds have been given informal/local names. See *Reference section* above.

Lithology

In the Cleveland Hills and on the North Yorkshire Coast the formation typically comprises marine ironstone, sandstone and mudstone. Two main lithological units are present; the lower unit, generally less than 3 m thick, consists of grey mudstone with subordinate sideritic ironstone, with a bed of ooidal ironstone at the base. The upper unit, typically 4 to 6 m thick, consists predominantly of fine- to medium-grained sandstone, commonly ripple laminated. Southwards, the formation passes into a more calcareous and finer-grained unit dominated by mudstones, argillaceous limestones and ferruginous sandstones (the 'Blowgill Member' of Hemingway and Knox, 1973). Fossil marine bivalves and bioturbation are common, especially in the mudstones and ironstones. *Diplocraterion* burrows are commonly present in the sandstones.

Lithogenetic description

Shallow-marine transgressive unit representing the first major marine transgression across the Mid Jurassic fluviodeltaic hinterland.

Landform description

The formation forms a bench on the sea cliffs of the Yorkshire coast between Peak Scar, Ravenscar [NZ 980 022] to just south of Hayburn Wyke [TA 017 964] and between Whitby, East Cliff [NZ 902 114] and Hawsker Bottoms [NZ 940 084]. Inland in the Cleveland, Hambleton and Howardian Hills, it generally forms a small, positive topographical feature where a distinctive sandstone bed is present (Barrow, 1877; Knox, 1973); the feature is less prominent in the Hambleton and Howardian Hills where the lithofacies change to mudstone, thin limestone and ironstone (Powell and Rathbone, 1983).

Definition of upper boundary

The upper boundary is conformable, or disconformable, at the sharp upward change from the fossiliferous mudstone and ripple laminated sandstones of the upper part of the Eller Beck Formation to the cross-stratified, plant debris-rich sandstones, siltstones and mudstones of the Cloughton Formation (Sycarham Member).

Definition of lower boundary

The lower boundary is conformable, at the sharp upward change from the plant debris-rich, cross-stratified sandstones, siltstones and mudstones of the Saltwick Formation to the fossiliferous, ooidal ironstone or ferruginous sandstone at the base of the Eller Beck Formation.

Thickness

Typically 4.5 to 6 m, up to a maximum of 8.2 m in the type section at Walk Mill Foss [NZ 833 023], Eller Beck, Goathland (Barrow, 1877; Hemingway and Knox, 1973). Thins south-eastwards in the Hambleton Hills to about 4 m thick.

Distribution

The Cleveland Hills, North York Moors, Hambleton and Howardian Hills in north-east England (Fox-Strangways, 1892; Hemingway and Knox, 1973; Hemingway, 1974). It has not been identified offshore in the Southern North Sea, but probably forms part of the Wroot Formation (Lott and Knox, 1994).

Previous names

Eller Beck Bed (Barrow, 1877; Hemingway, 1949).

Hydraulic Limestone (Fox-Strangways, 1892).

Blowgill Member, considered a separate unit (marine member) by Hemingway and Knox (1973); shown to be equivalent to the Eller Beck Formation by Powell and Rathbone (1983).

Age

Aalenian to Bajocian, ?Bradfordensis Zone to ?Discites Zone

References

Principal reference (Hemingway and Knox, 1973)

6.2.3 Cloughton Formation (CLH)

Name

Hemingway (1949) renamed the part of the Lower Estuarine Series (Fox-Strangways, 1892) above the Eller Beck Bed the Sycarham Subseries, and the Middle Estuarine Series (Fox-Strangways, 1892) the Gristhorpe Subseries. He defined his 'Middle Deltaic Series' as these subseries plus the intervening Millepore Series. Sylvester-Bradley (1949) opposed the term Middle Deltaic Series, preferring the use of 'Sycarham Beds', Millepore Series and 'Gristhorpe Beds' as units of equal rank with the Eller Beck Bed below and Scarborough Beds above. The Middle Deltaic Series was renamed as a formal formation with five formal member subdivisions by Hemingway and Knox (1973), after Cloughton Wyke on the North Yorkshire coast. Parsons (in Cope, 1980) criticised the grouping of members of fundamentally different origin in the Cloughton Formation and proposed (as a partial lateral equivalent) the Cayton Bay Beds (Richardson, 1912) as a formal formation. This comprised the marine Millepore Beds and Yons Nab Beds (=Lebberston Member of Hemingway and Knox, 1973), but it has achieved little currency. Instead Cloughton Formation, comprised of the Sycarham, Lebberston and Gristhorpe members, is preferred across the basin herein (J H Powell, verbal communication, 14/10/09). The Blowgill Member has been shown to be a correlative of the Eller Beck Formation (see above), and use of the Hawsker Member (for the formation where the Lebberston Member is absent) is abandoned.

Type section

Cliff/coast section between Iron Scar [TA 017 964] (base) and Cloughton Wyke [TA 020 950] (top). Yellow weathering, bioturbated sandstone and siltstone of the Eller Beck Formation are overlain by yellow weathering, cross-bedded, medium-grained sandstone and siltstone with sporadic plant fragments at the base of the Cloughton Formation. The upper boundary is well exposed at Hundale Point [TA 026 949], where grey, weakly bedded mudstone, locally with plant fragments and rootlets (Sycarham Member, Cloughton Formation) passes up to dark grey, well laminated, calcareous siltstone with sparse bivalves, overlain by heavily bioturbated sandstone with u-shaped *Diplocraterion* burrows (Scarborough Formation). The Lebberston Member is not well exposed in this section – see *Reference section*, (Hemingway and Knox, 1973).

Reference section(s)

Partial section through the upper part of the Sycarham Member, Lebberton Member and Gristhorpe Member. The section extends along the wave cut platform at Lebberton Cliff, from [TA 080 844] (upper part of Sycarham Member on foreshore) to [TA 085 843] where the Lebberton Member (including the Yons Nab Beds) and Gristhorpe Member are exposed below the overlying Scarborough Formation. Yellow, trough cross-bedded fine- to medium-grained sandstone with plant fragments (Gristhorpe Member) is overlain sharply by fossiliferous grey mudstone of the Scarborough Formation.

Formal subdivisions

Gristhorpe Member (GRPE) (Hemingway and Knox, 1973)
Lebberton Member (LEBB) (Hemingway and Knox, 1973)
Sycarham Member (SYCM) (Hemingway and Knox, 1973)

Lithology

The lower and upper parts of the formation (Sycarham and Gristhorpe members respectively) are dominated by planar-laminated grey mudstones and siltstones with yellowish grey, fine- to medium-grained, cross-stratified sandstones. Plant remains and rootlets are common in both members, with rare thin coals, and grey mudstone seatearths. Mudstones, ferruginous sandstones and ooidal limestones with a marine macrofossil and trace fossil assemblage occur in the middle part of the formation, differentiated as the Lebberton Member (Hemingway and Knox, 1973) and also known formerly as the Whitwell Oolite and/or the Millepore Bed.

Lithogenetic description

Fluvial, fluviodeltaic, paralic coal measures facies, with transient marine incursion facies.

Landform description

Forms steep cliffs on the North Yorkshire Coast, and generally steep slopes on the escarpments of the North York Moors, and a positive topographical feature in the Hambleton and Howardian Hills, especially where sandstone dominated. Mudstone units generally form topographical hollows.

Definition of upper boundary

The upper boundary is conformable, at the abrupt transition from the sandstones, siltstones and mudstones with rootlets and plant remains of the upper part of the Cloughton Formation, to the bioturbated and fossiliferous, variably calcareous mudstones, siltstones and fine-grained sandstones, and limestone of the lower part of the Scarborough Formation.

Definition of lower boundary

The lower boundary is conformable, or disconformable, at the abrupt upward transition from the fossiliferous mudstone and ripple laminated sandstones of the upper part of the Eller Beck Formation to the cross-stratified, plant debris-rich sandstones, siltstones and mudstones of the Cloughton Formation.

Thickness

50 to 70 m on the North Yorkshire Coast between Whitby and Scarborough and inland in the North Yorkshire Moors and Cleveland Hills; 36 to 50 m (thinning southwards) on the western escarpment of the North Yorkshire Moors (Frost, 1998; Powell et al., 1992).

Distribution

North Yorkshire Moors, Cleveland Hills and Howardian Hills; well exposed in several coastal cliff sections between Hawsker Bottoms (north-west of Robin Hood's Bay) and Gristhorpe Bay, south-east of Scarborough. South of the Howardian Hills the unit is truncated by the unconformity at the base of the Chalk. Equivalent strata in Humberside and Lincolnshire are dominated by limestones (Cave Oolite and Lincolnshire Limestone, Cope, 1980). Offshore, the formation is equivalent, in part, to the Strangways Formation of the West Sole Group (Lott and Knox, 1994).

Previous names

Middle Deltaic Series (Hemingway, 1949).

Combined Sycarham Beds, Millepore Series and Gristhorpe Beds of Sylvester-Bradley (1949).

Lower Estuarine Series (upper part), Millepore Bed/Series and Middle Estuarine Series of Fox-Strangways (1892).

Age

Bajocian, Discites Zone to Sauzei Zone

Supplementary Information

Hemingway and Knox (1973) erected a second marine unit termed the Blowgill Member, comprising mudstone and limestone, at the base of the Cloughton Formation. This was subsequently shown to be part of the underlying Eller Beck Formation, and not a member of the Cloughton Formation (Powell and Rathbone, 1983).

References

Principal reference (Hemingway and Knox, 1973)

6.2.4 Scarborough Formation (SCR)

Name

The term 'Scarborough Formation' has the greatest longevity of the Ravenscar Group units having been named as the Scarborough Limestone (Series) by Hudleston (1874) after the town on the Yorkshire coast. This name was adopted by Fox-Strangways (1880), although he added the alternative 'Grey Limestone Series'. Richardson (1912) changed the name to Scarborough Beds, recognising its relative lack of limestone, and this was formalised by Parsons (1977). As a result largely of its deposition in a shallow marine to nearshore environment, the formation displays great lateral facies and thickness variation, as set out by Parsons (in Cope, 1980, p. 17, fig. 5) and this is reflected in the plethora of local subdivisions that have been described and proposed as members over the years (see *Formal subdivisions* and *Other subdivisions* below), although many are not widely recognised. It is not possible to review the validity of all of these here, although the units comprehensively described by Gowland and Riding (1991), plus the Lambfold Hill Grit Member are regarded as having most merit (listed under *Formal subdivisions*). The Scarborough Formation is well exposed in several coastal cliff sections near Hundale Point [TA 026 948] between Cloughton Wyke and Long Nab, north-west of Scarborough, and at Black Rocks [TA 050 870] to the south of Scarborough.

Type section

The type section at Hundale Point [TA 026 948] was described by Bate (1965, p.83) and later by Parsons (1977) and Gowland and Riding (1991). Here, grey mudstone with plant fragments of the Cloughton Formation are overlain by calcareous siltstone, calcareous mudstone, calcareous fine- to medium-grained sandstone and thin beds of argillaceous limestone; calcite concretions are present in the uppermost calcareous siltstone beds. The sandstone and siltstone beds have a rich and diverse trace fossil assemblage, including *Diplocraterion*, *Rhizocorallium*,
British Geological Survey

Thalassinoides and *Chondrites* burrows. Bivalves and sparse ammonites (Humphriesianum Zone and Subfurcatum Zone – early to late Bajocian) are present. Seven members have been recognised at Hundale Point (Parsons, 1977; Gowland and Riding, 1991) but these are not readily traceable away from the coastal cliff exposures. The members at Hundale Point comprise, in upward sequence, the Helwath Beck Member, the Hundale Shale Member, the Hundale Sandstone Member, the Spindle Thorn Limestone Member, the Ravenscar Shale Member, the White Nab Ironstone Member and the Bogmire Gill Member.

Reference section(s)

Quarry near Kirby Knowle [SE 4744 8777] exposes the Brandsby Roadstone Member (Phillips, 1829) and Crinoid Grit Member (Richardson, 1912) typical of the Scarborough Formation lithofacies in the west and south-west of the Cleveland Basin (Fox-Strangways et al., 1886).

Comparative sections in the Hambleton Hills are illustrated in Powell et al. (1992, fig. 13 and p. 48) and Powell (1992). The most complete section is at Brockholes [SE 4744 8777]. Here, grey mudstone with plant fragments of the Cloughton Formation is sharply overlain by yellow, sandy limestone and grey, lime mud-rich, peloidal limestone with bivalves that passes up to calcareous sandstone with pentacrinoid columnals and *Diplocraterion* burrows (Brandsby Roadstone Member). Above, the Crinoid Grit Member comprises yellow, medium-grained, cross-bedded, calcareous sandstone with bivalves, pentacrinoid columnals and abundant burrows; the upper boundary with the white to pale grey, fine-grained, orthoquartzitic sandstone of the overlying Moor Grit Member (Scalby Formation) is poorly exposed.

Formal subdivisions

Hundale Point type section, in north-east of Cleveland Basin
Bogmire Gill Member (Gowland and Riding, 1991)
White Nab Ironstone Member (Parsons, 1977)
Ravenscar Shale Member (Parsons, 1977)
Spindle Thorn Limestone Member (Richardson, 1912) (some variations in spelling seen).
Hundale Sandstone Member (Gowland and Riding, 1991)
Hundale Shale Member (Parsons, 1977)
Helwath Beck Member (Gowland and Riding, 1991)

Kirby Knowle, in south-west of Cleveland Basin
Crinoid Grit Member (CRG) (Richardson, 1912)
Brandsby Roadstone Member (BRBY) (Phillips, 1829)

Lambfold Hill Grit Member (Parsons, 1977; Richardson, 1912)

Other subdivisions of uncertain status or obsolete

Black Rock Nodule Bed

Lower Belemnite Bed

Transition Shales – see Bogmire Gill Member

Lithology

Variable lithology comprising: fossiliferous argillaceous limestone (peloidal calcilutite and wackestone), calcareous mudstone, calcareous siltstone, calcareous medium-grained sandstone, calcareous concretions and ironstone. Peloidal limestones are locally cross-bedded.

Lithogenetic description

A fully marine unit that represents the most widespread marine transgression within the predominantly fluviodeltaic deposits of the Ravenscar Group.

Landform description

Forms steep cliff and rock platforms on the North Yorkshire coast. Inland, throughout the North York Moors, it forms a small positive topographical feature, especially where the Brandsby Roadstone and Crinoid Grit members are present in the Hambleton and Howardian Hills.

Definition of upper boundary

The upper boundary is disconformable, at the sharp upward change from grey shelly mudstone or shelly sandstone of the Scarborough Formation to cross-bedded sandstone with plant fragments of the lower part of the Scalby Formation (Moor Grit Member) (Bate, 1965, p.83; Gowland and Riding, 1991; Parsons, 1977; Powell et al., 1992).

Definition of lower boundary

The lower boundary is conformable, or disconformable, at the sharp upward change from plant debris-rich, mudstone with plant rootlets, or cross-bedded sandstone of the upper part of the Cloughton Formation (Gristhorpe Member) and well-laminated calcareous mudstone, or limestone of the Scarborough Formation (Bate, 1965, p.83; Gowland and Riding, 1991; Parsons, 1977; Powell et al., 1992).

Thickness

Up to 30 m in the coastal type section at Hundale Point [TA 026 949] (Gowland and Riding, 1991); thins westward to between 9 and 14 m in the Hambleton Hills [SE 477 898] (Powell et al., 1992, p. 46); at Yons Nab [TA 085 841] south of Scarborough it is only 3 m thick (Rawson and Wright, 1992).

Distribution

Present throughout the North Yorkshire Moors, Cleveland Hills, Hambleton Hills and Howardian Hills. Equivalent strata in Humberside and Lincolnshire are dominated by limestones (Lincolnshire Limestone Formation, see Cope, 1980). Offshore, the formation is equivalent, in part, to the Strangways Formation of the West Sole Group (Lott and Knox, 1994).

Previous names

Scarborough Limestone (Series) (Fox-Strangways, 1880; Hudleston, 1874).

Grey Limestone Series (Fox-Strangways, 1880).

Scarborough Beds (Richardson, 1912)

Age

Bajocian, Humphriesianum Zone

References

Principal reference (Hemingway and Knox, 1973)

6.2.5 Scalby Formation (SCY)

Name

The uppermost unit of the Ravenscar Group was originally named 'Upper Estuarine Series', then 'Upper Deltaic Series' (Hemingway, 1949) indicating its long recognition as the final phase of Mid Jurassic paralic deposition in the Cleveland Basin, following the shallow marine Scarborough Formation. Sylvester-Bradley (1949) proposed renaming them 'Scalby Beds', after the coastal type section, and later Hemingway and Knox (1973) adopted it as a formal formation. The sandstone unit at the base has long been recognised as the Moor Grit Member (Fox-Strangways, 1881, 1892), and the overlying mudstone, siltstone and sandstone beds were named Long Nab Member by Leeder and Nami (1979). Torrens (in Cope, 1980, p. 42, fig. 6b, col. B16) claimed the formation represented more-or-less continuous sedimentation throughout the late Bajocian, Bathonian and earliest Callovian. Cox and Sumbler (in prep) infer an age ranging only into the late Bathonian by making a correlation between the Scalby Formation and the Rutland Formation of the East Midlands Shelf.

Type section

Coastal cliff section (Scalby Cliff) near Scalby Mills, north of Scarborough, between Long Nab [TA 028 943], Scalby Ness [TA 037 907] and southwards to Castle Hill [TA 048 893].

Along this 10.5 km section, the formation consists of medium- to coarse-grained, trough cross-bedded sandstone (Moor Grit Member, about 15 m thick) overlain by grey mudstone, siltstone and sandstone, with local channel sandstone bodies. Plant fragments, rootlet horizons and drifted logs are common in the upper member, and thin coals are locally present. Dinosaur footprints occur sporadically. The lower, erosional boundary of the Moor Grit Member with the shelly mudstone of the Scarborough Formation is well exposed north of Long Nab [TA 028 943]. The upper boundary with the overlying Cornbrash Formation is not exposed until farther south, on the north side of Castle Hill [TA 048 893], Scarborough (Fox-Strangways, 1892). A better, intermittently exposed upper boundary at Cayton Bay is given in the reference section.

Type area

None designated.

Reference section(s)

Reference section for the upper boundary on the south side of Cayton Bay [TA 078 841], south of Scarborough, (see *Definition of upper boundary* below).

Formal subdivisions

Long Nab Member (LNAB) (Leeder and Nami, 1979)
Moor Grit Member (MRG) (Fox-Strangways, 1881, 1892)

Lithology

The lowermost part of the formation (Moor Grit Member) is dominated in coastal exposures by grey, medium- to coarse-grained, sporadically pebbly, trough cross-bedded sandstone, with thin siltstone and mudstone beds; plant fragments and fossil wood casts are common. Inland, in the Hambleton Hills (Powell et al., 1992) it is represented by grey to white, fine-grained, orthoquartzitic sandstone, with low-angle cross stratification and planar bedding. The overlying Long Nab Member comprises laminated grey mudstone and siltstone with yellowish grey, fine- to medium-grained, planar bedded and cross-stratified sandstone beds. Plant fragments and rootlets are common in both members, together with sporadic thin coals and grey mudstone seatearths.

Lithogenetic description

The formation comprises paralic ('coal measures') lithofacies, and was deposited in fluvial, fluviodeltaic and coastal plain environments (Butler et al., 2005; Fisher and Hancock, 1985; Leeder and Nami, 1979; Livera and Leeder, 1981; Nami and Leeder, 1978; Powell et al., 1992; Riding and Wright, 1989).

Landform description

Forms steep cliffs on the North Yorkshire Coast, and generally a steep scarp slope in the North York Moors. The lowermost Moor Grit Member forms a prominent bench-like feature in the coastal cliff, and a positive topographical feature in the Cleveland, Hambleton and Howardian hills. The overlying Long Nab Member is mudstone-dominated with thin channel sandstones, and generally forms less prominent topographical features.

Definition of upper boundary

The upper boundary is conformable or disconformable, at the boundary between siltstone, mudstone or cross-bedded sandstone with plant fragments of the Long Nab Member (Scalby Formation) and the Cornbrash Formation, which at Cayton Bay [TA 078 841], comprises red-brown, sandy, nodular, bioturbated limestone with oysters and other bivalves; U-shaped burrows extend down from the base of the Cornbrash Formation into the underlying grey siltstone and silty sandstone of the Scalby Formation (Wright, J K, 1977). Inland in the Hambleton Hills and Howardian Hills, the Cornbrash Formation (limestone) is generally absent (Powell et al., 1992, p. 53) and the upper boundary is taken at the base of a yellow-brown, calcareous medium-grained sandstone with bivalves, the Kellaways Rock Member (Osgodby Formation). This member is referred to as the Redcliff Rock Member by Page (1989).

Definition of lower boundary

The lower boundary is disconformable or unconformable, at the sharp upward change from grey, shelly mudstone or shelly sandstone of the Scarborough Formation to grey, cross-bedded and planar laminated sandstone with sporadic plant fragments of the lower part of the Scalby Formation (Moor Grit Member) (Gowland and Riding, 1991; Nami and Leeder, 1978; Powell et al., 1992). The boundary is commonly a scoured, erosional surface.

Thickness

Up to 60 m on the North Yorkshire coast; 32 to 48 m in the Hambleton Hills in the west of the outcrop.

Distribution

North Yorkshire Moors, Cleveland Hills, Hambleton Hills and Howardian Hills. Equivalent strata in Humberside and Lincolnshire are probably represented by the Bajocian to Bathonian Rutland Formation (Cox and Sumbler, in prep). Offshore, the formation is equivalent, in part, to the Hudleston Formation of the West Sole Group (Lott and Knox, 1994).

Previous names

Upper Estuarine Series (Fox-Strangways, 1892; Fox-Strangways et al., 1886).

Upper Deltaic Series (Hemingway, 1949).

Scalby Beds (Sylvester-Bradley, 1949)

Age

?Bajocian–Bathonian, ?Subfurcatum Zone to ?Discus Zone

References

Principal reference (Hemingway and Knox, 1973)

6.3 STAND-ALONE FORMATIONS ABOVE THE RAVENSCAR GROUP

A thin sequence of limestone beds above the ‘(Upper) Estuarine Series’ (now Ravenscar Group) in the northern part of the Cleveland Basin has long been known as the Cornbrash, despite some early observations of its lithological dissimilarities from, and doubts about its equivalence with the formation in southern England (see Fox-Strangways, 1892). A thorough account of it is given by John Wright (1977), who recognised four subdivisions in exposures at the coast. In addition, an overlying sequence of dark moderately fossiliferous mudstone beds was included by Thomas Wright (1860) in the unit as ‘Clays of the Cornbrash’, later ‘Shales with *Avicula echinata*’ (Hudleston, 1874), but recognised as having more affinity with the Kellaways Beds by Fox-Strangways (1892). It was later renamed ‘Shales of the Cornbrash’ by which name it continued to be described despite comments by Douglas and Arkell (1932). The same name was formalised as a member by Wright (1977). Page (1989) rejected Wright’s (1977) division of the formation in North Yorkshire into a Cornbrash Limestone Member and Shales of the Cornbrash Member, maintaining the former as his Abbotsbury Cornbrash Formation, and naming the latter the Cayton Clay Formation, which correlates approximately with the Kellaways Clay Member of the Kellaways Formation of southern and eastern England. See section 5.2.4 for the Cornbrash Formation definition.

The Osgodby Formation, comprised of paralic sand and sandstone, is restricted to the Cleveland Basin and correlates with the Kellaways Formation and Peterborough and Stewartby members of the Oxford Clay Formation of southern England.

6.3.1 Cayton Clay Formation (CAYC)

Name

Named after Cayton Bay [TA 07 84], near Cayton, North Yorkshire (Page, 1989).

Type section

Red Cliff [TA 076 840] at the south-east end of Cayton Bay, North Yorkshire where the formation is often poorly exposed at beach level; where fully exposed it is 2.53 m thick and comprises of dark grey, shelly silty mudstone with very fine-grained sandstone laminae; small phosphatic nodules are also present. The boundaries with the underlying Cornbrash Formation and overlying Osgodby Formation (Redcliff Rock Member) are conformable (Wright, J K, 1977, p 339).

Type area

None designated

Reference section(s)

Havern Beck [SE 847 948], Newtondale, near the Saltersgate Hotel; fully exposed, about 2.4 m thick of grey, fissile clay, bituminous in part, with traces of small bivalves (Douglas and Arkell, 1932) underlain by sandy limestone of the Cornbrash Formation, and overlain conformably by sandstone of the Osgodby Formation (Redcliff Rock Member) (Cox and Sumbler, 2002, pp. 343-345; Riding and Wright, 1989; Wright, J K, 1968b, 1977, 1978).

Formal subdivisions

None

Lithology

Clay and mudstone, dark grey, laminated in part, becoming silty at the top and passing up gradationally into the Osgodby Formation (Redcliff Rock Member). The clay contains numerous small grey phosphatic nodules which may enclose the shrimp *Meyeria* or the ammonite *Macrocephalites* spp. and bivalves *Meleagrinella* aff. *braamburiensis*, *Modiolus bipartus*, and *Nuculana* sp.

Lithogenetic description

Marine littoral shelf, shallow to moderate water depths.

Landform description

Generally forms a negative topographical feature, where present, between the underlying Cornbrash Formation and the overlying Osgodby Formation.

Definition of upper boundary

Gradational conformable boundary where the soft, grey mudstone of the Cayton Clay Formation passes gradationally up to the pale yellow, clayey sandstone of the overlying Osgodby Formation (Redcliff Rock Member).

Definition of lower boundary

Generally a sharp, conformable boundary between bioclastic, berthierine (chamosite) ooid-rich, sandy limestone of the underlying Cornbrash Formation and the dark grey, locally shelly, silty mudstone of the Cayton Clay Formation.

Thickness

Up to 3 m (Wright, J K, 1968b, 1977); locally absent in the west of the Cleveland Basin.

Distribution

The Cleveland Basin, North Yorkshire, but locally absent in the west (Powell, 2010) and south of the basin (Page, 1989).

Previous names

Clays of the Cornbrash (Wright, T, 1860, p 26)

Shales-of-the-Cornbrash (Fox-Strangways, 1892)

Shales-of-the-Cornbrash Member (Wright, J K, 1977)

Parent

None

Age

Early Callovian, Herveyi Zone (Page, 1989; Rawson and Wright, 2000; Wright, J K, 1968b, 1978).

References

Principal reference (Wright, J K, 1968b)

6.3.2 Osgodby Formation (OSBY)

Name

Named after the type section at Osgodby Point or Nab, Cornelian Bay, near Osgodby, North Yorkshire (Wright, J K, 1978).

Type section

Osgodby Point or Nab [TA 065 854], exposes the type section of the Osgodby Formation conformably overlying the Cayton Clay Formation (Wright, J K, 1968b, 1977). All three members are present (compare Red Cliff reference section, below). The Redcliff Rock Member (Page, 1989), 3.5 m thick, comprises red-brown, ferruginous fine-grained sandstone with chamosite (berthierine) ooids; bivalves and the ammonite *Kepplerites* are present. The overlying Langdale Member, 3.8 m thick, comprises grey-brown, bioturbated, fine-grained sandstone and bioturbated siltstone; the bivalve *Gryphaea* and decalcified moulds of belemnites are common in

the lower part. The overlying Hackness Rock Member, 0.78 m thick, is grey-brown, sandy limestone with abundant chamosite (berthierine) ooids; it is bioturbated and yields bivalves, belemnites and the ammonites *Quenstedtoceras* and *Kosmoceras* (Rawson and Wright, 2000). The conformable boundary with the grey-green silty mudstone of the overlying Oxford Clay Formation is clearly seen (Cox and Sumbler, 2002, pp. 333-336; Page, 1989; Rawson and Wright, 2000; Wright, J K, 1968b, 1978).

Type area

None designated

Reference section(s)

Red Cliff [TA 076 840] at the south-east end of Cayton Bay, North Yorkshire exposes the Redcliff Rock Member, which comprises red-brown, fine-grained sandstone with abundant chamosite (berthierine) ooids; spheroidal carbonate concretions are present in the lower part; bivalves and occasional ammonites (including *Kepplerites*) are present. The boundary with the underlying Cayton Clay Formation is generally obscured by fallen blocks. At Red Cliff the Langdale Member is absent due to penecontemporaneous erosion (Wright, J K, 1968b). Consequently, the overlying Hackness Rock Member rests disconformably on the Redcliff Rock Member. The Hackness Rock Member comprises grey-brown, bioturbated limestone, 1–2 m thick, with abundant chamosite (berthierine) ooids; it has yielded the ammonites *Quenstedtoceras* and *Kosmoceras* (Rawson and Wright, 2000). The conformable boundary with the grey-green, silty mudstone of the overlying Oxford Clay can be seen in the cliff face (Wright, J K, 1968b, pp.371-372).

Formal subdivisions

Hackness Rock Member (HACR) (Wright, J K, 1968b, 1978)
Langdale Member (LANG) (Wright, J K, 1968b)
Redcliff Rock Member (RDCR) (Page, 1989)

Lithology

Sandstone, calcareous, and poorly lithified sand; generally massive bedded, greenish-grey, weathering at outcrop to yellow-brown, fine- to medium-grained, with beds of berthierine (chamosite) ooids, calcareous siltstone and thin limestone. Sandstone beds are generally highly bioturbated with horizontal and vertical burrows

Lithogenetic description

Shallow-marine shoreface to prodelta lithofacies

Landform description

Inland, the Osgodby Formation generally forms a positive topographical feature above the Scalby Formation mudstone, Cornbrash Formation and Cayton Clay Formation (where the last two named are present), and below negative topographical feature of the softer Oxford Clay Formation. On the Yorkshire coast the Osgodby Formation generally forms a small cliff.

Definition of upper boundary

Generally a fairly sharp, but conformable junction between the yellow-brown sandstone of the Osgodby Formation (Hackness Rock Member) and the green-grey silicate-mudstone (locally with occasional berthierine ooids) of the overlying Oxford Clay Formation. Locally in the Hambleton Hills, the Oxford Clay Formation and upper part of the Osgodby Formation are absent so that the Lower Calcareous Grit Formation (Oldstead Oolite Member) rests unconformably on the Osgodby Formation (Redcliff Rock Member) (Powell, 2010; Powell et al., 1992; Wright, J K, 1983)

Definition of lower boundary

Gradational, conformable boundary where the soft grey mudstone of the underlying Cayton Clay Formation passes gradationally up to the pale yellow, clayey sandstone of the overlying Osgodby Formation (Redcliff Rock Member). Where the Cayton Clay Formation and the underlying Cornbrash Formation are absent in the Hambleton Hills (in the west of the Cleveland Basin) the Osgodby Formation rests unconformably on nonmarine mudstone or sandstone of the Scalby Formation.

Thickness

Up to 28.5 m on the North Yorkshire coast (Rawson and Wright, 2000; Wright, J K, 1968b, 1978); thins to about 20 m in the Hambleton Hills (Powell et al., 1992)

Distribution

Cleveland Basin, North Yorkshire, north of the Market Weighton High

Supplementary information

Three members are present. In upward succession these are: the Redcliff Rock, Langdale and Hackness Rock. The Redcliff Rock Member (Page, 1989) (formerly the Kellaways Rock Member of Wright, J K, 1968a; Wright, J K, 1968b, 1978) [type section Red Cliff [TA 076 840], Cayton Bay, North Yorkshire (Wright, J K, 1968b, pp. 371-72) comprises up to 11.5 m of pale yellow, massive bedded, bioturbated fine-to medium-grained sandstone with occasional calcareous concretions and beds of brown weathering sandstone with berthierine (chamosite) ooids. Ammonites indicate a Koenigi Zone age (Page, 1989). The overlying Langdale Member (Wright, J K, 1968b) comprises up to 15 m of massive bedded, silty sandstone, laminated and bioturbated, in part; ripple cross-lamination is present. Ammonites indicate a Coronatum Zone age (Page, 1989). The uppermost member, the Hackness Rock Member (Wright, J K, 1968b, 1978) comprises up to 2 m of grey marl and siltstone and sandstone passing up to pale bluish grey limestone (weathering pale brown) with beds of berthierine (chamosite)-rich ooids, commonly bioturbated with small horizontal and vertical burrows; ammonites include *Kosmoceras spinosum*, *Quenstedtoceras* spp. and *Reineckeia* (*Collotia*) sp. indicate an age ranging from latest Athleta Zone to Lamberti Zone (Wright, J K, 1968b).

Previous names

Kellaways Rock (Fox-Strangways, 1892; Phillips, 1829). Former general term for Callovian sandstone and sands in the Cleveland Basin.

Kellaways Rock Member (Wright, J K, 1978). Formal name proposed by Wright (1978) to distinguish the Callovian sandstone succession in the Cleveland Basin from that south of the Market Weighton High.

Parent

Age

Callovian; Koenigi to Lamberti zones (Rawson and Wright, 2000)

References

Principal reference (Wright, J K, 1968b)

Additional reference (Wright, J K, 1968a)

7 Moray Firth Basin (onshore)

In contrast with western Scotland, the onshore outcrops of Middle Jurassic strata around the Moray Firth are small and poorly exposed. However their continuation into the thicker offshore sequence is very well known, as a consequence of the latter's importance to the North Sea oil industry, resulting in much investigation through geophysical surveys and cored boreholes (see Chapter 9).

Interest in the geology of the Jurassic of the Moray Firth originates from the discovery of coal at the end of the sixteenth century and its early exploitation which continued somewhat intermittently into the late twentieth century (see Trewin and Hurst, 1993, p.33). Consequently the area was visited by many Victorian geologists, and early accounts of the geology include those of Sir Roderick Murchison (1829a, b) and J W Judd (1873). After some studies by H B Woodward (1905), Geological Survey activity was led notably by G W Lee (1925; Lee and Pringle, 1932) who coined a large number of stratal names – unfortunately many bearing the geographical epithet 'Brora'. With the emergence of the North Sea oil industry in the 1970s, research was renewed into the strata exposed onshore that were deemed to be equivalent to the offshore rocks with reservoir potential. Lithostratigraphical schemes were published for the Bathonian by Hurst (1981) and the Callovian to Oxfordian by Sykes (1975), largely formalising the nomenclature of Lee (1925) but complying with modern practise in setting out full definitions. Neves and Selley (1975) followed Sykes' scheme and also described the underlying Lower and overlying Upper Jurassic successions. The district was described and sections figured in an excursion guide by Trewin and Hurst (1993). Subsequently, BGS republished the two 1:50 000 scale maps, Helmsdale (S 103E) and Golspie (S 103W), that cover the Brora area (British Geological Survey, 1998b, 2002c), introducing two new formation names for the Middle Jurassic succession.

The current review of the lithostratigraphy of the region has identified a number of problems:

- The same place name (i.e. 'Brora') appears in the names of three adjacent formations (the place name also appears in the names of a number of the minor units), against the recommendations of current stratigraphical procedure (Rawson et al., 2002, p. 6) .
- The terms 'argillaceous' and 'arenaceous' are outmoded.
- In republishing the geological maps of the Brora area, BGS found that the mapped boundaries did not coincide with Sykes' formations and erected a new (workable) scheme. However, this ignored a formation that is mappable onshore and recognised offshore.
- At Balintore, the Brora Argillaceous, Brora Arenaceous, and old Balintore formations are not satisfactory. For example the boundary between the Brora Argillaceous and Brora Arenaceous formations lies within a sequence of sandy siltstone.
- The successions at Brora and Balintore (now over 30 km apart) are significantly different, each comprising several satisfactory locally defined members. Generally above the Brora Coal Formation they cannot be directly correlated. The only Callovian–Oxfordian unit recognised in both areas is the Brora Roof Bed.

In view of the above, we propose that:

- The Brora Coal Formation is retained, and includes the well known Brora Coal seam.
- The Brora Shale (including the Brora Roof Bed), Glauconitic Sandstone and Brora Brick Clay members, all of Sykes (1975), constitute the new **Strathsteven Mudstone Formation**. This is a mudstone-dominated, generally coarsening-upwards succession. Its

base was proved in a coal shaft at Strathsteven, which place name is unused in other stratigraphical terms. It is restricted to the Brora area.

The Fascally Siltstone, Fascally Sandstone, Clynelish Quarry Sandstone, Brora Sandstone and Ardassie Limestone members, all of Sykes (1975), and the overlying sandstone unit up to the base of the Helmsdale Boulder Beds (regarded as the Clynekirkton Sandstone Member of the Balintore Formation by Wright and Cox, 2001, p. 192) constitute the **Clynekirkton Sandstone Formation**. This term was used on the recently published BGS maps of the area: Helmsdale (S 103E) and Golspie (S 103W) (British Geological Survey, 1998b, 2002c). The formation is sandstone-dominated, and generally coarsens upwards. It is restricted to the Brora area.

The much thinner Callovian–Oxfordian succession above the retained Brora Coal Formation at Balintore should be in a single formation. Hence, the Cadh'-an-Righ, Shandwick Clay, Shandwick Siltstone, Port-an-Righ Ironstone, and Port-an-Righ Siltstone members together constitute the (expanded) **Balintore Formation**.

We consider this scheme (Table 8) to be pragmatic and workable.

	Stage	Former formational nomenclature (BRORA and BALINTORE)	Proposed formational nomenclature		GROUP
			BRORA	BALINTORE	
MIDDLE JURASSIC (part)	Oxfordian	BALINTORE	CLYNEKIRKTON SANDSTONE	BALINTORE	SUTHERLAND (part)
		BRORA ARENACEOUS			
	Callovian	BRORA ARGILLACEOUS	STRATHSTEVEN MUDSTONE		
		BRORA COAL	BRORA COAL	BRORA COAL	
	Bathonian	----- ? -----	----- ? -----	----- ? -----	

Table 8 Lithostratigraphy of the Middle Jurassic strata of the Moray Firth (onshore) to formation level.

7.1 SUTHERLAND GROUP (SUTH)

Name

See Chapter 4. Named after the former county of Sutherland in north-east Scotland, formally proposed herein.

Type section

Coastal section, at high water mark from Dunrobin Pier 2 km east-north-east of Golspie to Ord Point 4 km east-north-east of Helmsdale, a distance of 27 km. Exposes highly discontinuous section including incomplete Dunrobin Bay, Brora Coal, Strathsteven Mudstone, Clynekirkton Sandstone and Helmsdale Boulder Beds formations [NC 851 005 – ND 062 175] (Batten et al., 1986; Hurst, 1981; Sykes, 1975; Wright, J K and Cox, 2001)

Type area

Onshore Moray Firth coastal area.

Reference section(s)

Lossiemouth No. 4 Borehole (NJ26NW4) [NJ 2157 6985] from 12.8 m to 82.3 m (terminal depth). Sequence of sandstone and mudstone, calcareous in part, thought to be all Sinemurian (Berridge and Ivimey-Cook, 1967)

Formal subdivisions

Helmsdale Boulder Beds Formation* (HBB) (Lee, 1925)
Balintore Formation (BALR) defined herein
Clynekirkton Sandstone Formation (CYK) defined herein
StrathSteven Mudstone Formation (SSTV) defined herein
Brora Coal Formation (BOCO) (Neves and Selley, 1975)
Dunrobin Bay Formation** (DRB) (Batten et al., 1986)

* entirely Upper Jurassic

** entirely Lower Jurassic

Lithology

Sequence of predominantly mudstone, siltstone and sandstone, with common shelly fauna at many levels, variously calcareous, carbonaceous, bituminous, with thin sandy limestone beds, ironstone beds, thin coal seams, a basal conglomerate and boulder beds towards the top.

Lithogenetic description

Generally shallow marine with periodic and significant terrigenous sediment input and transient paralic conditions. Significant fault-influenced nearshore coarse clastic deposition in late Jurassic times.

Landform description

None

Definition of upper boundary

Top of the interbedded boulder beds, sandstone and mudstone beds of the Helmsdale Boulder Beds Formation, not at outcrop onshore. Overlying bedrock formation is unknown.

Definition of lower boundary

Unconformity: nodular carbonate rock of the Stotfield Cherty Rock Formation (Triassic) overlain by interbedded conglomerate and sandstone of the Dunrobin Pier Conglomerate Member of the Dunrobin Bay Formation

Thickness

At least 1400 m.

Distribution

Coastal strips of Moray Firth, north-east Scotland, from Golspie to Helmsdale, near Balintore, near Lossiemouth. Correlates offshore in the Inner Moray Firth with the combined Dunrobin Bay and Fladen groups and the Heather and Kimmeridge Clay formations (Hudson and Trewin, 2002, fig. 11.7)

Previous names

None

Age

?Hettangian to Tithonian

References

As above.

Brora district formations

7.1.1 Brora Coal Formation (BOCO)

Name

Named as formal formation after the town of Brora, Sutherland by Neves and Selley (1975) .

Type section

Foreshore south of the River Brora estuary, Sutherland, between the Brora Fault and the railway, and the sea (Hurst, 1981, fig. 1). The Brora Coal Formation on the foreshore has subdued relief, is submerged at high tide and is partially covered by erratic boulders. However it is fully exposed and the top of the formation is easily located because the immediately overlying Brora Roof Bed forms prominent outcrops on the foreshore. Hurst (1981, fig. 1) illustrated four west–east transects through the formation in the type area, [NC 900 030] (Hurst, 1981; Neves and Selley, 1975).

Type area

Brora area, Sutherland, Scotland.

Reference section(s)

None

Formal subdivisions

Brora Coal Bed
Inverbrora Member (Hurst, 1981)
Doll Member (Hurst, 1981)

Lithology

Sandstone, medium-grained, white, soft, pure quartz, massive and cross-bedded, cross-laminated and parallel laminated, up to 20 m thick (Doll Sandstone Unit (= Bed) of Hurst (1981), overlain by over 30 m of grey shaly mudstone with thin interbedded sideritic mudstone beds (‘cementstones’ of early usage) that are laterally extensive; together these two units constitute the Doll Member. Its top is marked by a prominent brecciated siderite-cemented mudstone horizon (Bed 1 of Hurst, 1981). Overlying Bed 1 are about 15 m of grey and black, laminated, bituminous fissile mudstones, some of which approach oil shale composition. Two coals are developed in this succession (the Inverbrora Member), including a thin coal developed about 8 m below the top of the formation and a prominent seam, 1 m thick, forming the uppermost bed and termed the Brora Coal (Bed). Biota is relatively sparse and comprises bivalves, plant debris and fish scales. Two bivalve-rich beds, largely comprising *Isognomon* and *Neomiodon*, are present between 3 and 4 m below the top of the formation and these beds were interpreted as a maximum flooding surface by Stephen and Davies (1998).

Lithogenetic description

The Doll Member was interpreted as representing an alluvial plain by Hurst (1981). The overlying Inverbrora Member was considered to represent a phase of fluvial abandonment, stagnating into a delta swamp (Hurst, 1981) with a stratified water column and anoxic bottom conditions. The presence of *Isognomon* represents the first indications of sporadic marine influence in this unit (Hudson, 1962a). The intermittently marine nature of the uppermost part of the formation was confirmed by the presence of marine palynomorphs (MacLennan and Trewin, 1989; Riding, 2005). The drifted Brora Coal (Bed) represents a phase of clastic starvation, and its top was interpreted as a combined transgressive surface/sequence boundary by Stephen and Davies (1998).

Landform description

The formation, including the Doll Member has subdued relief.

Definition of upper boundary

Onshore, the boundary with the overlying unit is sharp and planar and although apparently conformable is probably erosional. The Brora Coal is overlain by the transgressive, intensely bioturbated medium-grained sandstone of the Brora Roof Bed, which is the lowermost bed of the Brora Shale Member (StrathSteven Mudstone Formation) at Brora, or of the Cadh'-an-Righ Shale Member (Balintore Formation) at Balintore.

Offshore, the boundary with the overlying Beatrice Formation is a sharp, planar junction between a coal-bearing mudstone or coal, which is equivalent to the Brora Coal (Bed), and the fine- to medium-grained sandstones of the Beatrice Formation (Richards et al., 1993, p. 78).

Definition of lower boundary

The base of the Brora Coal Formation is not exposed onshore. The putative contact is thought to be a sharp unconformable contact between the grey mudstones of the Lady's Walk Shale Member (Dunrobin Bay Formation; Lower Jurassic, Hettangian to Pliensbachian) and the white medium sandstone of the Doll Sandstone Unit of the Doll Member.

Offshore in the Great Glen Sub-basin in the western part of the Inner Moray Firth, the Brora Coal Formation overlies the Orrin Formation (Table 10). Richards et al. (1993, p. 79) illustrated the boundary between the fine- to medium-grained sandstones of the Orrin Formation, and the interbedded sandstones and mudstones of the Brora Coal Formation as unconformable. However, in well 11/25-1, this boundary is gradational and is marked by a transitional passage from the massive sandstones of the Orrin Formation to the interbedded mudstones and sandstones with sporadic coaly horizons of the Brora Coal Formation (Richards et al., 1993, p. 78). Further offshore the Brora Coal Formation is partially or entirely absent due to erosion (Andrews, I J et al., 1990, figs. 27, 28), and in some wells the Brora Coal (Bed) directly overlies the Orrin Formation (Richards et al., 1993, panel 8).

Thickness

Onshore, at the type section, Hurst (1981) reported a thickness of at least 65 m. This contrasts with at least 31.5 m reported by Neves and Selley (1975). A significant part of the Doll Member forms approximately half the thickness of the section at a foreshore outcrop [NC 893 025] 400 m north-east of Sputie Burn (Hurst, 1981, p. 174). South of Brora at Balintore [NH 851 728], the Brora Coal Bed is significantly thinner than at Brora, where it is only 20 cm thick. The total thickness of the underlying Brora Coal Formation at Balintore is unknown because the base is not exposed. Approximately 3 m of the Inverbrora Member have been observed and Judd (1873) reported at least 8 m.

Offshore, in the western part of the Inner Moray Firth Basin, the Brora Coal Formation is significantly thicker than observed onshore; for example, in offshore wells 11/25-1, 11/30a-9 and 12/21-3, it is 116, 183 and 113 m thick respectively (Richards et al., 1993, p. 79).

Distribution

The Brora Coal Formation is confined to the Moray Firth area, north-east Scotland. Onshore, it forms an outcrop, bounded to the north-west by a fault, along a coastal strip from the type section [NC 900 030], south of the River Brora estuary, and further south-west along the foreshore, to a point [NC 893 025] 400 m north of Sputie Burn (Hurst, 1981, fig. 1), and is thought to continue at depth through to StrathSteven [NC 88 01]. It is also at depth north-west of the fault in the Brora area. It crops out on the foreshore south of Balintore [NH 849 723 to 857 739]. This is a narrow sliver, between the Great Glen Fault Zone offshore to the east and a parallel fault in the cliffs to the west (Riding, 2005, fig. 1).

Offshore it is present in the western part of the Inner Moray Firth Basin, where it thins rapidly toward the east (Andrews et al., 1990, figs. 27, 28).

Previous names

Estuarine Series of Lee (1925)

Age

Bathonian to Callovian. See also (Richards et al., 1993).

References

Principal reference (Neves and Selley, 1975)

See also (Trewin and Hurst, 1993).

7.1.2 StrathSteven Mudstone Formation (SSTV)

Name

Formerly part of the Brora Argillaceous Formation (Brora Roof Bed to Brora Brick Clay Member at Brora) of Sykes (1975). Defined herein. Named after StrathSteven village on Moray Firth coast near Brora.

Type section

The type section is a composite of the foreshore south of the River Brora estuary and the cliffs of the River Brora. The type section of the Brora Shale Member is the foreshore [NC 904 031] south of the River Brora estuary, to the east of Inverbrora Farm [NC 893 034]. The stratotype of the Glauconitic Sandstone Member is in the cliffs in the north bank of the River Brora [NC 889 040]. The type sections of the Brora Brick Clay Member are at the west end of cliffs of the River Brora [NC 887 038], and on the foreshore [NC 907 032] south of the mouth of the River Brora, (Sykes (1975) as modified herein; British Geological Survey, 1998b; Trewin and Hurst, 1993).

Type area

Brora area, Sutherland, Scotland.

Reference section(s)

Brick pit section [NC 897 040] near the village of Brora, exposes middle to upper part of the Brora Brick Clay Member, (Sykes, 1975).

Shaft for coal [NC 8831 0185] at StrathSteven exposes Brora Roof Bed near the surface, overlying Brora Coal (Lee, 1925, p.79)

Formal subdivisions

Brora Brick Clay Member (BROBC) (Arkell, 1933; Sykes, 1975).
Glauconitic Sandstone Member (GLCSA) (Sykes, 1975).
Brora Shale Member (BROR) (Arkell, 1933; Sykes, 1975), including Brora Roof Bed (BRORO).

Lithology

Mudstone and siltstone, generally bituminous with significant subordinate units of silty sandstone, commonly muddy and glauconitic. At Brora, the overall thickness is about 55 m. The lowermost unit is the Brora Roof Bed – up to 2.3 m of bioturbated, shelly medium-grained sandstone with scattered quartzite pebbles and coal fragments. It is overlain by about 2.3 m of silty sand grading up into about 25 m of bituminous fissile mudstone with thin interbedded glauconitic sandstone beds. This is the Brora Shale Bed that, together with the Brora Roof Bed, makes up the Brora Shale Member (Arkell, 1933; Sykes, 1975). This is overlain by 10.1 m of coarsening-upwards glauconitic muddy and silty sandstones with a siltstone interbed – the Glauconitic Sandstone Member (Sykes,

1975), overlain by 15 m of bituminous sandy siltstone with mudstone intercalations; five fining-upwards cycles have been recognised – the Brora Brick Clay Member (Arkell, 1933; Sykes, 1975). The formation yields marine biota and marine microfossils throughout. The macrofauna is dominated by ammonites, belemnites, bivalves, brachiopods and gastropods (Cox and Sumbler, 2002, p 374), and dinoflagellate cysts are abundant and diverse (Riding, 2005). The sequence stratigraphy of the formation was interpreted by Stephen and Davies (1998).

Lithogenetic description

Persistent open marine deposition with some phases of mild seabed anoxia represented by the bituminous mudstone.

Landform description

Unknown.

Definition of upper boundary

The upper boundary is defined by a change up from the bituminous sandy siltstone with mudstone intercalations of the Brora Brick Clay Member to the coarse siltstone to silty fine-grained sandstone of the Fascally Siltstone Member of the Clynekirkton Sandstone Formation. The boundary is conformable.

Definition of lower boundary

The formation overlies the Brora Coal (Bed) of the Brora Coal Formation. The boundary is marked by a sharp planar lithological change where bioturbated medium-grained sandstone (the Brora Roof Bed) rests on the Brora Coal. The boundary appears to be erosional.

Thickness

At the type section at Brora, the thickness of the formation is about 55 m.

Distribution

The StrathSteven Mudstone Formation is confined to the onshore Moray Firth area, north-east Scotland. It is present in the coastal strip around Brora, up to the Brora–Helmsdale Fault, at outcrop and at depth.

It correlates offshore in the Inner Moray Firth with the lower part of the Beatrice Formation of the Fladen Group (Richards et al., 1993)

Previous names

Part of Brora Argillaceous Series of Lee and Pringle (1932, p. 202).

Part of Brora Argillaceous Formation (BRARG) of Sykes (1975).

Age

Callovian: Koenigi Zone to Athleta Zone.

References

Defined herein.

7.1.3 Clynekirkton Sandstone Formation (CYK)

Name

A new formation published on BGS maps of the area (British Geological Survey, 1998b, 2002c), and defined herein to include Fascally Siltstone, Fascally Sandstone, Clynelish Quarry Sandstone, Brora Sandstone and Ardassie Limestone members, all of Sykes (1975), and the overlying sandstone unit up to the base of the Helmsdale Boulder Beds (regarded as the Clynekirkton

Sandstone Member of the Balintore Formation by Wright and Cox, 2001, p. 192). Named after a settlement north of Brora.

Type section

The type section of the Clynekirkton Sandstone Formation is a composite one in the foreshore south of Brora and in cliff sections on the south bank of the River Brora. The foreshore [NC 909 031] south of the River Brora estuary includes the type section of the Fascally Siltstone Member (Sykes, 1975). The type section of the Fascally Sandstone Member is on the north bank of the River Brora [NC 899 040]. The Clynelish Quarry Sandstone Member was named after Clynelish Quarry [NC 893 045], however the stratotype is in cliffs on the south bank of the River Brora: the lower part is 800 m west-south-west of the A9 road bridge [NC 898 038] and the upper part is 250 m downstream opposite the disused Brora colliery [NC 899 039] (Trewin and Hurst, 1993, localities 4 and 5, with amendments).

The type section of the Brora Sandstone Member is composite. The majority of the section is in the cliffs on the south bank of the River Brora [NC 905 039], with the uppermost beds exposed south of Ardassie Point. The base of the section is 540 m west of the A9 road bridge, running eastwards to the fault, 140 m east of the bridge. From the fault, there is a gap in the exposure until the uppermost beds are seen on the foreshore south of Ardassie Point [NC 911 038 to 913 041] overlain here by the Ardassie Limestone Member at its type section. There is no type section for the Clynekirkton Sandstone Member but it was reported exposed near Clynekirkton church [NC 8940 0616] by Lee (1925, pp 96, 99) (Cox and Sumblar, 2002; Trewin and Hurst, 1993).

Type area

Brora area, Sutherland, Scotland.

Reference section(s)

None.

Formal subdivisions

Clynekirkton Sandstone Member (Wright, J K and Cox, 2001, p. 192)
Ardassie Limestone Member (Sykes, 1975).
Brora Sandstone Member (Sykes, 1975).
Clynelish Quarry Sandstone Member (Sykes, 1975).
Fascally Sandstone Member (Sykes, 1975).
Fascally Siltstone Member (FCYSI) (Sykes, 1975).

Lithology

Sandstone, variably cemented, sandy siltstone, and sand. Some carbonaceous or calcareous beds and minor amounts of sandy limestone. Lower part has a rich marine shelly fauna.

At Brora, the overall thickness is at least 500 m. The lowermost Fascally Siltstone Member comprises 33.5 m of coarse siltstone, passing upwards into silty, fine-grained sandstone. It is overlain by 6.5 m of intensely bioturbated fine-grained muddy sandstone in several fining-upward cycles, rich in ammonites and bivalves, the Fascally Sandstone Member, that culminate in a massive sandy siltstone. Above are about 20 m of friable, fine-grained yellow sand with occasional carbonaceous debris, forming the Clynelish Quarry Sandstone Member, in which cemented sandstone with horizons of nodular silicified sandstone, flame structures and a rich fauna of ammonites and bivalves are locally seen. The overlying Brora Sandstone Member is at least 30 m of fine-grained friable sandstone with trough cross bedding and some lenticular quartz conglomerates.

This is overlain by the Ardassie Limestone Member comprising at least 12 m of interbedded muddy carbonaceous sandstone and sandy limestone beds 0.3 to 1.1 m thick. Younger strata are present in boreholes to the north of Brora, and comprise about 400 m of pale grey, calcareous and silica-cemented sandstones with rare pebbles and subordinate shelly siltstones and mudstones or carbonaceous beds (Lee, 1925). These beds are not well known at outcrop and have been assigned to the Clynekirkton Sandstone Formation by BGS (1998b), but there was no formal description given, nor type/reference sections proposed.

The formation yields marine biota and microfossils throughout the beds up to the top of the Ardassie Limestone. The macrofauna is dominated by ammonites and bivalves; dinoflagellate cysts are abundant in the Fascally Sandstone Member (Riding, 2005). The beds overlying the Ardassie Limestone are of inferred mid and late Oxfordian (possibly earliest Kimmeridgian) age. The sequence stratigraphy of this formation was interpreted by Stephen and Davies (1998).

Lithogenetic description

The formation represents shallow open marine deposition with substantial periodic terrigenous sediment and organic material input from nearby land areas to the west.

Landform description

Unknown.

Definition of upper boundary

Change up (not exposed) from sandstone to matrix-supported conglomerate of cobbles and boulders of sandstone, interbedded with laminated siltstone and sandstone (Kintradwell Boulder Beds Member of the Helmsdale Boulder Beds Formation, and Allt na Cuile Sandstone [Formation]) (Wright, J K and Cox, 2001, fig. 5.2)

Definition of lower boundary

The lower boundary is defined by a change up from the bituminous sandy siltstone with mudstone intercalations of the Brora Brick Clay Member of the Strathsteven Mudstone Formation to the coarse siltstone to silty fine-grained sandstone of the Fascally Siltstone Member. The boundary is conformable.

Thickness

At the composite type section at Brora, the aggregated thickness of the exposed, lower part of the formation is at least 102 m, with an estimated additional 400 m of unexposed strata above.

Distribution

The Clynekirkton Sandstone Formation is confined to the onshore area around Brora, on the Moray Firth, north-east Scotland. It is exposed on the foreshore around the River Brora estuary and in the cliffs bordering the River Brora. Its outcrop extends inland up to the Brora–Helmsdale Fault.

It correlates offshore in the Inner Moray Firth with the upper part of the Beatrice Formation of the Fladen Group, plus at least part of the Heather Formation of the Humber Group (Richards et al., 1993).

Previous names

Upper part (Fascally Siltstone Member) of Brora Argillaceous Formation (BRARG) (= Series of Lee, 1925, p.86), plus Brora Arenaceous Formation (BRARE) (= Series of Lee and Pringle, 1932, p.202), plus overlying Ardassie Limestone Member of Balintore Formation, all of Sykes (1975).

This unit was considered to be a member of the Balintore Formation of Sykes (1975) by Wright and Cox (2001).

Age

Callovian-?Kimmeridgian.

References

References as above.

Balintore district formations

7.1.4 Brora Coal Formation (BOCO)

See Section 7.1.1.

7.1.5 Balintore Formation (BALR)

Name

Substantial redefinition herein of Sykes (1975, p. 58, 59; 60–62). Named after Balintore village on Moray Firth coast.

Type section

The type section of the Balintore Formation is entirely on the foreshore at Cadh'-an-Righ and Port-an-Righ [NH 849 723 to 853 733]. This exposes the formation continuously from the base upwards to the uppermost beds seen before they dip into the sea (Cox and Sumbler, 2002, pp. 376-379; Sykes, 1975; Wright, J K and Cox, 2001, pp. 188-190).

Type area

Balintore area, Ross and Cromarty, Scotland.

Reference section(s)

Bow Buoy Skerry [NH 7696 6214], near Eathie, Ross and Cromarty. Exposes, only at low tide, about 30 m of shelly bioturbated very fine-grained sandstone beds, dipping at 70° to south-east, base and top of formation not exposed (Sykes, 1975).

Formal subdivisions

Port-an-Righ Siltstone Member (Arkell, 1933; Sykes, 1975).
Port-an-Righ Ironstone Member (Buckman, S S, 1923; Sykes, 1975)
Shandwick Siltstone Member (SWKSI) (Arkell, 1933; Sykes, 1975).
Shandwick Clay Member (Sykes, 1975).
Cadh'-an-Righ Shale Member (CARSH) (Sykes, 1975)

Lithology

The Balintore Formation is dominated by moderately to richly fossiliferous sandstone, sand and sandy siltstone (variously calcareous or glauconitic), and mudstone, bituminous in parts. The formation is about 68 m thick at Balintore. The lowermost unit, the Cadh'-an-Righ Shale Member, is 4.2 m of sparsely fossiliferous bituminous fissile mudstone, with interbedded thin glauconitic siltstone, and includes the 0.5 m-thick bioturbated sandstone of the Brora Roof Bed at the base. The overlying Shandwick Clay Member is about 28 m thick: the lower 24 m are bioturbated grey-green clay with layers of limestone nodules at the base, and the uppermost 4.1 m comprises sandy siltstone. Above is the Shandwick Siltstone Member – 12.1 m of fossiliferous siltstone, with alternating beds that are more or less calcareous. Overlying it is the Port-an-Righ Ironstone Member (Buckman, S S, 1923) comprising 2.2 m of muddy, glauconitic sand with interbedded bands of red-weathering nodular glauconitic limestone, all rich in ammonites. The overlying Port-an-Righ Siltstone Member is 21.7 m thick, and largely consists of relatively sparsely fossiliferous

bituminous coarse silt. This unit comprises thin (0.1 to 1.8 m) rhythmic units that coarsen upwards from carbonaceous shale or silt, to fine-grained muddy sandstone. The uppermost bed is 5.7 m of fine-grained muddy sandstone. There is strong evidence that there are fine-grained beds above the Port-an-Righ Siltstone Member that are not exposed onshore (Sykes, 1975, p. 62).

The Balintore Formation yields marine biota and marine microfossils throughout. The macrofauna is dominated by ammonites and bivalves, with belemnites, brachiopods and gastropods, and dinoflagellate cysts are generally abundant and diverse (Riding, 2005).

Lithogenetic description

The Balintore Formation represents consistent open marine deposition with some phases of mild seabed anoxia represented by the bituminous shale.

Landform description

The lithologically contrasting beds result in prominent ridges at some levels in the foreshore outcrops.

Definition of upper boundary

The upper boundary of the Balintore Formation at Balintore is not exposed. The Port-an-Righ Siltstone Member is the youngest unit seen, and the uppermost beds dip off into deep water at low tide. Limestone nodules with Early Oxfordian ammonites are found on the foreshore, and Sykes (1975, p. 62) inferred the probable presence of a relatively soft, claystone-dominated succession. It may be present in offshore boreholes (MacLennan and Trewin, 1989).

Definition of lower boundary

The lower boundary is a sharp non-sequential change up from the Brora Coal (Bed) of the Brora Coal Formation to bioturbated medium-grained sandstone of the Brora Roof Bed of the Cadh'-an-Righ Shale Member (MacLennan and Trewin, 1989)

Thickness

At the type section at Balintore, the thickness of this formation is about 68 m although the top is unseen. At Bow Buoy Skerry, about 30 m of strata are exposed, base and top unseen.

Distribution

The Balintore Formation is confined to the onshore Moray Firth area, north-east Scotland forming a narrow strip along the coast at Port-an-Righ, Balintore, and an outcrop exposed only at low tide near Eathie. Both are bounded to the west by a fault parallel to the Great Glen Fault Zone, which lies close offshore to the east.

It correlates offshore in the Inner Moray Firth with the lower part of the Beatrice Formation of the Fladen Group (Richards et al., 1993)

Previous names

Brora Argillaceous Formation plus Brora Arenaceous Formation plus Balintore Formation (at Balintore) of Sykes (1975).

Age

Callovian–Oxfordian: Koenigi Zone to Tenuiserratum Zone or younger.

References

Defined herein.

8 Hebrides Basin

As stated above (Chapter 4), the study of the stratigraphy of the Middle Jurassic of the Hebrides has a long history, and early nomenclature generally referred to or inferred (but in some cases erroneous) correlations with units in England, based on macrofossil content or conspicuous physical characteristics, and sometimes qualified by relative position in the sequence. These terms were generally adopted and refined by the Geological Survey for the primary geological survey of the islands which was undertaken in the 1890s (SW and parts of north-east Skye and Raasay) (Lee, 1920; Peach et al., 1910), 1900s (Eigg and Muck) (Harker, A, 1908), 1920s (Mull and Ardnamurchan) (Richey and Thomas, 1930) and 1930s (northern Skye) (Anderson and Dunham, 1966).

Since the 1960s, formal names conforming to modern stratigraphical conventions have been applied to the entire succession. Foremost in the study and classification of the succession have been Morton, Hudson, Harris and Sykes (see especially Harris and Hudson, 1980; Hudson, 1962b; Hudson and Harris, 1979; Morton, 1965, 1976; Morton and Hudson, 1964). Thorough accounts of the history of research are given by Hudson (1962b) and Cox and Sumblar (2002). Although no systematic resurvey of the region has taken place, several new and revised BGS 1:50 000 scale sheets, a memoir and a British Regional Guide have been published employing the later nomenclature and confirming the essential mappability of the formations (British Geological Survey, 1994a, 2002a, 2006a, b, c, 2007) (Emeleus, 1997; Emaleus and Bell, 2005).

Subdivisions within the Great Estuarine Group ('Series') were recognised early on (see Anderson and Dunham, 1966) and generally named by reference to inferred correlations with units in England, macrofossil content or conspicuous physical characteristics, sometimes qualified by relative position in the sequence. A full revision of the scheme was undertaken by Harris and Hudson (1980) conforming to modern stratigraphical practices.

	Stage / Substage	FORMATION	GROUP
MIDDLE JURASSIC	Lower Oxfordian		
	Upper Callovian	STAFFIN SHALE (part)	
	Middle Callovian		
	Lower Callovian	STAFFIN BAY	
		?	
	Upper Bathonian	SKUDIBURGH	GREAT ESTUARINE
		KILMALUAG	
		DUNTULM	
	Middle Bathonian	VALTOS SANDSTONE	
		LEALT SHALE	
	Lower Bathonian	ELGOL SANDSTONE	
	Upper Bajocian	CULLAIDH SHALE	
	Lower Bajocian		
	Aalenian	BEARRERAIG SANDSTONE	
	Toarcian		

Table 9 Lithostratigraphy of the Middle Jurassic strata of the Hebrides Basin to formation level.

8.1 STAND-ALONE FORMATION BENEATH THE GREAT ESTUARINE GROUP

8.1.1 Bearreraig Sandstone Formation (BEAS)

The formation contains the thickest sandstone in the British Jurassic (Cox and Sumblar, 2002), and despite the separation of the outcrops on several islands and by igneous rocks, the formation is recognised across the basin, with well-documented successions differing in detail, notably in Trotternish and Strathaird on Skye and on Raasay (Figure 7). From its relatively rich marine fauna it is known to range from uppermost Toarcian to Upper Bajocian (Morton, 1965). This interval overlaps to a very large extent with that of the English Inferior Oolite Group and as a result this stratal interval was termed ‘Inferior Oolite’ by early workers (e.g. Arkell, 1933), even up to the 1960s, although by then several subdivisions with local names had been recognised (Anderson and Dunham, 1966, p. 12). Even allowing for its usage as an essentially chronostratigraphical term, the name ‘Inferior Oolite’ was inappropriate and highly misleading, and Morton and Hudson (1964) proposed the term ‘Bearreraig Sandstone Series’, using a local place name from the type section and a lithological epithet. They also distinguished several subdivisions and local variants (Morton, 1965; Morton and Hudson, 1964) with mainly different (informal) names from Anderson and Dunham. Morton later (1976) revised the name to Bearreraig Sandstone Formation, at the same time formalising nine of the subdivisions as members, mainly using the geographical/lithological combinations of Anderson and Dunham (1966). Six of these are recognised at the type section in Trotternish, although none have proved separately mappable hereabouts. Of these only the youngest, Garantiana Clay (now Garantiana Mudstone Member) is also known from Raasay and Strathaird. In Strathaird the formation includes a single locally named member (the Druim An Fhurain Sandstone) beneath the

Garantiana Mudstone. This name was later also adopted by BGS (British Geological Survey, 2006b) on Raasay where the five members seen include two given local names.

The formation has no parent group. A case might be made for redefining the Berreraig Sandstone as a group with some or all of the members as formations, but in the interests of nomenclature stability this is not proposed.

Name

Named after type section at Berreraig Bay (Morton, 1976).

Type section

Well-exposed coastal and cliff outcrops at Berreraig Bay [NG 518 527] on the east coast of the Trotternish Peninsula, 10 km north of Portree, northern Skye. Five of the six members (apart from the uppermost, Garantiana Mudstone) are exposed, and described by Morton (1965; 1976; 1991), Morton and Hudson (1995) and Cox and Sumblar (2002).

Formal subdivisions

Trotternish type area
Garantiana Mudstone Member (GASH) (British Geological Survey, 2007; Lee, 1920)
Rigg Sandstone Member (Morton, 1976)
Holm Sandstone Member (Morton, 1976)
Udairn Shale Member (Morton, 1976)
Ollach Sandstone Member (Morton, 1976)
Dun Caan Shale Member (DCSH) (Buckman in Lee, 1920; Morton, 1976)

Raasay
Garantiana Mudstone Member (GASH) (British Geological Survey, 2006b; Lee, 1920)
Druim An Fhurain (also spelled Fhuarain) Sandstone Member (DAFS) (British Geological Survey, 2006b; Morton, 1965)
Balachuirn Sandstone Member (BLCS)
Beinn na Leac Sandstone Member (BENL) (Morton, 1976)
Dun Caan Shale Member (DCSH) (Morton, 1976)

Strathaird
Garantiana Mudstone Member (GASH) (British Geological Survey, 2002a; Lee, 1920)
Druim An Fhurain Sandstone Member (DAFS) (Morton, 1965)

Lithology

The formation is dominated by fossiliferous calcareous sandstone with subordinate limestone and fissile mudstone. The successions present in Trotternish, Dunan and Strathaird on Skye, on Raasay, Mull and Ardnamurchan (Morton, 1965) and also offshore (Fyfe et al., 1993) differ significantly in

thicknesses and lithologies and locally different members have been established (British Geological Survey, 2009; Emeleus and Bell, 2005; Parsons, 1980a) .

Supplementary lithological information

At the type section six members are present totalling 209 m (thicknesses from Morton, 1965): in ascending order the Dun Caan Shale Member comprises 12 m of dark grey sandy mudstone with limestone nodules; succeeded by the Ollach Sandstone Member – 16 m of silty and sandy limestone overlain by massive sandstone with calcareous nodules; succeeded by the Udairn Shale Member (70 m). At the base, this member is mudstone with nodules, passing upwards into siltier lithotypes, passing gradationally into fine-grained sandstone of the Holm Sandstone Member (37 m). Close to the top of the Holm Sandstone Member, the sandstones become coarser and paler with nodules and cross-bedding. It passes up into the Rigg Sandstone Member, 72 m of medium- to coarse-grained sandstone, variously calcareous, muddy, cross-bedded and shelly. The youngest member is the Garantiana Mudstone Member (not exposed at Bearreraig Bay). This is around 2 m of dark grey mudstone, locally sandy.

On Raasay the formation is represented by the Dun Caan Shale Member (5 to 38 m) overlain by the Beinn na Leac Sandstone Member (12 to 21 m) and Balachuirm Sandstone Member (45 m) that are broadly coeval; followed by the Druim An Fhurain (also spelled Fhuarain) Sandstone Member (100 to 210 m) and the Garantiana Mudstone Member (0 to 3.5 m). The Beinn na Leac Sandstone is calcareous sandstone with intercalated siltstone and thin limestone. The Balachuirm Sandstone is massive sandstone. The Druim An Fhurain Sandstone (and Cox and Sumblar, 2002; Morton and Hudson, 1995; renamed by BGS from the Raasay Sandstone Member of Parsons, 1980a) is calcareous cross-bedded sandstone with sandy limestone interbeds. It is overlain by the Garantiana Mudstone Member, which may be difficult to distinguish from the overlying Cullaidh Shale Formation (Great Estuarine Group).

On Strathaird, Skye, two subdivisions of the formation are recognised (Morton, 1965), below is the Druim An Fhurain Sandstone Member comprising 230 to 485 m of cross-bedded sandstone interbedded with sandy bioclastic limestone and massive sandstone. This unit includes a ‘basal limestone’, comprising a thin (0 to 6.0 m) fossiliferous sandy limestone with mudstone and sandstone partings. The Druim An Fhurain Sandstone is overlain by the Garantiana Mudstone Member, which comprises 18.0 m of dark grey micaceous fissile mudstone. As on Raasay, this unit may be difficult to distinguish from the overlying lithologically similar Cullaidh Shale Formation (Great Estuarine Group).

A succession of metasedimentary rocks probably referable to the Bearreraig Sandstone Formation has been recorded from Glas Bheinn Beag, near Dunan (Morton, 1965; Smith, S M, 1960).

On Ardnamurchan, a succession of fossiliferous limestone, mudstone and calcareous mudstone, overlain by yellow and red sandstone is named the Maol Buidhe Sandstone Member (British Geological Survey, 2009). A succession of sandy limestone and calcareous sandstone on south-east Mull is attributed by Emeleus and Bell (2005) to the formation.

The macrofauna of the formation includes ammonites, belemnites, bivalves, brachiopods, crinoids, dinosaurs and trace fossils (Morton, 1991). Dinoflagellate cysts were recorded by Riding et al. (1991).

Lithogenetic description

The formation is interpreted as representing open marine deposition. The sandstones generally represent shallow marine sheet sands and deposition was initiated by basin subsidence and hinterland rejuvenation.

Landform description

The formation is much more resistant than the adjacent sedimentary Jurassic formations, particularly where recrystallised through hydrothermal alteration, and forms bluffs and cliffs, some of which are hundreds of metres high, e.g. on Strathaird and at Berreraig Bay.

Definition of upper boundary

The blocky grey or brown fissile mudstone with ammonites of the Garantiana Mudstone Member passes gradationally into the black, bituminous, fissile mudstone of the Cullaidh Shale Formation. The base of the Cullaidh Shale Formation is taken at the first upsection occurrence of carbonaceous, fissile mudstones with fish scales. There are marked facies variations which make the boundary between the Garantiana Mudstone Member and the Cullaidh Shale Formation difficult to identify (Harris and Hudson, 1980, pp. 234, 235). The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The lower boundary of the formation is a sharp, planar, apparently conformable lithological change upward from ferruginous limestone of the Raasay Ironstone Formation to the grey fissile mudstones of the Dun Caan Shales Member.

Thickness

Thicknesses quoted by authors for the same localities may be at considerable variance, due to the nature of the topography (e.g. sea cliffs), the nature of much of the strata (laterally variable shallow marine sandstone), and due to the difficulties of aggregating thickness ranges given for components. All thicknesses below are from Morton (1965) except where indicated. In Trotternish, north Skye, including the type section, the formation ranges from 156 to 228 m thick (see also Morton, 1976). On Strathaird [NG 52 11 to 56 21], it varies between 256 m (Faoilean) and 488 m (southern tip), and on Raasay attains up to about 214 m. The succession at Glas Bheinn Beag [NG 585 257], near Dunan is approximately 235 m. On Ardnamurchan, the formation is between 20 m (British Geological Survey, 2009) and 37 m (Richey and Thomas, 1930) thick. Strata attributed to the formation on south-east Mull total about 30 m. Greater thicknesses may be present offshore (Fyfe et al., 1993).

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Ardnamurchan (Richey and Thomas, 1930), Mull, Eigg (Emeleus, 1997), Raasay, Skye (Dunan, Strathaird and Trotternish) (Morton, 1965). Outcrops are separated/interrupted by Palaeogene igneous intrusions. Some continuity of the formation offshore within the sub-basins is inferred but extent is uncertain (Fyfe et al., 1993).

Previous names

Inferior Oolite (e.g. Anderson and Dunham, 1966; Lee and Pringle, 1932)

Berreraig Sandstone Series (Morton, 1965; Morton and Hudson, 1964).

Parent

None.

Age

Latest Toarcian to late Bajocian, Pseudoradosa Zone to Garantiana Zone

References

Principal reference (Morton, 1976)

8.2 GREAT ESTUARINE GROUP (GEST)

Name

Originally the 'Great Estuarine Series' of Judd (1878, p.722) which excluded the underlying and overlying marine 'Inferior Oolite' and 'Oxford Clay'. Proposed as a group by Harris and Hudson (1980). See also Chapter 4.

Type section

See component formations, forming composite.

Type area

Trotternish to Strathaird districts [NG 47 to NG 51], Skye, Inner Hebrides (Morton and Hudson, 1995, p.216)

Formal subdivisions

For child units of formations, see individual entries below.

Skudiburgh Formation (SKU) (Harris and Hudson, 1980)
Kilmaluag Formation (KML) (Harris and Hudson, 1980)
Duntulm Formation (DTM) (Harris and Hudson, 1980)
Valtos Sandstone Formation (VTS) (Harris and Hudson, 1980)
Lealt Shale Formation (LASH) (Harris and Hudson, 1980)
Elgol Sandstone Formation (ESA) (Harris and Hudson, 1980)
Cullaidh Shale Formation (CUD) (Harris and Hudson, 1980)

Lithology

Succession of heterolithic, dominantly siliciclastic, sedimentary rocks dominated by mudstone and sandstone with subordinate variously shelly, algal and dolomitic limestone beds. There are no fully marine fossils (e.g. ammonites), and no zonal faunas. Seven formations are recognised.

Lithogenetic description

Variety of paralic depositional settings including low-salinity anoxic, fluvial deltaic, brackish-marine lagoonal, tidally influenced littoral lagoon with fluvial delta lobes, shallow, ephemeral lagoons, alluvial floodplain/mudflats.

Definition of upper boundary

The top of the group is coincident with the top of the Skudiburgh Formation. The top of the Skudiburgh Formation is sharply defined, and is marked by the change from mottled red and grey-green mudstones to dark, shelly fissile mudstones (Upper Ostrea Member, Staffin Bay Formation) in Trotternish and a non-sequence overlain by sandstone (Carn Mor Sandstone Member, Staffin Bay Formation) in Strathaird. The group is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The base of the Group is coincident with the base of the Cullaidh Shale Formation. The latter unit overlies the Garantiana Mudstone Member of the Berreraig Sandstone Formation. At the type section of the Cullaidh Shale, this boundary is gradational and conformable. The fossiliferous blocky grey or brown mudstone of the Garantiana Mudstone passes up gradationally into the black, bituminous, fissile mudstone of the Cullaidh Shale. The base of the Cullaidh Shale is taken at the first upsection occurrence of carbonaceous, fissile mudstones with fish scales. There are marked facies variations to the north and south which make the boundary

between the Cullaidh Shale and the Garantiana Mudstone difficult to identify (Harris and Hudson, 1980, p. 234, 235).

Thickness

The thickest composite section is on the Trotternish Peninsula, where Harris and Hudson (1980, fig. 3), give a thickness of 264 m for the group, but aggregating the quoted formations' thicknesses gives up to 289 m. It thins dramatically southwards from Trotternish via Raasay, estimated 137 to 139 m on Strathaird (British Geological Survey, 2002a), about 120 m on Eigg (Emeleus, 1997), seen to 33 m on Muck (Harris and Hudson, 1980, fig. 3).

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird, Trotternish and Waternish districts), Raasay, Eigg and Muck. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the Great Estuarine Group within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

Loch Staffin Beds (Murchison, 1829a, b)

Estuarine Series, Great Estuarine Series (Judd, 1878).

Parent

None

Age

?late Bajocian to Bathonian

References

Principal reference: (Harris and Hudson, 1980)

Additional references (Judd, 1873) (Lee and Pringle, 1932)

8.2.1 Cullaidh Shale Formation (CUD)

Name

Given the distinctive part of the name of Port Na Cullaidh bay where the type section is located, plus the distinct lithology (Harris and Hudson, 1980).

Type section

Foreshore at Port Na Cullaidh [NG 517 137], Elgol, Strathaird, southern Skye. Discontinuous exposures on storm beach that vary with beach state, and typically expose 1 to 2 m of dark mudstone with fish scales and a sparse shelly fauna, intruded by basaltic sills. Base not seen, top exposed at foot of cliff (Cox and Sumbler, 2002, pp. 385-387; Harris and Hudson, 1980; Morton and Hudson, 1995, p 237).

Formal subdivisions

None.

Lithology

The formation comprises up to 6 m of black, bituminous, fossiliferous fissile mudstone. Oil shale is developed, in the lowermost 2 m of the unit. The uppermost unit is sandy fissile mudstone; locally black fine-grained sandstones are developed. The fauna is restricted and is largely fish scales and bivalves, together with sparse crinoids, fish, small gastropods, echinoids, trace fossils (*Planolites*) and conchostracans (Chen and Hudson, 1991).

Lithogenetic description

Deposited as a prodelta in low-salinity anoxic conditions

Landform description

The formation forms a hollow between adjacent Jurassic sandstone formations, although may be more resistant where recrystallised through hydrothermal alteration by igneous intrusions.

Definition of upper boundary

The boundary of the formation with the overlying Elgol Sandstone Formation is gradational, and thus conformable. The base of the Elgol Sandstone Formation is marked by the first appearance of relatively intensely bioturbated, clay-rich sandstone intercalated with the dark fissile mudstone typical of the Cullaidh Shale Formation (Harris, 1989, figs. 3, 6, 8, 10; Harris and Hudson, 1980, fig. 5; Hudson and Harris, 1979, figs 2 to 4; Morton and Hudson, 1995, fig. 19). The Cullaidh Shale Formation is more fossiliferous than the Elgol Sandstone Formation.

Definition of lower boundary

The formation overlies the Garantiana Mudstone Member of the Bearreraig Sandstone Formation. At the type section, the boundary is gradational and hence conformable. The blocky grey or brown mudstone with ammonites of the Garantiana Mudstone Member passes gradationally into the black, bituminous, fissile mudstone of the Cullaidh Shale. The base of the formation is taken at the first upsection occurrence of carbonaceous, fissile mudstone with fish scales. There are marked facies variations to the north and south which make the boundary between the Cullaidh Shale Formation and the Garantiana Clay Member difficult to identify (Harris and Hudson, 1980, p. 234, 235).

Thickness

On the Trotternish Peninsula, Skye, the formation is 6 m thick. Further south it is 3 m on Raasay and at the type section at Port Na Cullaidh, Strathaird, Skye it is 4 to 6 m and it may be about 6 m thick on Eigg (all thicknesses from Harris and Hudson, 1980) although Emeleus (1997) suggests it is not present on Eigg.

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird and Trotternish), Raasay and Eigg. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The extent of the formation offshore within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

Oil Shale (Peach et al., 1910)

Basal Oil Shale (Hudson, 1962b).

Age

Late Bajocian possibly to Bathonian

References

Principal reference (Harris and Hudson, 1980)

8.2.2 Elgol Sandstone Formation (ESA)

Name

Named after the village of Elgol where the type section is located, (Harris and Hudson, 1980, pp. 235-238).

Type section

Coastal exposure at the north side of Port Na Cullaidh [NG 517 138], Elgol, Strathaird, southern Skye (Cox and Sumblar, 2002; Harris and Hudson, 1980).

Formal subdivisions

None.

Lithology

The formation comprises bioturbated, clay-rich sandstone intercalated with silty fissile mudstone, overlain by coarsening-upwards white, pure, noncalcareous sandstone. At the type section, the lowermost beds are sandy fissile mudstones intercalated with dark silty fissile mudstones (Harris and Hudson, 1980, pl. 1a), overlain by fine- to medium-grained sandstones with spectacularly developed honeycomb weathering (Emeleus and Bell, 2005, pl. 6). These are succeeded by moderately well-sorted, medium- to coarse-grained sandstones with large scale, low angle cross bedding. The uppermost beds are trough and planar stratified very coarse sandstones with granules and pebbly lenses. In south Trotternish and on Raasay, the formation comprises fine- to medium-grained greenish white sandstone. In north Trotternish, the succession is significantly thinner, and includes fining-upwards sandstone facies underlying coarsening-upwards sandstone. It may be represented on Eigg by thin brown silty fissile mudstones (Harris and Hudson, 1980, fig. 3). The macrobiota is relatively sparse, and comprises plant remains, rootlets and trace fossils including *Diplocraterion*, *Monocraterion*, *Planolites* and *Thalassinoides*. No shelly body fossils have been recovered, however moulds of the bivalve *Unio* are present in life position the uppermost beds at the type section. Riding et al. (1991) recorded both marine and nonmarine palynomorphs.

Lithogenetic description

A classic fluvial deltaic coarsening-upwards succession; the delta prograded south-eastwards into the lagoonal basin. In Strathaird, the lowermost beds are prodeltaic mudstone, overlain by delta front sandstone. These are succeeded by the distributary mouth bar sediments. The uppermost beds represent a wave and current reworked bar crest succession. Lateral facies variations include the development of crevasse splay deposits. In north Trotternish, the succession includes fining-upwards distributary channel facies underlying the coarsening-upwards distributary mouth bar sandstones (Harris, 1989).

Landform description

The formation forms cliffs, and may be particularly resistant where recrystallised through hydrothermal alteration by igneous intrusions.

Definition of upper boundary

The boundary of the formation with the overlying Lealt Shale Formation is sharply defined. The uppermost bed is a very coarse sandstone with local developments of granules and pebbles, and this is abruptly overlain by the silty or bituminous fissile mudstones of the Lealt Shale (Harris and Hudson, 1980, fig. 5). The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The formation overlies the Cullaidh Shale Formation with a gradational boundary. The base is marked by the first appearance of relatively intensely bioturbated, prodeltaic clay-rich sandstones intercalated with the dark fissile mudstones typical of the Cullaidh Shale Formation (Hudson and Harris, 1979, figs 2 to 4; Harris and Hudson, 1980, fig. 5; Harris, 1989, figs. 3, 6, 8, 10; Morton and Hudson, 1995, fig. 19). The Elgol Sandstone Formation is significantly less fossiliferous than the underlying Cullaidh Shale Formation.

Thickness

Thicknesses from Harris and Hudson (1980) except where indicated. At the type section in Strathaird, the Elgol Sandstone Formation is 22 m thick. Northwards, on the Trotternish Peninsula, its thickness varies between 9 m at Rigg, at least 12 m at Invertote and 17 to 32 m (BGS, 2007) in south Trotternish and Raasay. Further south, the formation is discontinuous with thin (up to 1 m) of brown silty fissile shale present on Eigg, although Emeleus (1997) disputes their correlation with the Elgol Sandstone.

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird and Trotternish districts), Raasay and possibly Eigg. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the parent Great Estuarine Group within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

‘Great white sandstone’ (Murchison, 1829b)

White Sandstone (Donovan and Hemingway, 1963) (Anderson and Dunham, 1966) .

Age

?Bajocian to Bathonian, ?Parkinsoni Zone to Zigzag Zone

References

Principal reference (Harris and Hudson, 1980).

8.2.3 Lealt Shale Formation (LASH)

Name

Named after Lealt village and Lealt River where an important reference section is located (Harris and Hudson, 1980, pp. 238-240).

Composite type section

The type section of the Kildonnan Member is a coastal exposure [NM 495 870], 23 m thick, located 2.5 km north of Kildonnan, Eigg (Harris and Hudson, 1980, fig. 6; Hudson and Harris, 1979, fig. 5).

The type section of the Lonfearn Member is a composite succession [NG 517 638 to NG 521 627], 30 m thick, north of Port Earlish, Trotternish (Cox and Sumblar, 2002; Harris and Hudson, 1980, fig. 6).

Reference section(s)

Outcrops at the Lealt River and cliffs north of the Lealt River mouth, Trotternish [NG 515 604] provide an accessible reference section for the Lealt Shale Formation which is 48 m thick. The Lonfearn Member is especially well developed here. The different exposures in this area can be readily correlated using marker beds, and a composite section has been made by Hudson and Harris (1979, figs. 2 to 4).

Formal subdivisions

Lonfearn Member (LONFN) (Harris and Hudson, 1980).
Kildonnan Member (KILDN) (Harris and Hudson, 1980)

Lithology

The Lealt Shale Formation typically comprises fossiliferous silty fissile mudstones with subordinate thin limestones and septarian nodules. A gradual coarsening-upward trend is discernible. The lower unit, the Kildonnan Member, is dominated by silty fissile mudstones intercalated with shell beds, shelly limestones, bone beds and one sandstone bed (Emeleus, 1997, appendix 1). The biota comprises bivalves, conchostracans, gastropods and plants (ferns), shark teeth and plesiosaur bones. There is a prominent bed of stromatolitic algal limestone, 0.20 m thick, with gypsum pseudomorphs at the top of the member recognisable throughout the Hebrides Basin. The upper unit, the Lonfearn Member, comprises dark grey-brown finely laminated fissile mudstone ('paper shale') with interbedded ooidal limestone. Brackish water faunas, including bivalves, conchostracans, gastropods and ostracods are present. Desiccation cracks, indicating emergence, are present in the uppermost beds.

Lithogenetic description

The formation was deposited in a brackish-marine lagoonal setting.

Landform description

The formation forms a hollow between adjacent Jurassic sandstone formations, although may be more resistant where recrystallised through hydrothermal alteration by igneous intrusions.

Definition of upper boundary

The Lealt Shale Formation–Valtos Sandstone Formation transition is a gradational boundary characterised by interbedded fissile mudstones, silty fissile mudstones and siltstones. The top of the Lealt Shale is marked by the range top of the conchostracan *Cyzicus*. The base of the Valtos Sandstone is marked by the lowermost occurrence of silty mudstone with monotypic *Neomiodon* beds. The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The boundary of the formation with the underlying Elgol Sandstone Formation is abrupt. The uppermost bed of the Elgol Sandstone is a very coarse-grained sandstone with occasional granules and pebbles, and is overlain by the fissile mudstones of the Lealt Shale (Harris and Hudson, 1980, fig. 5).

Thickness

Typically between 45 m and 50 m. However, thicknesses quoted by authors for the same localities may be at considerable variance, due to the nature of the topography (e.g. sea cliffs) and of the laterally variable sequences, and to the difficulties of aggregating thickness ranges given for components. All thicknesses below from Harris and Hudson (1980), except where indicated.

In Trotternish, north Skye, including the Lonfearn Member type section, the formation ranges from 39 m on the Portree (S 80E) sheet (British Geological Survey, 2007) to 43 m thick, and on the Raasay (S 81W) sheet from 50 to 62 m (British Geological Survey, 2006b). On Strathaird it is about 46 m thick, on Eigg between 45 m (Emeleus, 1997) and 52 m and on Ardnamurchan, 2 to 3 m (Richey and Thomas, 1930).

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird and Trotternish districts), Raasay, Eigg and Ardnamurchan. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the parent Great Estuarine Group within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

Estheria Shales (Anderson, 1948; Anderson and Dunham, 1966) and Mytilus Shales (Hudson, 1962b, 1966). The succession of fossiliferous fissile mudstones with interbedded limestones between the dominantly sandstone Elgol and Valtos Sandstone formations was termed the Estheria Shales by Anderson (Anderson, 1948). The fauna in the lower part of the Lealt Shale Formation contains a characteristic bivalve assemblage dominated by a mytilid form. Hudson (1962b, 1966) termed these beds the Mytilus Shales.

Age

Bathonian, Zigzag Zone to Progracilis Zone

References

Principal reference (Harris and Hudson, 1980)

Additional references (Andrews, J E and Hudson, 1984; Hudson et al., 1995; Riding et al., 1991; Tan and Hudson, 1974).

8.2.4 Valtos Sandstone Formation (VTS)

Name

Named after the village of Valtos near the type section (Harris and Hudson, 1980, pp. 240-243).

Type section

Cliffs [NG 517 638 to NG 509 653] between Valtos and Mealt Falls, Trotternish, northern Skye, about 95 m seen from lower boundary on Lealt Shale Formation through to capping of microgabbro sill. Strata dominated by sandstone but with a median unit including mudstone and limestone beds. The formation's stratigraphical top is well exposed about 2 km to the north-north-west (Cox and Sumblar, 2002; Harris and Hudson, 1980; Morton and Hudson, 1995).

Reference section(s)

Foreshore exposures at Camas Sgiotaig [NM 468 905 to NM 472 885], north-west Eigg, about 60 m of strata dominated by sandstone but with minor mudstone, siltstone and limestone interbeds. Base on Lealt Shale Formation seen in north, top beneath Duntulm Formation present but not exposed (Cox and Sumblar, 2002; Emeleus, 1997; Hudson and Harris, 1979, fig. 7).

Formal subdivisions

None.

Informal subdivisions:

Cyrena Limestones (Wedd *in* Peach et al., 1910)

Five 'Cycles' are recognised by Anderson and Dunham (1966)

Lower Sandstone Division, Middle Limestone Shale Division, Upper Sandstone Division (Harris and Hudson, 1980, fig. 7) .

Lithology

The formation is dominated by sandstone, medium- to coarse-grained, white to pale yellow, friable, cross-bedded in sets up to about 6 m thick with prominent large (up to 1 m in diameter), ovoid to near-spherical calcareous concretions or doggers produced after burial. Some of the medium-grained sandstone beds are significantly carbonaceous. The sandstone units are normally upward coarsening and capped by thin shelly limestone beds, that are normally coarse, sandy *Neomiodon* bioclastic grainstone. Bioturbated green silty fissile mudstone and *Neomiodon* limestone beds occur within the sandstone units. Cyclic sedimentation can be identified; five cycles of fissile mudstone and limestone passing upward into sandstones with concretions have

been observed (Anderson and Dunham, 1966). Wedd in Peach et al. (1910) termed the monotypic *Neomiodon* beds the 'Cyrena Limestones'. The base of the formation is marked by silty fissile mudstones with monotypic beds of the opportunistic bivalve *Neomiodon*; the thick sandstone beds overlie these mudstones. The macrobiota is dominated by the typically brackish water bivalve *Neomiodon* with subordinate dinosaur bones and footprints, fish debris (fin spines, scales and teeth), gastropods (*Viviparus*), trace fossils (e.g. *Lockeia*, *Monocraterion*, *Planolites* and *Thalassinoides*) and coniferous wood. Riding et al. (1991) recorded nonmarine palynomorphs comprising brackish/freshwater alga (*Botryococcus*), pollen and spores.

In Trotternish, the Valtos Sandstone Formation is subdivisible into three distinct units. These have not been given member status. The lowermost Lower Sandstone Division is 48 m of cross-bedded coarsening-upwards sandstones with intercalated silty fissile mudstones. This is overlain by 27 m of fine-grained sandstones, silty fissile mudstones and coarse, sandy *Neomiodon* bioclastic grainstone termed the Middle Limestone Shale Division. The youngest Upper Sandstone Division is 46 m of coarsening-upwards sandstone with intercalated silty fissile mudstone beds. The formation exhibits significant lateral facies variations and is much thinner, less sandy and lacks calcareous concretions in Strathaird compared with Trotternish to the north, and with Eigg to the south. The sand in the strata on Trotternish and Eigg on petrographical evidence derives largely from land areas in mainland Scotland to the east, according to Hudson (1964).

Lithogenetic description

The depositional environment is interpreted as a tidally influenced shallow littoral lagoon which was inundated by an extensive system of fluvial delta lobes. The delta channels were associated with a major source of coarse clastic sediment and plant debris, which built out into the lagoons of the underlying Lealt Shale Formation. There is evidence of periodic emergence.

Landform description

The formation forms cliffs, including sea cliffs up to 100 m high, and may be particularly resistant where recrystallised through hydrothermal alteration by igneous intrusions.

Definition of upper boundary

The top of the formation is defined by the first upsection occurrence of the oyster *Praeexogyra hebridica* (Forbes) in the lowermost beds of the Duntulm Formation. Lithologically, this boundary is gradational with the fissile mudstones with freshwater faunas of the uppermost Valtos Sandstone Formation being overlain by fissile mudstones with marine fossils of the lowermost Duntulm Formation. The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The base of the formation in the type area is marked by the first upsection occurrence of silty fissile mudstones with monotypic *Neomiodon* beds. These beds overlie the fissile mudstones of the Lealt Shale Formation; hence this boundary is gradational.

Thickness

Thicknesses from Harris and Hudson (1980) except where indicated. A maximum onshore thickness of 120 m is estimated in Trotternish, Skye. Southwards, the formation thins significantly to about 70 m in north-west Skye (British Geological Survey, 2006a), up to 52 m on Raasay (British Geological Survey, 2006b), around 21 m in Strathaird, Skye and about 60 m on Eigg. At least 15 m are present on Muck.

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird, Duirinish, Waternish and Trotternish districts), Raasay, Eigg and Muck. Outcrops are separated/interrupted by Palaeogene igneous intrusions.

The offshore extension of the parent Great Estuarine Group within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

Concretionary Sandstones (Anderson and Dunham, 1966)

Concretionary Sandstone Series (Lee, 1920)

Cyrena Limestones (Wedd in Peach et al., 1910) for a sequence of shelly, sandy limestone and calcareous sandstone beds in Strathaird.

Age

Bathonian, Subcontractus Zone

References

Principal reference (Harris and Hudson, 1980)

Additional references (Clark et al., 1995).

8.2.5 Duntulm Formation (DTM)

Name

Named after the village of Duntulm near the type section by Harris and Hudson (1980, pp. 243–245). No lithology dominates, so a lithological epithet is inappropriate.

Type section

Foreshore at Cairidh Ghluimaig [NG 411 739] and stream at Lon Ostaoin [NG 406 728], Duntulm, Trotternish, northern Skye. Composite section with uncertain correlations, gaps and obscured parts. Harris and Hudson (1980) estimate 55 m of strata at maximum but they recognise that only about 30 m are seen and from mapping 40 m is the minimum. Andrews and Walton (1990, figs 4 and 5) show a total of about 33 m of strata, (Cox and Sumbler, 2002; Harris and Hudson, 1980)

Reference section(s)

Foreshore north of Elgol, [NG 521 160 to 516 146], discontinuous but shows top and base, limestones more dominant than Trotternish, 17 m of strata seen with a few-metre gap near base (Andrews, J E and Walton, 1990; Morton and Hudson, 1995).

Formal subdivisions

None.

Lithology

The formation is a heterolithic succession dominated by fissile mudstones and monospecific oyster beds, with subordinate limestone, algal limestone and calcareous sandstone beds. The oysters are *Praeexogyra hebridica* (Forbes), indicating strong marine influence. They are preserved in limestone or mudstone matrices and the shell beds vary from a single shell plaster to oyster beds 2 m thick. Within the Great Estuarine Group, *Praeexogyra hebridica* is confined to the Duntulm Formation. At Lon Ostaoin, northern Skye, nonmarine strata with *Neomiodon*- and *Unio*-dominated bivalve faunas are developed. The abundant and relatively diverse macrobiota comprises belemnites, bivalves, bone fragments, branchiopods (*Cyzicus*), dinosaur footprints, echinoderm fragments, fish fragments, foraminifera, gastropods, ostracods, plant and wood fragments, rhynchonellid brachiopods, shark fin spines, trace fossils (including *Lockeia*, *Monocraterion*, *Thalassinoides*) and worm burrows. Andrews and Walton (1990) and Riding et al. (1991) recorded marine and nonmarine palynomorphs from the type section at Cairidh Ghluimaig and Lon Ostaoin, and from north-west Skye and Muck. On Raasay, up to 10 m of shelly limestone, formerly termed the (Raasay) Cornbrash (Lee, 1920, pp 58, 65) is referred to the formation.

Lithogenetic description

The oyster-rich beds of the Duntulm Formation represent the best developed marine phase in the Great Estuarine Group, with marine–brackish palaeosalinities developed in a shallow water lagoonal setting (Hudson, 1963a, b; Hudson and Harris, 1979). The presence of algal limestones, carbonaceous fissile mudstone and mud cracks in this unit are indicative of lagoon–marginal mudflat settings (Andrews, J E, 1986; Hudson, 1970). Hudson and Andrews (1987) interpreted the environment of the algal beds as a supralittoral fringe to a microtidal marine–brackish lagoon and inferred that the open lagoon was nearby, as marine fossils were washed onto these algal marsh deposits.

Landform description

The formation tends to form a hollow between outcrops of more resistant igneous intrusions and lavas, although may be more resistant where recrystallised through hydrothermal alteration by igneous intrusions.

Definition of upper boundary

The top of the formation is marked by the range top of *Praeexogyra hebridica*, and the first upsection occurrence of the ostracod-bearing limestone beds interbedded with shale, of the Kilmaluag Formation. This boundary is not observed at the type section at Trotternish. The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The base of the formation is defined by the first upsection occurrence of the oyster *Praeexogyra hebridica* (Forbes). Lithologically, this boundary is gradational with the fissile mudstones with marine fossils of the lowermost Duntulm Formation being underlain by the fissile mudstones with freshwater faunas of the uppermost Valtos Sandstone Formation (Harris and Hudson, 1980, fig. 8; Cox and Sumbler, 2002, fig. 6.29).

Thickness

Thicknesses from Harris and Hudson (1980) unless otherwise indicated. They also claim Anderson and Dunham's (1966) 60 feet (18 m) estimate for Trotternish is incorrect, probably repeated on the Staffin (S 90) sheet (British Geological Survey, 2006c). The greatest thickness cited is at the type section in Trotternish: Harris and Hudson (1980) estimate 55 m thick, Andrews and Walton (1990) give about 33 m. The unit thins southwards: Raasay (S 80E) sheet 0 to 10 m (British Geological Survey, 2006b), Strathaird at least 17 m (Andrews, J E and Walton, 1990), although Harris and Hudson (1980) give 8 m, Eigg at least 9 m and Muck at least 11 m (Andrews, J E and Walton, 1990).

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird, Duirinish, Waternish and Trotternish districts), Raasay, Eigg and Muck. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the parent Great Estuarine Group within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

Lower *Ostrea* Beds (Anderson, 1948)

Ostrea hebridica beds, (Wedd in Peach et al., 1910)

Cornbrash (Lee, 1920, pp 58, 65)

Raasay Cornbrash (Parsons, 1980a)

Age

Bathonian, Morrissi Zone to Retrocostatum Zone

References

Principal reference (Harris and Hudson, 1980)

Additional references (Emeleus and Bell, 2005; Hudson and Palmer, 1976).

8.2.6 Kilmaluag Formation (KML)

Name

Named after Kilmaluag Bay containing the type section by Harris and Hudson (1980, pp. 245–247). No lithology dominates, so a lithological epithet is inappropriate.

Type section

Partial type section: Kilmaluag Bay [NG 437 750], Trotternish, northern Skye, about 20 m of strata, including base. Affected by intrusions, particularly at the top (Harris and Hudson (1980); Morton and Hudson (1995, table 3).

Partial type section: The north shore at Glen Scaladal [NG 519 165], Strathaird, southern Skye, almost fully exposed, mildly metamorphosed and lacks sandstones, but displays desiccation cracks and dolomitised breccias (Harris and Hudson, 1980, fig. 9) (Cox and Sumblar, 2002, fig. 6.21).

Formal subdivisions

None.

Lithology

Succession of interbedded grey calcareous mudstone, fissile mudstone and argillaceous limestone, commonly nodular. This calcareous unit contrasts markedly with the dominantly siliciclastic character of the remainder of the Great Estuarine Group. Prominent desiccation cracks are common, and some of the calcareous beds are dolomitic. Thin beds of fine-grained sandstone are developed in Trotternish; this is the ‘clastic facies’ of (Andrews, J E, 1985). Within the Great Estuarine Group, the formation is defined by the range of ostracod-rich calcareous strata. The ostracods are dominated by *Darwinula* and *Theriosynoecum*. Other fossils present are bivalves (e.g. *Neomiodon* and *Unio*), branchiopods, charophytes, fish, gastropods (e.g. *Viviparus*), mammals, plant debris and reptile bones. The vertebrate faunas have been described by Waldman and Savage (1972) and Waldman and Evans (1994). Riding et al. (1991) recorded marine and nonmarine palynomorphs from the Kilmaluag Formation from Trotternish. The marine microplankton is low in abundance and does not include dinoflagellate cysts. The foraminiferal test linings and prasinophytes were probably swept into the barred lagoons during storms.

Lithogenetic description

The formation represents shallow, ephemeral lagoons. The lagoons were physically separated from open marine environments and were fed by small rivers; sublittoral environments have been identified (Andrews, J E, 1985).

Landform description

The formation tends to form a hollow between outcrops of more resistant igneous intrusions and lavas, although may be more resistant where recrystallised through hydrothermal alteration by igneous intrusions.

Definition of upper boundary

The top of the formation is gradational and is marked by top of ostracod-bearing calcareous mudstones and marls/fissile mudstones, and the base of the red, grey and green mudstones of the

Skudiburgh Formation. The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The base of the formation is defined by the first upsection occurrence of ostracod-bearing calcareous mudstones and marls/fissile mudstones, and the highest occurrence of *Praeexogyra hebridica* in the Duntulm Formation below.

Thickness

Thicknesses from Harris and Hudson (1980, figs. 3, 8). They also claim Anderson and Dunham's (1966) 90 to 100 feet (27 to 33 m) estimate for Trotternish is incorrect, probably repeated elsewhere (as 30 m) on the Staffin (S 90) and Portree (S 80E) sheets (British Geological Survey, 2006c, 2007). In Trotternish and on Strathaird, the formation is about 25 m thick, and may be up to 23 m on Waternish. It thins significantly southwards to 6 and 12 m on Eigg and Muck respectively.

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird, Duirinish, Waternish and Trotternish districts), Raasay, Eigg and Muck. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the parent Great Estuarine Group within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

Ostracod Limestones (Anderson and Dunham, 1966) .

Age

Bathonian, *Retrocostatum* Zone

References

Principal reference (Harris and Hudson, 1980)

8.2.7 Skudiburgh Formation (SKU)

Name

Named after Skudiburgh promontory near Uig containing the type section by Harris and Hudson (1980, pp. 247–248). No lithology dominates, so a lithological epithet is inappropriate.

Type section

Partial type section: Coastal outcrop at Skudiburgh [NG 374 649], Trotternish, northern Skye, displaying about 4 m of ripple-marked silty mudstone and cross-bedded sandstone. The base and top are not exposed, (Cox and Sumblar, 2002, figs 6.24-6.26; Harris and Hudson, 1980).

Partial type section: Foreshore at Digg [NG 472 709], Staffin Bay, Trotternish, northern Skye, base not seen and affected by strike faulting, (Anderson and Dunham, 1966) (Harris and Hudson, 1980).

Formal subdivisions

None.

Lithology

Succession of mottled red and grey-green silty mudstone sporadically rich in small (2–10 cm in diameter) calcareous septarian concretions. Green-weathering lenticular siltstones are common and thin, lenticular fining-upwards calcareous sandstones are developed in Trotternish. The

sparse fossils are all freshwater types, and comprise bivalves (e.g. *Unio*), gastropods (e.g. *Viviparus*), fish teeth and plant fragments.

Lithogenetic description

The palaeoenvironment is interpreted as an alluvial floodplain, mudflat setting where the water table is close to the surface. The mottling in the mudstone represents alternations between partial dehydration and reduction. The calcareous nodules are syndepositional and are components of a calcrete or caliche implying a warm climate, with limited seasonal rainfall and seasonal aridity (Andrews, J E, 1985) – isotope geochemistry suggests formation from meteoric derived soil waters which may have undergone evaporation (Hudson and Andrews, 1987). The impersistent siltstone beds probably represent overbank deposits, crevasse splays and small channels and the upward-fining sandstones are fluvial channel deposits (Andrews, J E, 1985; Hudson and Harris, 1979). No palaeosols or rootlet horizons are developed. The coastal plain setting represents the final phase of a late Bathonian regressive trend (Andrews, J E, 1985). Riding et al. (1991) recorded nonmarine palynomorphs from the type section at Digg, Trotternish.

Landform description

The formation tends to form a hollow between outcrops of more resistant igneous intrusions and lavas, although may be more resistant where recrystallised through hydrothermal alteration by igneous intrusions.

Definition of upper boundary

The top of the formation is sharply defined, marked by the change from mottled red and grey-green mudstones to dark, shelly fissile mudstones (Upper Ostrea Member, Staffin Bay Formation) in Trotternish and at a non-sequence overlain by sandstone (Carn Mor Sandstone Member, Staffin Bay Formation) in Strathaird. The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The base is gradational, defined by the base of mottled red and grey-green mudstones, and the top of ostracod-bearing calcareous mudstones and fissile mudstones of the Kilmaluag Formation.

Thickness

A composite of the two partial type sections gives a thickness of about 15 to 16 m in Trotternish. Thicknesses quoted for Strathaird vary from 10 to 11 m (Harris, 1992; Harris and Hudson, 1980) to 16 to 18 m (Hudson, 1962b; Hudson and Harris, 1979). The formation may be present in Waternish, but has not been recognised on Raasay, Eigg or Muck (Harris and Hudson, 1980, fig. 3) (Emeleus, 1997).

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins or troughs), north-west Scotland: onshore outcrops on Skye (Strathaird, Trotternish and possibly also Waternish districts); not recorded on Raasay, Eigg and Muck. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the parent Great Estuarine Group within the sub-basins is inferred but uncertain (Fyfe et al., 1993).

Previous names

Mottled Clays (Anderson, 1948)

Age

Bathonian, Retrocostatum Zone to Discus Zone

References

Principal reference (Harris and Hudson, 1980)

8.3 STAND-ALONE FORMATIONS ABOVE THE GREAT ESTUARINE GROUP

In his monumental work on the sedimentary rocks of western Scotland, Judd (1878, pp. 722-728) included in his 'Great Estuarine Series' 150 feet of 'black shales', beneath his 'Oxford Clay'. Anderson and Cox (1948) retained this division (as well as identifying 'Corallian Shales' and 'Kimmeridge Clay' above), and gave names to their subdivisions of the Great Estuarine Series, including at the top, the 'Belemnite Sands' (25 feet thick) on the 'Upper Ostrea Beds' (35 feet), which they recognised as marine. Hudson (1962b), however, placed the top of his Great Estuarine Series at the base of the Upper Ostrea Beds, where it overlies the 'Mottled Clays' (now Skudiburgh Formation, see above) – the least marine part of the succession, and gave the grouped Upper Ostrea Beds and Belemnite Sands a local name – the 'Staffin Bay Beds', of possible latest Bathonian to early Callovian age. At the same time he named a 9 m-thick shelly marine sandstone found in Strathaird the Carn Mor Sandstone. The overlying Lower Callovian to Lower Kimmeridgian argillaceous 'Oxford Clay', 'Corallian Shales' and 'Kimmeridge Clay' were then called the 'Staffin Shales' by Turner (1966). Sykes (1975), criticising the earlier use of southern England nomenclature, then formalised the two formations and the two Staffin Bay Formation members, and included the Carn Mor Sandstone as a member, and erected ten new members of the Staffin Shale Formation, including one for the Isle of Eigg. This scheme has proved workable, and is used on the Rum (S 60), Broadford (S 71W) and Staffin (S 90) sheets (British Geological Survey, 1994a, 2002a, 2006c) and has achieved considerable currency (Cox and Sumbler, 2002; Emeleus and Bell, 2005; Morton and Hudson, 1995).

8.3.1 Staffin Bay Formation (STBA)

Name

Named Staffin Bay Beds by Hudson (1962b, pp. 145-146) after Staffin Bay, north Skye, as formalised by Sykes (1975, pp. 63-64).

Type section

Coastal outcrop (foreshore) at Dunans [NG 473 708], Staffin Bay, Trotternish, north Skye: this is 'Point 5' of Anderson and Dunham (1966, fig 10) and Morton and Hudson (1995, fig. 38). The formation is fully exposed, 15.95 m thick, (Morton and Hudson, 1995, p. 272)

Reference section(s)

Foreshore south of Rudha na h'Airigh Baine [NG 516 172 to 518 168] Strathaird, south Skye: exposes 9 m of fossiliferous, bioturbated, medium-grained sandstone (Carn Mor Sandstone Member), (Sykes, 1975, p.68)

Formal subdivisions

Carn Mor Sandstone Member (CMSA) (Hudson, 1962b; Sykes, 1975)
Belemnite Sands Member (BSSK) (Anderson and Cox, 1948; Sykes, 1975)
Upper Ostrea Member (UOST) (Anderson and Cox, 1948; Sykes, 1975)

Lithology

The formation is a succession of fissile mudstones and sandstones, and is 15.95 m thick at the type section at Staffin Bay, Trotternish, north Skye. A coarsening-upward trend is discernible from the dark grey, fissile mudstone with a shelly limestone bed, minor shell beds and laminated and rippled sandstones (the Upper Ostrea Member, 11.20 m thick) being overlain by 4.75 m of fine- to medium-grained bioturbated, carbonaceous sandstones with siltstones (the Belemnite Sands Member).

The Belemnite Sands Member is dominated by dark, carbonaceous, fine- to medium-grained, bioturbated sandstone. Small-scale cross bedding and flaser bedding is present. The uppermost 0.75 m is coarse-grained and glauconitic. This bed contains a prominent bed of nodular *Spongliomorpha suevica*.

On the west coast of Strathaird, south-west Skye, the formation is represented by the Carn Mor Sandstone Member comprising 9 m of dark medium- to coarse-grained, bioturbated, calcareous, pebbly, fossiliferous, fully marine sandstone.

Lithogenetic description

The mudstone-dominated Upper Ostrea Member was deposited in a coastal lagoonal setting and the fauna indicate brackish water deposition (Hudson, 1963a, b). The Belemnite Sands Member exhibits more open marine influence and has been interpreted as an offshore sand bar which transgressed across coastal lagoons. The Carn Mor Sandstone Member is also fully marine.

Landform description

The formation tends to form a concave slope between outcrops of more resistant igneous intrusions and lavas, and outcrops are largely concealed by superficial deposits and landslides in Trotternish, notably north of The Storr [NG 50 54].

Definition of upper boundary

The top of the formation in Trotternish is abruptly defined; marked by a sharp facies change from the fine- to medium-grained sandstone of the Belemnite Sands Member to the bituminous fissile mudstones with thin glauconitic silts of the overlying Dunans Shale Member of the Staffin Shale Formation.

In Strathaird, the uppermost surface of the Staffin Bay Formation is sharp, with a marked facies change from the medium- to coarse-grained sandstone of the Carn Mor Sandstone Member to the overlying silty clays of the Tobar Ceann Siltstone Member of the Staffin Shale Formation (Sykes, 1975, fig. 6). The formation is unconformably overlain by extrusive rocks of the Paleocene Skye Lava Group in places.

Definition of lower boundary

The base of the formation in Trotternish is sharply defined by the base of dark-grey fissile mudstones with shell beds of the Upper Ostrea Member which abruptly overlie the mottled green-grey-red clays of the Skudiburgh Formation. In Strathaird, the base of the Staffin Bay Formation is also abrupt at a well-developed erosion surface where the medium- to coarse-grained Carn Mor Sandstone Member sharply overlies the Skudiburgh Formation.

Thickness

At the type section [NG 473 708] at Staffin Bay, the formation is 15.95 m thick and attains 19 m in the wider Trotternish district (Hudson and Harris, 1979). The unit is significantly thinner to the south on Strathaird, where it is 9 m (Sykes, 1975, p. 68).

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird and Trotternish districts); not present on Raasay or Muck and not recorded on Eigg. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the formation within the sub-basins is uncertain (Fyfe et al., 1993).

Supplementary information

The fauna of the Upper Ostrea Member is dominated by low diversity, high density bivalve assemblages. The bivalve genera include *Isocyprina*, *Isognomon*, '*Liostrea*', *Neomiodon*, *Praeexogyra*, *Staffinella* and *Vaugonia*. Gastropods including *Neridormus* and *Viviparus* have

also been reported. No ammonites have been recovered. Riding (1992) and Riding and Thomas (1997) recorded marine and nonmarine palynomorphs from the member. The dinoflagellate cysts are indicative of an early Callovian age (Cox and Sumblar, 2002, p 405).

In the Belemnite Sands Member, the bivalve genera include *Astarte*, *Camptonectes*, '*Liostrea*', *Neomiodon*, *Oxytoma*, *Pleuromya* and *Trigonia*. These bivalves are more diverse and open marine than in the underlying Upper Ostrea Member. Other fauna include ammonites (*Cadoceras* and *Kepplerites*), belemnites (*Cylindroteuthis*), plesiosaurs and trace fossils (*Spongeliomorpha suevica*). The ammonites are indicative of the Koenigi Zone. Riding and Thomas (1997) recorded abundant marine palynomorphs from the Belemnite Sands Member.

The fauna of the Carn Mor Sandstone Member includes rare ammonites (*Kepplerites* and *Proplanulites*) and locally abundant belemnites and brachiopods (largely *Thurmanella acuticosta*). The belemnites are mainly *Cylindroteuthis* and are concentrated into the uppermost 0.45 m. Many of these belemnites are moulds due to leaching and thermal metamorphism. The ammonites are indicative of the Koenigi Zone. The ichnofauna is dominated by *Thalassinoides*, and these burrows extend down into the underlying Skudiburgh Formation. The correlation of the Upper Ostrea, Belemnite Sand and Carn Mor Sandstone members was illustrated by Cox and Sumblar (2002, fig. 6.23).

Previous names

Staffin Bay Beds (Hudson, 1962b)

The Upper 'Ostrea' Beds and Belemnite Sands were previously included in the Great Estuarine 'Series' of Anderson and Dunham (1966)

Parent

None

Age

Early Callovian, Herveyi Zone to Calloviense Zone

References

Principal reference (Sykes, 1975)

Additional references (Hudson and Morton, 1969).

8.3.2 Staffin Shale Formation (SFSH)

Name

Named Staffin Shales by Turner (1966, p. 248) after Staffin Bay, north Skye, as formalised by Sykes (1975, pp. 63-64).

Type section

Composite of coastal outcrops on the foreshore of Staffin Bay, Trotternish, northern Skye:

[NG 472 708] Dunans Shale Member – Point 5; [NG 473 699] Dunans Clay Member – midway between Points 3 and 4; [NG 472 708 and NG 473 698] Glashvin Silt Member – south of Point 5 and Point 3; [NG 474 694] Digg Siltstone Member – south of Point 1; and [NG 474 694 and NG 473 696] Flodigaray Shale Member – Points 1 and 2. Points are shown on fig. 38 of Morton and Hudson (1995). See also Sykes (1975, pp. 64-67), Morton and Hudson (1995, table 4), Riding and Thomas (1997, figs. 2, 3)

Reference section(s)

Foreshore at Rudha na h'Airigh Baine [NG 516 172], Strathaird; Scaladal Sandstone, Camasunary Sandstone and Camasunary Siltstone members, unconformably overlain by Upper Cretaceous Strathaird Limestone Formation. Presence/exposure here of basal Tobar Ceann

Siltstone Member uncertain, but it is exposed at its type section at Tobar Ceann [NG 506 195], Druim an Fhuarain, Strathaird (Sykes, 1975).

Formal subdivisions

Trotternish type area
Flodigarry Shale Member (FLOS) (Sykes, 1975)
Digg Siltstone Member (DIGS) (Sykes, 1975)
Glashvin Silt Member (GVIN) (Sykes, 1975)
Dunans Clay Member (DUNCL) (Sykes, 1975)
Dunans Shale Member (DUNSH) (Sykes, 1975)

Strathaird
Camasunary Siltstone Member (CASI) (Sykes, 1975)
Camasunary Sandstone Member (CASA) (Sykes, 1975)
Scaladal Sandstone Member (SCSA) (Sykes, 1975)
Tobar Ceann Siltstone Member (TCN) (Sykes, 1975)

Eigg
Laig Siltstone Member (LAGSL) (Sykes, 1975)

Lithology

The formation is a succession of fissile and massive mudstone, siltstone, sandy siltstone and sandstone, with minor calcareous, phosphatic and sideritic nodules. A coarsening-upward trend is discernible in Trotternish, north Skye, with the locally nodular mudstone of the Dunans Shale and Dunans Clay members, giving way to the carbonaceous siltstone and sandy siltstone of the overlying Glashvin Silt and Digg Siltstone members (Sykes, 1975, pp. 64-67). The youngest unit is the Flodigarry Shale Member comprising siltstone and mudstone.

In Strathaird, four members are recognised in the formation, which also exhibit a generally upwards-coarsening trend (Sykes, 1975, pp. 68-70). The lowermost Tobar Ceann Siltstone Member, comprising silty mudstone, is overlain in turn by the Scaladal Sandstone and Camasunary Sandstone members. The uppermost unit in Strathaird is a siltstone unit, the Camasunary Siltstone Member.

Measured sections were given for Staffin Bay, Points 1 to 5 by Sykes (1975, pp. 64–71); for Tobar Ceann by Riding (1984, fig. 2); for Staffin Bay by Morton and Hudson (1995, table 4), Riding and Thomas (1997, figs. 2, 3) and Cox and Sumbler (2002, p. 406).

On the north-west coast of Eigg there is a sequence of slightly glauconitic medium-grained grey fossiliferous siltstone with glauconitic sandstone and calcareous mudstone beds – the Laig Siltstone Member of Sykes (1975). It is latest Callovian to early Oxfordian in age (Sykes, 1975; Wright, J K, 1964). There are several small occurrences of fossiliferous fissile mudstone in northern Trotternish (Sykes, 1975, p. 71). These beds are of Oxfordian and earliest Kimmeridgian age on the basis of their ammonite faunas. Occurrences of Oxfordian indurated fissile mudstone and sandy mudstone are reported from Scalpay, south of Raasay and Strollamus, Skye (Sykes, 1975, p. 71). These are not assigned member status but are referable to the Staffin Shale Formation. A small fault-bounded sliver of mudstone and sandstone at Duart

Bay on eastern Mull is ascribed an early Kimmeridgian age by Arkell and Callomon (1963), (see also Cope, 1980, p. 85), and is referred here to the Flodigarry Shale Member.

Lithogenetic description

Open marine clastic

Landform description

The formation tends to form a concave slope between outcrops of more resistant igneous intrusions and lavas, and outcrops are largely concealed by superficial deposits and substantial landslides in Trotternish, notably north of The Storr [NG 50 54].

Definition of upper boundary

The top of the formation is not well exposed but is thought to be unconformably overlain widely by extrusive rocks of the Paleocene Skye Lava Group. At Kildorais, Trotternish, the uppermost, dark grey mudstone bed of the Flodigarry Shale Member (SS45 of Morton and Hudson, 1995) is seen to be overlain by Paleocene palagonite tuff. The grey siltstone of the Camasunary Siltstone Member in Strathaird and the mudstone of the formation at Strollamus and Scalpay are overlain unconformably locally by pebbly limestone and sandstone of the Upper Cretaceous Strathaird Limestone Formation (Sykes, 1975, p. 71).

Definition of lower boundary

The base of the formation is sharply defined. In Trotternish, it is represented by the base of bituminous fissile mudstones with thin glauconitic siltstones with *Chondrites* (Dunans Clay Member) abruptly overlying the fine- to medium-grained sandstone of the Belemnite Sands Member, Staffin Bay Formation. In Strathaird, the lowermost surface of the formation is also sharp. There is a significant upward facies change from the medium- to coarse-grained sandstone of the Carn Mor Sandstone Member (Staffin Bay Formation) to the silty mudstone of the Tobar Ceann Siltstone Member (Sykes, 1975, fig. 6).

Thickness

At the type section at Staffin Bay in Trotternish, the formation is at least 116.8 m thick and in the wider Staffin (S 90) district attains 151 m (British Geological Survey, 2006c). In Strathaird, the formation is seen to at least 150.5 m, on Scalpay it is about 100 m thick and on Eigg, at least 33 m thick (Sykes, 1975). The thickness present on Mull is unknown.

Distribution

Hebrides Basin (Inner Hebrides and the Sea of the Hebrides sub-basins/troughs), north-west Scotland: onshore outcrops on Skye (Strathaird and Trotternish districts and Strollamus [NG 601 266]), Scalpay, Eigg and Mull [NM 7244 3457]; not present on Raasay or Muck. Outcrops are separated/interrupted by Palaeogene igneous intrusions. The offshore extension of the formation within the sub-basins is inferred but uncertain (Fyfe et al., 1993, p.43).

Supplementary information

The fauna comprises ammonites, belemnites, bivalves, crinoids, scaphopods, trace fossils and wood fragments (Cox and Sumblar, 2002; Morton and Hudson, 1995). Riding and Thomas (1997) recorded abundant and diverse marine palynomorphs from Trotternish. The ammonites and dinoflagellate cysts are indicative of a Middle Callovian to Early Kimmeridgian age. Riding (1984) described late Callovian dinoflagellate cyst assemblages from the lower part of the Tobar Ceann Siltstone Member.

Previous names

The Staffin Shale Formation was previously included in the combined Oxford Clay, Corallian, and Kimmeridge Clay by, for example, Lee and Pringle (1932) and Anderson and Dunham (1966, pp 56-72).

Oxford Clay (in Strathaird) (Peach et al., 1910)

Parent

None.

Age

Middle Callovian to Early Kimmeridgian, Jason Zone to Cymodoce Zone

References

Principal reference (Turner, 1966)

Additional references (Sykes and Callomon, 1979).

9 Offshore Middle Jurassic

Middle Jurassic stratigraphical frameworks for UK continental shelf areas have been formally established by the UK Offshore Operators' Association (UKOOA, now Oil and Gas UK) only in the North Sea area (Lott and Knox, 1994; Richards et al., 1993) and in the north-west margin (Ritchie et al., 1996).

North Sea

The first comprehensive lithostratigraphical schemes for the North Sea Basin were established by Deegan and Scull (1977) for the UK and Central and Northern North Sea, and by Rhys (1974) for the UK Southern North Sea. The subsequent acquisition of an increasing body of new stratigraphical data lead to piecemeal additions to these early formal nomenclature schemes and also to a proliferation of informal names, some of which were becoming widely used by oil companies. This, together with increasing divergence in the application of existing formal names, lead to considerable uncertainty as to the meaning of many lithostratigraphical terms. The UKOOA scheme (e.g. Lott and Knox, 1994; Richards et al., 1993) rationalises lithostratigraphical usage and provides a nomenclature that is widely accepted within the oil industry as a whole, the main users and benefactors of the scheme.

SOUTHERN NORTH SEA				CENTRAL NORTH SEA				NORTHERN NORTH SEA			
MIDDLE JURASSIC	Stage / Substage	FORMATION	GROUP	Inner Moray Firth	Outer Moray Firth	FORMATION	GROUP	FORMATION	GROUP	FORMATION	GROUP
	Oxfordian	SEELEY	HUMBER								
	Callovian	LECKENBY	WEST SOLE	BEATRICE	HEATHER			EMERALD	HUMBER		
	Bathonian	HUDLESTON		BRORA COAL	HUGIN						
	Bajocian	STRANGWAYS			PENTLAND			TARBERT	BRENT		
	Aalenian	WROOT						NESS			
	Toarcian	CERDIC	LIAS	ORRIN				ETIVE			
								RANNOCH	BRENT		
								BROOM			
								DRAKE	DUNLIN		

Table 10 Lithostratigraphy of the Middle Jurassic strata of the North Sea to formation level.

9.1 WEST SOLE GROUP (WSTS)

The West Sole Group was established by Rhys (1974, p. 7) for the succession lying between the top of the Lias Group below and the Humber Group above in the southern North Sea. Rhys made no attempt to subdivide the succession except to comment that probable equivalents of the Lincolnshire Limestone ooid-limestones and the Cornbrash of eastern England had been proved offshore in some wells. The revision of the West Sole Group (Lott and Knox, 1994) created four

new subdivisions; in ascending order these are the Wroot, Strangways, Hudleston and Leckenby formations.

The West Sole Group is characterised by a transition from fluviodeltaic sandstone- and mudstone-dominated successions, in the north and east of the basin, to shallow marine carbonates and estuarine clastics in the south and west. In more complete sections the lower boundary of the group is characterised by a change from paralic sandstone-dominated lithologies to finer grained marine sandstones and siltstones of the underlying Phillips Member of the Cerdic Formation (Lias Group). However, over much of the basin there is evidence of extensive pre-Aalenian erosion which has truncated the underlying Lias Group so that the basal West Sole Group boundary is often marked by a significant erosive break.

The West Sole Group reaches a maximum thickness of 300 m within rim synclinal developments adjacent to some Zechstein salt diapirs, but in general is less than 100 m thick over the East Midlands Shelf, thickening to 200 m in the Sole Pit Trough (Figure 1; Figure 3) (Cameron et al., 1992). In onshore eastern England the West Sole Group sediments are coeval with those of the Dogger Formation and Ravenscar Group of the Cleveland Basin (Hemingway and Knox, 1973) and the Inferior and Great Oolite groups of south Yorkshire and Lincolnshire. The group is absent over the Mid North Sea High and is coeval, at least in part, with the Fladen (Section 9.2) and Brent Group (Section 9.3) successions of the Central and Northern North Sea (Richards et al., 1993).

The Wroot Formation (WROT) is a heterogeneous unit of paralic to marine sandstones, siltstones and mudstones lying between fully marine sandstones, siltstones or mudstones of the Lias Group (Cerdic Formation) below and the marine to paralic sediments of the Strangways Formation above. The Wroot Formation passes laterally into the varied marine and paralic successions of the onshore Dogger and Saltwick formations (Ravenscar Group, Hemingway and Knox, 1973) in Yorkshire; and of the Inferior Oolite Group (Grantham and Northampton Sand formations, Gaunt et al. 1992) in Lincolnshire.

The Strangways Formation (STRW) is a heterogeneous unit of paralic to marine sandstones, mudstones and limestones, lying between the Wroot Formation below and the paralic sediments of the Hudleston Formation above. The Strangways Formation passes laterally into the varied marine and paralic successions of the Cloughton and Scarborough formations (Yorkshire: Hemingway and Knox 1973) and of the Inferior Oolite Group (Lincolnshire: Lincolnshire Limestone Formation, Gaunt et al., 1992). The formation is absent over the Mid North Sea High and is coeval, at least in part, with the Fladen and Brent groups' successions of the central and northern North Sea (Richards et al., 1993).

The Hudleston Formation (HDST) is a heterogeneous unit of variegated paralic mudstones with thin sandstones lying between the Strangways Formation below and the dominantly marine sandstones of the Leckenby Formation above. The Hudleston Formation passes laterally into the paralic successions of the Scalby Formation (Yorkshire: Hemingway and Knox 1973) and of the Great Oolite Group (Rutland Formation, Blisworth Limestone Formation, Blisworth Clay Formation, Lincolnshire: Gaunt et al. 1992), in eastern England. The formation is absent over the Mid North Sea High and is coeval, at least in part, with the Fladen and Brent groups' successions of the central and northern North Sea (Richards et al., 1993).

The Leckenby Formation (LKNB) is a thin unit of pale grey, variably carbonate-cemented, shallow-marine sandstones lying between the Hudleston Formation below and the marine mudstones of the Woodward Formation above. The Leckenby Formation is the topmost unit of the West Sole Group. The Leckenby Formation passes westwards into the Cornbrash and Kellaways formations of eastern England. Lateral equivalents have not so far been proved in the central and northern North Sea successions.

9.2 FLADEN GROUP (FLDN)

The Fladen Group was originally defined by Deegan and Scull (1977) to encompass the coal-bearing Pentland Formation and the volcanic Rattray Formation in the Central North Sea and South Viking Graben. The group was subsequently redefined by Richards et al. (1993) whose scheme is followed here. The Fladen Group now comprises four formations, the Brora Coal (BOCO), Beatrice (BETR), Pentland (PNTL) and Hugin (HUGI) formations; and five members, the Rattray Volcanics Member (RAVL), Ron Volcanics Member (ROVL), Stroma Member (STRM) (all Pentland Formation), and the Louise Member (LOSE) and Carr Member (CARR) (Beatrice Formation). The Brora Coal Formation extends onshore in the Moray Firth, and the lower part of the Beatrice Formation correlates approximately with the newly proposed StrathSteven Mudstone Formation onshore.

The Pentland Formation has been expanded from its Deegan and Scull (1977) definition to include the Rattray Volcanics Member, previously termed the Rattray Formation, together with an additional volcanic unit, here termed the Ron Volcanic Member, in the southern part of the Central North Sea. In the Outer Moray Firth, the uppermost part of the Pentland Formation contains the newly defined Stroma Member, which equates with the arenaceous and coal-bearing part of the Skene Member (Sgiath Formation) of Harker et al. (1993).

The Fladen Group extends northwards to about 60°N in the Viking Graben. Beds of comparable facies in the East Shetland Basin (Ness Formation) are assigned to the Brent Group (Section 9.3), which is differentiated from the Fladen Group by a distinctive vertical succession of marine and paralic units.

9.3 BRENT GROUP (BRNT)

The definition of the Brent Group used here follows that of Deegan and Scull (1977). Five constituent formations are recognised: the Broom Formation (BROM), Rannoch Formation (RANN), Etive Formation (ETVE), Ness Formation (NESS) and Tarbert Formation (TARB). Deegan and Scull (1977) named the individual formations after Scottish lochs, arranging the names in ascending order to form the acronym BRENT. The group forms a broadly regressive–transgressive wedge of coastal and marine sediments, recording the progradational outbuilding and subsequent retreat of a deltaic system that extends across the East Shetland Basin into the North Viking Graben (Richards, 1992). The basal Broom Formation represents laterally derived fan-delta deposits (Richards and Brown, 1987), whilst the overlying Rannoch and Etive formations record shallow-marine shoreface and barrier-bar systems sourced dominantly from the south and south-west (Brown et al., 1987; Richards, 1990; Richards and Brown, 1986). The heterolithic, coal-bearing Ness Formation, which overlies barrier-bar sediments of the Etive Formation, represents a delta-top succession deposited initially during progradation of the delta system, but subsequently during its landward retreat (Graue et al., 1987). The Tarbert Formation, at the top of the group, represents the progressive drowning of the delta (Brown et al., 1987).

9.4 HUMBER GROUP (HMBG)

In the central and northern North Sea, the Fladen and Brent groups respectively are overlain by the Heather Formation (HTHE) of the Humber Group, which is largely Oxfordian in age but ranges down into the Callovian, or possibly in the northern North Sea, the Bathonian. Where present the lower part of the Heather Formation comprises grey marine mudstone and siltstone. It correlates approximately with the newly proposed Clynekirkton Sandstone Formation onshore in the Moray Firth.

English Channel

There is no distinct formal stratigraphical framework for the Middle Jurassic strata of the English Channel area. The succession is closely comparable with that of the contiguous onshore basin

areas of Southern England. It is dominated by interbedded shallow marine, ooidal and bioclastic limestones and deeper-water calcareous and silicate mudstones. Thus the current stratigraphical and lithostratigraphical schemes used for onshore southern England are extended into the up to 500 m-thick succession in the English Channel using the formations of the Inferior Oolite and Great Oolite groups, and the Kellaways and Oxford Clay formations as defined in Chapter 5; (see Hamblin et al., 1992). As the Bridport Sand Formation and its equivalents are absent over most of the basin area the Middle Jurassic succession shows an erosive, unconformable relationship with the underlying Lower Jurassic mudstones. The upper boundary of the succession shows a conformable relationship with the overlying Upper Jurassic succession.

Western Approaches

Early to early Mid Jurassic sedimentation in the Western Approaches was dominated by mud and carbonate, but localised uplift caused a hiatus in sedimentation across this basin in the late Bathonian. Later more widespread uplift and rifting led to much of the succession being removed by subsequent Late Jurassic to Early Cretaceous erosion. The limited preservation of poorly known Middle Jurassic strata in fault blocks west of the Channel Islands (Figure 4) has meant that no formal stratigraphical framework for the area has been produced (see Evans, 1990).

Bristol Channel and St George's Channel–Cardigan Bay

There is no formal distinct stratigraphical framework for the Middle Jurassic strata of the Bristol Channel and St George's Channel–Cardigan Bay areas. The succession is somewhat similar to onshore southern England: dominated by shallow marine limestone and deeper-water marine shale with interbedded, paralic sandstone and reddened mudstone becoming more prevalent to the north in the Cardigan Bay Basin. Hence the current stratigraphical and lithostratigraphical schemes used onshore are extended into the successions that are up to 1000 m-thick, using the formations of the Inferior Oolite and Great Oolite groups, and the Kellaways and Oxford Clay formations as defined in Chapter 5; (see Tappin et al., 1994).

Hebrides Basin (offshore)

The Middle Jurassic succession in the offshore Hebrides Basin is relatively poorly known, but is inferred to be lithologically similar to that onshore, although probably thicker (Fyfe et al., 1993). The succession is dominated by marine sandstone and mudstone (referred to the Bearreraig Sandstone Formation; Section 8.1.1), overlain by a sequence of more variable nonmarine sediments (Great Estuarine Group; Section 8.2), followed by a return to marine mudstone and sandstone (Staffin Bay and Staffin Shale formations; sections 8.3.1 and 8.3.2). Hence the terminology used is an extension of the onshore Hebridean stratigraphical and lithostratigraphical schemes...

West Shetland and Faroe–Shetland basins

Proven occurrences of Middle Jurassic strata west of the Shetland Platform are the sandstone-dominated Rona Formation (RONA) in the West Shetland Basin, which is thought to range from Bajocian to Tithonian in age, and the mudstone-dominated Pliensbachian to Oxfordian Heather Formation (HTHE) further north in the Faroe–Shetland Basin, both of the Humber Group (Ritchie et al., 1996). Ritchie et al. (1996) suspect that the occurrence of the Heather Formation may be more extensive than so far proved.

Appendix 1 Tables showing lithostratigraphical hierarchies

Tables list units alphabetically, commencing with group, then formation and member.

Group	Formation	Member
Ancholme (AMG) (only Middle Jurassic formations listed)	Kellaways (KLB)	Cave Rock Kellaways Clay (KLC) Kellaways Sand (KLS)
	Oxford Clay (OXC)	Peterborough (PET) Stewartby (SBY) Weymouth (WEY)
Great Estuarine (GEST)	Cullaigh Shale (CUD)	
	Duntulm (DTM)	
	Elgol Sandstone (ESA)	
	Kilmaluag (KML)	
	Lealt Shale (LASH)	Kildonnán (KILDN) Lonfearn (LONFN)
	Skudiburgh (SKU)	
	Valtos Sandstone (VTS)	
Great Oolite (GOG)	Athelstan Oolite (AOL)	
	Blisworth Clay (BWC)	Grange Ketton Heath Tinwell Lodge
	Blisworth Limestone (BWL)	Ardley (ARDY) Longthorpe (LONG) Roade (ROAD)
	Chalfield Oolite (CFDO)	Bath Oolite (BHO) Combe Down Oolite (CODO) Twinhoe (TW)
	Chipping Norton Limestone (CNL)	
	Cornbrash (CB)	Lower Cornbrash (LCB) Upper Cornbrash (UCB)
	Corsham Limestone (CSHF)	
	Forest Marble (FMB)	
	Frome Clay (FRC)	Wattonensis Limestone (WAB)
	Fuller's Earth (FE)	Dodington Ash Rock (DASHR) Eyford (EYF) Fuller's Earth Rock (FER) Hawkesbury Clay (HACL) Lower Fuller's Earth (LFE) Througham (TT) Upper Fuller's Earth (UFE)
	Hampen (HMB)	
	Horsehay Sand (HYSA)	
	Lansdown Clay (LDN)	
	Rutland (RLD)	Castle Stamford (STAM) Thorncroft Sand (THS) Wellingborough Limestone (WBRO)
	Sharp's Hill (SHHB)	
	Taynton Limestone (TY)	Charlbury (CHAR) Minchinhampton Limestone (MHPL)
	Tresham Rock Formation (TRR)	
	White Limestone (WHL)	Ardley (ARDY) Bladon (BLAD) Shipton (SHIP) Signet (SI)

Group	Formation	Member
Inferior Oolite (INO)	Aston Limestone (ASLS)	Gryphite Grit (GRGR) Lower Trigonía Grit (LTG) Notgrove (NGRV) Rolling Bank (ROBA)
	Birdlip Limestone (BLPL)	Cleeve Cloud (CLCL) Crickley (CRKY) Harford (HFD) Leckhampton (LECK) Scottsquar (SQAR)
	Grantham (GRF)	Stainby (STAI)
	Lincolnshire Limestone (LL)	Lower Lincolnshire Limestone (LLL) Upper Lincolnshire Limestone (ULL)
	Northampton Sand (NS)	
	Salperton Limestone (SALS)	Clypeus Grit (CG) Upper Trigonía Grit (UTG)
Ravenscar (RAG)	Cloughton (CLH)	Gristhorpe (GRPE) Lebberston (LEBB) Sycarham (SYCM)
	Eller Beck (EBB)	
	Saltwick (SWK)	
	Scalby (SCY)	Long Nab (LNAB) Moor Grit (MRG)
	Scarborough (SCR)	Bogmire Gill Brandsby Roadstone (BRBY) Crinoid Grit (CRG) Helwath Beck Hundale Sandstone Hundale Shale Lambfold Hill Grit Ravenscar Shale Spindle Thorn Limestone White Nab Ironstone
Sutherland (SUTH) (only Middle Jurassic formations listed)	Balintore (BALR)	Cadh'-an-Righ Shale (CARSH) Port-an-Righ Ironstone Port-an-Righ Siltstone Shandwick Clay Shandwick Siltstone (SWKSI)
	Brora Coal (BOCO)	Doll Inverbrora
	Clynekirkton Sandstone (CYK)	Ardassie Limestone Clynesh Quarry Sandstone Fascally Sandstone Fascally Siltstone (FCYSI)
	StrathSteven Mudstone (SSTV)	Brora Brick Clay (BROBC) Brora Shale (BROR) Glaucónitic Sandstone (GLCSA)

Group	Formation	Member
No parent	Bearreraig Sandstone (BEAS)	Balachuirn Sandstone Beinn na Leac Sandstone (BENL) Druim An Fhurain Sandstone (DAFS) Dun Caan Shale (DCSH) Garantiana Mudstone (GASH) Holm Sandstone Ollach Sandstone Rigg Sandstone Udairn Shale
	Cayton Clay (CAYC)	
	Dogger (DGR)	
	Osgodby (OSBY)	Hackness Rock (HACR) Langdale (LANG) Redcliff Rock (RDCR)
	Staffin Bay Formation (STBA)	Belemnite Sands (BSSK) Carn Mor Sandstone (CMSA) Upper Ostrea Member (UOST)
	Staffin Shale Formation (SFSH)	Camasunary Sandstone (CASA) Camasunary Siltstone (CASI) Digg Siltstone (DIGS) Dunans Clay (DUNCL) Dunans Shale (DUNSH) Flodigarry Shale (FLOS) Glashvin Silt (GVIN) Laig Siltstone (LAGSL) Scaladal Sandstone (SCSA) Tobar Ceann Siltstone (TCN)

North Sea units

Group	Formation	Member
Brent (BRNT)	Broom (BROM)	
	Etive (ETVE)	
	Ness (NESS)	
	Rannoch (RANN)	
	Tarbert (TARB)	
Fladen (FLDN)	Beatrice (BETR)	Carr (CARR) Louise (LOSE)
	Brora Coal (BOCO)	
	Hugin (HUGI)	
	Pentland (PNTL)	Rattray Volcanics (RAVL) Ron Volcanics (ROVL) Stroma (STRM)
Humber (HMBG) (only Middle Jurassic formations listed)	Emerald (EMLD)	
	Heather (HTHE)	Alness Spiculite (ALNS) Bruce Sandstone (BUSA) Fair Sandstone (FAIR) Freshney Sandstone (FESA) Gorse (GORS) Ling Sandstone (LISA)
	Rona (RONA)	
West Sole (WSTS)	Hudleston (HDST)	
	Leckenby (LKNB)	
	Strangways (STRW)	
	Wroot (WROT)	

Appendix 2 Discontinued or obsolete lithostratigraphical terms and codes

Code	Redundant name	New name or alternative
BHO	Bath Oolite	Bath Oolite Member
BRARE	Brora Arenaceous Formation	part of Clynekirkton Sandstone Formation (CYK) or Balintore Formation (BALR)
BRARG	Brora Argillaceous Formation	part of Strathsteven Sandstone Formation (SSTV) or Balintore Formation (BALR)
CHAR	Charlbury Formation	Charlbury Member
CHR	Cross Hands Rock	Dodington Ash Rock Member (DASHR)
CML	Cleatham Limestone	part of Lower Lincolnshire Limestone Member (LLL)
CODO	Combe Down Oolite	Combe Down Oolite Member
CVO	Cave Oolite	part of Upper Lincolnshire Limestone Member (ULL)
ELL	Ellerker Limestone	part of Lower Lincolnshire Limestone Member (LLL)
GLF	Glenthams Formation	use Rutland Formation (RLD), Blisworth Limestone Formation (BWL) and Blisworth Clay Formation (BWC)
GOF	Great Oolite Formation	Chalfield Oolite Formation (CFDO)
GOL	Great Oolite Limestone	Chalfield Oolite Formation (CFDO) or Blisworth Limestone Formation (BWL)
HACL	Hawkesbury Clay	Hawkesbury Clay Member
HIL	Hibaldstow Limestone	part of Upper Lincolnshire Limestone Member (ULL)
INOW	Inferior Oolite Formation (Wessex)	Inferior Oolite Group
KCMK	Kirton Cementstone Beds (knoll-reef)	part of Lower Lincolnshire Limestone Member (LLL)
KCMK	Kirton Cementstone Beds	part of Lower Lincolnshire Limestone Member (LLL)
RAAS	Raasay Sandstone Member	Druim An Fhurain Sandstone Member (DAFS)
RDBN	Redbourne Group	use Inferior Oolite Group and Great Oolite Group
RVB	Raventhorpe Beds	part of Lower Lincolnshire Limestone Member (LLL)
SNL	Snitterby Limestone Formation	Blisworth Limestone Formation (BWL)
SNO	Santon Oolite	part of Lower Lincolnshire Limestone Member (LLL)
SYL	Scawby Limestone	part of Lower Lincolnshire Limestone Member (LLL)
TT	Througham Tilestone Formation	Througham Member
TW	Twinhoe Beds	Twinhoe Member

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